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Original Research Paper

Design and Implementation of a DC to AC Power Electronics-Based Inverter that Produces Pure Sine Wave Output for Critical Engineering Applications

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Abstract: Power inverters play a crucial role in the field of engineering, particularly in applications where power stability is imperative. In devices such as Uninterruptible Power Supplies (UPS), the conversion of raw power to DC, subsequent filtering, and inversion to AC are executed through pure sine wave inverters. These inverters exhibit remarkable stability, making them ideal for powering sensitive equipment like data switches and Remote Terminal Units (RTUs). This study delves into the intricate process of converting DC power into a pristine sine wave signal. The heart of this power conversion lies in the utilization of the KA3525A integrated circuit (IC) in conjunction with MOSFETs of the PN55 series, supported by capacitors and resistors for effective power filtration. The KA3525A, a monolithic IC, encompasses all essential control circuits for a pulse width modulating regulator. Within this IC, a voltage reference, error amplifier, pulse width modulator, oscillator, under-voltage lockout, soft start circuit, and output driver collaborate seamlessly. The MOSFETs function as switches, synchronized with the oscillating signal from the KA3525A IC. This coordination, combined with the filter and other signal conditioning units, enables the conversion process. The design achieves the conversion of raw power into a stable pure sine wave signal of 170V AC at the H-bridge terminals, demonstrating the success of the designed approach.

Keywords: Alternating Current, Direct Current, Microcontroller, MOSFET, Sine Wave.

1. Introduction

In the ever-evolving landscape of engineering innovation, the pursuit of stable and reliable power solutions stands as a cornerstone for the seamless operation of critical applications. Among the array of power inverters, the quest for purity in sine wave generation has garnered particular significance, especially in scenarios where precision and dependability are non-negotiable. This study propels itself into the forefront of technological advancement, presenting the meticulous design and implementation of a power inverter that achieves the pinnacle of stability — a stable pure sine waves [1][2][3]. At the center of this technological endeavor lies the strategic integration of the KA3525A integrated circuit (IC) and MOSFETs from the esteemed PN55 series. This synergistic pairing, fortified by capacitors and resistors meticulously chosen for effective power filtration, not only represents a cutting-edge amalgamation of components but also epitomizes the convergence of sophistication and reliability [4][5][6]. In the crucible of critical engineering applications, where the resilience of power systems is paramount, this design seeks to redefine the benchmarks of performance. The KA3525A, a monolithic IC of unparalleled prowess, emerges as the linchpin in this innovative power inverter design. Within its silicon confines, an entire ecosystem of control circuits orchestrates the delicate ballet of pulse width modulation. A voltage reference, error amplifier, pulse width modulator, oscillator, under-voltage lockout, soft start circuit, and output driver unite seamlessly, their harmonious collaboration transcending the conventional boundaries of power regulation [7][8].

Complementing this symphony of control, the MOSFETs of the PN55 series step forward as the virtuoso switches, synchronized in perfect unison with the oscillating signal emanating from the KA3525A IC. This synchronous dance, coupled with a carefully curated ensemble of filters and signal conditioning units, forms the backbone of the power transformation process. The result is nothing short of extraordinary — the conversion of raw power into a stable pure sine wave, resonating at 170V AC at the H-bridge terminals [9][10].

Pure sine wave inverters generate an output waveform that precisely mimics the sine wave of conventional electrical sockets. In contrast to modified sine wave inverters, pure sine wave devices offer a seamless and high-quality power supply, making them suitable for running sensitive equipment like laser printers, laptop computers, power tools, digital clocks, and medical devices [11]. This type of AC power is especially advantageous as it minimizes the risk of damage to connected devices. Additionally, pure sine wave inverters contribute to reduced audible noise in appliances such as fluorescent lights, and they enhance the efficiency and quiet operation of inductive loads like motors which leads to low harmonic distortion [12][13]. This pursuit of excellence in stable power inversion for critical engineering applications is not merely an exploration of circuits and components rather it is a testament to the relentless commitment to pushing the boundaries of what is achievable in the realm of power systems.

