Implementing Problem-Based and Experiential Learning for Undergraduate Students in Power Electronics Applied to Renewable Energy

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***Abstract*— This full paper presents an innovative approach to undergraduate engineering education by integrating Problem-Based Learning (PBL) and Experiential Learning with traditional Lecture-Based Instruction to enhance student engagement and performance. The approach is exemplified through a project where undergraduate students develop a DC-AC inverter, control strategy, and learning experience. The objective is to bridge classroom theory with real-world application by having students design, simulate, and implement the inverter. This hands-on experience emphasizes careful consideration in choosing the appropriate topology, electronic components, and microcontroller. The project illustrates how applying PBL and Experiential Learning helps students develop intuitive, creative, and critical thinking skills, addressing nuances that often go unnoticed in lecture-based learning. The paper highlights the benefits of this methodology, including improved problem-solving abilities, increased student engagement, and enhanced professional readiness. Additionally, it underscores the positive impact on workforce development and diversity, particularly through the involvement of female students in a traditionally male-dominated field. This approach not only enhances technical skills but also prepares students for advanced challenges in the field of power electronics, contributing to their academic and career trajectories.**

Keywords*— *Undergraduate Engineering Education, Power Electronics, Renewable Energy, Problem-Based Learning (PBL), Experiential Learning

I. Introduction

This paper is an innovative practice in undergraduate education specifically in the area of power electronics applied to renewable energy. As humanity embraces the rapid changes towards a technology-enhanced world, new challenges in engineering education have emerged. To address these challenges and maintain undergraduate students' engagement and performance, an innovative combination of project-based learning techniques is proposed. Specifically, this approach integrates Problem-Based Learning (PBL) and Experiential Learning in an undergraduate setting. Implementing PBL with current and relevant engineering problems ensures that students remain at the forefront of technological advancements, actively engaging with real-world challenges. Additionally, Experiential Learning provides students with hands-on experiences to reinforce and expand their theoretical knowledge, fostering deeper understanding and skill development. As a result of combining these techniques with typical ones such as Lecture-Based Instruction, students are able to learn the theory, simulate, and implement it not only in class and corresponding laboratories, but also in extracurricular settings.

Extracurricular activities such as research teams and technical projects are excellent examples of the implementation of this approach. Therefore, in this paper the previously mentioned combination of techniques will be depicted in a research project within the field of renewable energy and power electronics, focusing on the design and implementation of a DC-AC inverters to enhance undergraduate engineering education. Additionally, the research team of this project is mainly composed of female students as part of an initiative that aims to enhance the participation and visibility of women in power electronics, which is a field traditionally dominated by men. In this project the team learned to utilize simulation and prototyping tools to design and test inverters. The details of what the process entailed will be discussed in the paper to showcase the benefits that this novel combination of learning techniques has on the undergraduate students.

Furthermore, the paper discusses the broader implications of this approach, such as increasing undergraduate involvement in graduate studies, training the next generation of researchers, establishing industry partnerships, and contributing to workforce development. The involvement of undergraduate students in this project serves as a bridge to their contribution to the development of grid-forming inverter technology, as well as state of the art technology in the energy sector. This research aims to address challenges in engineering education by implementing innovative combination of project-based learning techniques, ultimately preparing students for success in their future careers and contributing to the advancement of the field.

To further introduce more background information of the project done in the area of power electronics applied to renewable energy, the concept of power electronics first has to be explained. Power electronics devices, like power converter (DC-DC), rectifiers (AC-DC) and inverters (DC-AC), are used for the integration of renewable energy sources into the power grid and solar home integration. The converters controls the voltage levels while the inverters turn direct current (DC) energy to alternating current (AC) energy. Solar power generates DC energy and needs to be converted to AC, while wind power generates AC energy that rectified from AC to DC, then converted from DC to AC again. The power grid and most home appliances use AC energy, therefore the need for power electronics. Converters, rectifiers and inverters help the seamless integration to the power grid by synchronizing the voltage and frequency levels to the one used in the power grid.

The project developed to depict the innovative practice of implementing Problem-Based and Experiential Learning in power electronics applied to renewable energy is the design, simulation, and implementation of a modular inverter. In the next sections the process to achieve this will be explained in detail.

II. DESIGN

A. *Inverter Topology Classification and Selection*

Inverters have a wide range of classifications starting from current, voltage, and Z-source. As seen in figure 1 under the voltage source classification there are a variety of multilevel inverters which can be classified into four main topologies: the neutral point clamped (NPC), the flying capacitor (FC), the H-bridge, and the cascaded H-bridge. The NPC topology has a neutral point where the voltage source is divided in half with a positive and negative voltage $(V_{DC}/2\,,\,0,-V_{DC}/2\,)$ with 2 capacitors at the input that connect to each side of the neutral point. There are coupling diodes connected to the neutral point on the branches with two switching devices that act as clamping diodes to create the third output of 0 V_{DC}. The flying capacitor is similar to the NCP with a neutral point connected to two capacitors to divide the voltage source in half with a positive and negative voltage $(V_{DC}/2\,,0,-V_{DC}/2)$. There are four switching devices connected in series with an auxiliary capacitor to fix unbalanced voltages. The H-bride has four switches to change the polarity of the DC voltage source at the output of the circuit. The distinct difference in this topology is that each single H-bridge inverter needs a separate DC source. These topologies can be used in single-phase applications or be turned into three phase inverters by doing a three-phase connection.

