KAU SMART CONVERTER CHALLENGE

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TEAM NO.: 10 **FALL-2021 INTAKE**

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A senior project report submitted in partial fulfillment of the requirements for the degree of

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بسم الله الرحمن الرحيم
والصلاة والسلام على خير الورى عدَّ الحصى والرمل والثرى
وعلى آله وأصحابه ومن تبع هداهم واهتدى
نحمد الله العلي القدير الذي قدَّرنا على إنهاء هذا المشروع في الوقت المحدد

DEDICATION STATEMENT

To our beloved ones who have been supportive to us during this trip, we are so greatful and speechless for what you have done for us. When we feel stress, you always there. When we are falling down, you always rise us again. You never leave us alone and we will never let you down. From the bottom of our hearts, we would like to say THANK YOU.

ABSTRACT
KAU SMART CONVERTER CHALLENGE

The growth of power electronics technologies is increasing. Many methods have been discovered with a significant efficiency which was a revolution in the power electronics world. In the past, the power electronics technologies were suffering with the loss of energy, but the new efficient methods end that misery. The purpose of this project is to establish a way to protect the sensitive devices from incompatible frequencies and voltages of the main power source by utilizing power electronics technological methods. In addition, we can describe the problem we have as sensitive devices face problems with connection to external power supplies, which will impact the device and may lead to harm the user.

The project has two higher level objective which are providing user friendly interface and ensuring the safe operation of sensitive devices according to listed voltage and frequency standards and specifications. Also, the customer requirements are 85% efficiency, ± 5% voltage and frequency variation, 5% total harmonic distortion, selectable output 220/110 V_{AC} with 50/60 Hz and the output power is 500W.

Moving to the alternatives of the project, there are not many differences between the alternatives. The major difference is the power electronics technologies used in each alternative e.g., choosing between using flyback or buck-boost as DC-DC converter or not using this stage at all and choosing between multilevel, SPWM or PWM DC-AC inverter.

We decided that the optimum solution and the baseline design of this project is using a full-wave rectifier, Arduino and PWM inverter. The baseline design works as follow: full-wave rectifier for converting AC to DC, Arduino for giving the proper switching frequency based on the read of the voltage and the frequency switch and finally H-Bridge inverter for inverter form DC to a desired AC. In our project, we manage to have a converter with a selectable output 220/110 V_{AC} with 50/60 Hz.

Index Terms — Power Electronics Technologies, Switched-Mode Power Supply (SMPS), Pulse-Width Modulation (PWM), Sinusoidal Pulse Width Modulation (SPWM) Total Harmonic Distortion (THD).

ACKNOWLEDGEMENT

No words can describe our feeling toward Dr. Muhammed Bilal who guides us to the success of this project. We are so grateful for him. Without him this dream would not be completed. Thus, Thanks Dr. Muhammed Bilal. Also, we would like to express our special thanks of gratitude to Dr. Khaled Sedraoui and Prof. Sreeram Kumar for answering our questions. In addition, we would like to thank Eng. Ahmed who is the manager of Al-Ahmad Electronics Est. At the end, we would love to give our special thanks to CEIES Robotics Lab members.

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CHAPTER – 1 INTRODUCTION

1.1 ABOUT THE PROJECT

This project will attempt to develop a safe method of assisting sensitive devices such as motors, medical and healthcare devices to be compatible with the frequency and voltage of the main power source. The project will try to solve the problem technically by building a universal converter to output the desired voltage and frequency. Therefore, the project will be utilized the safe operation of sensitive devices in accordance with the voltage and frequency specifications and standards listed.

1.2 BACKGROUND

Before jumping to the project, some background information will be discussed to make it easier to understand what the project all about. Linear power supply was used for decades. It is older than the advent of semiconductors [1]. It has a bad efficiency comparing to the power electronics methods. However, converters and inverters have variety in size and functionality with increasing in efficiency due to the help of the power electronics technologies that has been growing. For instance, the mobile charger is a very small converter that converts 220 V_{AC} to 5 V_{DC}. Nowadays, a method called switched-mode power supply is used to implement mobile charger [2]. In addition, there are many efficient methods of converting. We will give example of each conversion. First, an efficient method of DC-DC conversion is a flyback converter. Also, the DC-AC SPWM inverter can be used instead of flyback converter to decrease and increase the voltages. Second, DC-AC conversion has variety of efficient methods such as multilevel and PWM or SPWM inverters. Third, AC-DC conversion has SMPS which we mentioned earlier. The project is centred on these power electronics topologies to solve the problem we have.

CHAPTER – 2 CONCEPTUAL DESIGN

2.1 SITUATION DESCRIPTION

The current system situation of the project is to convert AC voltage to various voltages and frequencies to establish a safe method for assisting sensitive devices in becoming compatible with the voltage and the frequency of the main power source. Besides, the smart converter will be developed by using efficient power electronics topologies and programmable digital control for flexible operation. Therefore, the system has been divided into four subsystems which are rectifier, chopper converter, control system and inverter. The inputs of the system are constant AC voltage and frequency, and user command, while the outputs are various AC voltage and frequency.

2.2 DEFINING THE PROBLEM

Sensitive devices such as motors, medical and healthcare devices, have certain criteria and specifications. It is important to be concerned about it, such as frequency and voltage across it. Accordingly, these devices' frequencies must be 50Hz or 60Hz. Furthermore, sensitive devices face some problems with connection to external power supplies and wall-mounted power supply adapters, which impact the performance, deterioration of the device and may lead to harm the user, such as the patient. Besides, the frequency of some sensitive devices can be incompatible with the feeders' frequency. Some imported devices do not satisfy our local specifications and standards. This project will make a universal frequency and voltage converter to solve this problem.

2.3 PROJECT OBJECTIVES

Our project objectives should be negotiable and specific goals. Thus, the team developed the following higher-level objectives that serve our project planning in a variety of ways:

- Safe operation of sensitive devices according to listed voltage and frequency specifications and standards.

- User friendly interface.

On other hand, the following lower-level objectives should be serving the customer needs, the technical design and the design characteristics of the project that provided by the customer as follows:

- Build a universal converter to output the desired voltage and frequency.
- Build the circuit using efficient power electronics topologies.
- Use programmable digital control for flexible operation.

2.4 APPLICABLE ENGINEERING STANDARDS

Every project should follow certain standards. In this section, the engineering standards that were used in this project will be illustrated and explained whether if the standard is a safety or technical standard.

The SASO IEC 61558 Standard [3]

The Saudi Standards, Metrology and Quality Organization (SASO) has taken the International Electrotechnical Commission (IEC) in the consideration for decades. The SASO IEC 61558 Standard is dealing with the safety of the transformers, the reactors, the power supplies and similar products.

The Saudi Arabian Distribution Code (PC.4.2.1 & PC.4.2.2.1 & PC.4.3.2) [4]

The Saudi Arabian Distribution Code is provided by Saudi Electricity Company. The project used three technical standards from that code. The first one is PC.4.2.1 which is about the frequency. The frequency change must be within ± 5% of the desired frequency. The second one is PC.4.2.2.1 which is about the voltage. The voltage variation must be within ± 5% of the desired output voltage. The last one is PC4.3.2 which is about the harmonic distortion. The total harmonic distortion should be 5% or less in the output.

2.5 REALISTIC CONSTRAINTS

In order to develop the desired device, it is necessary to be realistic about what it requires also to be aware of our capabilities. In furthermore, the project should include constraints, which are the limitations of any design prerequisites that are imposed on the project by the client and specifically demanded. This project is constrained by the following factors:

Table 1: The Constraints of the Project

Constraints
Laboratory tools' availability.
The project must not exceed 3,000 SR.
Following the SASO IEC 61558 standard.
Following The Saudi Arabian Distribution Code.
Customer satisfaction.
220 VAC availability in the building.
Delivering the project before the deadline.

2.6 PRODUCT DESIGN SPECIFICATIONS (PDS)

After the information that was given earlier in this chapter, the project can be described as designing a device that can protect sensitive devices such as medical devices from undesirable input by utilizing power electronics technological methods. However, the in-scope specifications (musts) alongside the out-of-scope specifications (wants) will be illustrated as in the following table:

Table 2:The Musts and Wants of the Project

Musts	Wants
Efficiency musts be 85%.	Efficiency should be 90%.
Safety material must be used.	The price is not exceeding 2,500 SR.
Input and Output must be AC voltage.	The weight is not exceeding 2 kg.
The cost must be within the budget.	The device has touch screen user interface.
The device must be portable.	-
Easy to use.	-
Input must be 220V with 50Hz or 60Hz.	-
The voltage variation is ± 5%.	-
The frequency variation is ± 5%.	-
The total harmonic distortion is 5%.	-
Output must be selectable as 110V or 220V with 50Hz or 60Hz.	-
The output power is 500W.	-

In addition, every project has risks, and it should be considered. The remedies should be defined for these risks as well. The following table will be shown the risks of this project and their remedies:

Table 3: The Risks and Their Remedies

Risk	Remedy
Parts not available.	Online ordering.
Electrocution hazard.	Use safety material.
Difficulty using the device.	Design an instruction manual.

Moreover, the project must have assumptions which are made about conditions required for the project to work. The assumptions of this project will be illustrated in the following table:

Table 4:The Assumptions of the Project

Assumptions
The facility has electricity.
Universal wall socket needed.
Input is 220V with 50Hz or 60Hz.

2.7 LITERATURE REVIEW

It is important to identify some articles or research products that are similar or dissimilar to your project and may own some functions that are comparable to yours. A major purpose of this section is to make these products or articles research in order to assist us with improving our project.

ITECH IT7321 [5]

The IT7321 line establishes a new benchmark for high-performance AC power supplies. Power line disturbance (PLD) simulation, Dimmer, Sweep, and thorough measurement operations are among the many strong features included. These capabilities make the IT7321 series suited for bench-top testing through mass production in commercial, power electronics, and military test applications. The newest linear technology is used in the IT7321 series AC source, which considerably reduces output noise and ensures good operating stability. This series AC source can help the user acquire a more precise measuring result because of the decreased ripple index. For actual RMS voltage, actual RMS current, for real power, frequency, power factor, and peak value, the IT7321 AC source employs an innovative DSP circuit to provide improved precision and high-speed measurement. Its high resolution of 0.01W/0.1mA also expands the potential for Energy Star certification. The IT7300 series is a strong meter as well as an AC source. IT7321 has a lot of features that can simulate various forms of power line disturbances. The STEP and PULSE modes allow you to perform a single step or a series of output adjustments. For more sophisticated waveform generating needs, the LIST Mode (up to 100 sequences) enhances this function. In this approach, the IT7321 can simulate a wide range of voltage dips, surges, and trapped waves.

Figure 1: The ITECH IT7321

1655A [6]

The variable isolated AC power supply of the 1655A model is ideal for testing AC line changes or any product that requires AC power. 0 to 150 VAC isolated variable output with 3 A continuous output. The gadget also utilizes an isolation transformer to prevent shock hazards when repairing "hot chassis" equipment by displaying voltage and current with analogy values. The device's additional features are an integrated soldering iron temperature control, an expanded leakage scale, and a circuit breaker overload for safety.

Figure 2: The 1655A

2.8 ANALYZING ALTERNATIVE SOLUTIONS

In this section, a brainstorming technique is required to generate and find several electrical engineering designs. After generating alternative designs that must satisfy all the in-scope specifications, each alternative will be described and shown the components that are needed to implement that alternative alongside a block diagram for each alternative. At the end of this section, it will be clear that one of the alternatives has been chosen to implement this project.

First, let us illustrate the system of the project and then divide it into sub-systems to make it simple and understandable. The system of this project will be shown in the following block diagram. Also, it shows the inputs and the outputs of the system.

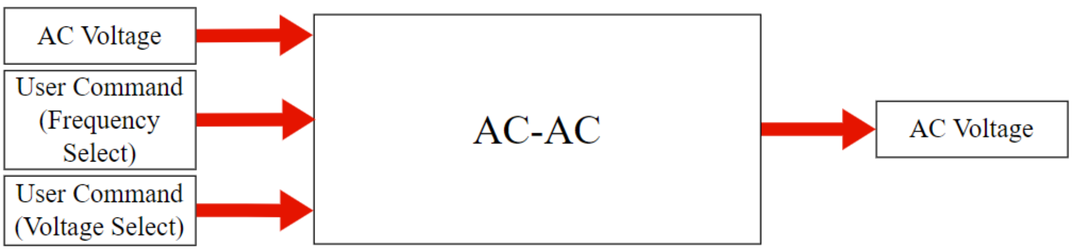


Figure 3: The Block Diagram of the System

However, the main system will be divided into four sub-systems to help us to satisfy the project in-scope specifications. Each sub-system will be defined and explained briefly. Thus, the four sub-systems will be illustrated in the block diagram below:

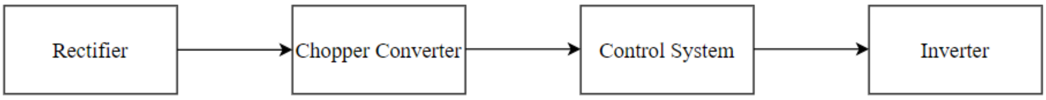


Figure 4: The Block Diagram of the Sub-Systems

AC-DC Converter (Rectifier) Power Electronics Circuit

There are two common methods to apply the conversion of AC to DC. The first method is full-wave rectifier which is shown in figure 5. The second method is half-wave rectifier that will be seen in figure 6. One of These methodologies will be the first stage of the AC-AC system. Also, it is needed to convert the AC that is coming from the wall-socket into DC which will be going to the next stage of the AC-AC system that is DC-AC SPWM inverter.

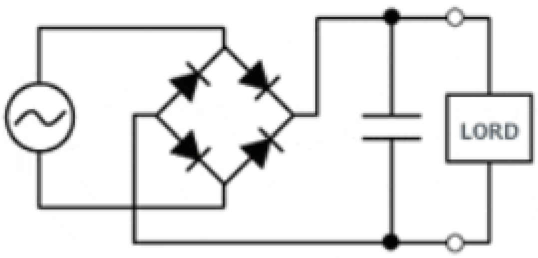


Figure 5: Full-wave Rectifier Circuit

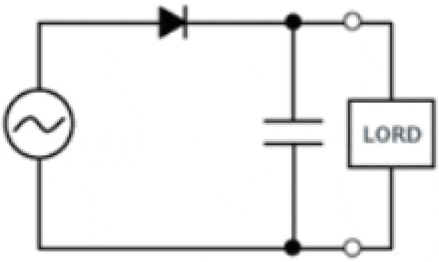


Figure 6: Half-Wave Rectifier Circuit

DC-DC Converter (Chopper) Power Electronics Circuit

There are four common methods to apply the step-down and step-up conversion of DC to DC. The first method is buck (step-down) converter which is shown in figure 7. The second method is boost (step-up) converter that will be seen in figure 8. The third method is a step-down and step-up converter that depends on the duty cycle of the switch coming from the control system. This converter is called the buck-boost converter which is shown in figure 9. The fourth method is a step-down and step-up converter that depends on the turns' ratio of the transformer and the duty cycle of the switch. This converter is called the flyback converter as shown in figure 10. One of These methodologies will be the second stage of the AC-AC system. Also, it is needed to convert the DC that is coming from the previous stage (AC-DC) into DC which will be going to the next stage of the AC-AC system that is DC-AC inverter.

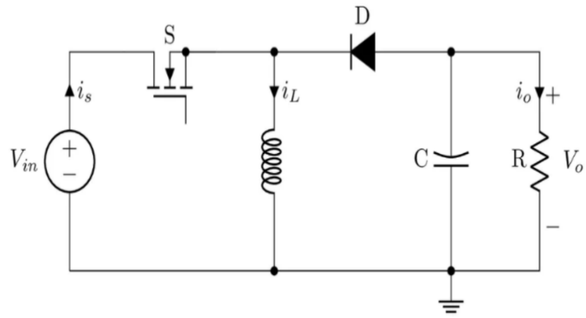


Figure 7: Buck (Step-Down) Converter Circuit

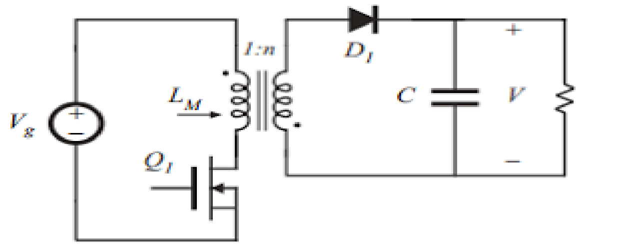


Figure 8: Boost (Step-Up) Converter Circuit

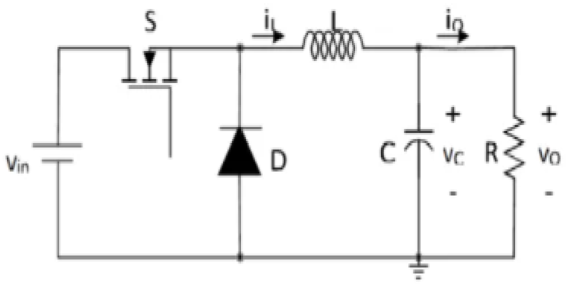


Figure 9: Buck-Boost Converter Circuit

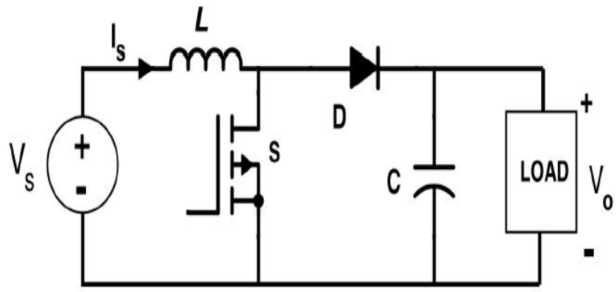


Figure 10: Flyback Converter Circuit

Microcontroller (Control System)

The microcontroller is the brain of the system. It controls the whole system by sending and receiving signals. It controls the MOSFETs in the system and receives the user commands. The user commands will be received as an SPDT switch. There are many types of microcontrollers. The most common one is Arduino which is very easy to program and handle.

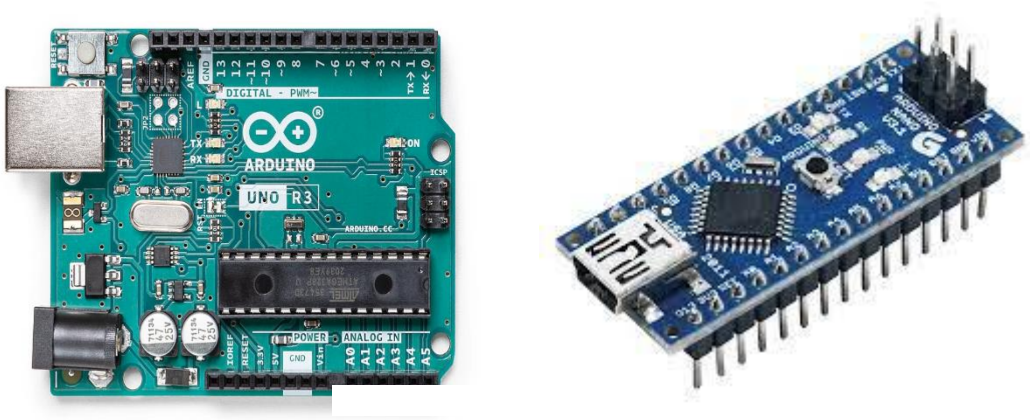


Figure 11: Picture of the Arduino [10]

DC-AC (Inverter) Converter Power Electronics Circuit

The main purpose of using an inverter is to convert DC to AC which is the last step that is needed in this project. To modify DC to AC, a microcontroller is needed to control the MOSFETs to generate pulses that will eventually give the desired voltage and frequency. However, there are two excellent methods which are PWM inverter and Multilevel inverter as shown in the following figures:

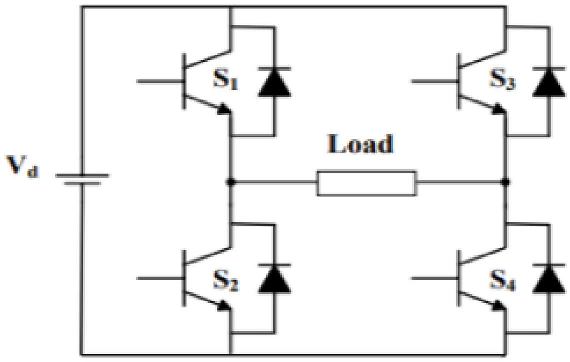


Figure 12: PWM Inverter Circuit

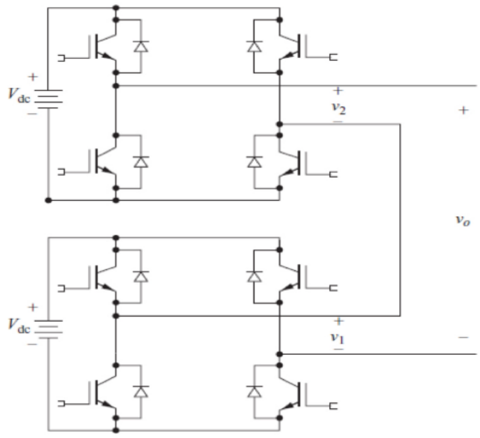


Figure 13: Multilevel Inverter Circuit

MOSFET Driver Circuit

The MOSFET driver circuit is one of the important parts in the DC-AC inverter circuit. This circuit used as isolation between the Arduino and the MOSFETs because our circuit worked in high voltages. Also, the driver circuit can drive the gates with hundreds of milliamperes or even several amperes. The rapid charge and discharge of the gate capacitance results in extremely fast switching. Actually, they are sometimes too fast and must be slowed down by inserting resistors between the drivers and the MOSFETs. The project will be used two types of drivers:

1- **Bipolar Junction Transistor (BJT)**

The project used BJT as first isolation. The BJT reversed the signals the come from the Arduino and sent it to the IC. The project used MPSA44 NPN Channel. As seen in the figures below, the circuit of MPSA44 and the part:

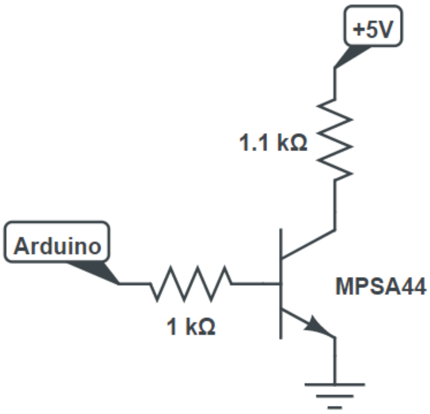


Figure 14: The Circuit of the BJT

Figure 15: MPSA44 NPN Channel [11]

2- Integrated Circuit IC IR2110

The IC IR2110 used as a second isolation circuit. The Arduino will send signals to the high and low side of the IC. The IC will increase the amplitude of the output signals and these signals will be detected by the gate of the MOSFET to switch on. As seen in the figures below, the circuit of IR2110 and the part:

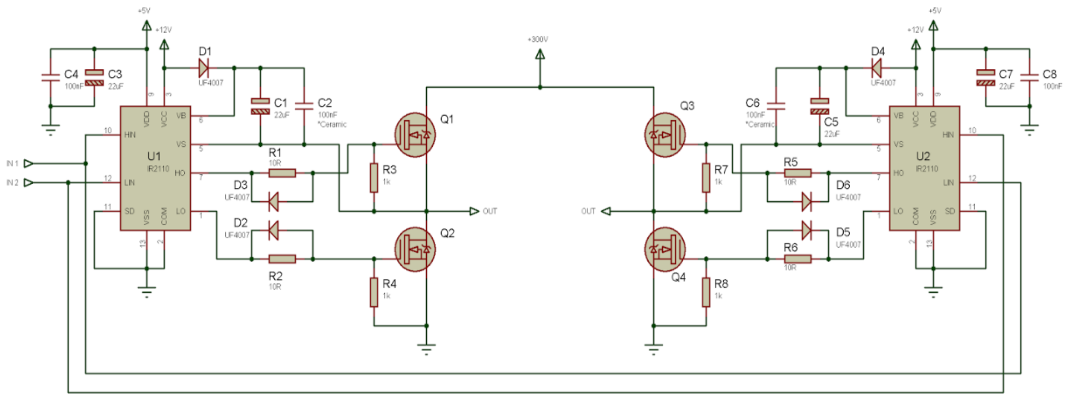


Figure 16: The IR2110 Circuit with H-Bridge

Figure 17: The IR2110 [12]

After going through all the sub-systems and explaining them briefly, generating alternative designs will be much easier. Now, let us move on to introduce the alternative designs of this project.