For the base topology of the single-phase inverter, we choose the H-Bridge topology shown in figure 2. The single-phase H-bridge has one DC voltage source with four switches in an H formation connected to the load at the output of the circuit. One gate driver controls the switches using Pulse Width Modulation (PWM) to turn on and off the two switches of half the H-bridge. This topology offers the advantage of a high output voltage level, which is necessary for applications like photovoltaic systems.

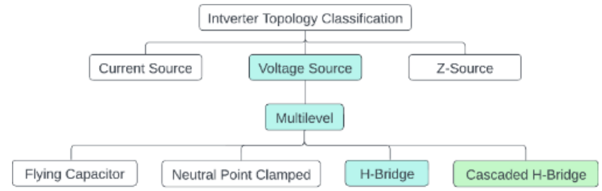

Fig. 1. Topology Classification

By combining three or more H-bridge inverters, two other topologies can be implemented converting this into a modular setup. These topologies are the single-phase cascaded H-bridge and a three-phase inverter. The single-phase cascaded H-bridge topology is implemented by taking two or more H-bridges and connecting them in series as seen in figure 3. With three H-bridges connected in series, a multilevel inverter of seven levels can be achieved. The inverter will be symmetrical since the voltage source of each inverter will have the same DC voltage value and separate voltage sources. The three-phase inverter will be in Wye (Y) formation with three inverters connected into a neutral point as shown in figure 4.

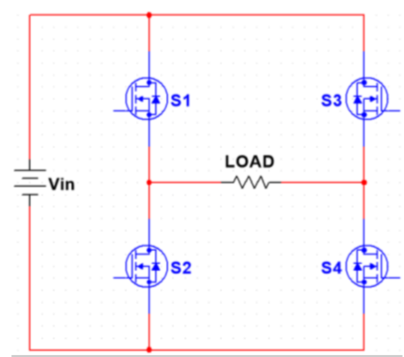

Fig. 2. Single-Phase H-Bridge Inverter Topology

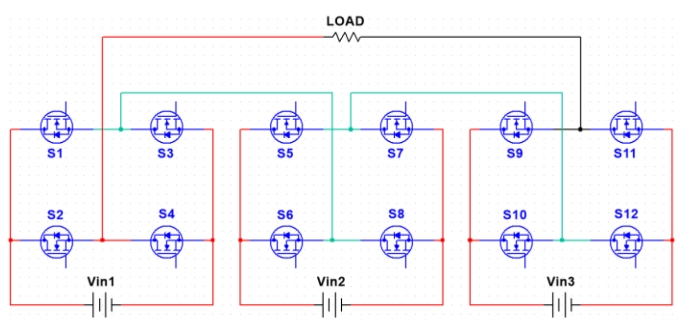

Fig. 3. Cascaded H-Bridge Inverter Topology

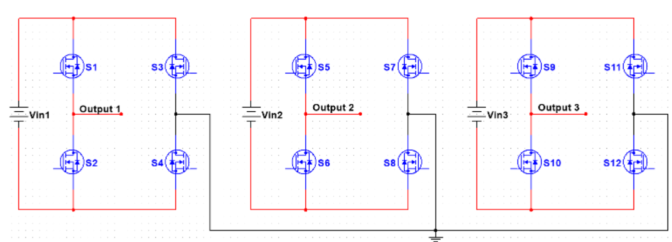

Fig. 4. Three- Phase H-Bridge Inverter Topology

To implement a modular configuration, three H-bridge inverters will serve as the foundation for the project. These three inverters will be connected in series or Wye (Y) connection to allow the individual inverters to work in unison with the help of three microcontrollers that will communicate with each other. This modular design presents the advantage of having several topologies that output different qualities of waveforms and serve for different applications. This is important because when a singular H-bridge inverter is working independently the output waveform quality isn't the best but when the three inverters are connected in series obtaining a cascaded h-bridge, a 7-level output waveform is obtained. The advantage of this topology is that the output waveform approaches a similar shape to the sine waveform, therefore has better quality and as a result lower total harmonic distortion without the assistance of filters. Lastly, the three-phase inverter is three single-phase inverters connected in Wye (Y) with a phase shift of 120° which is specifically used for three-phase applications. The output voltage of these topologies can be calculated from equations 1-3.

Single-Phase H-Bridge Inverter Output:

$$V_{rms} = \sqrt{\frac{1}{\pi/2}\int_0^{\pi/2} V_{DC}^2\, d\theta} = \sqrt{\frac{2}{\pi}V_{DC}^2\left(\frac{\pi}{2}-0\right)} = \sqrt{V_{DC}^2} = V_{DC} \qquad (1)$$

Single-Phase 7-Level Cascaded H-Bridge Inverter Output:

$$V_{rms} = \sqrt{\frac{1}{\pi/2}\int_0^{\pi/2} V_{DC}^2\, d\theta} = V_{DC}\sqrt{\frac{2}{\pi}\left(-\alpha_\alpha - 3\alpha_b - 5\alpha_c + \frac{9\pi}{2}\right)} \qquad (2)$$

Where α, b and c are the delay angles of the wave.

Three-Phase H-Bridge Inverter Output for Wye (Y) connection:

$$V_{LL} = \sqrt{3}\cdot V_\phi \qquad (3)$$

B. Single-Phase H-Bridge Inverter Design and Component Selection

For the design of the H-bridge inverter there are several components that must be carefully selected to ensure the optimal functionality of the inverter. These components will be outlined in the next points.

1) Power Switch

A power switch is a device that acts as a switch that controls the flow of the current by different voltages or currents applied to its terminals. These devices are semiconductors called transistors, like the Bipolar Junction Transistor (BJT), Metal-Oxide Semiconductor Field-Effect Transistor (MOSFET) and Insulated Gate Bipolar Transistor (IGBT). The BJT is a current-controlled device for low current applications, while the MOSFET and IGBT are voltage-controlled devices. A voltage-controlled transistor is a better option for the inverter since it's easier to apply a voltage source than a current source from a microcontroller. The IGBT and MOSFET are devices that are normally used in power electronics for DC to AC converters. The IGBTs work in a higher range of voltage in the kilovolts with medium switch frequency (50 kHz). While power MOSFETs work in a lower range of voltage less than 1 kV with a high switching frequency (1 MHz). The power MOSFET is the most suitable switching device for our application since our voltage domain is lower and closer to what it is going to be used for this project. Therefore, the switching device selected for the H-bridge was the N-channel MOSFET (NMOS) IRF540N [2].

TABLE I. IRF540N MAIN DATASHEET SPECIFICATIONS

IRF540N		
Drain to Source Voltage	V_{DS}	100 V
Gate to Source Voltage	V_{GS}	± 20 V
Gate to Source Threshold Voltage	$V_{GS(TH)}$	2 – 4 V
Drain Current	I_D	33 A

2) Gate Drive Method

When designing the H-bridge with the N-channel MOSFETs, a couple of challenges were encountered. First, when the MOSFETs are connected in the H-bridge configuration the MOSFETs in the upper part of the bridge have a floating ground. This means that the source of the high-side NMOS does not have a reference voltage, and the terminal is floating since no current flows through. To resolve this issue several methods with gate drivers were researched and the most efficient was selected.

Gate drivers are electronic circuits used to assist the switching of MOSFET for high power applications by inputting a voltage into the gate. There are various gate drivers, but the most used are high-side, low-side and half bridge. High-side gate drivers are used for transistors that are connected to a positive potential but have no ground reference creating a floating ground. However, low-side gate drivers are used in transistors connected to a negative supply. Half-bridge gate drivers have both components making them ideal for the application of this project and was the one selected. The specific model selected was the IR2110 [3], which can sustain voltages of up to 500V and an output voltage for the MOSFET's gate of up to 20V.

As part of the half-bridge gate driver, a bootstrap circuit mainly composed of a diode and capacitor must be implemented. This bootstrap helps resolve the issue of the floating ground by creating a bias for the high-side MOSFET. To do this, the application note "Bootstrap Circuitry Selection for Half-Bridge Configurations" by TI will be used as a guide [1]. The process for the selection of the capacitor values is a followed:

TABLE II. PARAMETRS USED FOR THE BOOTSTRAP CAPACITOR

Bootstrap Capacitor Parameters		
Charge at the Gate	Q_g	71 nC
Gate Driver Voltage Supply	V_{DD}	5 V
Forward Voltage of Bootstrap Diode	$V_{BootDiode}$	1.7 V
Voltage at the Gate	V_{Qg}	3.3 V
Minimum Bootstrap Capacitor	$C_{BootMin}$	215 nF
25% Safeguard for Bootstrap Capacitor	C_{Boot25}	0.3 µF
Bootstrap Capacitor	C_{Boot}	2 µF
Bypass Capacitor	C_{VDD}	10 µF

$$V_{Q_g} = V_{DD} - V_{BootDiode} \qquad (4)$$

$$C_g = \frac{Q_g}{V_{Q_g}} \quad (5)$$

$$C_{boot} \geq 10 \times C_g \quad (6)$$
$$C_{boot} = 0.25 \times C_{Boot} \quad (7)$$
$$C_{V_{DD}} \geq 10 \times C_{Boot} \quad (8)$$

3) Microcontroller

In the context of this project, a careful evaluation of various microcontroller options was conducted to identify the most suitable candidate meeting the specific requirements of the inverter system. The key criteria established as prerequisites in the selection process were that the microcontroller must possess PWM pins for generating the required signals, user-friendly interface, and ease of use were essential considerations.

After a comprehensive review, two primary contenders emerged as potential choices: the Arduino Uno and the Raspberry Pi. Consequently, the decision was made to compare and choose between the Arduino Uno and the Raspberry Pi for implementation in this project.

TABLE III. COMPARISON ARDUINO UNO VS RASPBERRY PI:

Feature	Arduino UNO	Raspberry Pi
Microcontroller Type	Microcontroller	Single-board Computer (SBC)
Processing Power	Limited (ATmega328P)	Moderate to High (varies by model)
Programming Language	C, C++	Multiple languages (Python default)
Memory	Flash: 32 KB, RAM: 2 KB	Varies by model (512 MB to 8 GB or more)
I/O Pins	Limited	Abundant GPIO pins and additional features
Operating System	None	Linux-based (Raspbian, others)
Networking	Limited capabilities	Built-in Ethernet and/or Wi-Fi (model dependent)
Multitasking	No	Yes
Graphics	Basic	GPU for graphical applications
Cost	Generally lower	Moderate to higher (depends on model)
Power Consumption	Low	Higher (depends on model and usage)
Use Case	Embedded systems, simple projects	General-purpose computing, IoT, projects

In summary, we opted for the Arduino Uno over the Raspberry Pi for our project due to its cost-effectiveness, lower power consumption, compatibility with C and C++ programming languages, and user-friendly interface. Despite acknowledging the Raspberry Pi's advanced capabilities, the Arduino Uno emerged as a practical choice that aligns with our needs and streamlines the development process for our specific application.