2.8.1 First Alternative Design

In the first alternative design, we decided to go with two DC-DC converters circuit. The first one is buck converter which will help us to have 110Vac and the second one is boost converter which will help us to have 220Vac. That was the main different from the other alternatives. The following block diagram is for the first alternative design:

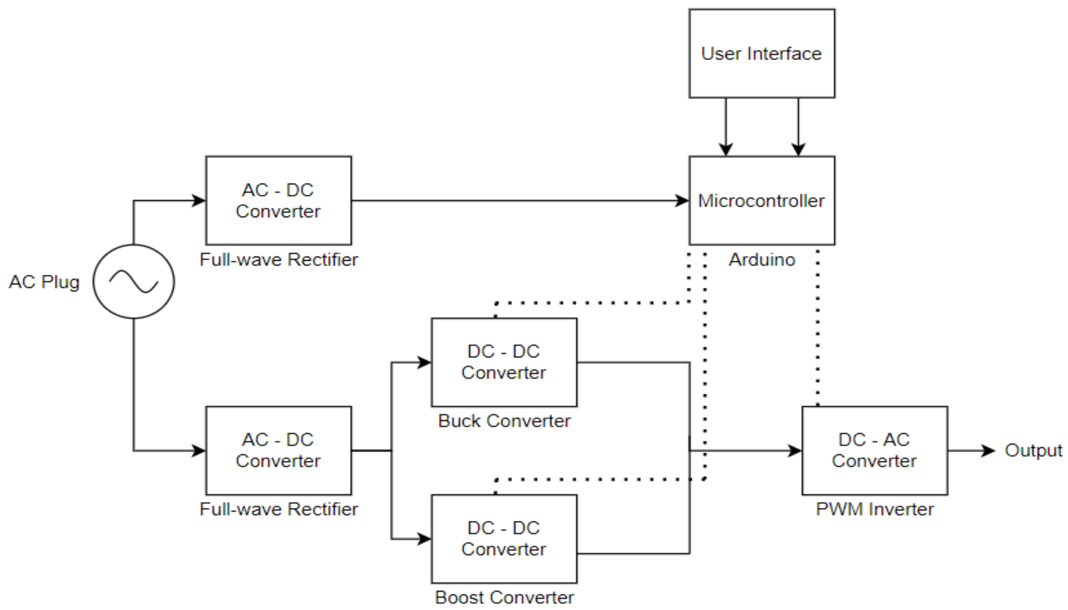


Figure 18: Block Diagram of the 1st Alternative

The first stage which is converting AC-DC, we have used a full-wave rectifier which is much better than the half-wave rectifier. Next, the DC-DC converters which we illustrated earlier. Moreover, this alternative has Arduino to give signals to the MOSFETs in the circuit based on the user input. In the final stage, we have used a PWM inverter which will give us the desired output. In this alternative, we have used the best methods according to the efficiency. Thus, this alternative was capable to satisfy all the in-scope specifications. Also, it didn't satisfy any of the out-scope specifications. However, this alternative is more complex than the others due to the two DC-DC converters.

2.8.2 Second Alternative Design

This alternative is similar to the previous one in that it starts with a full-wave rectifier, converts DC-DC in the second stage, and then uses a PWM inverter to achieve the desired output. The critical difference is in the DC-DC converter, which is accomplished by utilizing the flyback converter, which is a buck-boost converter with a transformer for voltage step up and step down.

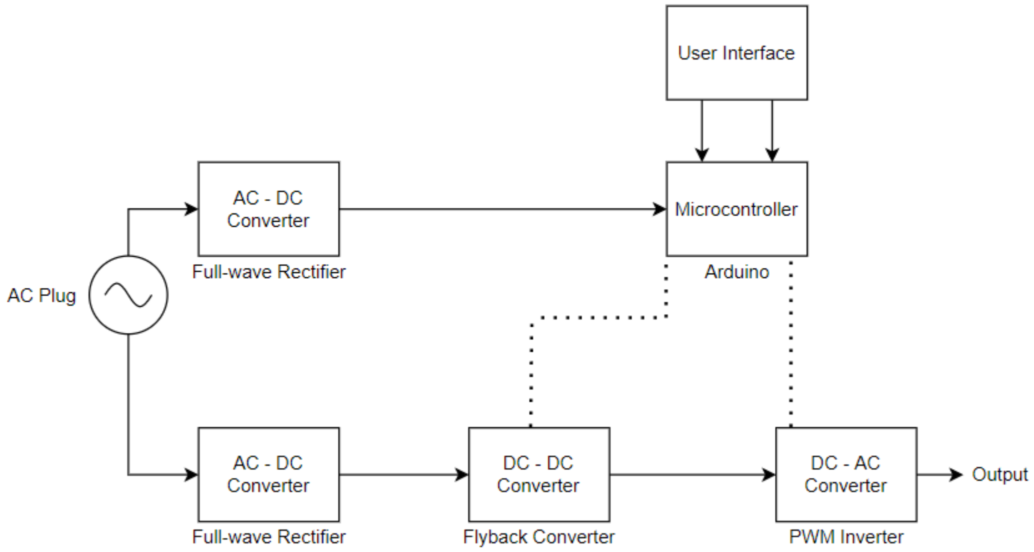


Figure 19: Block Diagram of the 2nd Alternative

As shown above, after getting the input power and the user commands. The first stage will be the AC-DC converter. To satisfy our In-scope in this stage, it has been used a Wheatstone bridge to minimize the voltage variation. Moreover, it has been used an LC filter to enable DC elements to pass through. The following stage is the DC-DC converter used flyback converter. In the flyback converter, there is a transformer which will be used to increase or reduce the voltage. Although, the flyback converter has a switch that is controlled by the Arduino via a signal sent to the MOSFETs. Lastly, the inverter is used to convert DC to AC can change the frequency by manipulating the sinusoidal wave. In this stage, we used Pulse Width Modulated (PWM) which is the more effective for converting DC-AC. Moreover, we utilized the most efficient ways accessible in this alternative. As an outcome, this alternative was able to meet all of the in-scope requirements. It also failed to meet any of the out-of-scope standards.

2.8.3 Third Alternative Design

A buck-boost converter and multilevel inverter are used in the third alternative design. In the DC-DC converter and DC-AC inverter, this alternative design will be distinct from the other alternative designs.

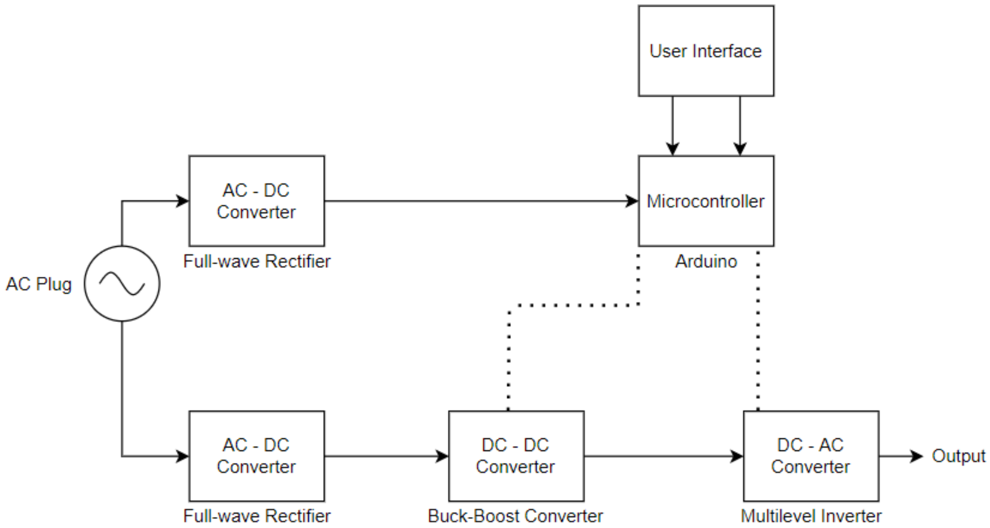


Figure 20: Block Diagram of the 3rd alternative

As shown in figure 20, the first stage converts AC to DC using a full-wave rectifier and an LC filter to reduce voltage variation. This stage has two feeders. The first feeder converts 220 V_{AC} to 5 V_{DC} in order to supply the Arduino. The second feeder will be approaching the next stage as it converts 220 V_{AC} to 220 V_{DC}. Therefore, the second stage will be a DC-DC converter that will use a buck-boost converter to increase and decrease voltage to achieve the desired output. We used a DC-AC inverter with a multilevel inverter in the final stage. As a necessary consequence, the frequency and voltage will be converted by the inverter to obtain the required frequencies and voltages. Furthermore, the DC-DC converter and DC-AC inverter have a switch that the Arduino will control by sending a signal to the MOSFET. Accordingly, we used the most efficient methods available in this alternative. As a result, this alternative could satisfy all of the in-scope specifications. Furthermore, it did not satisfy any of the requirements that were outside of its scope. However, due to the multilevel inverter, this option is more complicated than the others because it will use a significant number of MOSFET.

2.8.4 Fourth Alternative Design

In the 4th alternative design, we decided to go with only two stages, and we excluded the DC-DC stage. The DC-AC SPWM inverter will do the principle of DC-DC converter circuit by controlling the Arduino. That was the main different from the other alternatives. The following block diagram is for the 4th alternative design:

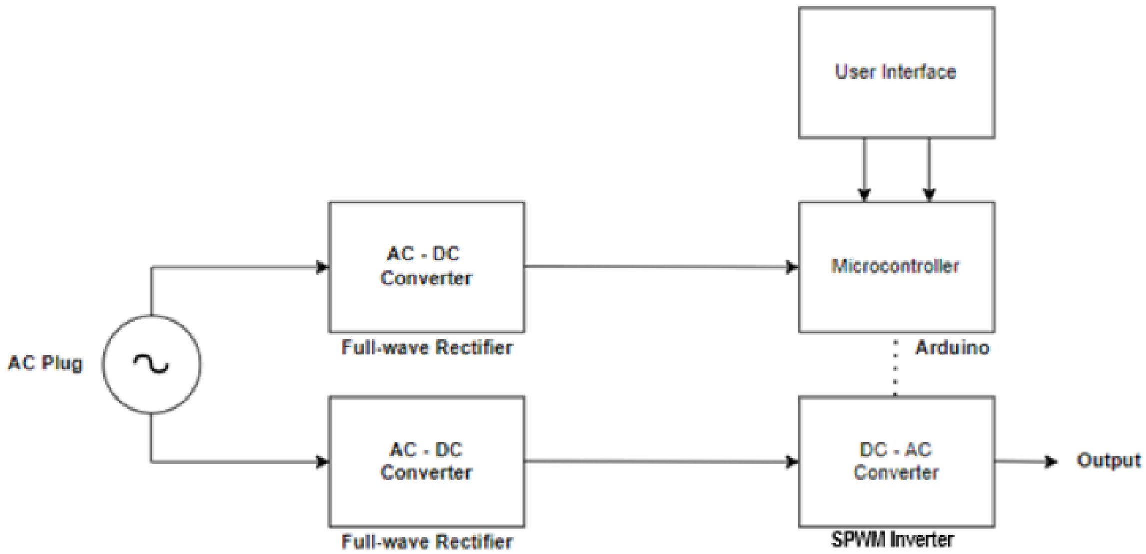


Figure 21: Block Diagram of the 4th alternative

As shown in figure 21, the first stage converts AC to DC using a full-wave rectifier and an LC filter to reduce voltage variation. This stage has two feeders. The first feeder converts 220 V_{AC} to 5 V_{DC} in order to supply the Arduino. The second feeder will be approaching the next stage as it converts 220 V_{AC} to 220 V_{DC}. Therefore, as we discussed earlier the SPWM inverter will be used instead of DC-DC converter. Also, we used a DC-AC inverter with a SPWM inverter in the final stage. As a necessary consequence, the frequency and voltage will be converted by the inverter to obtain the required frequencies and voltages. Furthermore, the DC-AC inverter has a switch that the Arduino will control by sending a signal to the MOSFET. As well, the Arduino will be controlled the output voltages to give 220V and 110V by using intelligent code to do this principle. Accordingly, we used the most efficient methods available in this alternative. Lastly, the inverter is used to convert DC to AC can change the frequency by manipulating the sinusoidal wave. In this stage, we used Sinusoidal Pulse Width Modulated (SPWM) which is the more effective for converting DC-AC by using H-bridge. Moreover, we utilized the most efficient ways accessible in this alternative. As an outcome, this alternative was able to meet all of the in-scope requirements. It also failed to meet any of the out-of-scope standards.

After we illustrated and described all the three alternatives briefly, it is time to show and list the pros and cons for each alternative design. That will help us to decide which will be our final baseline design. The following table will be shown with the pros and cons of each alternative:

Table 5: Pros and Cons of the Alternatives

Alternative	Pros	Cons
First Alternative	Less voltage variation.	Complex connections.
	Easy to control switching.	More components.
	Less THD.	Highest cost.
Second Alternative	Controllability of high range voltage.	More power consumption.
	Less complexity.	Complex connections
	Lowest cost.	-
Third Alternative	Pure sine wave.	Difficult to control.
	Buck and boost the voltage in one circuit.	Limitation in the duty cycle of the DC-DC switching.
	-	Complex connections.
Fourth Alternative	Perfect and pure sine wave	Difficult to control
	Controllability of obtained high range voltage.	-
	Less complexity	-

After we differentiated all the pros and cons for each alternative design in the above table, we can finally observe what is the best alternative design from these three. Thus, we chose the fourth alternative to be our baseline design in this project. As we mentioned before, the fourth alternative design has satisfied all the in-scope specifications. However, it failed to meet the out-of-scope specifications.

We will select one alternative based on the objective specification upon discussing all alternatives with benefits and drawbacks. Furthermore, the best option will be determined by assigning a score to each objective ranging from 0 to 10.

Table 6: Evaluation of Alternatives

#	Objective	1st	2nd	3rd	4th
1	Efficiency	6	9	8	10
2	Controlling	7	10	9	7
3	Implementation	5	7	7	10
4	Ability	6	9	8	9
5	Cost	7	8	5	9
	Total score	31	43	37	45

2.8.5 Best Design Alternative

As shown in the preceding table 6, the best option with the best rating is number 4, which will be our selected alternative. However, there is a minor distinction between alternatives 2 and 4, the issue with alternative 2 is that it required a stage to convert DC-DC converter with two output voltages which are 220V and 110V. Therefore, after did a lot of research we figured out that DC-AC SPWM inverter will do the principle of DC-DC converter just by controlling the Arduino and come up with intelligent code.

2.9 MATURING BASELINE DESIGN

The maturity of the chosen alternative is an important consideration and maturity comes with more digging besides knowing the component and, specification of each block diagram. Furthermore, the deep thinking led us to come up with the best option for the alternative of our baseline design, this option has been found after did a lot of research. Therefore, the project minimized into two stages by excluded the DC-DC converter after figuring out that the DC-AC inverter can did the same principle of the DC-DC converter by controlling the Arduino. Additionally, the Arduino needs to be fed without an additional source, such as a battery. Furthermore, a part has been added that is AC-DC rectifier which will use a Switched Mode

Power Supplies (SMPS) which has a high frequency transformer that reduces the voltage from 220V to 5V. So, that it can supply the Arduino with the appropriate amount of power. Each phase in the block diagram will require a switch to regulate the duty ratio. Thus, we have a reason for using an MOSFETs to be capable of dealing with high switching frequency.

CHAPTER – 3 PRODUCT BASELINE DESIGN

3.1 BLOCK DIAGRAM

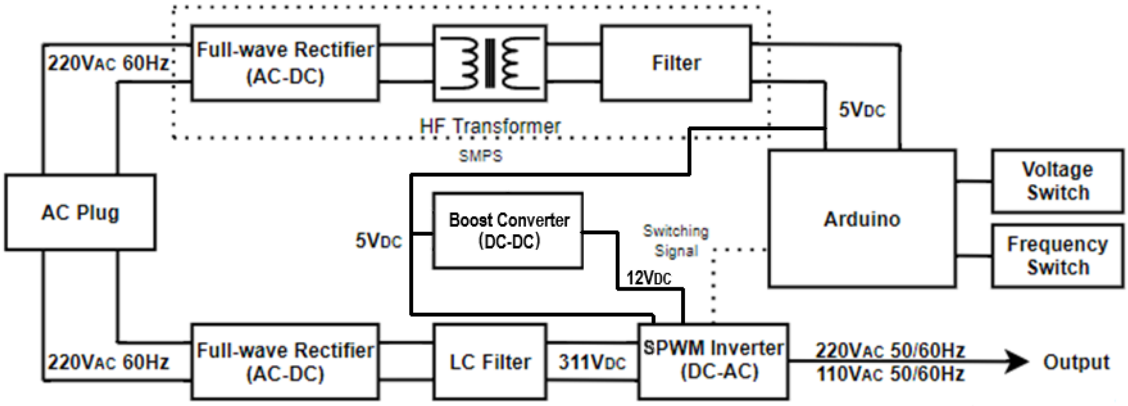


Figure 22: Block Diagram of the Project

As illustrated in the block diagram above, after getting the input power and the user command. The first stage will be the AC-DC converter. In this stage, it has been used a Wheatstone bridge to convert AC-DC voltage. Moreover, an LC filter was used to cut through the noise and identify the specific signals that will obtain pure DC voltage. At this point, there are two feeders at this stage. To supply the Arduino, the first feeder converts 220 V_{AC} to 5 V_{DC}. After getting 5 V_{DC}, there is a feeder goes to the boost converter to step-up the voltage to 12 V_{DC} . The second feeder will connect to the next stage as it converts 220 V_{AC} to 220 V_{DC}. After that, it comes the SWPM Inverter that converts DC-AC. This stage is the most important stage in our project since it can provide us with different output by controlling the switching frequency. In addition, this stage will generate 220V 50/60Hz or 110V 50/60Hz. Finally, the DC-AC inverter have four switches (H-Bridge) that the Arduino will control by sending a signal to the MOSFETs after reading the inputs of frequency and voltage switches that is provided by the user interface.

3.2 SYSTEM DESCRITPION

This section used referenced engineering drawings to explain the characteristics of each block. As a result, the block diagram of the baseline design will be discussed in further detail. The circuit schematic will be used to simulate all of the necessary components, and the flowchart will be used to accomplish the project's function before moving on to the code. Furthermore, the specifications in each component's datasheet should be followed because they are relevant to engineering standards and the mechanical specifications of the case will show by the 3D projection drawing of the design which will be like an enclosing box, so we will use SolidWorks to draw the 3D design. In addition, the product will be more convenient with possible aesthetics. Finally, this section will end with the input/output specifications of the whole system and the operating instructions.

3.2.1 Circuit schematics

In this section, it will take off the cover of the blocks of the baseline design and illustrate all the circuits used in the project.

AC-DC Full-Wave Rectifier with LC Filter:

This is the first circuit in the project which will convert 220 V_{AC} to 311V_{DC}. The input of this circuit will be from the wall-socket and the output of this circuit will go to the SPWM inverter DC-AC. The circuit schematic will be shown in the following figure:

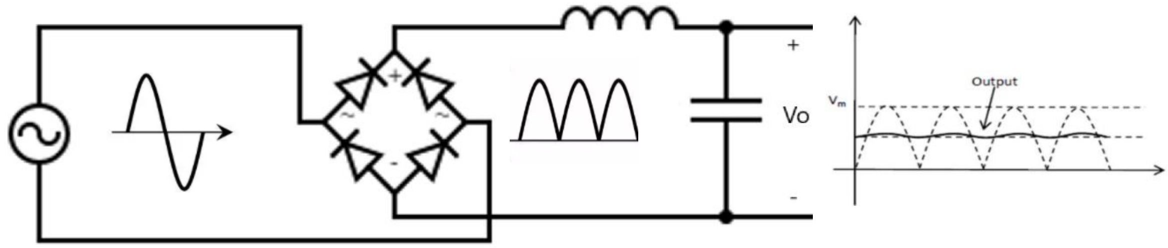


Figure 23: Schematic of AC-DC Full-Wave Rectifier with LC filter

AC-DC Full-wave Rectifier using SMPS:

This circuit will convert 220 V_{AC} to 5 V_{DC} by using SMPS. SMPS stands for Switched-Mode Power Supply which is a circuit that converts power using switching devices that are turned on and off at high frequencies, and storage components like capacitors to supply power when the switching device is in its non-conduction state [13]. The input of this circuit will be from the wall-socket and the output will supply the Arduino. The following figure shows the schematic of the circuit:

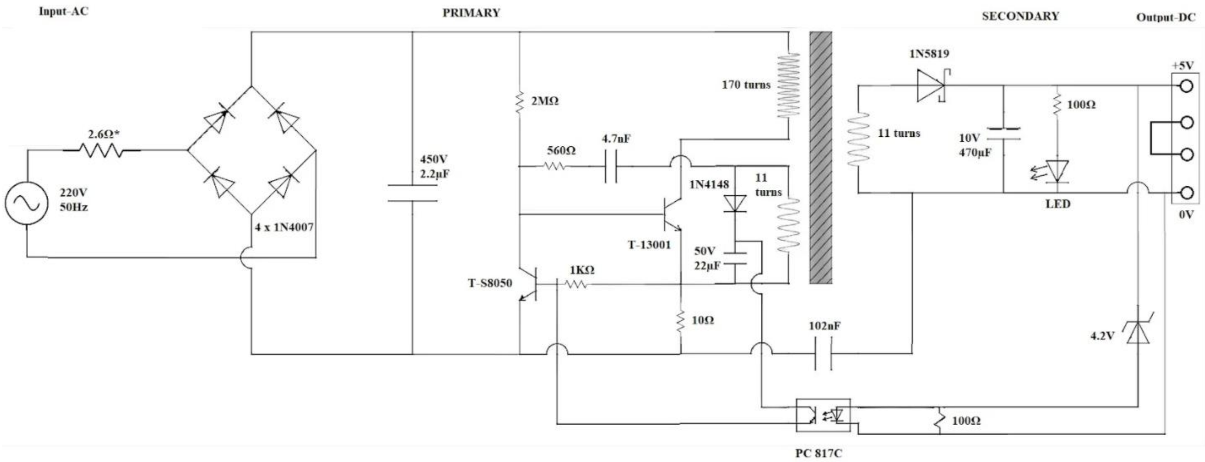


Figure 24: Schematic of SMPS [14]

DC-DC Boost Converter:

This circuit will convert 5 V_{DC} to 12 V_{DC} by using DC-DC boost converter. This DC-DC Module is based on IC XL6009E1 which is a high-performance step-up switching current (BOOST) module. The module uses the second generation of high frequency switching technology XL6009E1 core chip that offers superior performance over the first-generation technology LM2577. XL6009 replaces LM2577 module as LM2577 is about to be phased out [15]. The input of this circuit will be from the SMPS, and the output will supply the low side fixed voltage (pin3) of the IC IR2110. The following figures shows the schematic of the circuit and part:

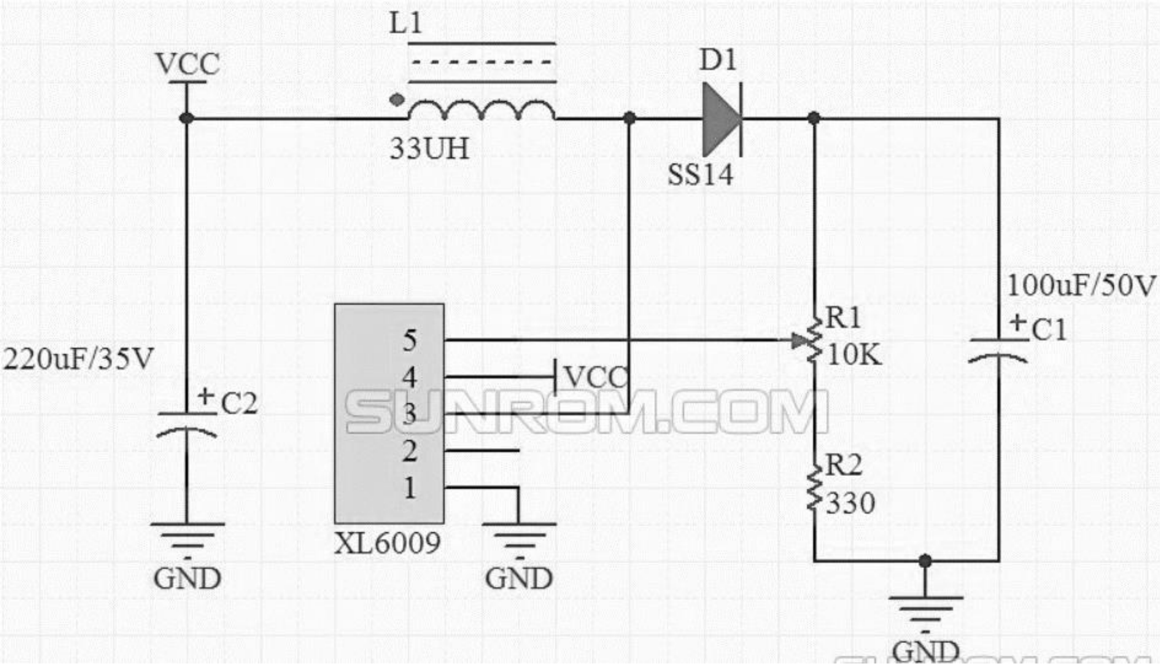


Figure 25: The Circuit Schematic of the Boost Circuit [16]

Figure 26: The DC-DC Step-Up [17]

DC-AC Inverter by Using SPWM:

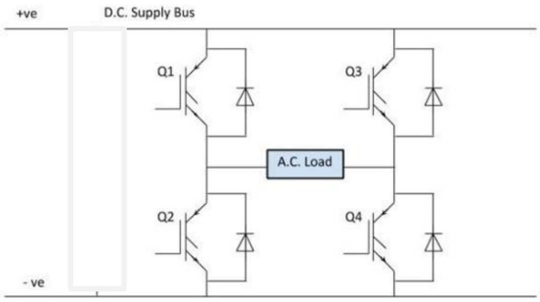


Figure 27: Circuit Diagram for Inverter with H-Bridge

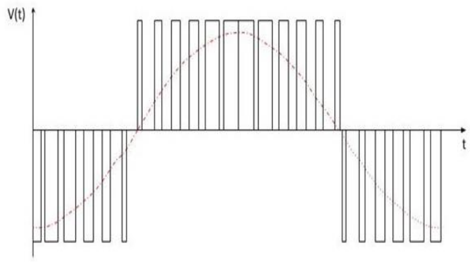


Figure 28: Sin Wave by Using SPWM

As a final stage, the objective of this stage is to take the output of the previous phase, which is the AC-DC converter, and convert it to AC. As a result, it is capable of meeting the load's requirements. Moreover, in order for converting DC-AC, here comes the reason for applying a single-phase H-Bridge circuit which is consists of four Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFETs). As shown in figure 27, by providing the proper signal the Insulated Gate Bipolar Transistors work as ON/OFF switch. The Q1 and Q4 will operate to absorb the positive DC supply. Besides, Q2 and Q3 will operate to absorb the negative DC supply across the load. Eventually, this will provide a sine wave as shown in figure 28. Further information, the control circuits are employed to generate the gate signals required to generate the requisite SPWM waveform. In addition, this stage is supplied by $5V_{DC}$ & 12 V_{DC}. The reason is that the MOSFET Gate Driver needs to be supplied with this value to function right. [18]

3.2.2 Circuit Component Specifications

Table 7: AC-DC Full-Wave Rectifier with LC Filter Components [19] [20].

Item	Symbol	Approx. Value	Unit
Bridge Rectifier	V_{max}	1000	V
	I_{max}	3	A
Inductor	L	34	mH
	I_{max}	3	A
Capacitor Filter	C	820	uF
	V_{max}	450	V
	T_{max}	105	ºC

Table 8: AC-DC Full-Wave Rectifier Using SMPS Component[21].

Item	Symbol	Approx. Value	Unit
AC-DC 220V TO 5V	V_{in}	100 - 240	Vac
	V_{out}	5	Vdc
	Freq	50 - 60	Hz
	P	3	W
	Dimensions	34 * 20.2 * 15.4	mm

Table 9: The inverter Specification [22] [23] [24].

Item	Symbol	Approx. Value	Unit
MOSFET IRFP460	V_{DSS}	**500**	**V**
	I_D	***20***	**A**
	T	**25-150**	**ºC**
	t_d(ON)	**20**	**ns**
	t_d(OFF)	**55**	**ns**
	F	**1**	**MHz**
IC IR2110	V_{OFFSET}	**500**	**V**
	I_O	**2**	**A**
	$t_{on/off}$	**120 & 94**	**ns**

BJT MPSA44	**V_{CEO}**	**400**	**V_{DC}**
	V_{CBO}	**500**	**V_{DC}**
	I_C	**300**	**mA_{DC}**

3.2.3 Flowcharts for software blocks

As shown in the block diagram in section 3.1, the project has two SPDT switches one for the frequency and the other for the voltage. Also, it has an on-off switch. The project depends on these switches. Thus, the following flowchart will illustrate how the microcontroller receives and reacts due to these inputs' switches.

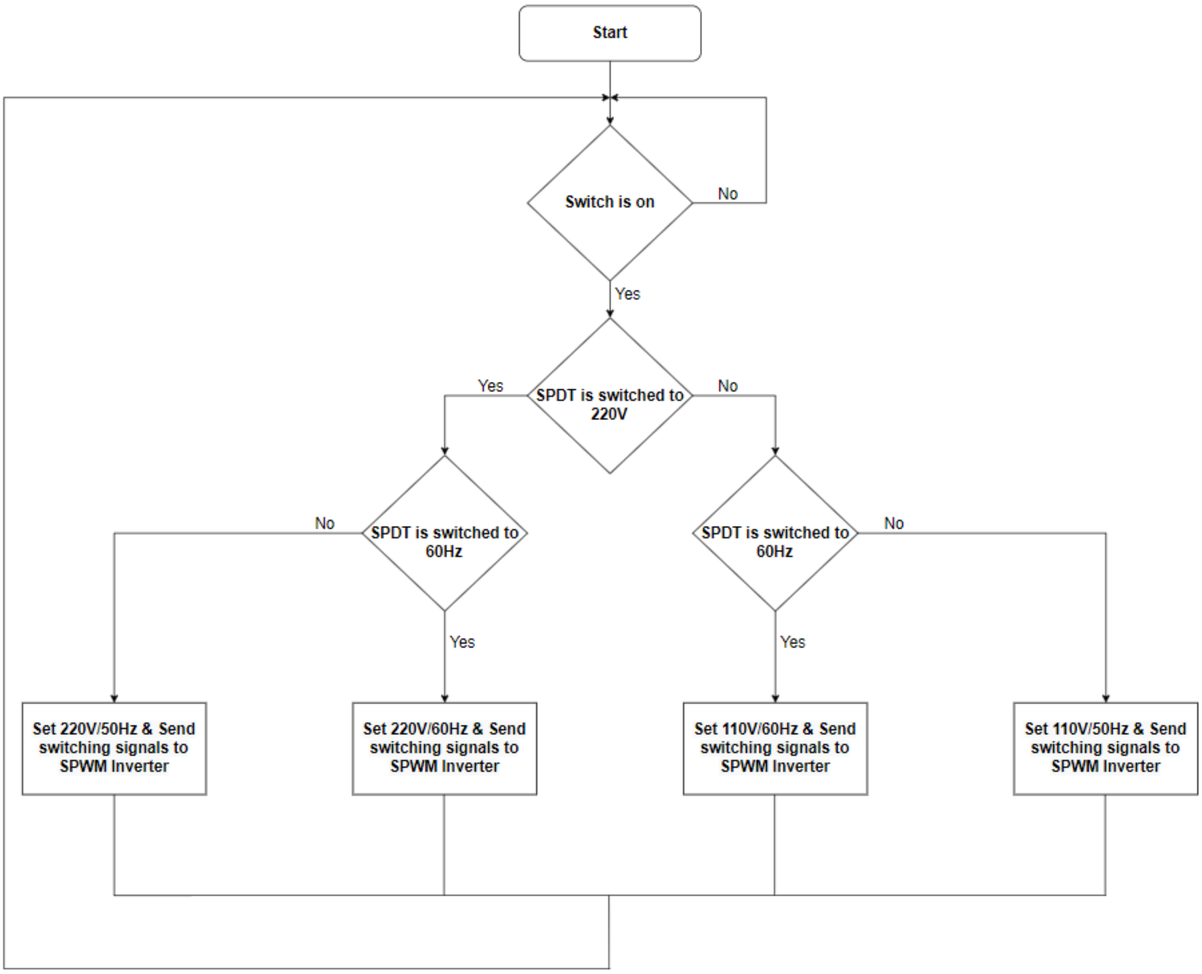


Figure 29: Flowchart for Software

3.2.4 Mechanical specifications of the case

In this section, we will make a 3D drawing for the project, and ilstrate its dimensions and weight. First, the project will be much similar to figure 30 but slightly different. However, it will have an extra switch. Also, in the back of the box, it will have a wall-socket for the output. After we clarified how the project looks like, we will talk about the dimensions and the weight of the project. the dimensions of the project will be assumed that it has a length of 20cm, a width of 15cm and a height of 7cm. The weight will be around 2kg.

Figure 30: 3D Drawing of The Project. [25]

3.2.5 Possible aesthetics

In this section, we will discuss the product's aesthetics. The product will be more convenient with possible aesthetics that will appear professional and will be constructed with safe materials. Therefore, most converter devices used special materials that prevent electric shock. It will seem like box-shaped, and the box will be painted black. Also, the box will have ventilation holes for escape the heat and switches will be high quality.

3.2.6 Input/output specifications

The specification of the device is essential to make the customer aware of the inputs and outputs of the project. For input, a single-phase AC voltage of 220 volts is required alongside 50/60Hz. Conversely, the outputs as shown in the table below:

Table 10: The Outputs Values

Output	Value		Unit
Voltage	220	110	V_{rms}
Frequency	50/60	50/60	Hz
Current max	2.27	5	A
Power	500		W

3.2.7 Operating Instructions

Steps specified for the user to run the product:

- Connect the device to the source input (220volts 50/60Hz).
- Make sure the power switch (ON/OFF) of the device is ON.
- Switch the SPDT to the voltage desired.
- Select the desired frequency.
- Connect the load to the device.

When these steps are followed, the output of the device will be as expected.

3.3 SIMULATION RESULTS

In this section, our target in the implementation part is simulating the first and second circuit which are AC-DC full-wave rectifier with LC filter and DC-DC chopper converter by using flyback converter. This section will begin by simulating the first circuit, which is the AC - DC full-wave rectifier with an LC filter mentioned in section 3.2.1. By using Multisim software, the results of simulating will be focused on the output voltage of the circuit. The output voltage will be shown as waveform along-side the read of the voltmeter in the following figures:

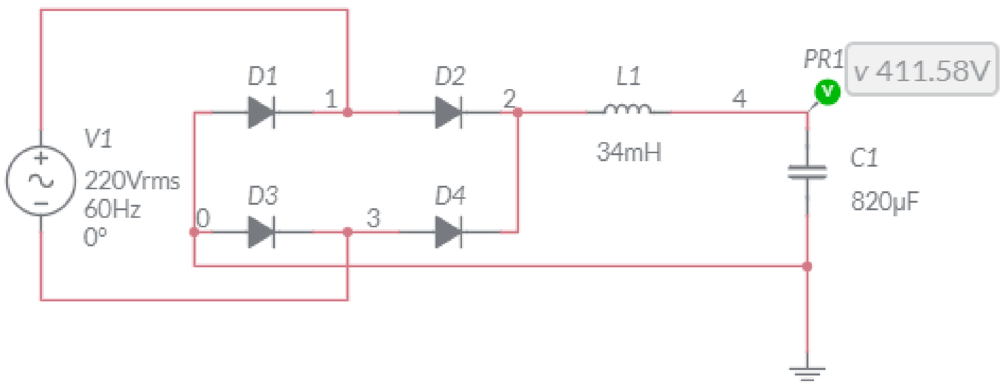


Figure 31: Simulation Results of AC-DC Full-Wave Rectifier with LC Filter

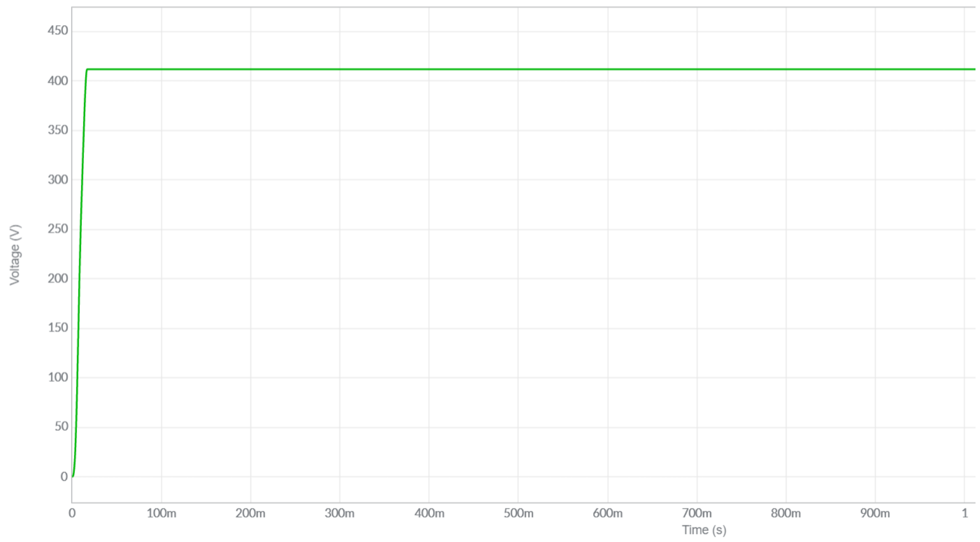


Figure 32: The Waveform of the Output Voltage

The following simulation shows the last phase DC-AC which is SPWM inverter by using H-bridge. To achieve one of the desired voltages, we employed a SPWM inverter instead of using DC-DC converter. As shown above, we got 311V from the first phase while here in the second phase we convert the $311V_{DC}$ to $220V_{AC}$. By using Simulink, the result we be seen below:

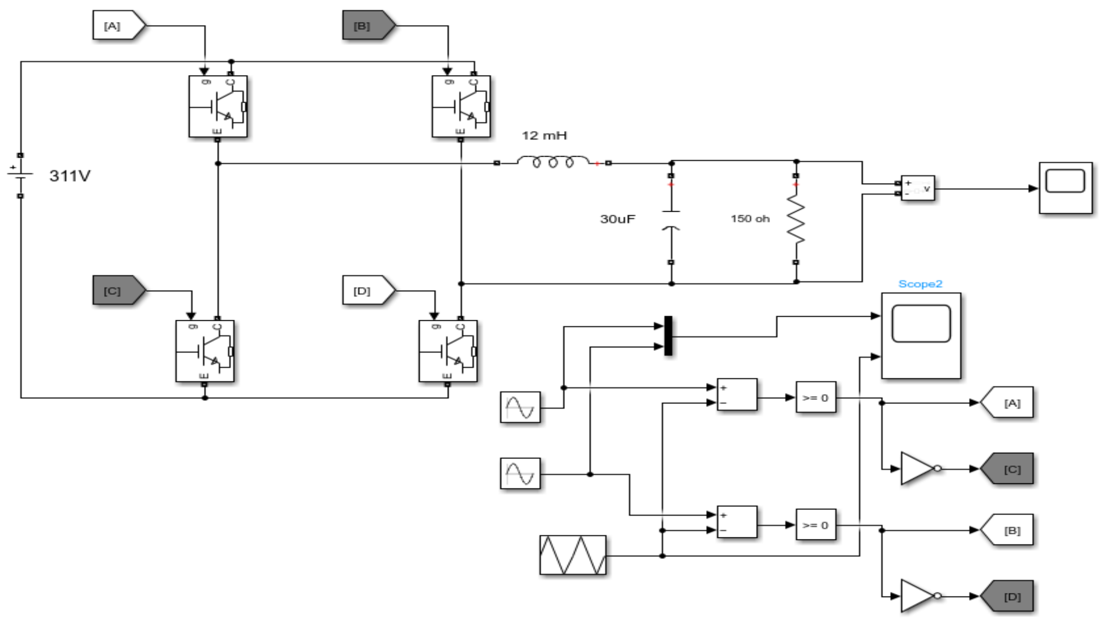


Figure 33: Simulation Results of SPWM Inverter

The following figures show the output voltage beside the voltmeter's reading:

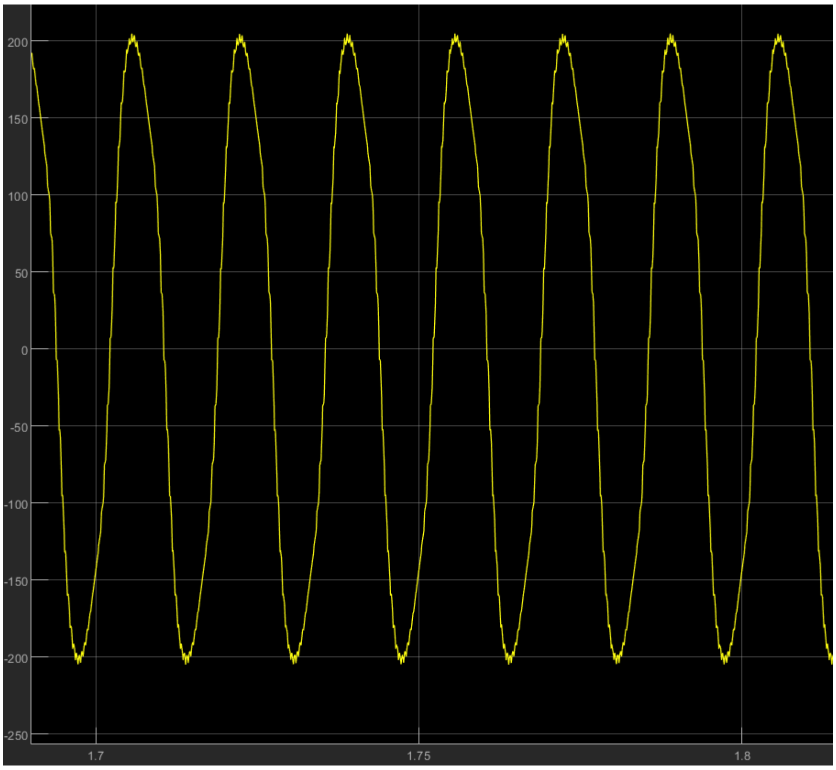


Figure 34: The Output Voltage's Waveform

CHAPTER – 4 IMPLEMENTATION

4.1 RECTIFIER CIRCUIT

This section explains the first block of the SMART CONVERTER challenge, how it was tested, and how we arrived at the final design of the rectifier circuit, as well as all of the critical points we noted. As shown below this is the theoretical circuit of the rectifier (AC to DC converter).

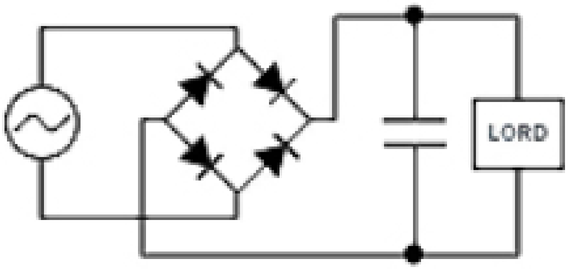


Figure 35: Theoretical Drwing for Rectifier

4.1.1 First trial

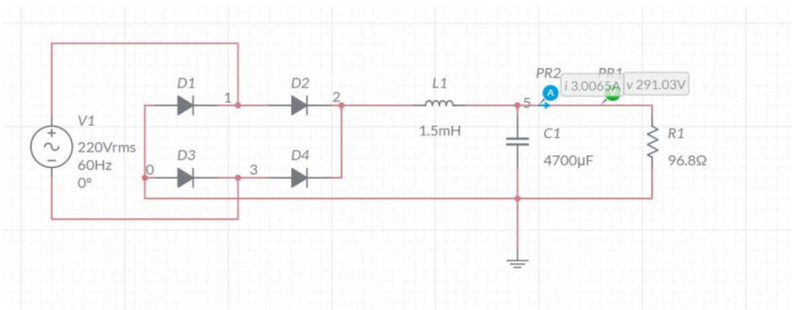


Figure 36: Simulation of the Rectifier

To be able to identify what the expected values are and to avoid any misconfigurations, we must first simulate the rectifier before attaching it to the circuit. as seen in the previous figure 36. And as you can see, we have an issue with the current and voltage being too high, as well as the voltage ripple not being at the desired level. As a result, we have changed the values of the inductor and capacitor in order to get a pure DC.

4.1.2 Second trial

Successfully completing the simulation, we decided to proceed with the application of the circuit on the breadboard at a low voltage for safety reasons, in order to observe how we would deal with the rectifier in reality.

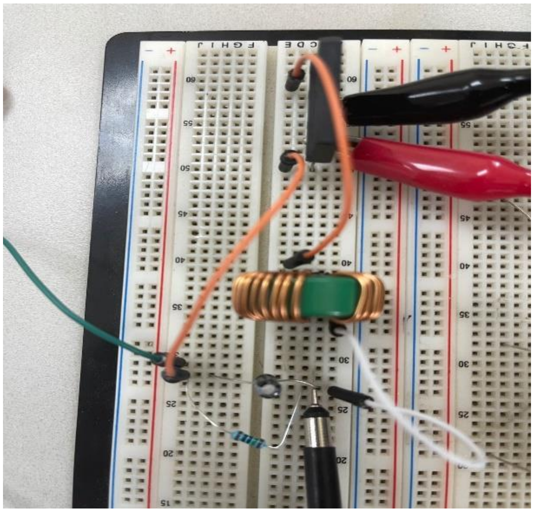


Figure 37: The Circuit of the Rectifier

As shown above, after connecting the circuit with the function generator to obtain low alternating current voltage, the circuit functions properly. However, we face some problem with the capacitor, which becomes dangerous when it is fully charged, and the load is disconnected. As a result, we return to the simulation to connect a discharge circuit for the capacitor. As shown below:

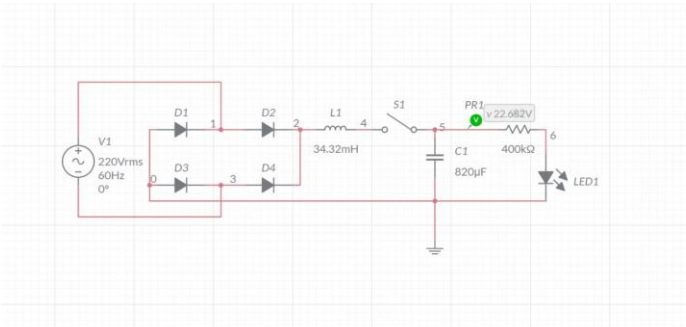


Figure 38: Rectfier with Discharge Circuit

4.1.3 Third trial

After thoroughly examining each component and determining the expected value, we run the circuit in high voltage. As a result, we solder the component to the printed circuit board. However, we had several difficulties throughout the soldering process. The PCB was not of great quality, and it kept burning each time while soldering the component. Additionally, the circuit did not provide us with a pure dc, and the noise and spikes were excessive. As a result, we design a PCB utilizing EASY EAD in order to prevent any of the concerns listed above. A fuse is added to the circuit to provide further protection. The circuit seen in the figure below.