During our investigation, the Software Division explored potential communication methods and protocols for intercommunication among three Arduinos. The assessed communication methods included Serial Peripheral Interface (SPI), Universal Asynchronous Receiver-Transmitter (UART), Inter-Integrated Circuit (I2C), Bluetooth, Wi-Fi, Long Range (LoRa) and a bi-directional transceiver module called NRF24L01. SPI, UART, and I2C were considered for physically connecting the Arduinos. UART was promptly excluded due to its inability to support a Master-Slave configuration. SPI involves four cables: Serial-Clock Line (pin 13), Master-Out Slave-In (pin 11), Master-In Slave-Out (pin 12), and Chip-Select (pin 10). I2C employs two pins for communication: Serial-Data Line and Serial-Clock Line (pin 13). Between SPI and I2C, SPI was chosen for its smaller time delay and higher bit rate. Bluetooth, Wi-Fi, LoRa and the NRF24L01 module enable wireless communication among Arduinos. Since the Arduino Uno lacks inherent wireless communication capabilities, each Arduino uses a respective module. Among the wireless options, Bluetooth and the NRF24L01 were deemed the most consistent. Considering the proximity of the three Arduinos in our project, SPI was selected over Bluetooth and the NRF24L01 due to its smaller time delay and higher bit rate, which are crucial for project requirements.

TABLE IV. COMPARISON BETWEEN COMMUNICATION PROTOCOLS

Communication Protocol	Time Delay (s)	Bit Rate (bps)	Master Slave	Multiple Slaves	Cabled or Wireless
SPI	5e-8s	20Mbps (2e7bps)	Yes	Yes	Cabled
UART	104e-6s - 159e-6s	9600bps	No	N/A	Cabled
I2C	104e-6s	9600bps	Yes	Yes	Cabled
Bluetooth	2.604 e-5s	Command: 38400bps	Yes	Yes	Wireless
	104e-6s	Data: 9600bps			
Wifi	8.68e-6s	115200bps	Yes	Yes	Wireless
LoRa	Variable	250bps-22Kbps	Yes	Yes	Wireless
NRF24L01	1e-3s to 10e-3s	250Kbps - 2Mbps	Yes	Yes	Wireless

4) Sensors

To synchronize the three inverters, sensors are needed to obtain data from each inverter and compare it to one another. In the case of the inverters, the specific function needed is for a sensor to detect when a specific condition is met, which in this case is when the edge cross is detected. In other words, when the inverter goes to zero from a negative value. With this data point, the frequency and angle of delay (time delay) can be determined, and the inverters can be synchronized according to the application needed. To achieve this, a voltage sensor was implemented.

C. Control Strategy

To effectively control the three inverters, each inverter will have a microcontroller where one of them will be the master and the other two the slaves. The master oversees the output of the base wave to which the other two inverters will be compared. This means that the slaves will gather the edge crossing data point and send it to the master to compare. The master then calculates the delays and if needed sends back the slaves a value to modify the PWM input for the other two inverters.

1) Theoretical Control Background

In control systems, there are two major configurations open loops and closed loops. An open loop system starts with an input transducer that is used by a controller. This controller drives a process or a plant to the output. Other signals are called disturbances and are added to the system by a summing junction which is an algebraic sum of the input signals represented by the signs. What distinguishes an open loop system is that it cannot compensate for any of the disturbances added to the controller's driving signal. They are simply commanded by input.

For a closed-loop system or a feedback loop, there is an input, controller; plant or process, and output or sensor that measures the response so that it can be converted and fed back to the controller. The sensor is used to measure variables or parameters set. This system compensates for disturbances by reading the parameters set, adjusting, comparing the results to the input, and feeding it back to the controller. Closed systems loops have greater accuracy than open loop systems.

In the design implemented the Arduino runs as a closed loop system. The master Arduino and the two slaves outputs two PWM signals to the inverters, and the inverters outputs a square wave. Each square wave is monitored with a voltage sensor to detect edge crossing, and this signal is fed back to the master Arduino. It monitors, compares, and adjusts the PWM delay between the slave Arduinos and the master to adjust the phase shift accordingly if necessary.

There are several types of control such as P (Proportional), I (integral), D (Derivative), PI (Proportional-Integral), and PID (Proportional-Integral-Derivative). A "P" control is best when used in systems needed for a quick response since it adjusts the control signal proportional to the error. An "I" control is best when eliminating steady-state control is crucial, but its response is slower. A "D" control is applied to systems where predicting future errors can significantly improve performance. A "PI" control is commonly used in processes where a balance between speed and accuracy is needed. It adjusts the control signal based on both current errors and the accumulation of past errors. The "PID" control adjusts the control signal based on current errors, past errors, and the rate of change of the error. It is mostly used when precise control over a wide range of conditions is required.