Figure 39: The PCB on the EASY EAD

Figure 40: The Component on the PCB

4.2 MOSFET DRIVER

4.2.1 First trial

The first design of the MOSFET driver was testing the MOSFET by sending signals to the gate of the MOSFET. This experiment was an important part of the final stage which is inverter DC to AC. First, we should be going through the datasheet of the MOSFET to see the specification of the gate and how is the threshold of the gate as figure 41 shows.

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
$V_{(BR)DSS}$	Drain-source breakdown voltage	V_{GS} = 0 V; I_D = 0.25 mA	500	-	-	V
$\Delta V_{(BR)DSS}$ / ΔT_j	Drain-source breakdown voltage temperature coefficient	V_{DS} = V_{GS}; I_D = 0.25 mA	-	0.1	-	%/K
$R_{DS(ON)}$	Drain-source on resistance	V_{GS} = 10 V; I_D = 10 A	-	0.2	0.27	Ω
$V_{GS(TO)}$	Gate threshold voltage	V_{DS} = V_{GS}; I_D = 0.25 mA	2.0	3.0	4.0	V
g_{fs}	Forward transconductance	V_{DS} = 30 V; I_D = 10 A	13	18	-	S
I_{DSS}	Drain-source leakage current	V_{DS} = 500 V; V_{GS} = 0 V	-	2	50	µA
		V_{DS} = 400 V; V_{GS} = 0 V; T_j = 125 °C	-	100	1000	µA
I_{GSS}	Gate-source leakage current	V_{GS} = ±30 V; V_{DS} = 0 V	-	10	200	nA

Figure 41: The Gate Threshold of IRFP460 [26]

So, we started connecting the MOSFET on the breadboard without using gate driver such as BJT or IC as figure 42 shows.

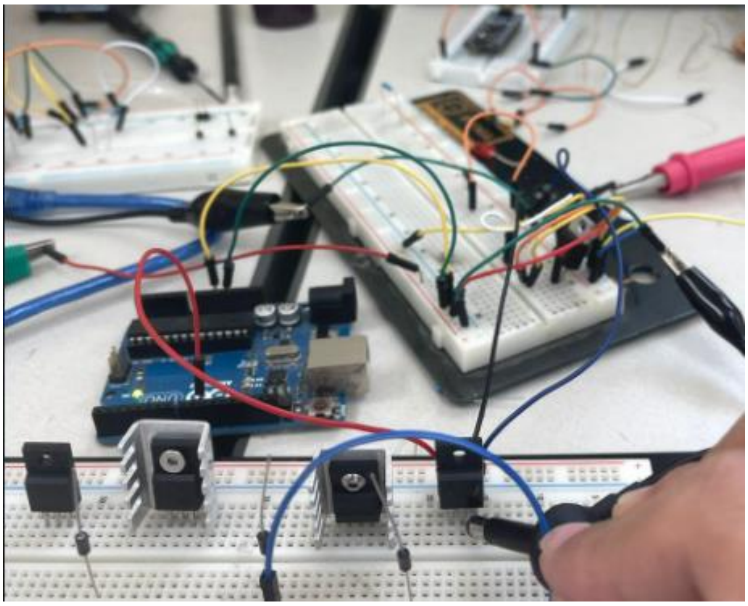


Figure 42: Testing MOSFET Without Gate Driver

As shown in the figure 42, we used breadboard to connect the components which are MOSFET, power supply and Arduino UNO. We turn on the supply and the Arduino sent signal to the gate. So, the main issue in this circuit was the output of the MOSFET was fixed voltage does not pulse as seen in figure 43.

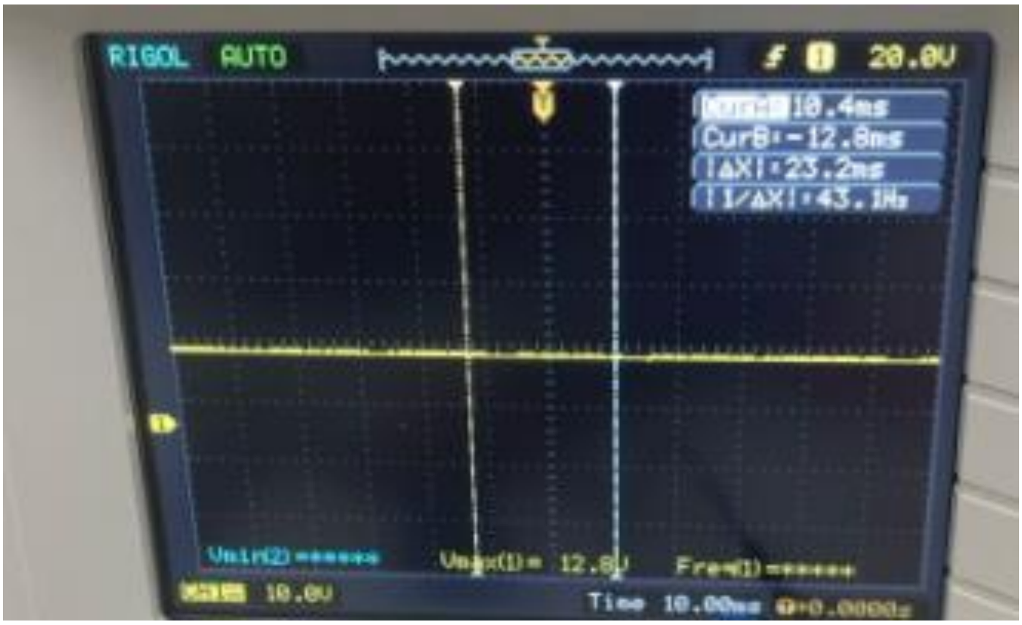


Figure 43: The Output of the First Trial

4.2.2 Second trial

After testing the first circuit and figure out the problem occur, we added BJT as a gate driver to the MOSFET. A gate driver is a power amplifier that takes a low-power input from a controller IC and converts it into a high-current drive input for the gate of a high-power transistor. The figure 44 shows the circuit of the BJT.

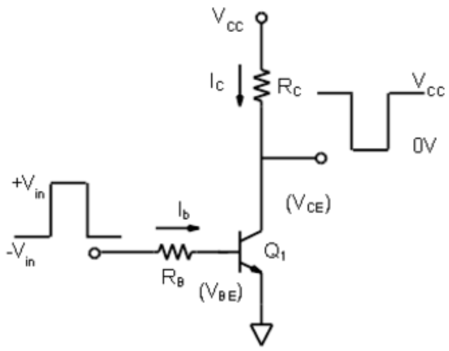


Figure 44: The Circuit of the BJT [27]

Figure 45: Arduino Signal's

As illustrated in figure 45, the Arduino sent signal to the gate of the BJT and the gate of the MOSFET received signals from the emitter of the BJT. However, the gate driver worked as insulator between the MOSFET and the Arduino to prevent any current inversed and protect the Arduino. Furthermore, we connected the gate driver to the MOSFET as figure 46 shows.

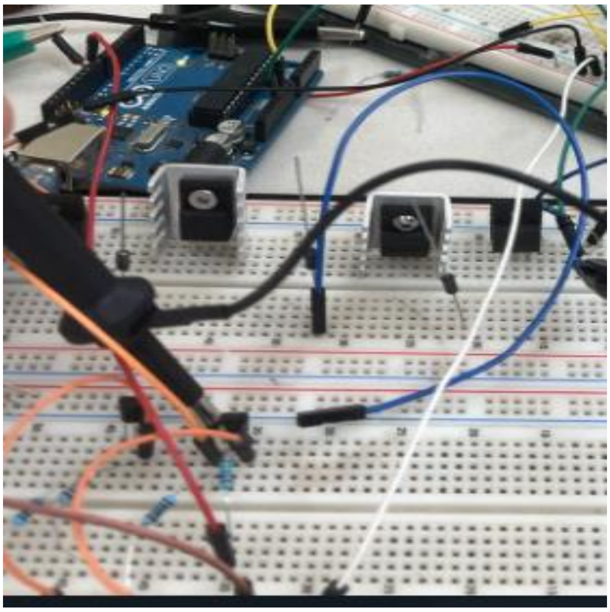


Figure 46: Second Trial Circuit

This experiment worked fine and the MOSFET gave us the desired output as we expected. Also, we test the MOSFET with 12V instead of 220V to prevent any dangers to the human and avoid damage the equipment. The figure 47 shows the desired output.

Figure 47: The Output of the MOSFET with Gate Driver

4.3 SPWM GENERATOR

After finding the proper Gate Driver for the MOSFETs, we will generate SPWM switching signals for the SPWM (H-Bridge) Inverter. First, we need to know that SPWM switching signals will be controlling the output of this project such as a 220V with 50Hz output needs a different SPWM switching signals from 220V with 60Hz output. Thus, it is a very important stage in our project.

4.3.1 First trial

First, we will test if the H-Bridge if it is working fine to do so. We will try to generate a simple Modified Sine Wave shown in figure 48. This will help us to know if the SPWM Inverter works properly or not.

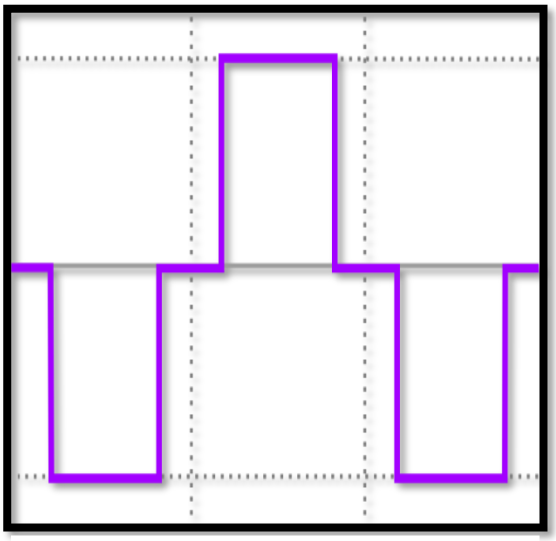


Figure 48: Modified Sine Wave

```
int pwm1 = 9;
int pwm2 = 10;
void setup(){
    pinMode(9,OUTPUT);
    pinMode(10,OUTPUT);
}

void loop(){
  digitalWrite(pwm1,LOW);
  digitalWrite(pwm2,LOW);
  delay(5);

  digitalWrite(pwm1,HIGH);
  digitalWrite(pwm2,LOW);
  delay(5);

  digitalWrite(pwm1,LOW);
  digitalWrite(pwm2,LOW);
  delay(5);

  digitalWrite(pwm1,LOW);
  digitalWrite(pwm2,HIGH);
  delay(5);
}
```

Figure 49: Modified Sine Wave Code

In figure 49, it shows the code that will generate signals in two pins which are 9 (pwm1) and 10 (pwm2). One pin represent the positive side and the other represent the negative side. First, it will set both pins to LOW. Then, it will set pwm1 to HIGH and pwm2 to LOW. After that, it will set both pins to LOW. Then, it will set pwm2 to HIGH and pwm1 to LOW and it will keep repeating. In addition, it worth to mention that a delay is a must to avoid interruption between the switches whenever changing signals occur. However, we manage to get the following output.

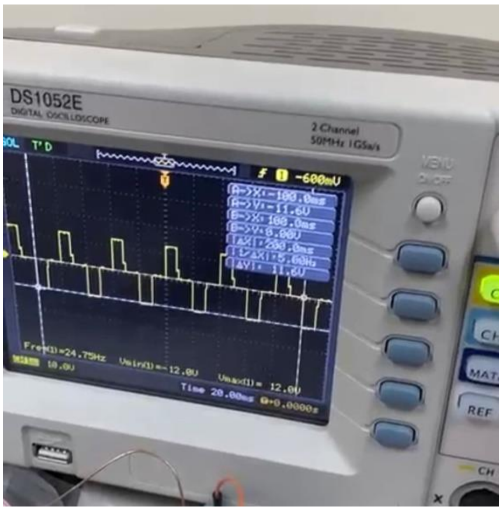


Figure 50: Modified Sine Wave Output

4.3.2 Second trial

After making sure that SPWM Inverter is working fine, we will try to produce a SPWM switching signals to MOSFETs to get desired outputs. We will use Timer One library which provides an easy way to change the switching frequency up to 100kHz. First, we will have two arrays that carry the values. These values were calculated by using the following formula: $x = ROUND(\sin(n \cdot 2\pi) \cdot 1024)$ while n is 90 values from 0.0 to 1.0. This formula was used for 220V array, but the following formula was used to find the value of the 110V array: $x = ROUND(\sin(n \cdot 2\pi) \cdot 512)$. After knowing how to find the values of the arrays that control the voltage of the sine wave, we will illustrate how we will control the frequency of the sine wave. We have 90 cycle that is repeated four times by using the next formula which is: $f = \frac{1}{T}$. the Arduino response time is around 8us. Then, we need only the value of a delay that can give us 50Hz or 60Hz sine wave. Thus, the equation for 60Hz is $60 = \frac{1}{(8+Delay)\cdot 10^{-6}\cdot 90\cdot 4}$ > Delay = 38us and for 50Hz it will be 47us. After finding all the required parameters, we can now test the SPWM switching signals. The code will be shown in Appendix – C. However, the following figures shows four outputs that were satisfying what we want.

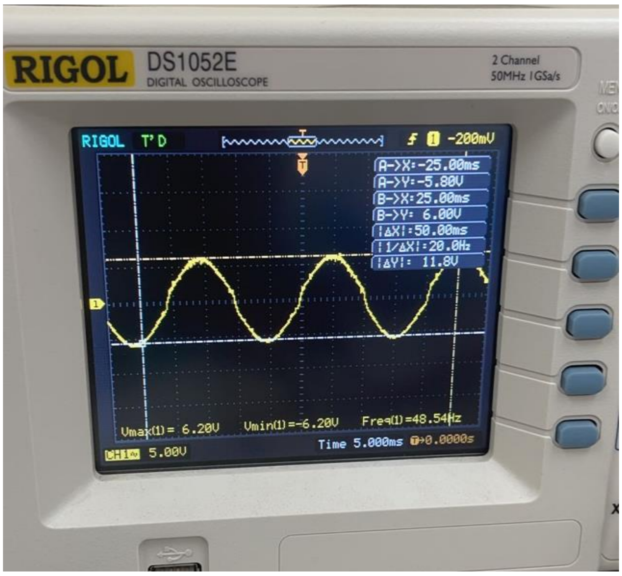


Figure 51: 6V with 50Hz

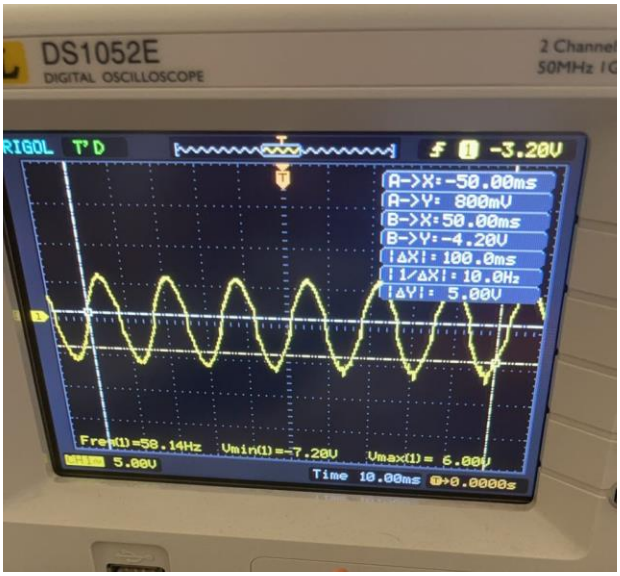


Figure 52: 6V with 60Hz

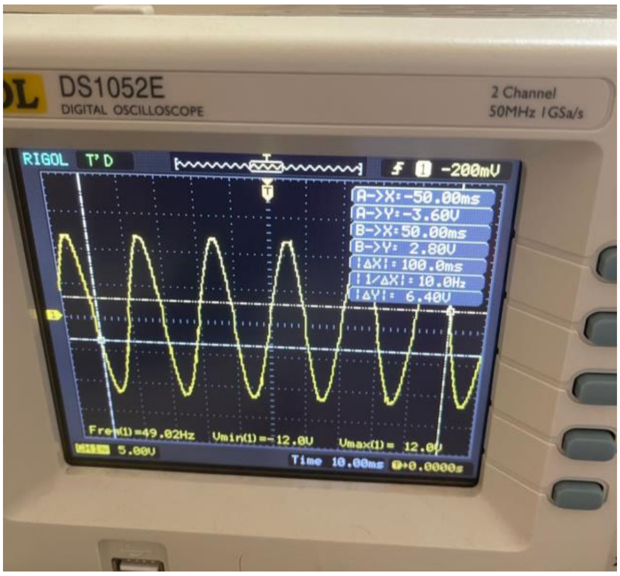


Figure 53: 12V with 50Hz

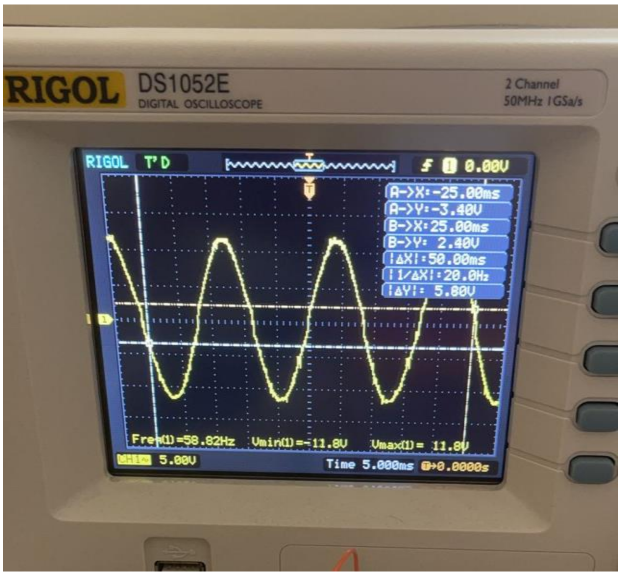


Figure 54: 12V with 60Hz

4.4 INVERTER

This part discusses the last block of the smart converter challenge, how it was tested, how we arrived at the final design of the inverter circuit, and all of the critical issues that we highlighted throughout our experiment and development of the inverter circuit. The theoretical configuration of the inverter is shown in the diagram below (DC to AC converter).

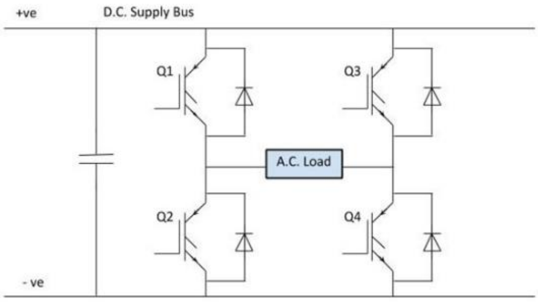


Figure 55: H- bridge Circuit

4.4.1 First trial

The usual connection was suggested for the testing circuit, and we began by connecting an H-bridge inverter circuit on the breadboard, as shown in the diagram above. Therefore, the primary problem with this circuit was that the pins of the components were not correctly linked to one another. Also, another problem is that some of the signals get distorted wherever it passes into the board, which leads to an error in the IR2110 driver and ultimately causes it to burn. As shown in the figure below.

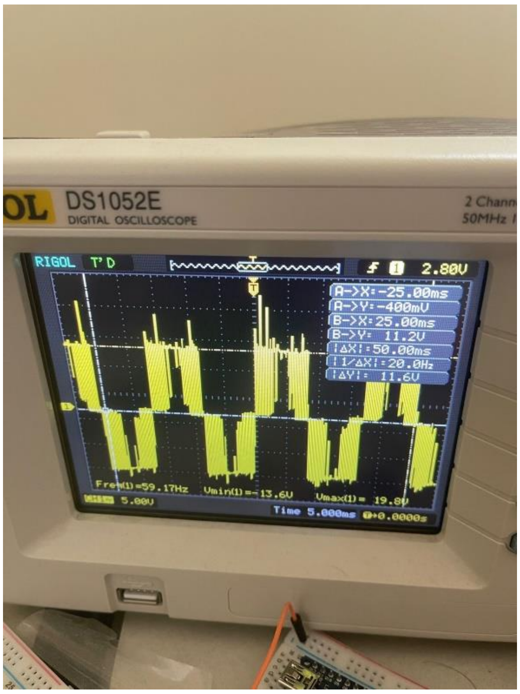


Figure 56: The Output of the Inverter Circuit in the Breadboard

Another point to consider is that the values of certain components were picked at random based on the results of some testing circuit that was found in other sources. However, the circuit functioned well for the low voltage application without any issues. Also, the input voltages of 12v and 5v were not explained clearly, and there was another problem with wires that went all the way around the circuit, making it difficult to track them down if a problem arose. As shown below.

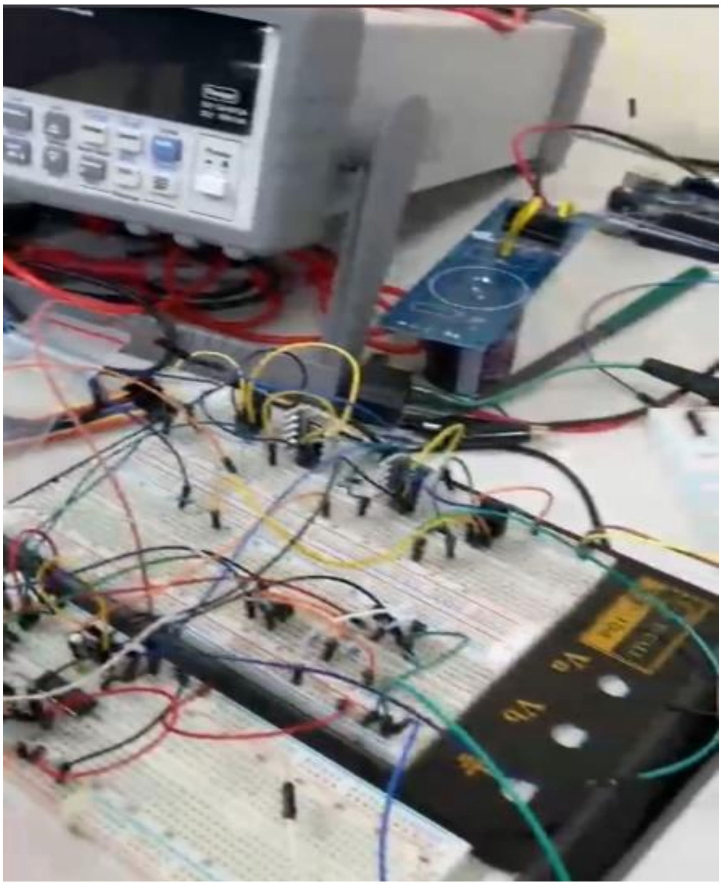


Figure 57: Inverter Circuit

4.4.2 Second trial

Following the successful completion of the previous circuit, we chose to design a PCB schematic and begin soldering. During this process, we added the things that were missing, such as the input and output voltages, and ensured that the wiring was done correctly in order to prevent noises and short circuiting, both of which are likely in power electronics due to the spike voltages that are present.

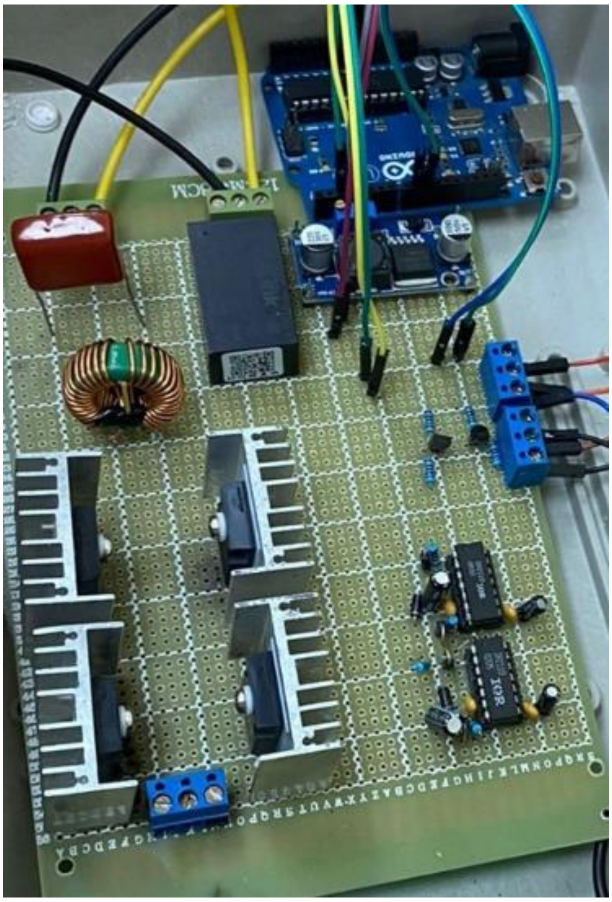


Figure 58: Inverter Circuit in PCB

4.5 FINAL PRODUCT

The smart converter challenge is what we provide as a product. The converter is made up of a number of critical building pieces, beginning with the AC-DC converter and ending with the inverter, which is both the last component and the most crucial component.

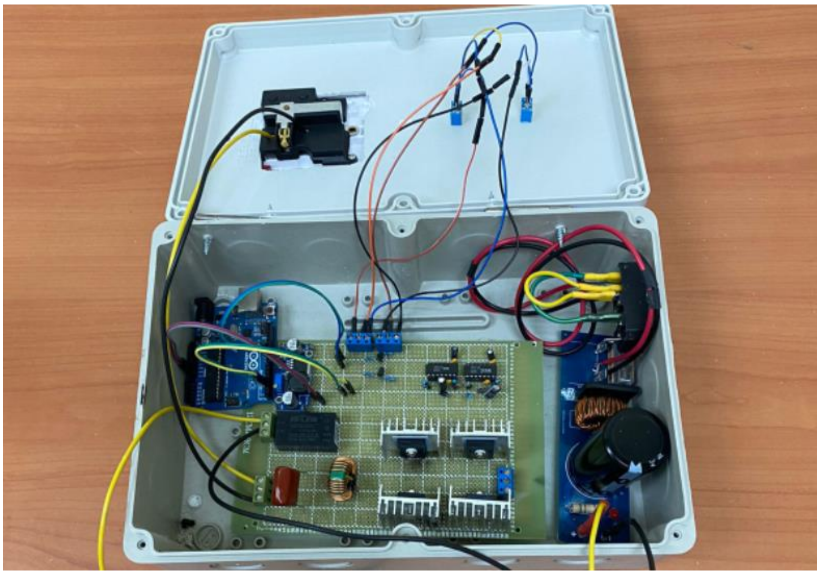


Figure 59: The Final Product

As can be seen in the figure that was provided before, the main board consists of two different circuits. The circuit for the power supply, where the input is an AC current of 220 volts and 60 hertz. In addition, the fuse was installed at this point in order to secure the circuit from a high current and high load. In order to convert the AC voltage into DC voltage, a full-bridge rectifier coupled with an LC filter is used. In addition, it includes two adapters, one of 12 volts (boost) and another one of 5 volts (SMPS), to feed the inverter and other devices such as microcontrollers (Arduino) as well as the MOSFETs driver IR2110. The photograph shows the converter where we have four power MOSFETs and two gate drivers (IR-2110). Additionally, the signals input that are required to link the SPWM signals that are required to operate the MOSFETs driver are already supplied from the microcontrollers (Arduino).

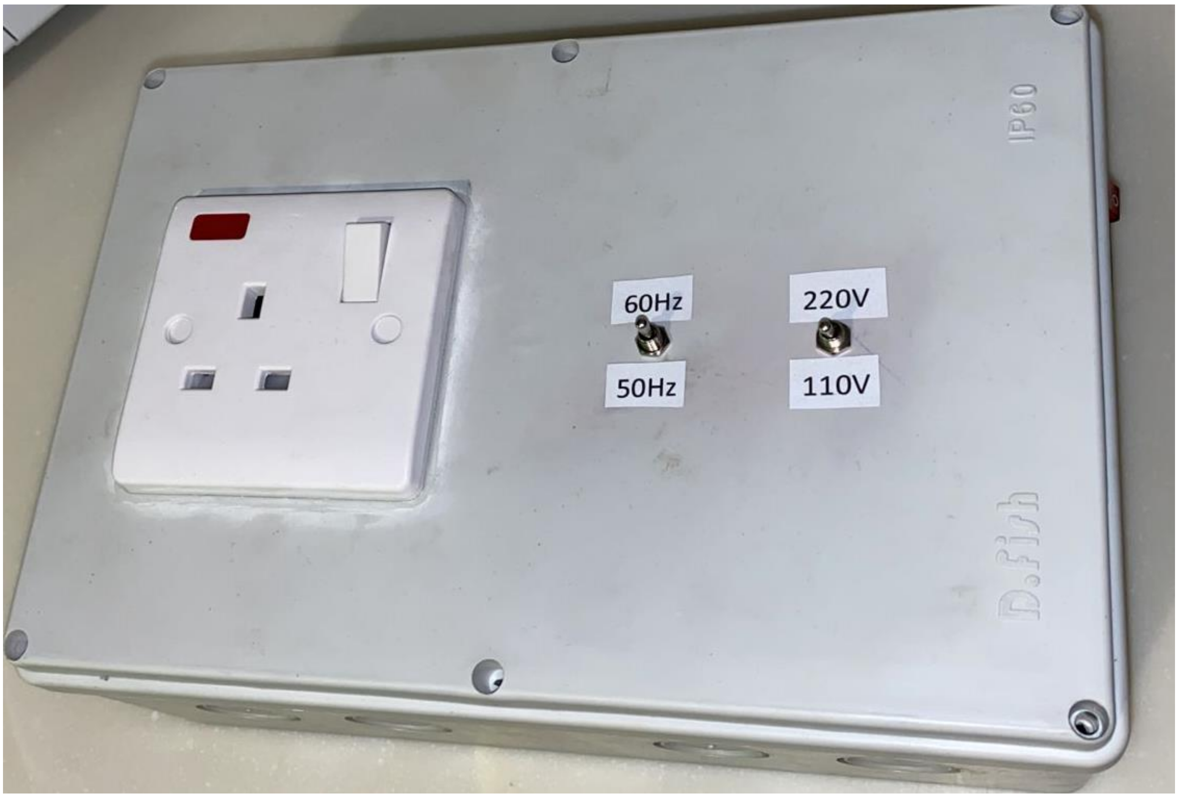


Figure 60: The Final Product from Top View

CHAPTER – 5 RESULTS, DISCUSSION, AND CONCLUSIONS

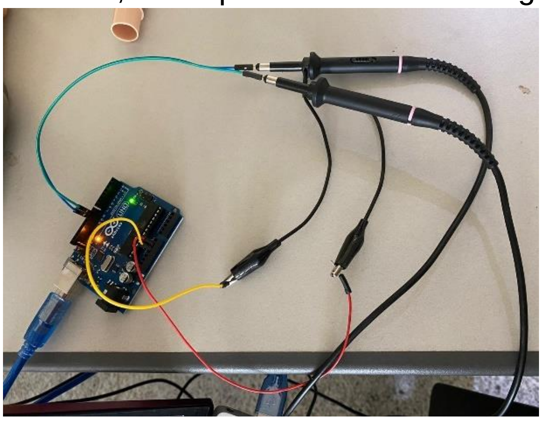
Due to the complexity of the device, it should be divided into a part and examined individually to see how each one operates. This will allow any issues to be identified and documented. Therefore, throughout the course 499 (SENIOR DESIG PROJECT) we have validated each block individually. Now we have to carry out an experiment for the system once it has been put together to make clear that the hardware as well as software system of the system devices are operating normally.

5.1 RESULTS AND DISCUSSION

This section will go into detail about how we validated all of the parts that went into the final product. Furthermore, using modern software tools such as Excel and MATLAB, the results of the validation procedure and the collected experimental data for each major subsystem of the final product will be collected and organized in the form of tables, oscilloscope graphs, and scattered plots. In addition, any assumptions, deviations, experimental uncertainties, and problems will be addressed in this section.

5.1.1 Pulse Generator

Here, we will show the output signals form the Arduino. Arduino Nano has been used in this project. We will generate PWM signals from pin 9 and pin 10. However, these pins will be connecting to BJTs and Gate Driver. The waveform and



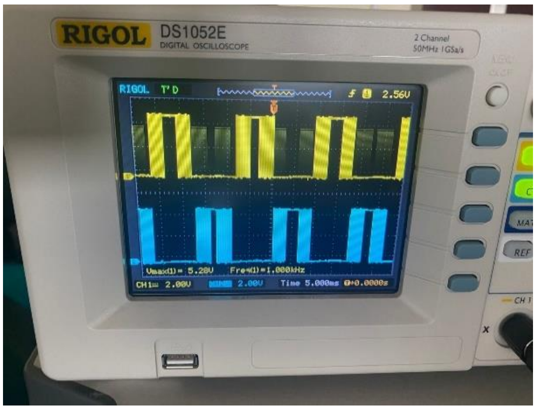


Figure 61: Circuit Used to Measure Signals. *Figure 62: The Outputs Waveform of pin 9 & 10.*

the circuit will be shown in the following figures:

As we can see, the outputs were as expected. A two PWM signals were appeared from pin 9 and pin 10. In addition, pin 9 will be connected directly to the high side unput of the gate driver and to a BTJ that its output will be connected to the low side input of the gate driver. However, pin 10 will be connected the same connection as pin 9. The reason is to isolate the Arduino from the high voltage and to improve the switching time since it might cause a problem to the H-Bridge.

5.1.2 LC Filter with The Switching Frequency

Before we go into this experiment, we will first talk about the spectrum of the SPWM. The spectrum of a wave is characterizing the conveyance of wave energy regarding recurrence and bearing. However, the spectrum of the SPWM is easier to be filtered than the PWM. Thus, we decided to go will the SPWM inverter. As shown in figure 63, we can illustrate that the fundamental frequency has a very large space between it and the nearest harmonic which makes it easy to be filtered as we said.

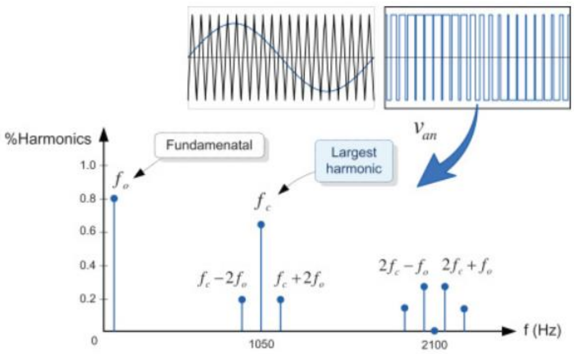


Figure 63: The Spectrum of SPWM. [28]

In this experiment, we will observe the relation between the LC filter with the switching frequency. First, we will show the equation of the cut off frequency:

$$fc = \frac{1}{2\pi \cdot \sqrt{LC}}$$

While the cut off frequency also equals to:

$$fc = \sqrt{fout \cdot fsw}$$

Thus, we will get:

$$\sqrt{fout \cdot fsw} = \frac{1}{2\pi \cdot \sqrt{LC}}$$

From the above equation, there is only one unknown parameter which is the switching frequency. After finding all the parameters, we will observe the output voltage and frequency. We have 4 capacitors and 3 inductors with different values. Thus, we will do the experiment 12 times. Each time we record the output and to finally see what is the best filter that we can use. The following table will show the output of these experiments:

Table 11: Outputs for LC Filter Experiments

Capacitor (uF)	Inductor (mH)	Fsw (Hz)	Fout (Hz)	Vout (v)
0.71	2.75	216221	-	-
0.71	5.27	112829	-	-
0.71	12.77	46563	62.86	11.2
1.53	2.75	100338	-	-
1.53	5.27	52358	61.33	13.0
1.53	12.77	21608	62.28	12.4
2.71	2.75	56648	58.87	12.0
2.71	5.27	29560	61.48	11.5
2.71	12.77	12199	61.44	12.1
4.78	2.75	32117	59.26	12.7
4.78	5.27	16759	61.68	12.2
4.78	12.77	6916	58.09	12.1

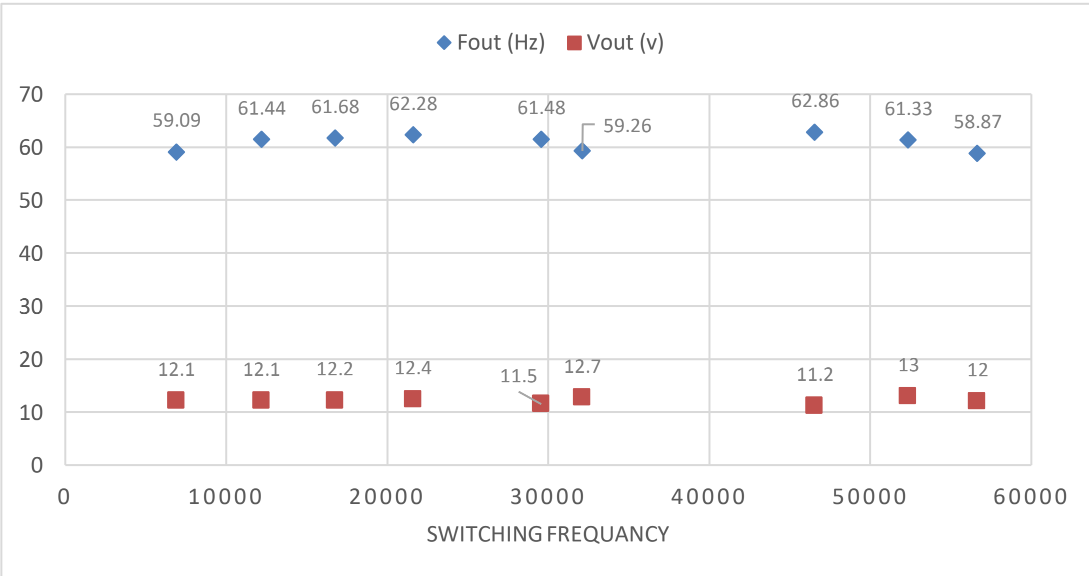


Figure 64: Graphical Representation of the Data

Discussion:

As we can see in table 11, some of the experiment were undoable due to the limitation in the switching frequency library which is 100kHz. In addition, we can observe that some noises were noticed which is not desired. It worth to mention that whenever we increase the switching frequency from what is written, the Gate driver get burned. In figure 63, we can clearly say that the best filter we observe from this experiments is 2.71uF, 2.75mH with 56kHz switching frequency which was the highest switching frequency we could do with these components because it gives us exactly 12V means that it reaches 0% voltage variation and 58.87Hz which manages to get -1.8% frequency variation.

5.1.3 Voltage Difference

After thoroughly examining each component and determining the expected value, we tried test the circuit in low voltage $12V_{DC}$ to make sure that everything works fine, and the component connected perfectly. Also, the test has been used to avoid any damages to the circuit. Therefore, after testing the circuit we come up with the desired output that we are looking for. Then, we decided to test the circuit in high voltage 311 V_{DC}. Thus, we connected the output of the AC-DC rectifier to H-bridge in DC-AC inverter. So, when we supplied the circuits with high voltage suddenly two MOSFETs was burned along with its gate driver. The figures below show the damages:

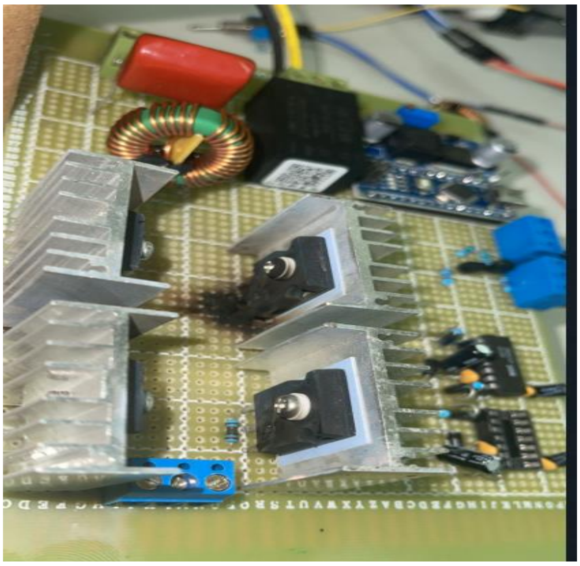


Figure 65: MOSFET After Burned

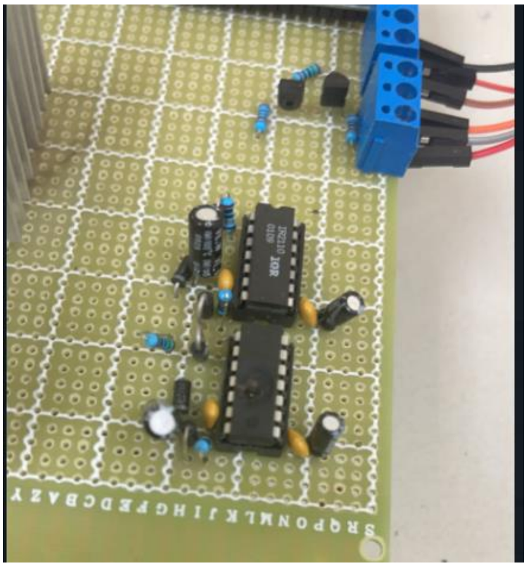


Figure 66: The Gate Driver After Burned

However, after destroying some parts of the circuit we found that the voltage difference was the only reason of destroyed the parts. There is voltage difference between the input of the rectifier and the output of the inverter it was around 152 V. Also, there was voltage difference between the measuring devices such as oscilloscope and the input of the rectifier. This problem was solving by checking the ground connection and make all parts with common ground. Also, we fed the circuit from one input to make sure that the common ground connected perfectly. Furthermore, we tested the circuit and it worked fine.

5.2 EVALUATION OF SOLUTIONS

In this section, we will reflect upon the final product based on the results that we discussed earlier.

5.2.1 Technical Aspects

Several significant considerations contribute to customer satisfaction in the baseline design of the project as well as avoid any constraints and relevant to the engineering standards So, the results were based on the validation procedures. As we mentioned earlier in the system description section, to satisfy the customer needs, all the in-scope items were fulfilled. Therefore, the first stage was AC-DC converter and LC filter have been used that help us to get pure DC voltage with fewer voltage. In this stage, there was a problem with discharging the capacitor, during no load condition the capacitor charged to the maximum value. This problem led to damage the circuit and it will be so danger to the human. This problem solved by adding LED as a load to discharge the capacitor. Also, there was another problem with the voltage of the wall socket it is about 327V which was unexpected value. This problem led to damage the protection device (fuse) because the limit of the fuse was 3A, so the current increase above the limit due to the increase in voltage of the wall socket. The solution of this problem was replaced the fuse with high limiting value like 10A.

Our desired output was 220V and 110V thus DC-AC inverter was used instead of DC-DC flyback converter to keep the input voltage constant and decreased to the desired output. There were many problems with the flyback, it was very difficult to deal with it and the output was unacceptable. Also, the main issue of the flyback was the spark voltages very high. All these problems caused damage to the equipment such as MOSFET. So, after doing some research, we found that we can decrease the voltage in the DC-AC inverter stage by decrease the width and numbers of the pulses. This technology has been very useful to us and the product size will be smaller. Furthermore, the last stage was DC-AC inverter and the SPWM with H-bridge have been used to convert DC to AC. Also, LC filter used to filter the pulses.

The main issue of the last stage was the gate driver which is IC (IR2110). This IC was highly sensitive, when there was instantaneous short circuit in millisecond the IC burned. This problem has been solved by using the correct code and working with it very accurately.

Finally, all these technical mistakes led us to have a good product with high efficiency, quality and hopefully the product will be improved in our design to get it work in the future.

5.2.2 Environmental Impacts

This section will show many things such as the toxicity of the components used in this project and its environmental impact. First, this project will use a lot of components such as PCBs, diodes, SMPS, full-wave rectifier, capacitors, inductors and MOSFETs. The materials of electrical components are used semiconductors materials alongside petroleum-based materials. For example, polystyrene, PVC and PET are commonly used in components like the capacitors. Moreover, silicon and copper are a fundamental material in constructing electronics components and PCBs. Luckily, copper has no bad effect on the environment which is one of main reasons behind using it [29]. However, these substances are well-known with their toxicity. It will affect the health of the workers during manufacturing these components [30]. This project will have no harm to the environment. In a matter of fact, this project will be made with safety materials.

5.2.3 Safety Aspects

There may be several safety risks in the project, but the majority of them are attributed to the electrical risks associated with the high voltage. However, these troubles can be mitigated by using safety aspects and isolating the circuits. In addition, we must protect our components from these hazards by using protection device such as fuses and using heat sinks as coolant for the MOSFET.

5.2.3.1 Chemical risk

Chemical risks exist, particularly for these large electrolytic capacitors, as any problem with either of these capacitors will result in emissions of MnO_2, polymer, and sulphonic when they exploded. These emissions will cause air pollution. As a result, we must be cautious of them and devise a method to discharge the capacitor after using the device and to protect the human against these emissions.

5.2.3.2 Electrical risk

Electrical risks are always present in such a project in the power electronics field. In our project, we will deal with a high voltage, these voltages are harmful for the us, so we have to be careful when performing the experiments. Also, when we use large capacitance and inductance components, there is a high possibility of voltage spikes, especially when there are many high switching devices with high frequencies. As a result, fuses for high voltage circuits and isolation for uncovered wires are required to maintain safety. Another point is that the project will be enclosed in a frame like box to protect the user from any problems or vibrations that may occur throughout procedure.

5.2.4 Financial Aspects

Analysis of costs are playing a significant role in the project's analysis. In order to get an idea of the project's cost, you should estimate the most expensive components. As can be seen in table 11 which represents the components and their prices, as well as the total cost, which is around 2000SAR.

As it’s discussed before this project will have a major impact on the local and global market in-short term if it is provided with the right marketing. The project will have a major impact in the short-term as long as sensitive devices need certain criteria, there will be a need for a converter. Conversely, in the long term as long as technology will advance, the demand for a converter may disappear.

When the product reaches the level of mass production which means high demand on the devices. This will reduce the prices by ordering a large number of components and dealing with the manufactory directly. Moreover, in order to reduce labor costs, the following should be done:

- Hiring highly efficient workers
- Automated production line

Eventually, many other ways should be done alongside what we have mentioned to make the project profitable such as providing investors that invest in this professional project.

Table 12: Project Cost Analysis

Component	Quantity	Price per Each (SR)	Total Price	Source
PCB	3	111	333	[31]
Arduino UNO	3	45	135	Local shop
Bridge Rectifier	2	15	30	Local shop
SMPS	1	19.09	19.09	[32]
SPST	1	7.50	7.50	[33]
SPDT	3	4	12	[34]
Heat sink	6	9.5	57	[35]
Inductor	5	8	40	Local shop
Capacitor 820uF	3	15	45	[36]
Diode (1N4007)	20	1	20	[37]
MOSFET IRFP460	8	15	120	[38]
Case	1	30	30	Local shop
Resisters	25	0.5	10	[39]
Soldering equipment	1	156.87	156.87	[40]
Capacitor kit	2	30	60	Local shop
IC IR2110	40	12	480	
Header Pins	4	5	20	Local shop
BJT MPSA44	6	2	12	Local shop
Boost XL6009	1	29	29	[41]
Fuses	7	2	14	Local shop
Fan	1	20	20	Local shop
Shipping	-	-	350	-
Total	-	-	2000.46	-

5.2.5 Social Impacts

Each device has an impact on the community from an economical view. In our case, the converter nowadays is crucial due to its wide uses (e.g., medical equipment. highly sensitive devices.). When there is a growth in the hand of technology and demand for devices that require concentration also certain inputs, there will be a need for a converter. Also, that will prevent any internal damage to the components of the devices and give a long life to the device, reduce the losses of power and make the devices more efficient. And here it comes to the effectiveness of our devices on society, by keeping their devices protected and more extra live time for the devices. Furthermore, there will be a major requirement for supervising for these types of equipment. Eventually, this will provide more jobs for the society. There are other relevant perspectives that interact with our future product. Furthermore, the product will be available in the local markets, and we hope that it will be available in the global markets. Also, it will challenge all other converters in terms of price, quality, and efficiency. Moreover, it will give the sensitive devices the best performance and protect them from undesirable input such as voltage and frequency.