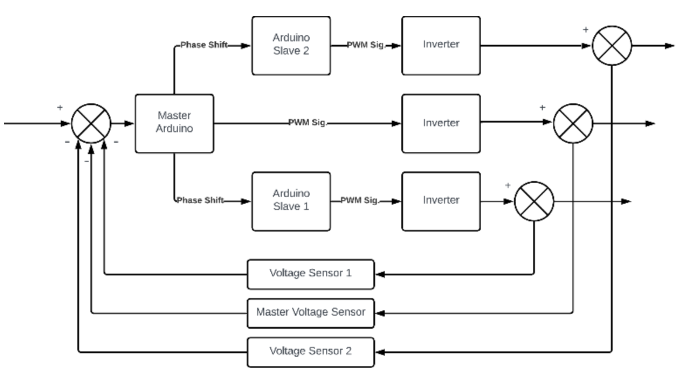

Fig. 5. Control Block Diagram

This system uses a PID controller, it provides comprehensive management of the system's stability, accuracy, and responsiveness.

2) Control Code Implementation

In this project, the implemented code for the Arduino, utilizing the SPI communication protocol in a Master-Slave configuration to enable data transmission between Arduinos. Each Arduino generated two PWM waves: one with a zero-degree phase shift and another with a 180-degree phase shift, with a one percent difference in their duty cycles. The output signal, with a frequency of approximately 60 Hz, was produced using the Timer1 library, which interacts with the Arduino's internal timers and registers. This PWM wave was then fed to the inverter circuits. Voltage sensors attached to each Arduino's A0 pin read the output from the inverter circuits, and the analog input was converted to a voltage value using the equation (9). This voltage value allows to detect changes between defined voltage thresholds (9 V – 10 V). When the voltage transitioned from zero volts to the threshold value, the time was recorded to calculate the operational frequency of each Arduino. Additionally, the Master Arduino (MA) saves communication times with the Slave Arduinos (SA) to calculate their operational frequencies and time delays relative to the MA. By using these values, we determined the phase differences between the three PWM waves. The SA's were expected to maintain delays of 5.56 ms and 11.11 ms, respectively, and about 60 Hz. If a SA deviated from these parameters, the MA calculated and sent a delay to correct the PWM wave's phase using the equation (10).

$$Voltage = Sensor\ value \times \frac{5}{1{,}024} \times \frac{30{,}000+7{,}500}{7{,}500} \quad (9)$$

$$T_{Correction} = \frac{1{,}000}{60} - \left(2T_{SA_{exp}} - 16.67 - T_{SA_{theo}}\right) \quad (10)$$

Where T_{SAexp} is the experimental time delay of SA and T_{SAtheo} is the theoretical time delay of SA.

TABLE V. PWM FREQUENCY OF THE ARDUINO PINS

PWM Frequency of each pin in Hertz (Hz)									
PINS	DEFAULT	OTHER VALUES						HIGHEST	LOWEST
D3 & D11	490.20Hz	31372.55H	3921.16Hz	980.39Hz	245.10Hz	122.55Hz	30.64Hz	31372.55H	30.64Hz
D5 & D6	976.56 Hz	62500.00H	7812.50Hz	244.14Hz	61.04Hz			62500.00H	61.04Hz
D9 & D10	490.20Hz	31372.55H	3921.16Hz	122.55Hz	30.64Hz			31372.55H	30.64Hz

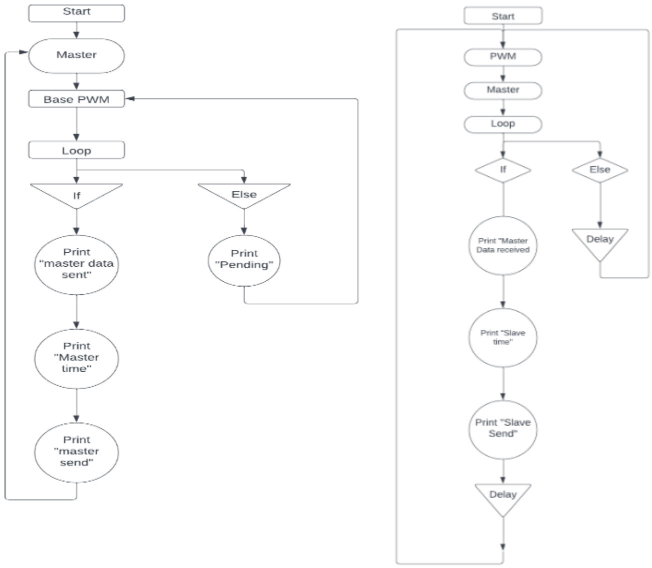

Fig. 6. Master and Slave Flowcharts

III. Simulation

Once the component selection was done, we proceeded to simulate the design in Multisim. During the simulations of the circuit, several scenarios were tested to observe the circuit's reactions to different cases. The simulation process makes the implementation phase easier and safer for initial experimentation with higher voltage circuits. It helps to put the circuit in action with minimal damage to several components after the simulation stage and during the prototype testing.

D. Inverter Simulation

The circuit developed for the H-bridge inverter is presented in figure 7. The H-Bridge formation can be seen with one half-bridge gate driver on each side. The bootstrap was implemented with 20 V connected between the high-side and low-side MOSFETs to fix the floating ground. Two PWM are fed into each gate driver to coordinate the switching ON and OFF of the MOSFETs. These have an amplitude of 5 V with a duty cycle of 48% and a diphase of 180˚ from each other. The PWMs have a duty cycle of 48% to ensure that the MOSFETs are completely off in between switching sequences.