5.3 CONCLUSIONS

In several paragraphs, summarize the need, the solution, and the final achievements of this project. List some recommendations for future improvements to the implemented prototype to reach the market in its final product form.

Many sensitive devices such as motors, medical and healthcare devices, have certain criteria and specifications. It is very important to concern about it. Thus, this project aims to provide a safe way for protecting these devices from unwanted input.

To do so, we have decided to build a Smart Converter. This converter handles 500W with an 85% efficiency. Also, it gives selectable outputs which are 220V 50/60Hz or 110V 50/60Hz. After we made this project, we found out that some designs have problems. Each has different solution. Moreover, some designs were not capable of satisfying the aim of this project.

We learn a lot of things during this journey. Also, we managed to utilize some power electronics. First, we implemented a full-wave rectifier & a SPWM H-Bridge inverter. In addition, we understood many principles such as implementing switching signals in power electronics, designing an LC filter and programming an Arduino. We also learned how to design a Printed Circuit Board (PCB) by using modern software tools. These PCBs that were designed by us, used in this project.

For some future improvements, we could have a better outer design by using 3D printer. Also, we could use touchscreen for user interface instead of two switches that we have. Finally, we could minimize the size of the PCBs that were designed to be much smaller and lighter.

APPENDIX – A: VALIDATION PROCEDURES

Boost Converter Validation by Ibrahim Bafaqeer

Introduction

To design a project, you must be realized the behavior and characteristics of the component that will be used in the project. In our case designing a project, the final stage which is convert DC to AC by using SPWM inverter will causes losses due to the high switching frequency and tripping the signal. This problem will be solved by a boost converter (step-up) that converts DC to DC. In addition, the components used in the boost circuit are responsible for dealing with the losses in SPWM. So, we will put it to the test and see what kind of results we get from the experiment.

Some assumptions are required to carry out this experiment. Assuming there is no error in the oscilloscope that will interfere with reading the value. Furthermore, the inductor's leakage inductance will be negligible, as will the losses caused by the MOSFET and the gate driver losses caused by the BJT. Furthermore, for safety reasons, we will conduct the experiment with lower voltages such as 12Vdc, but the voltage used in the main project will be 311Vdc.

Objective

Test the boost converter circuit with lower voltages to determine how the duty cycle of the gate signal will be affected and to determine the appropriate capacitor values with different load. These parameters will also have a significant impact on voltage variation.

Variables

- Output voltage
- Duty cycle
- Capacitor
- Switching power loss
- Voltage variation
- Load

Constants

- Input voltage
- Switching frequency
- Inductor
- Diode

Background

A DC-DC converter is a power converter that converts a direct current (DC) source from one voltage level to another by temporarily storing the input energy and then releasing it to the output at a different voltage. Electric energy can be stored in magnetic field storage components (inductors, transformers) or electric field storage components (capacitors).

There are several types of DC-DC converters, but we will mention one of them which is boost converter (step-up). The output voltage of a boost DC-DC converter is greater than the input voltage. The output current will be less than the input current due to power conservation (assuming no losses).[41]

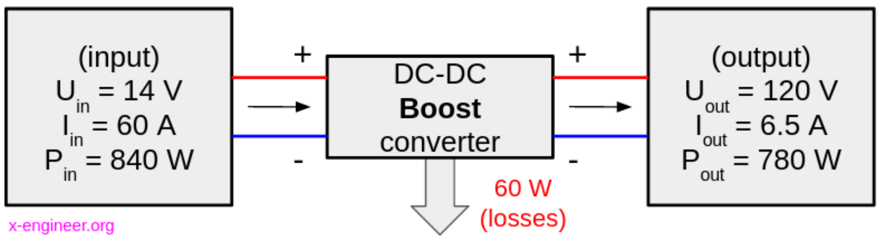


Figure 67: Principle of Operation of a DC-DC Boost Converter

The Body

Tools

The following tools were used to configure the experiment:

- DC power source 12V
- Oscilloscope
- Arduino
- Digital Multimeter
- Wires
- Breadboard

- FQP10N60C N-channel MOSFET
- MPSA44 BJT as gate driver
- Load (resistive load) 10 kΩ
- Computer
- Inductor 40mH
- Diode

Circuit Schematic

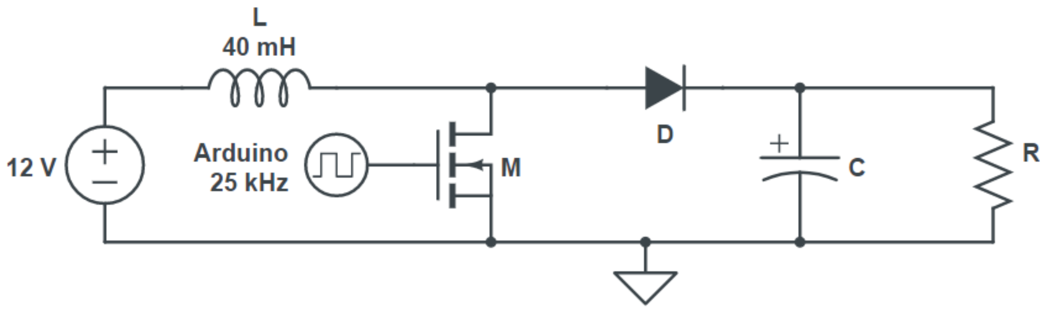


Figure 68: Schematic Circuit

Analysis for Boost (Step-up) Converter

The analysis assumes the following:

1- Steady-state conditions exist

2- The switching period is T, and the switch is closed for time DT and open for (1-D)T [42]. The figure below show the switching period:

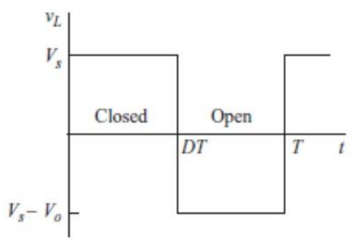


Figure 69: Switching Period

The analysis proceeds by examining the inductor voltage and current for the switch closed and again for the switch open.

Analysis for the Switch Open

When the switch is opened, the inductor current cannot change instantaneously, so the diode becomes forward biased to provide a path for inductor current. Also, the inductor will discharge through the capacitor and the load to increase the voltage [43].

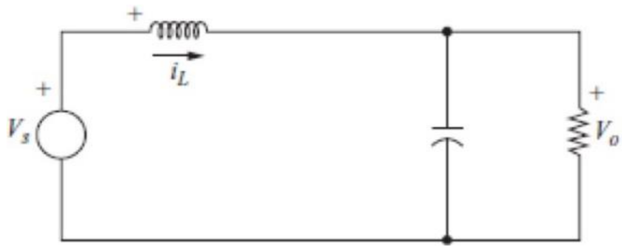


Figure 70: Equivalent Circuit for Switch Open

Analysis for the Switch Closed

When the switch is closed, the diode is reverse biased. The inductor will be charged during the t_{on} of the duty cycle. As well the t_{on} increase the voltage stored in inductor will be increased.

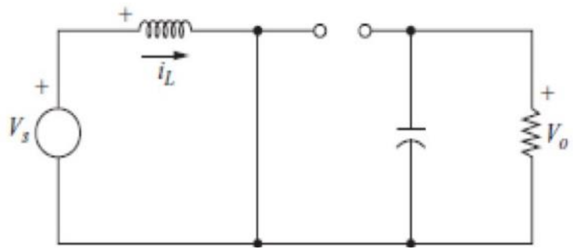


Figure 71: Equivalent Circuit for Switch Closed

Equations

$$V_o = \frac{V_s}{1-D} \qquad Eq1$$

The peak-to-peak output voltage ripple can be calculated from the capacitor current waveform. An expression of ripple voltage is then

$$\frac{\Delta V_o}{V_o} = \frac{D}{RCf}$$

Where: f is the switching frequency. Alternatively, expressing capacitor in terms of output voltage ripple yields

$$C = \frac{D}{R(\frac{\Delta V_o}{V_o})f}$$

Work Plan

1- Connect the circuit like figure 65
2- Connect the BJT as gate driver to the MOSFET

3- Connect the Arduino to the gate of the MOSFET
4- Make sure the value of the parameters is correct
5- Set the power supply to 12V
6- Turn on the power supply
7- Check the pulses by oscilloscope
8- Measure the voltage across the load by oscilloscope
9- Compare the calculated and measured value of voltage
10- Change the duty cycle and the capacitor values
11- Repeat the steps and write down the result

Data Collected

The data has been collected from this experiment will be shown below to compare the results. The testing condition are:

$$V_{in}=12Vdc,\ f=25\ kHz,\ L=40\ mH$$

In the table 13 below, shows the duty cycle that the experiment will be used, and the output voltage will be dependent on these values. We used Arduino to generate these values

Table 13: Duty Cycle Calculation

D	$T_{on\ (us)}$	$T_{off\ (us)}$
0.45	18	22
0.5	20	20
0.59	23.6	16.4
0.74	29.6	10.4
0.8	32	8

In the table 14 below, shows the ripple voltage with 50 uF. Also, the table has different values of load.

Table 14: Ripple Voltage with 50 uF

	50 uF			
Load (Ω)	Calculated (ΔV)	Measured (ΔV)	Error %	V_o (V)
1000	0.0036	0.005	38.88	21.81
2000	0.002	0.0024	20	24
3000	0.0016	0.002	25	29.26

5000	0.0011	0.002	81.81	46.15
10000	0.0006	0.00068	13.3	60

Thus, In the table 15 below, shows the ripple voltage with 200 uF. Also, the table has different values of load.

Table 15: Ripple Voltage with 200 uF

	200 uF			
Load (Ω)	Calculated (ΔV)	Measured (ΔV)	Error %	V_o (V)
1000	0.0009	0.00095	5.5	21.81
2000	0.0005	0.0006	20	24
3000	0.0004	0.00049	22.5	29.26
5000	0.0003	0.0004	33.33	46.15
10000	0.0001	0.00015	50	60

Results

The association between resistance and ripple voltage is depicted in Figure 69. As can be seen, there is big variation between the calculated and measured values due to the low capacitor value. As well, the ripple voltage decreases as the resistance increases.

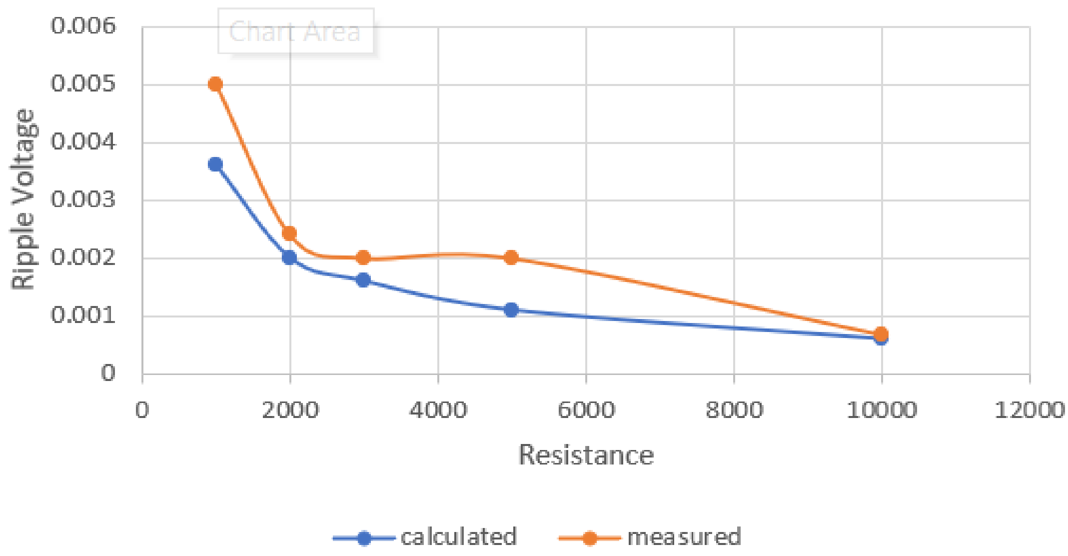


Figure 72: Compare the Values of Table 14

The association between resistance and ripple voltage is depicted in Figure 70. As can be seen, there is little variation between the calculated and measured values due to the high capacitor value. As well, the ripple voltage decreases as the resistance increases.

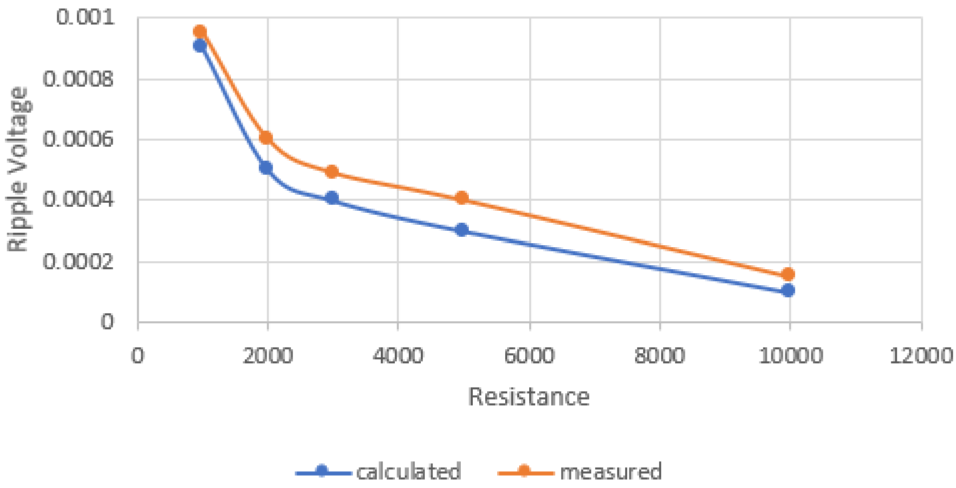


Figure 73: Compare the Values of Table 15

So, as we see the ripple voltage depend on two things resistance and the most effect parameter is the capacitor. The capacitor is playing big role in ripple voltage. Furthermore, when the capacitor increases the ripple will be decreased as well as the resistance.

Discussion

Based on the previous section's results, it can be seen that the ripple voltage in the first experiment (table 13), both calculated and measured, were roughly different due to the low value of capacitor and the ripple voltage has been affected. Whereas the second experiment (Table 14) exhibits a noticeable deviation due to the instrument used, specifically the oscilloscope, which was unable to measure the small values of ripple voltages. Also, the second experiment has better ripple voltage than first experiment because the second experiment has been used high value of capacitor.

Also, table 13 were determined by using two method MATLAB and calculation using this equation:

$$D = \frac{t_{on}}{T} = \frac{t_{on}}{t_{on}+t_{off}}, \; T = \frac{1}{f}$$

The figure below shows just one example of experiment 2 in table 14 by MATLAB:

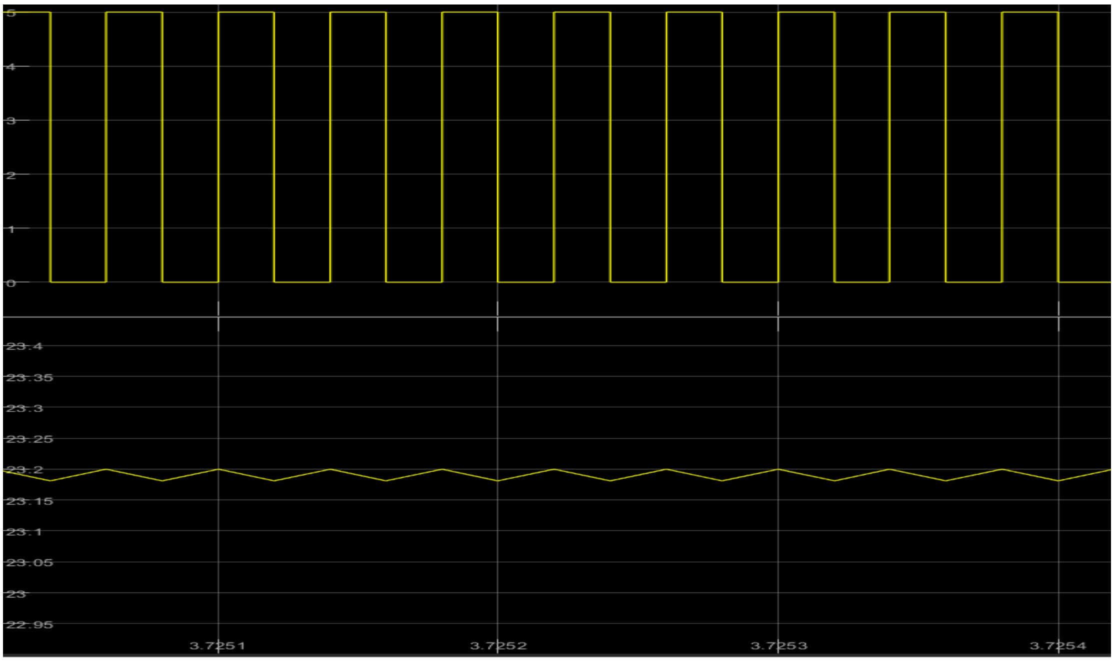


Figure 74: Shows the Pulses and ripple voltage of 50% DT with 200 uF.

Conclusion

The oscilloscope is affected the results. So, to overcome the drawback of the oscilloscope, a modern oscilloscope capable of measuring small voltage values is required to obtain an accurate result of the voltage waveform.

Voltage Ripple Validation by Ammar Alqrni

Introduction

The residual periodic fluctuation of the DC voltage inside a power supply obtained from an alternating current (AC) source is known as ripple voltage in electronics. After rectification, the alternating waveform is not completely suppressed, resulting in this ripple. It is an undesirable behavior that causes damage, heat, noise, and distortion to electronic equipment. This experiment was created to measure and observe the impact of observed ripple voltage, which will cause practical issues to the project circuit if it is used in its intended use. In addition, there will be a fluctuation in the internal heat, which will negatively impact the behavior of the integrated circuits. Furthermore, the purpose of this experiment is to make a comparison between the simulated ripple voltage and the actual observed ripple voltage.

Objective

This experiment was carried out to measure and compare the ripple voltage of the rectifier while it was operated with various loads and capacitors.

Variables and Constant

Variables and constants are both used. Load resistance and capacitance are the factors to consider. The voltage source and the frequency are the only constants in this equation.

Background

In a non-ideal DC voltage waveform, the constant DC component is combined with an alternating (AC) voltage, which is the ripple voltage, to generate a composite waveform. When compared to the DC component, the ripple component is frequently insignificant, but when measured in absolute terms, ripple may be measured in millions of volts. ripple itself is a composite waveform composed of harmonics of some fundamental frequency, which is usually the original alternating current line frequency, but in the case of switched-mode power supplies, the fundamental frequency can be in the tens of kilohertz to megahertz range, depending on the application. The features and components of ripple vary depending on the source: single-phase half- and full-wave rectification, as well as three-phase half- and full-wave rectification, are all possibilities. Rectification may be regulated through the use of Silicon Controlled Rectifiers (SCRs) or uncontrolled (by capacitors) (diodes). In this experiment we will used full-wave rectification with diodes (uncontrolled). As seen below, this is the waveform of a full wave with a capacitor to minimize the rectifying ripple, which is the situation in our experiment.

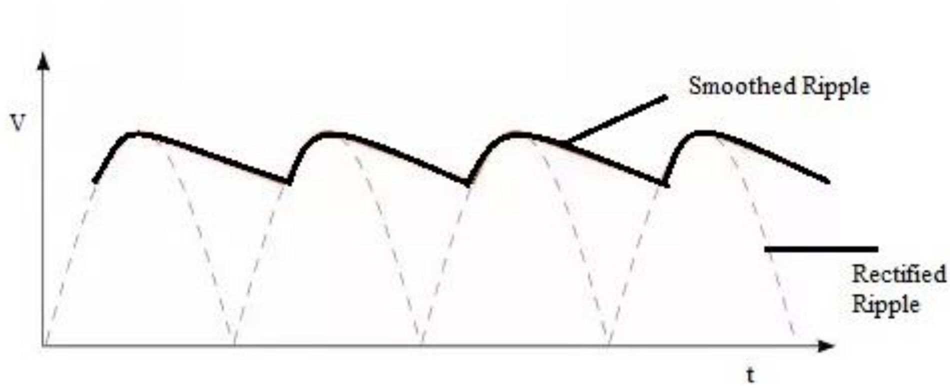


Figure 75: Full-Wave Rectifier's Ripple Voltage

Safety

When dealing with electricity, it's critical to follow all safety procedures. There must be no compromises in terms of safety, and basic ground rules must be observed initially. The following fundamental recommendations for safe electricity handling can assist you when dealing with electricity specially with AC/DC converting:

- When working, always use insulated tools.
- When working on any branch circuit, always wear suitable insulated rubber gloves and eyewear.
- Repairing electrified equipment should never be attempted. Always use a tester to ensure that it is de-energized first.
- Know your country's wire code.

The main issue we had was that when we attempted to replace the old capacitor with the new one, the old capacitor was still energized. By following the instructions above, we were able to resolve the problem.

The Body

The tools that were used:

- Power supply AC 220
- Oscilloscope
- Cable
- Capacitance (2x820uF-220)

- Resister ()
- Rectifier

Circuit Schematics

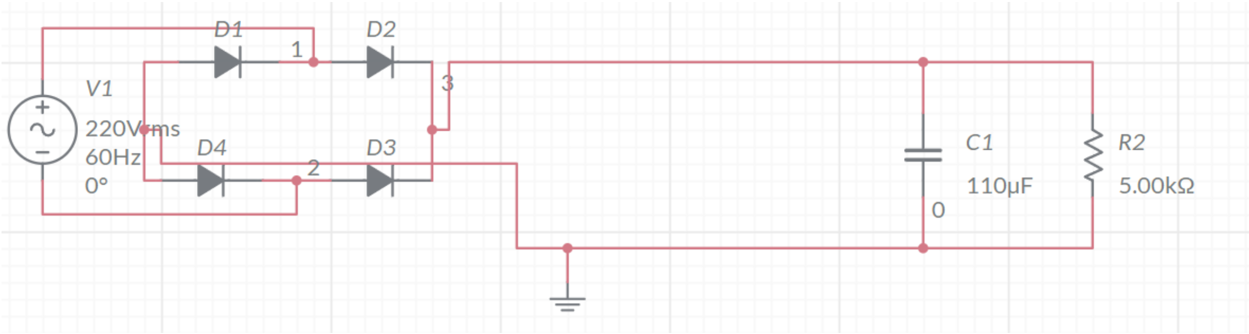


Figure 76: Schematic Representation of a Circuit

Experimental Setup

- Connect the rectifier to the power source.
- Connect the RC filter to the system.
- Connect the power source to the circuit so that it may be powered.
- Take the measurements.
- Make a change to the loads
- Replace the capacitor when needed.

Practical Issue

The main issue we had was that when we attempted to replace the old capacitor with the new one, the old capacitor was still energized. By following the instructions above, we were able to resolve the problem.

Data Analysis

Each table contains one capacitor with five distinct loads, as well as the voltage ripple for each load. The difference between simulated and measured results, as well as the mismatch between them. The only difference between this table and the other is the value of the capacitor.