The graph in figure 8 shows the output of the inverter when the input voltage is 25 V and the load is 8Ω, like the schematic of the circuit shown previously in figure 6. The resulting graph shows a modified square wave with a dead band to ensure that a short circuit does not happen in the switching process. The output voltage was 24.8 V, with 99.2% efficiency. During the switching ON/OFF of the MOSFETs there is an overshoot of voltage that needs to be smoothed out for a better output.

Several operating scenarios were simulated in Multisim to understand the capability of the inverter for the implementation of the circuit. It is important to understand how much voltage and current is going to be passing through the traces and cables to choose the appropriate size. Due to the physical limitations of the available equipment, the highest voltage depicted in the table for the input is 30 V. It is important to state that higher voltages, up to 100 V, can be sustained in the simulation. For such a voltage to be applied in the physical world, a more resistive load is needed to ensure that the current does not surpass 5 A, which is the limit of the current in the traces that will be used for the PCB design.

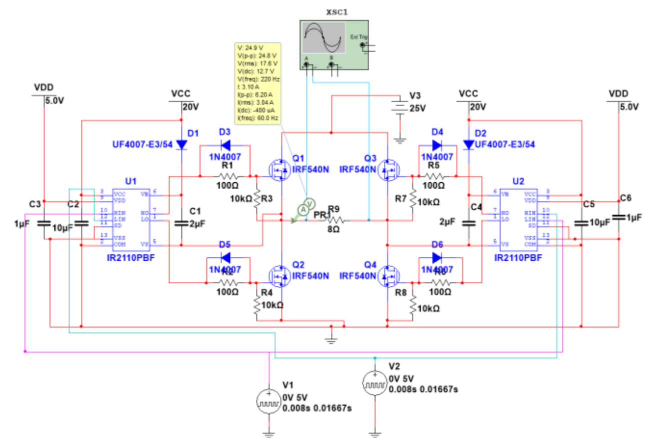

Fig. 7. DC/AC Inverter Circuit

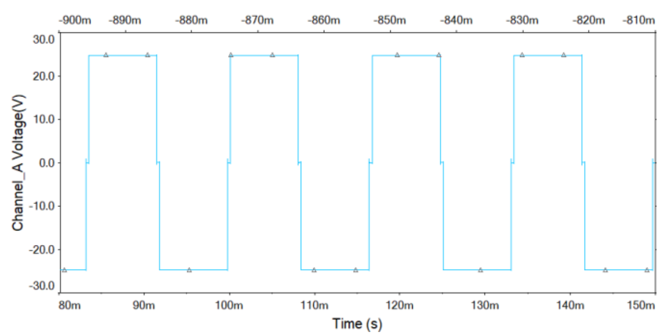

Fig. 8. Graph from Simulation Software

TABLE VI. Operating Scenarios

Input Voltage	Output at 5Ω	Output at 8Ω	Output at 10Ω
20 V	19.3 V 3.86 A 74.7 W	19.8 V 2.48A 49.1 W	19.9 V 1.98 A 37.8 W
25 V	24.6 V 4.93 A 121 W	24.8 V 3.10 A 73.6 W	24.8 V 2.48 A 59.1W
30 V	29.0 V 5.80 A 168 W	29.7 V 3.71 A 106 W	29.2 V 2.92 A 85.2 W

E. Microcontroller Implementation Simulation

Before uploading the code to the physical microcontrollers, the simulation software Thinkercad is used to test and validate the code. This is done to have a general idea of how the microcontrollers behave with snippets of simple code that interact with additional physical components connected to them. By doing this, the risk of damaging the devices decreases and changes can be made with anticipation.

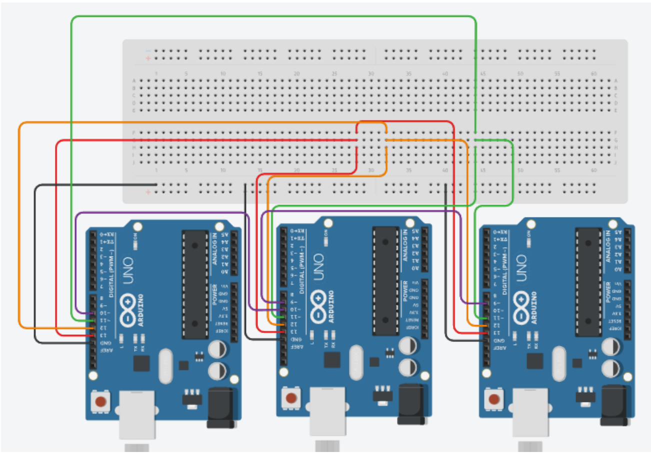

Fig. 9. Three Ardiunos Communication Connection

IV. IMPLEMENTATION

After the testing of the inverter design in Multisim, the first prototype is implemented in a breadboard as a preliminary trial to validate the durability of the circuit out of the simulation stage. Once the design was tested and validated, a PCB design was created using Fusion 360 Electronics, selected due to its user-friendly interface. The design is split into two parts: the 5V buck converter and the inverter. Once finished, both are merged in the final design. In figure 10, the schematic of the board can be seen.

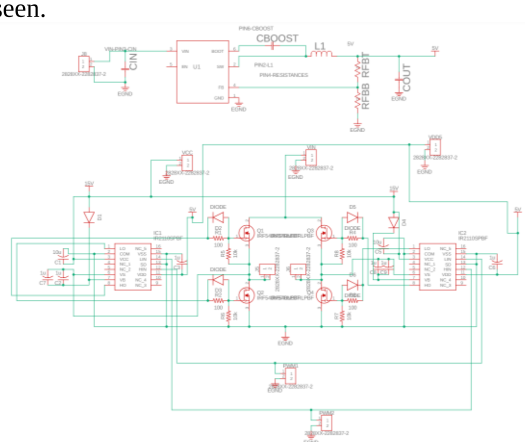

Fig. 10. Schematic with Buck Converter

The most important part of this process was the placement of the components on the board, this is to ensure that the PCB looks as organized as it can and orient components in a way that facilitates routing and minimizes trace lengths. The board is a 100 mm x 150 mm double-sided TE Connectivity AMP PCB board. This board contains two layers, the top layer is done with individual traces for all the nodes of each component. In the bottom layer, individual traces are done for the power supplies. A polygon pour is done to connect all grounds. This is a common technique used to create large areas of continuous copper on one side of the board. Connectors are used to connect power supplies to the board.

After the finalizing of the placement, certain design parameters are put in place to ensure a uniform design. The traces for the high-power side of the inverter are done with a size of 100 mil. The rest of the board has 12 and 32-mil traces due to the small sizes of the components and low amperage. Therefore, it is important to note that since the board has a 1-ounce PCB copper trace, the 100-mil trace can go up to 5 A, the 32 mil up to 2 A, and the 12 mil trace up to 1 A. The traces mostly have 45-degree corners to prevent signal reflections. In figure 11, the final PCB design depicts the previously mentioned characteristics and the inverter and the 5V buck converter merged into the design. The Computer Aided Manufacturing (CAM) View in figure 12 helps to visualize how the PCB will look like as a finished product. It can be used to determine if parts need to be fixed, moved, or separated.

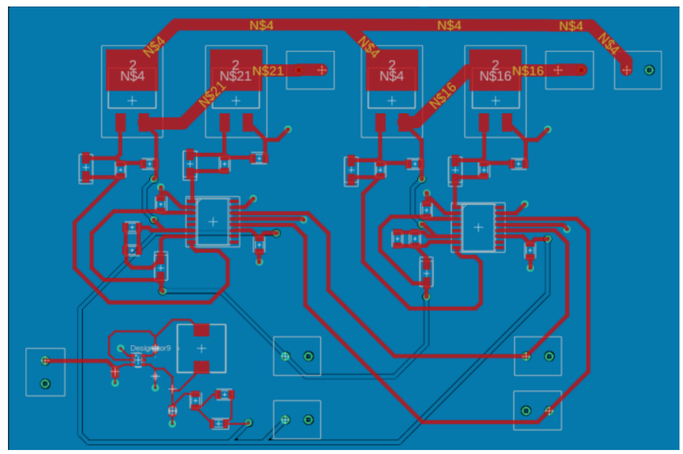

Fig. 11. PCB Desing

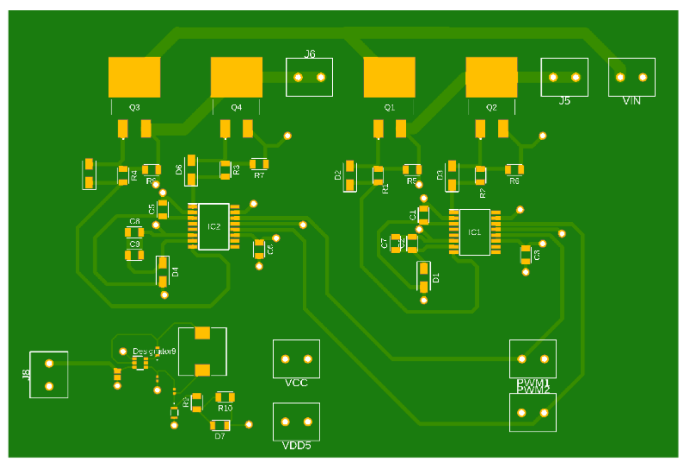

Fig. 12. Computer Aided Manufacturing View

V. STUDENT EDUCATIONAL AND PROFFESIONAL IMPACT

F. *Educational Impact*

As artificial intelligence (AI) use increases, it impacts many areas in society, such as education. Even though AI is promoting the growth of college students, the effects that it is having are positive as they are negative which has hindered the growth and talents of college students to a certain extent. Some risks and challenges for the growth of students are weakening the dominant position of college students, obliterating the value consensus, and restricting innovative thinking. These can be caused by insufficient teacher guidance, the AI's technical limitations, insufficient national investment and, by extent, insufficient supervision of the AI. Some countermeasures are recommended from several perspectives, but the most relevant for this paper is the perspective of the university in which it is recommended that professors increase their AI literacy and foster a moral and correct use of the AI. Additionally, it is recommended to increase the university involvement with the industry to foment the correct use of the AI technology [4].

From the engineering education perspective, AI tools have become popular which has its advantages and disadvantages as previously mentioned. Engineering education and the profession will eventually adopt such tools, and assessment strategies will have to evolve to prevent unethical conduct while still allowing for the productivity that can be achieved with these tools [5]. The previously mentioned countermeasures are just the beginning of the initiatives that universities will have to implement in the future. Another approach would be to implement problem-based and experiential learning as a solution to counteract AI's effect on college students.