Table 16: Displays the Capacitor 820uF's Simulated and Measured Values

Capacitor (uF)	Resistor load (Ω)	Simulated value (Volt)	Measure value (volt)	Miss match %
820	560	5.64	5.5	2.48%`
	660	4.78	4.5	5.85%
	760	4.15	3.6	13.25%
	860	3.67	3.18	13.35%
	1000	3.16	2.73	13.60%

Table 17: Displays the Capacitor 1040uF's Simulated and Measured Values

Capacitor (uF)	Resistor load(Ω)	Simulated value (Volt)	Measure value (volt)	Miss match %
1040	560	4.45	3.83	13.93%
	660	3.77	3.28	12.99%
	760	3.28	2.85	13.10%
	860	2.89	2.52	12.80%
	1000	2.49	2.16	12.49%

Table 18: Displays the Capacitor 1640uF's Simulated and Measured Values

Capacitor (uF)	Resistor load(Ω)	Simulated value (Volt)	Measure value (volt)	Miss match %
1640	560	2.82	2.46	12.76%
	660	2.39	2.08	12.97%
	760	2.08	1.81	12.98%
	860	1.8	1.60	11.11%
	1000	1.58	1.38	12.65%

Result

In this section, we will provide a graphical representation of the results of the previous tables. The link between resistance and ripple voltage is shown schematically in Figure 74. As can be seen, there is minimal difference between the estimated and observed values, indicating that the simulated value is greater than the measured value and that the ripple voltage decreases with increasing resistance.

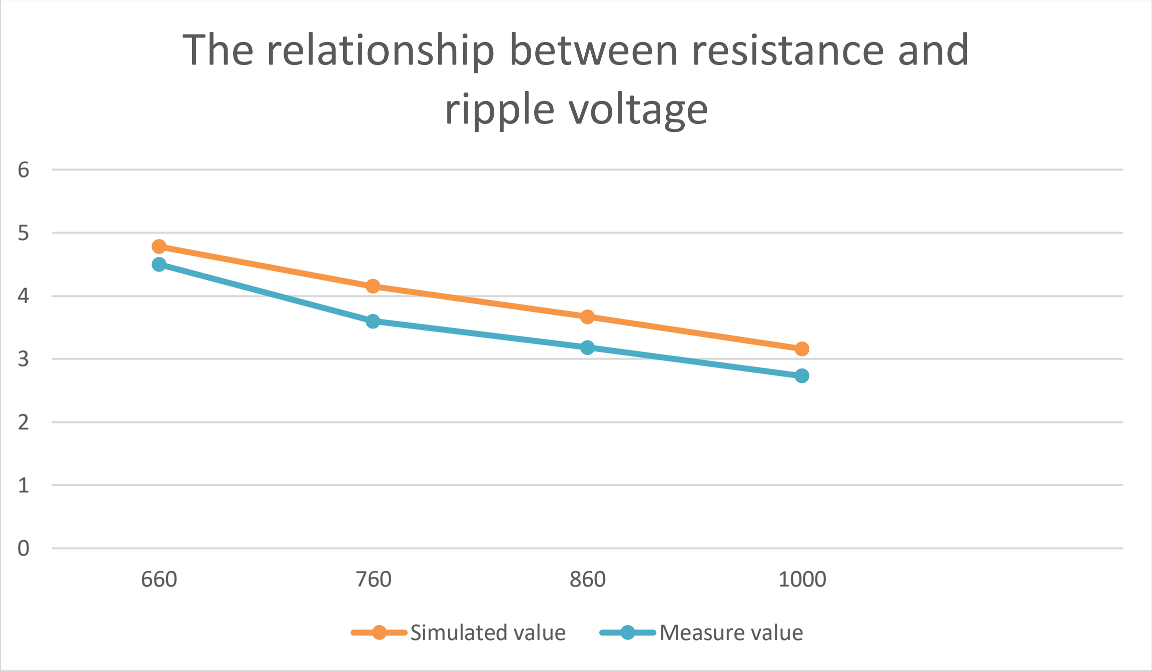


Figure 77: Shows the Relationship Between Resistor and Voltage Ripple when 820uF Is Used.

In Figure 77 you can see schematically how resistance and ripple voltage are related. Observed and estimated values show the minimal difference, indicating that the simulated value is greater than the measured value and that ripple voltage decreases with increasing resistance.

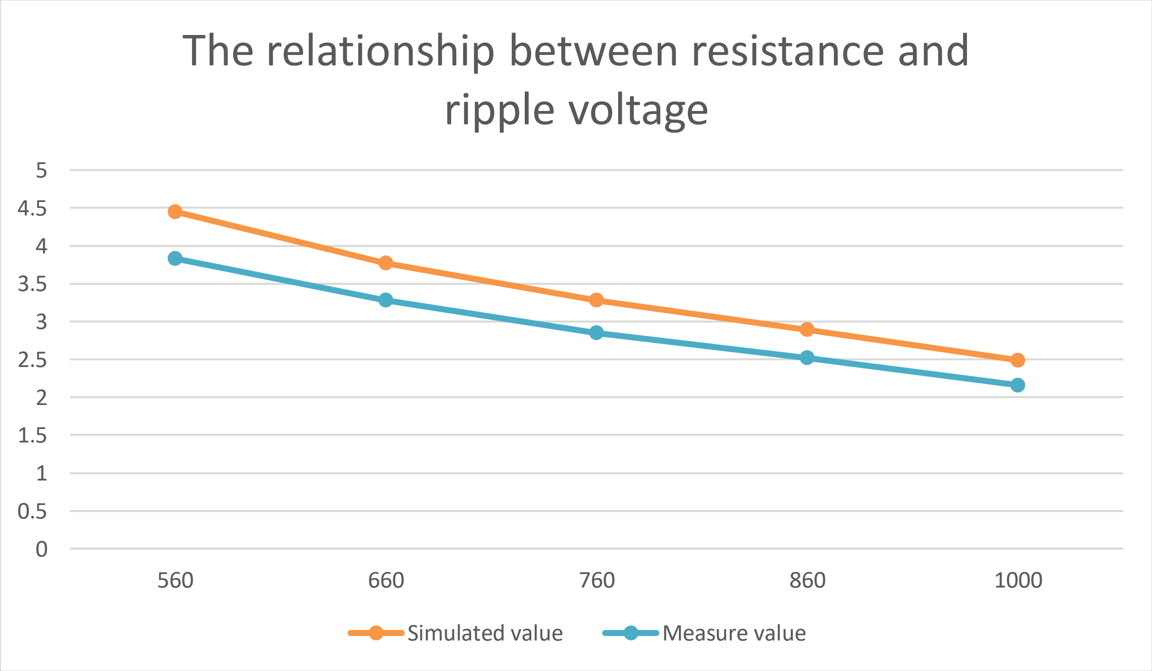


Figure 78: Shows the Relationship Between Resistor and Voltage Ripple when 820uF Is Used.

Resistance and ripple voltage are shown schematically in Figure 78 to demonstrate their relationship. The discrepancy between the observed and estimated values is minor, showing that the simulated value is bigger than the measured value and that ripple voltage reduces as the resistance increases in this experiment.

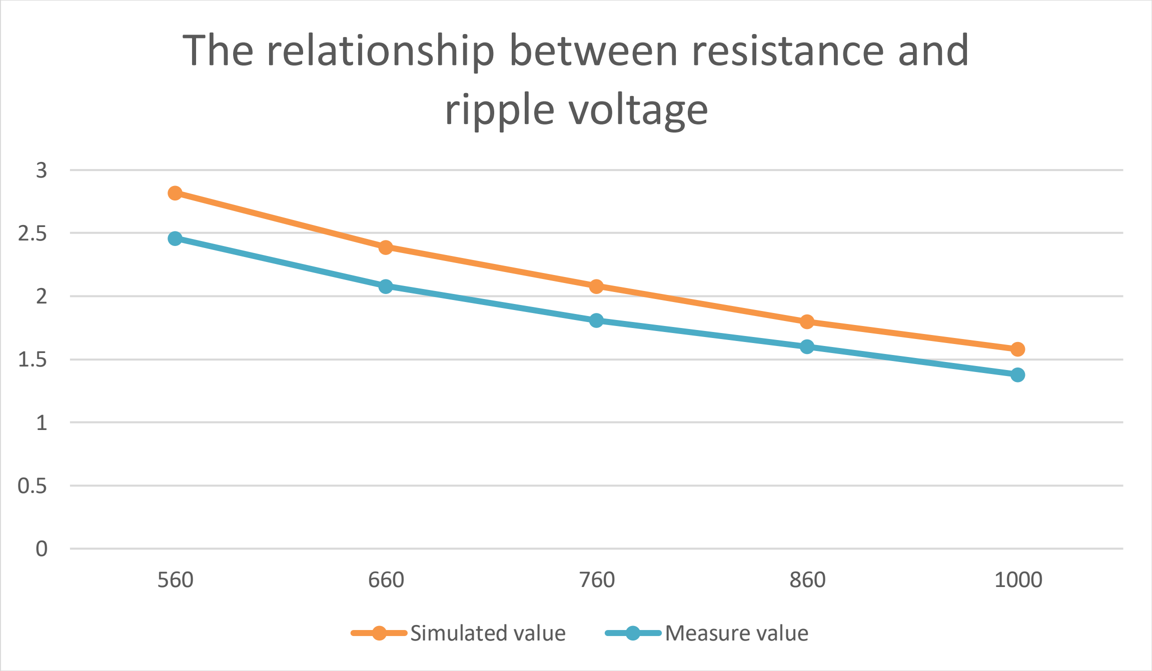


Figure 79: Shows the Relationship Between Resistor and Voltage Ripple when 820uF Is Used.

Discussion

On the basis of the results obtained in the previous section, it can be observed that the ripple voltage in the first know the expectations (Table 16) was approximately the same in both the calculated and measured ripple voltages, which is due to the large value of ripple voltage that the oscilloscope is capable of measuring. Whereas the second measurement set (Table 17) reveals a significant variance due to the instrument employed, notably the oscilloscope, which was unable to measure the tiny values of ripple voltages due to the equipment utilized. The identical situation exists for the third measurement set (Table 18), but this time with a higher variation owing to the oscilloscope that was used to make the measurements.

Conclusion

To summarize, in order to overcome the limits of the oscilloscope, it is necessary to utilize a contemporary oscilloscope capable of measuring tiny voltage values in order to get a good measurement for the ripple voltage.

Role of engineering standards

SASO IEC 61558 Standard as well as the Saudi Arabian Distribution Code state that a maximum of 5% of the voltage ripple is permitted, which means that this regen should be in not more. Consequently, in order to make our project suitable, we will stick to these standards.

MOSFET Switching Validation by Khalid Alsubhi

Introduction

In this report, we are required to take a main part from our project and test it out. In our project, one of the most important components is MOSFET. It is very important to observe the behavior of that component because our project depends on it. Our project uses MOSFETs in two stages DC-DC converter and DC-AC inverter. DC-DC converter uses only one MOSFET while DC-AC inverter uses four MOSFETs. Due to that, we need to make sure that MOSFETs work properly. However, we will test the MOSFET with its gate driver and see the components that are around the MOSFET if they may affect the functionality of MOSFET. We will mainly focus on the relation between the resistor gate and the rising and falling time. In addition, we will analyze and discuss the data that will be taken from our experiment. There must be some assumptions that we are needed to do which will leads us to get the results from this experiment. We will assume that the DC power supply is giving the desired output. Also, we will assume that the oscilloscope output signal has no errors and display a realistic waveform. In term safety, we should be careful because the circuit might have high current which could damage some of the components.

Objective

The objective of our experiment is to test and observe the behavior of a MOSFET by changing the RG (which is the resistor that is between the gate of the MOSFET and the Low side output of the IR2110 Driver) and measuring the rise and fall time.

Variables

- Resistor Gate “RG” **Ω**
- Output Voltage **Volt**

Constants

- Duty Cycle
- Switching Frequency **Hz**

Background

MOSFET stands for Metal Oxide Semiconductor Field Effect Transistor. It is one of the most popular insulated gate FET. MOSFET are used in many application such as power electronics. In power electronics, they use MOSFETs as switches to apply their concept in converting DC-DC or inverting DC-AC. Moreover, MOSFETs have two types N-channel and P-channel. We will talk about N-channel and how it works. The functionality of the N-channel MOSFETs as switch is when the gate input voltage V_{GS} is HIGH means applying voltage for example 5V, it will switch ON and let the current pass through. Also, when the gate input voltage V_{GS} is LOW means applying 0V, it will block the current and act like a short circuit. In figure 80, it shows the strcutre of the MOSFET [42].

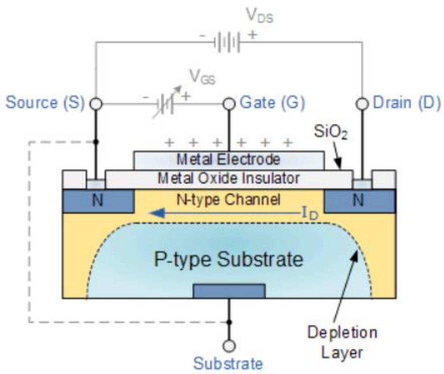


Figure 80: MOSFET's Structure

Basically, we describe how the MOSFET works as switch in a simple way. However, we will mention equations that is related to our experiment. The main equation is the slew rate. Slew rate is the max rate of output voltage change per time unit. Slew rate can be represented as the following equation:

$$S = 2\pi f_m V_m$$

In figure 79, we can see and understand what the slew rate is. Also, we can say that the slew rate is the time required for the MOSFET However, high slew rate will

Affect MOSFET switching badly. Therefore, the output voltage will contain so much noise [43].

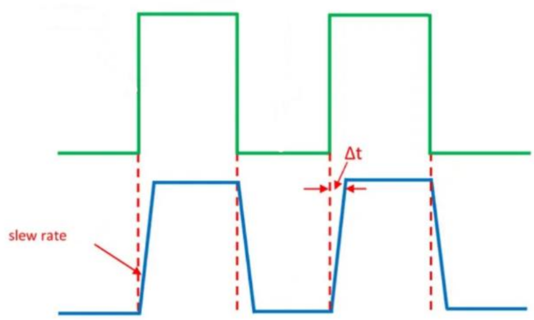


Figure 81: The Slew Rate

Tools

In this section, we will illustrate the tools needed to do the experiment. The tools are:

- ❖ Oscilloscope
- ❖ DC Power Supply 12V
- ❖ Laptop with Arduino IDE
- ❖ Arduino UNO
- ❖ Digital Multimeter
- ❖ IRFP460 MOSFET
- ❖ IR2110 Gate Driver
- ❖ Capacitors 22uF x2 & 100nF x2
- ❖ Diode x2
- ❖ Bunch of Resistors
- ❖ Wires

Work Plan

In figure 82, we are showing the circuit schematic that we need to follow to proceed the experiment. We have to do the same connection with the same values that is shown below.

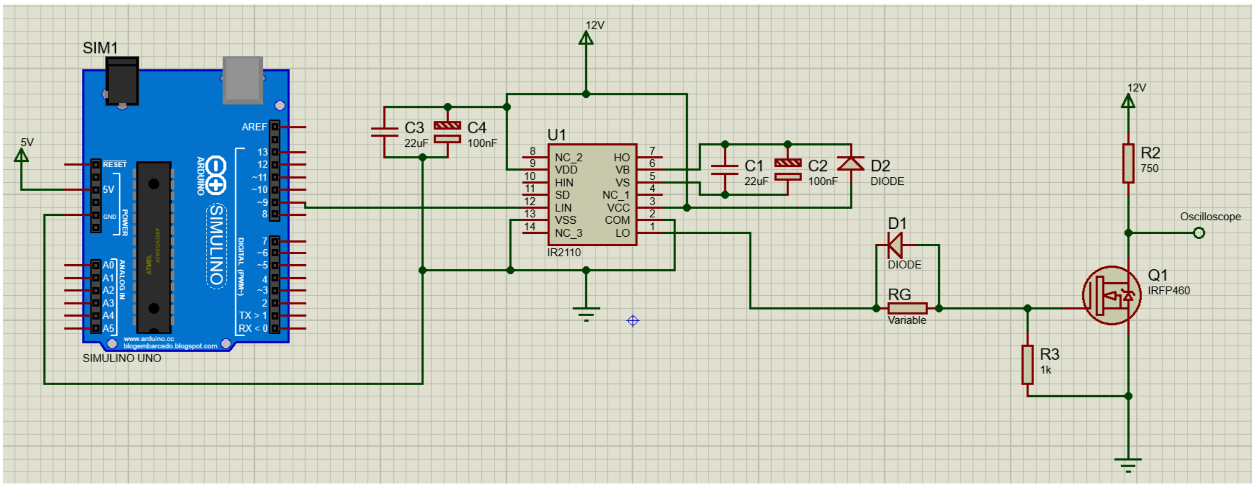


Figure 82: Circuit Schematic

After connecting the above circuit, we will show the steps of this experiment. The steps are:

1. Make sure that you connect the circuit as shown.
2. Upload the code that is provided in the Appendix to the Arduino.
3. Connect the oscilloscope to the output.
4. Put RG = 2.2Ω.
5. Measure and record the falling time by the oscilloscope.
6. Change the RG value.
7. Repeat step 5 & 6 until finished.

Data Collection

In this section, we will show the data the was collected from the experiment. We will compare the results and see what the outcome is. Also, we set the Switching Frequency = 10,000 Hz and the Voltage output = 12V. Theoretically, Slew Rate = 2π x F x V = 2π x 10,000 x 12 = 1.33us.

Table 19: Output Slew Rate for Each RG

No.	RG (Ω)	Slew Rate (us)
1	2.2	0.80
2	10	0.96
3	43	1.16
4	75	1.52
5	120	2.08
6	150	2.40

Results

In table 19, we observe that the slew rate was affected with the value of Resistor Gate. In a theoretically term, we calculated the slew rate and the result is 1.33us. this is the ideal slew rate. However, it changed whenever we change the value of RG. In figure 81, we can observe the relation between the RG and the Slew Rate which is represented in a curve. The relation is that they are proportional to each other. Whenever the value of RG increases, the slew rate is increasing which is poor.

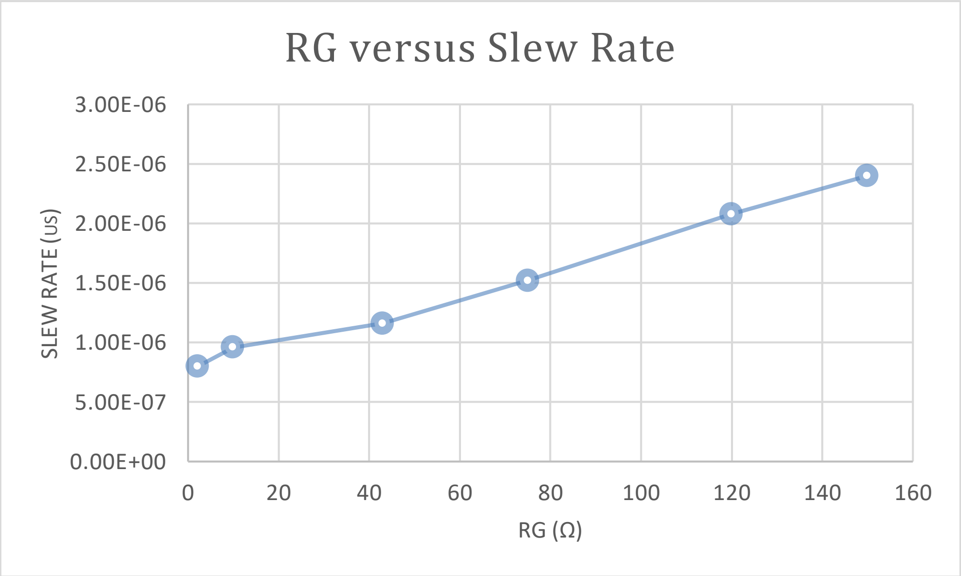


Figure 83: Graphical Representation of The Data

Discussion

In our experiment, we noticed that MOSFET's output can be affected by the RG. Thankfully, we manage to observe to before going to high voltage which might cause serious problems. However, we decided to go with RG = 10Ω. The reason is RG with 2.2Ω get heated fast. Due to that, we were afraid that the resistor get burned and causes short circuit. Thus, we think that going with RG = 10Ω is a perfect choose with a reasonable Slew Rate that can do the job.

Conclusion

To end up with, this experiment was around the MOSFET and its IR2110 Gate Driver. The results was interesting. It was very near the result that we calculated theoretically. Actually, we didn't expect that a resistor might affect the output voltage of a MOSFET. However, we benefit from this experiment a lot and it helps us to get a desired output without any noise.

Role of Engineering Standards

Based on SASO IEC 61204/2001, it considers the low-voltage power supply devices DC output in term of performance characteristics. In addition, SASO IEC 61204-7/2006 focuses on safety requirements of low-voltage power supply devices DC output.

Final project Validation

Objective

This experiment was carried out in order to measure the inputs and outputs of the project as well as to examine the completed project.

Variables and constant

Variables and constants are both used.

Constants

- Input voltage
- Input frequency

Variables

- Output voltage
- Output frequency

Background

This experiment includes two stages each one of these stages have been examinate indiviually. So now we will describe each one briefly. the process of changing alternating current into direct current. Figure 5 depicts the full-wave rectifier that was used by our team. the initial step of the AC-AC system makes use of these approaches. due to the fact that it is necessary to convert the AC that is coming from the wall-socket into DC, which will then be going to the following step of the AC-AC system, which is the DC-AC SPWM inverter. The second which is the last is (inverter). In the last step of the process, the goal is to take the output of the phase before, which was the AC-DC converter, and convert it into AC. This will complete the process. As a consequence of this, it is capable of satisfying the needs imposed by the load. In addition, in order to convert DC to AC, it is necessary to use a single-phase H-Bridge circuit, which is comprised of four (MOSFETs). This is done in order to accomplish the task of converting DC to AC Insulated Gate Bipolar Transistors are able to function as an ON/OFF switch when the appropriate signal is applied, as seen in figure.

Safety

When dealing with electricity, it's critical to follow all safety procedures. There must be no compromises in terms of safety, and basic ground rules must be observed initially. The following fundamental recommendations for safe electricity handling can assist you when dealing with electricity specially with AC/DC converting:

- When working, always use insulated tools.
- When working on any branch circuit, always wear suitable insulated rubber gloves and eyewear.
- Repairing electrified equipment should never be attempted. Always use a tester to ensure that it is de-energized first.
- Know your country's wire code.

The main issue we had was that when we attempted to replace the old capacitor with the new one, the old capacitor was still energized. By following the instructions above, we were able to resolve the problem.