Creative thinking and critical thinking are some of the skills that are looked for in students and workers alike in STEM fields. Creative thinking regards the flexibility and originality to express several original ideas to solve a problem and be able to elaborate thoughts and ideas others may not see. Critical thinking pertains to the ability to analyze, conceptualize, process information, decision making and drawing conclusions. It is important to grow and develop these life skills. The model of problem-based learning with experiential learning encourages students to study, analyze, assess, and interpret information more critically while being able to apply their ideas and knowledge in real contexts. The study conducted in Indonesia indicates that the use of problem base learning combined with experiential learning in science learning can improve students' creative and critical thinking skills to help develop the ability to generate innovative ideas and solutions in solving problems [6]. Furthermore, a study about Aalborg University's Problem Based Learning (PBL) model talks about how it has proven to be a robust framework for integrating engineering practice into the curriculum, proving to increase the number of graduates up to 50% during the 25 years of the PBL model's existence [7].

By combining problem-based learning and experiential learning with hands on work in a project in a technical field like power electronics applied to renewable energy, ABET engineering education objectives mentioned below, are accomplished. This is depicted in several ways along the process previously outlined in the beginning of the paper. Also, the classes mentioned in table VII are some examples of courses applied to the hands-on project.

Abet engineering education objectives [8]:

1) *An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.*

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.*

3) *An ability to communicate effectively with a range of audiences.*

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.*

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.*

6) *An ability to develop and conduct appropriate experimentation, analyze, and interpret data, and use engineering judgment to draw conclusions.*

7) *An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.*

TABLE VII. CLASSES APPLIED

Course Codification	Course Name	Description
INEL4115	Electrical Measurements Laboratory	Experiments with electronic components and equipment; measurement techniques.
ICOM4015	Advanced Programming	Advanced programming techniques applied to the solution of engineering problems: extensive use of subprograms, logical and specification statements. principles of multiprogramming, multiprocessing, and real time systems.
INEL 4201	Electronics 1	Semiconductor device characteristics; diodes, BJT, MOSFETs, Amplifiers. Analog circuit analysis and design. Introduction to integrated circuit.
INEL 4416	Power Electronics	Characteristics of power semiconductors, rectifiers, AC voltage controllers, DC-DC converters, and DC-AC inverters

Combining experiential learning and problem-based learning with hands-on work in technical fields significantly boosts undergraduate students' engagement in research and interest in graduate studies. Experiential learning enables students to gain practical experience by applying theoretical knowledge to real-world situations, deepening their comprehension of technical concepts. Problem-based learning, which focuses on solving real-life challenges, enhances critical thinking and problem-solving abilities. When these methodologies are integrated with hands-on activities, such as lab experiments or technical projects, students acquire essential practical skills and direct experience in their field. This comprehensive learning approach not only makes education more engaging and relevant but also sparks students' curiosity and passion for research. As they tackle real-world problems and devise innovative solutions, students become more motivated to pursue further studies and actively participate in research endeavors, effectively bridging the transition from undergraduate to graduate education. Another example of UPRM experiences is the paper "Training a new generation of solar developers with the latest tools and practices provided by NREL professionals: The UPRM experience [9]."

G. *Professional Impact*

Engaging in a technical hands-on extracurricular project equips students with vital skills that are crucial for their professional development. These projects offer practical experience that extends beyond classroom learning, enabling students to apply theoretical knowledge in real-world scenarios. By working on such projects, students develop essential software skills and gain hands-on experience with industry-standard tools and technologies. Moreover, these projects often foster increased industry involvement with the university, as companies frequently collaborate on or sponsor these initiatives. This collaboration not only provides students with insights into current industry practices but also enhances their networking opportunities. As a result, students who participate in technical hands-on projects are more likely to secure internships and job opportunities, as they can demonstrate practical experience and a proactive approach to learning and problem-solving. This experience makes them attractive to employers seeking job-ready graduates.

VI. CONCLUSION

The project had a significant positive impact on both the educational and professional development of the students involved. Throughout the project, students gained a deep understanding of technical concepts relevant to their field, as detailed in the design section of this paper. They not only acquired new knowledge but also effectively applied this understanding, along with insights from their coursework, during the project's implementation. In particular, the project was notable for its focus on increasing the participation of female students in power electronics—a traditionally male-dominated field. By involving a predominantly female research team, the project aimed to enhance visibility and opportunities for women in engineering, thus addressing gender disparities and promoting inclusivity within the field.

In addition to enhancing their academic learning, the project also equipped students with valuable skills that will benefit their professional careers. These include essential soft skills such as teamwork, communication, and analytical thinking, as well as proficiency in specific software tools commonly used in industry and research laboratories. Consequently, many students who participated in the project secured internships, which eventually led to full-time employment opportunities. Furthermore, the project inspired some students to pursue graduate studies, demonstrating its broader impact on their academic and career trajectories. Additionally to the technical knowledge obtained by the students, in this paper we also outline a list of recommended courses as well as the ABET canons applied.

This paper presents an innovative approach to undergraduate education by integrating two highly effective teaching methodologies—project-based learning and problem-based learning—into a specialized curriculum where such opportunities are often limited, especially in smaller universities. By combining theoretical knowledge, simulation, and hands-on experience, this practice enhances the technical skills of undergraduate students, preparing them for advanced challenges in the field of power electronics, particularly in renewable energy applications. This initiative is especially significant as it aims to elevate the technical expertise of students on smaller campuses, providing them with a competitive edge in a highly specialized and technical area. Moreover, the proposed approach serves as a workforce development tool, specifically targeting underrepresented students in power engineering, thereby contributing to the diversity and inclusivity of the field.

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