The body

The tools that were used:

- Power supply AC 220 with 60Hz
- Oscilloscope
- Rectifier
- Inverter

Circuit schematics

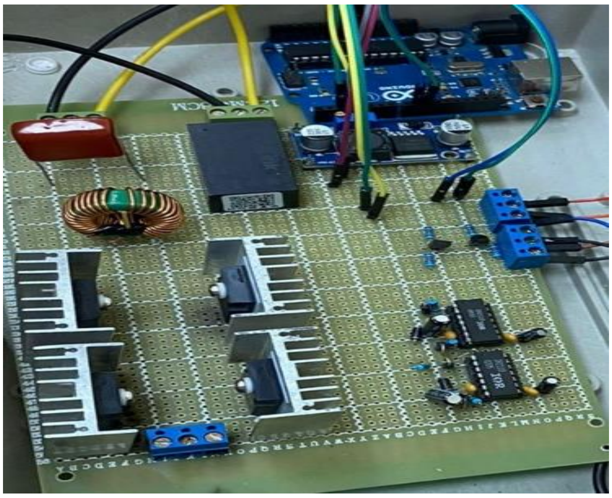


Figure 84: Inverter Circuit

Figure 85: Rectifier Circuit

Experimental setup

- Connect the rectifier to the power source.
- Connect the RC filter to the system.
- Connect the Inverter to the Rectifier.
- Connect the power source to the circuit so that it may be powered.
- Take the measurements.
- Switch the frequency toggle
- Switch the voltage toggle

Result

After combined the whole component this as result, this section the result of the multi output will be provided below. As it can be seen from the table below the input is constant which is 220v with 60Hz as well as the output can be 12v with either 50/60Hz or 6v with either 50/60Hz

Table 20: The Desired Outputs

Input		Output		
Voltage	Frequency	Voltage	Frequency	
220	60	12	50	60
		6	50	60

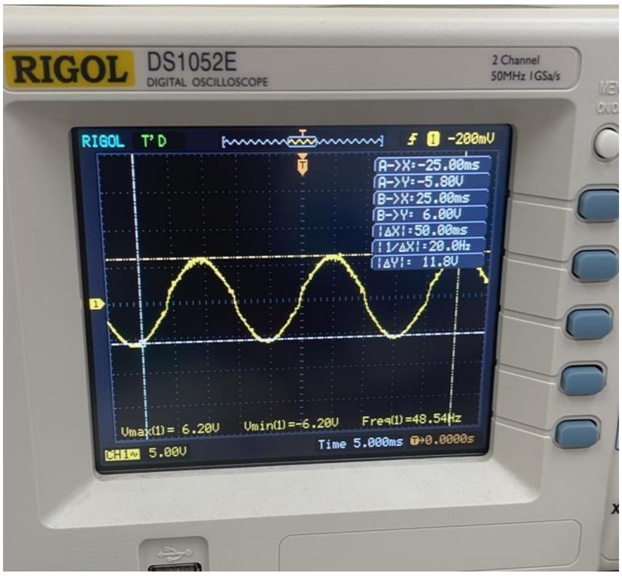


Figure 86: 6V with 50Hz

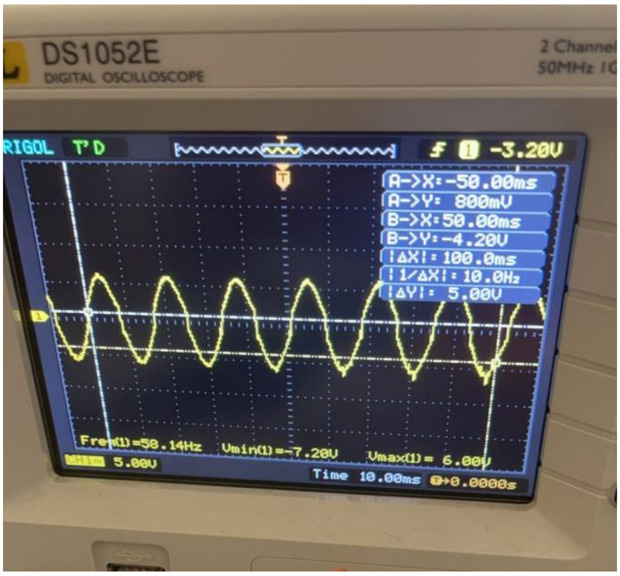


Figure 87: 6V with 60Hz

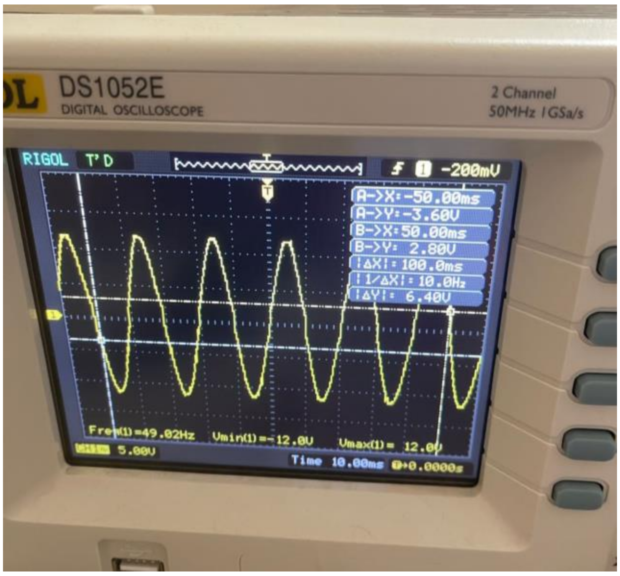


Figure 88: 12V with 50Hz

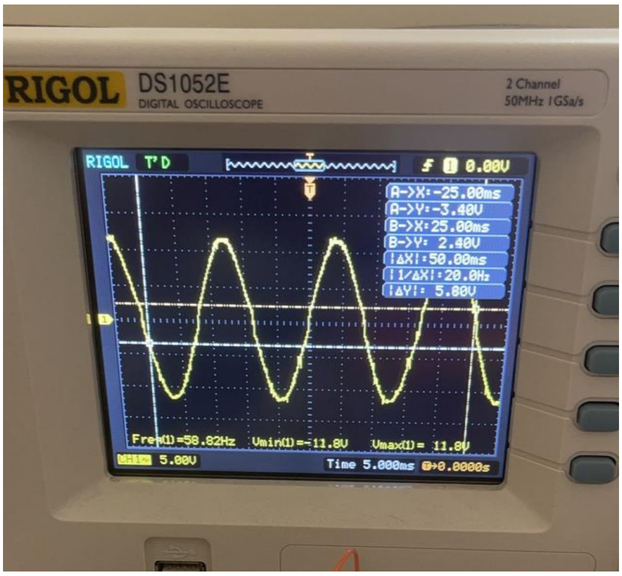


Figure 89: 12V with 60Hz

APPENDIX – B: SELF ASSESSMENT CHECKLIST

Use student outcomes (SOs 1 - 7) rubrics to fill the following table. Each member needs to fill in this table; it is important to enable the department to know to what degree the EE programs have been able to achieve the required KPIs of each SO. Please use the following grading letters:

E: Exemplary, **S:** Satisfactory, **D:** Developing, and **U:** Unsatisfactory.

Student Outcome (SO)	Key Performance Index (KPI)	Self-assessment (E, S, D, or U)		
		M1	M2	M3
1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics	1.1. Problem Identification	S	S	S
	1.2. Problem formulation	E	S	S
	1.3. Problem solving	S	E	S
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors	2.1. Design Problem Definition	S	S	E
	2.2. Design Strategy	E	E	E
	2.3. Conceptual Design	E	E	S
3. an ability to communicate effectively with a range of audiences	3.1. Effective Written Communication	S	S	E
	3.2. Effective Oral Communication	S	S	S
4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts	4.1. Recognition of Ethical and Professional Responsibility	S	S	S
	4.2. Consideration of Impact of Engineering Solutions	D	D	D
5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives	5.1. Effective Team Interactions	E	E	E
	5.2. Use of Project Management Techniques	D	D	S
6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions	6.1. Developing Appropriate Experiment	S	S	S
	6.2. Conducting Appropriate Experiment	S	S	S
	6.3. Analysis and interpretation of Experiment Data and Drawing Conclusions	S	E	S
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies	7.1. Effective Access of information	E	S	S
	7.2. Ability to learn and apply new knowledge independently	E	E	E

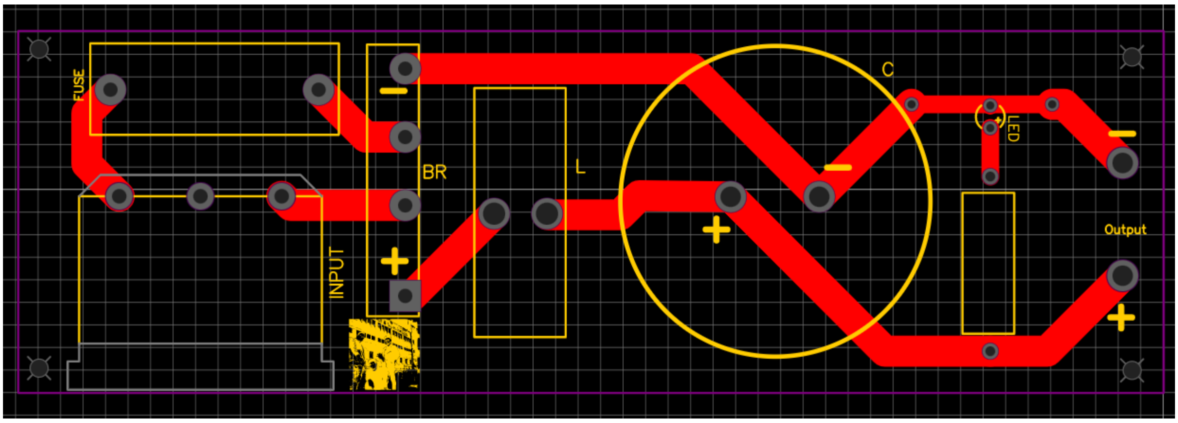
APPENDIX – C: PROJECT CODE

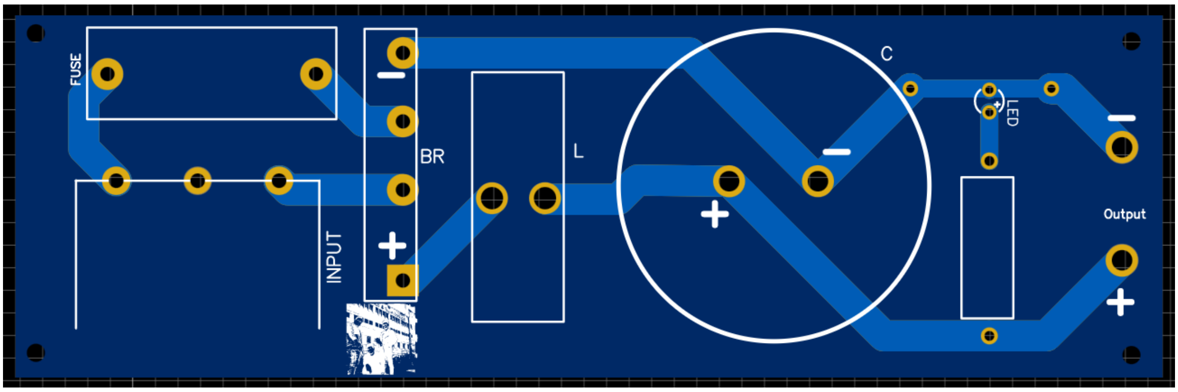
```
/*
  The values:
  |-------------------|
  |freq = ture  = 60Hz|
  |freq = false = 50Hz|
  |volt = true  = 220v|
  |volt = false = 110v|
  |-------------------|
*/
#include <TimerOne.h>
int pwm1 = 9;
int pwm2 = 10;
int freq60 = 36;
int freq50 = 45;
volatile boolean freq = true;
volatile boolean volt = true;
int pwmSin220v[]={0,18,36,54,71,89,107,125,143,160,178,195,213,230,248,265,282,299,316,333,350,367,384,
400,416,433,449,465,481,496,512,527,543,558,573,587,602,616,630,644,658,672,685,698,711,724,737,749,761,
773,784,796,807,818,828,839,849,859,868,878,887,896,904,912,920,928,935,943,949,956,962,968,974,979,984,
989,994,998,1002,1005,1008,1011,1014,1016,1018,1020,1022,1023,1023,1024}; // Timer1 100%
int pwmSin110v[] = {0,9,18,27,36,45,54,62,71,80,89,98,106,115,124,133,141,150,158,167,175,183,192,200,208,
216,224,232,240,248,256,264,271,279,286,294,301,308,315,322,329,336,343,349,356,362,368,374,380,386,392,398,
403,409,414,419,424,429,434,439,443,448,452,456,460,464,468,471,475,478,481,484,487,490,492,495,497,499,501,
503,504,506,507,508,509,510,511,511,512,512,512}; // Timer1 50%
```

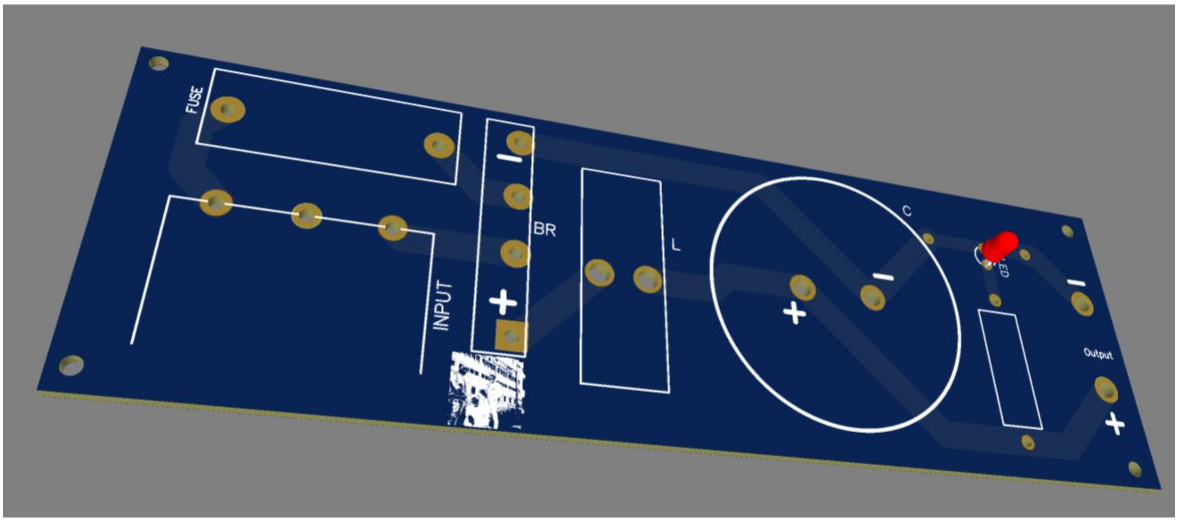
```
void setup(){
    // put your setup code here, to run once:
    Timer1.initialize(33);// 40kHz
    pinMode(2,INPUT); //FreqPin
    pinMode(3,INPUT); //VoltPin
    pinMode(9,OUTPUT);
    pinMode(10,OUTPUT);
}

void loop(){
    //The pin state specified in digitalRead()stored in the value variable.
    //"0" is stored if it is 0V or "1" if it is 5V.
    if (digitalRead(2) == 0) {
      freq = false;
    }
    else if (digitalRead(2) == 1) {
      freq = true;
    }
    if (digitalRead(3) == 0) {
      volt = false;
    }
    else if (digitalRead(3) == 1) {
      volt = true;
    }
  if (freq == true && volt == true) { //                                                  60Hz-220v
        loop_HF(freq60,pwmSin220v);
  } else if (freq == true && volt == false) { //                                          60Hz-110v
        loop_HF(freq60,pwmSin110v);
  } else if (freq == false && volt == true) { //                                          50Hz-220v
        loop_HF(freq50,pwmSin220v);
  } else { //                                                                             50Hz-110v
        loop_HF(freq50,pwmSin110v);
  }
}
```

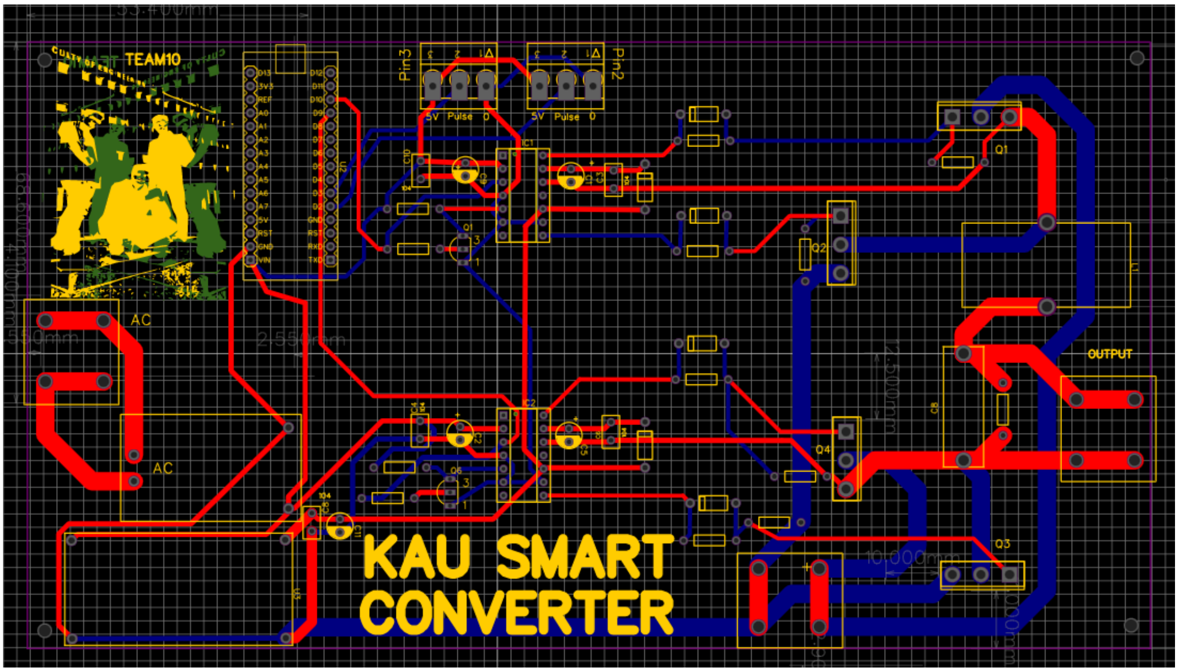
```
void loop_HF(int freq, int pwmSin[]){
    digitalWrite(pwm2,LOW);
    for (int i=0;i<=89;i++) {
      Timer1.pwm(pwm1 , pwmSin[i]);
      delayMicroseconds(freq); // 50Hz=45, 60Hz=36
    }
    for (int i=89;i>=0;i--) {
      Timer1.pwm(pwm1 , pwmSin[i]);
      delayMicroseconds(freq); // 50Hz=45, 60Hz=36
    }

    digitalWrite(pwm1,LOW);
    for (int i=0;i<=89;i++) {
      Timer1.pwm(pwm2 , pwmSin[i]);
      delayMicroseconds(freq);// 50Hz=45, 60Hz=36
    }
    for (int i=89;i>=0;i--) {
      Timer1.pwm(pwm2 , pwmSin[i]);
      delayMicroseconds(freq);// 50Hz=45, 60Hz=36
    }

}
```

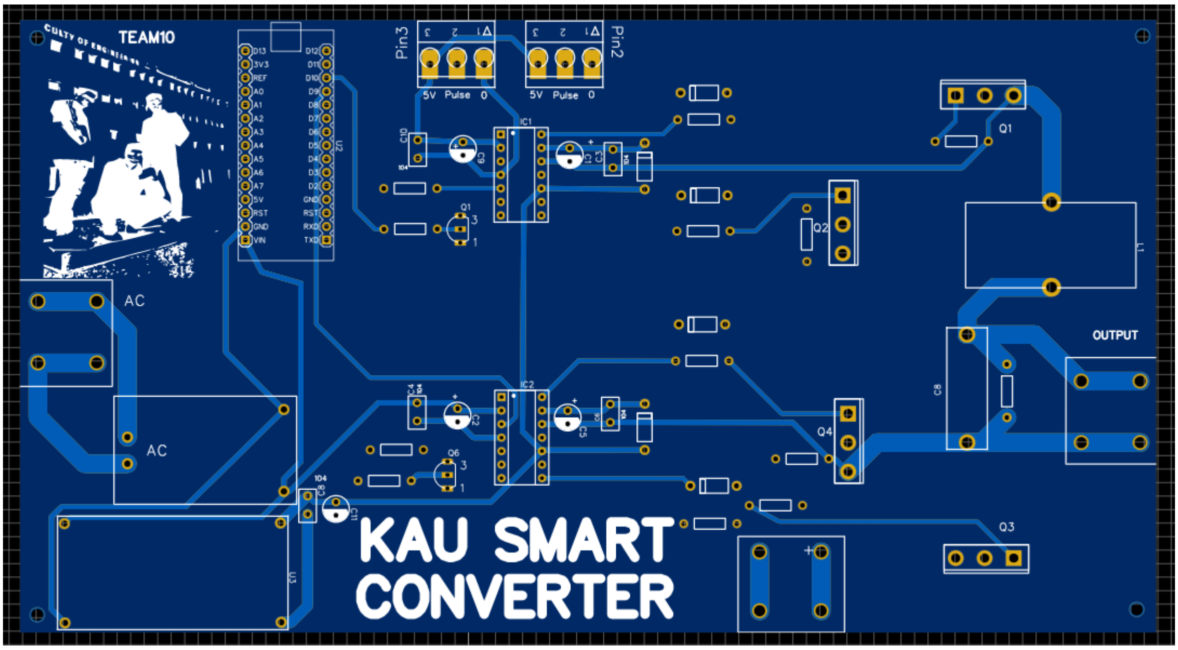
APPENDIX – D: DESIGN THE PCB

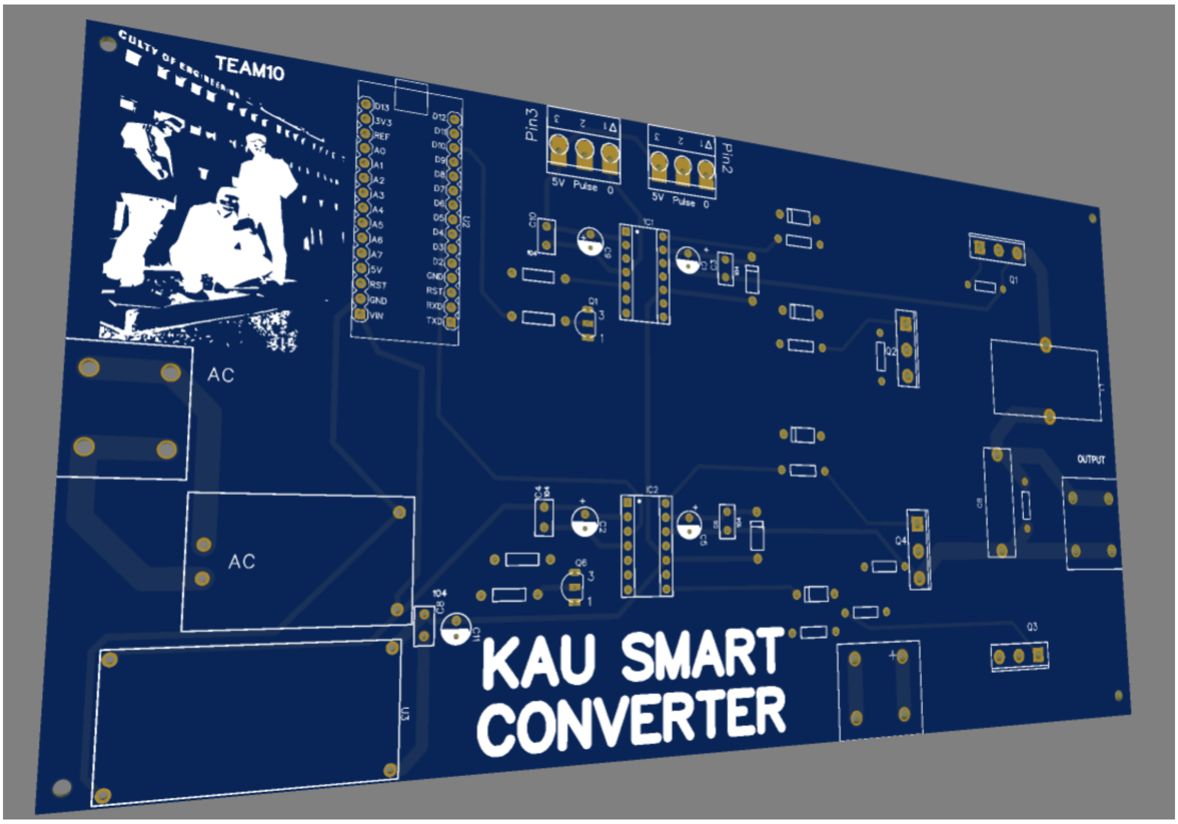







TEAM10
AC
AC
Pin3
Pin2
5V Pulse 0
5V Pulse 0
Q1
Q2
Q3
Q4
IC1
IC2
OUTPUT
KAU SMART CONVERTER


TEAM10
AC
AC
Pin3
Pin2
5V Pulse 0
5V Pulse 0
Q1
Q2
Q3
Q4
IC1
IC2
OUTPUT
KAU SMART CONVERTER


TEAM10
AC
AC
KAU SMART
CONVERTER
OUTPUT

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