2. Literature Review

Since the initial release of the Application Manual for IGBT and MOSFET power modules, these components have seen widespread adoption in various new applications. This surge is primarily fueled by the escalating demand for efficient utilization of fossil fuels, a commitment to reduce environmental impact, and the resulting surge in the use of renewable energy sources. Evolving development trends, such as minimizing space requirements, cost considerations, and enhancing energy efficiency, coupled with the exploration of novel application domains like decentralized setups in challenging conditions, impose more stringent requirements on devices featuring cutting-edge power semiconductors [15][16].

Ensuring the consistent performance of devices, circuits, and systems over a designated timeframe is a crucial consideration in the development of semiconductor technology. Device reliability encompasses two broad categories: the gradual decline in device performance over time and sudden failures, both of which are significant for logic, memory, RF, and power devices. The author in [17] further discuses device reliability based on advancement of electrical or physical characterization methods, exploration and modeling of specific phenomena, the influence of materials and processes on reliability, and the creation of technologies that are tolerant to reliability problems.

The researcher in [18] introduced an enhancement to the conventional three-phase diode bridge rectifier with a DC output capacitor. The circuit aimed to improve the power factor at the AC input and reduce ripple current stress on the smoothing capacitor. The key innovation involved inserting an active voltage source between the diode bridge output and the smoothing capacitor, controlled to emulate an ideal smoothing inductor. The configuration transforms the high peak amplitudes of diode bridge input currents into a 120-degree rectangular shape, achieving an ideally improved power factor of 0.955. The active voltage source is implemented through a low-voltage switch-mode converter of a small power rating compared to the rectifier's output power [19][20]

The Laser Interferometric Gravitational-Wave Observatory (LIGO) operated two US facilities with kilometer-scale interferometers to detect gravitational waves caused by violent astronomical events. LIGO's sensitivity, particularly around 100 Hz, was affected by Brownian noise in reflective coatings. This noise stemmed from mechanical losses in coatings and was crucial to understand for future cryogenic detectors. The dissertation focused on constructing a thermal noise test bed at the University of Florida to explore better coatings and prepare for cryogenic detectors. The work included a novel frequency stabilization method applicable to LISA and CryoTHOR experiments. The study adapted LISA technology to assess coating Brownian noise in the LIGO band, with detailed experimental information and preliminary measurements [21]

The experimental evaluation of a low-voltage Gallium Nitride (GaN) inverter was specifically created for power steering applications according [22]. It was highlighted that the inverter incorporates the most recent generation of low-voltage enhancement-mode normally-off GaN Field-Effect Transistors (FET). The advantages of these devices, such as a high switching frequency resulting in reduced passive component volume, were discussed. However, the paper also mentioned challenges in layout and packaging aimed at minimizing parasitic inductances. The benefits and challenges of employing GaN FETs in two-level Pulse Width Modulation (PWM) motor drive applications were thoroughly explored, with the paper providing detailed experimental evidence and design guidelines [22].

The researcher highlighted the importance of improving efficiency and power density in power switching converters for energy conversion, particularly in motor control. It discussed the challenges with pure silicon switch technologies and introduced Gallium Nitride (GaN) devices, which offered better static and dynamic characteristics. The paper provided guidelines for the optimal use of GaN FETs in motor control, emphasizing their advantages and addressing key issues. Experimental evaluation in low-voltage electrical drives demonstrated GaN FETs' benefits, such as fast switching, reduced resistance, and decreased power losses. The impact on power loss management, output waveform quality, input filter capacitor design, and voltage transient slope effect was analyzed [23][24].

This research delves into the significance of light e-Mobility in transportation and emphasized the advantages of adopting gallium nitride transistors (GaN FET) in low-voltage motor drive applications. The benefits of GaN FET technology for electric powertrains were discussed, comparing its features with silicon-based transistors. Experimental tests on a typical e-powertrain layout with a GaN FET inverter revealed advantages in inverter output waveforms quality, system efficiency, and power density. The study also addressed DC-bus filter size and dead-time selection, showcasing improvements in filters and electrical motor performance. The insights provided were particularly relevant for understanding GaN FET operations in low-voltage systems, characteristic of light e-Mobility application [25][26][27].

There are different types of sine wave inverters and they are used in different applications. Square wave, modified sine wave, and pure sine wave inverters. The different research that was done before, it was focusing on the production of the modified sine waves using power MOSFETS and 555 timers. But in this research, the production of a pure sine wave is proposed using Pulse width modulation and MOSFETS configured in H Bridge [26][27]

The introduction of harmonic-rich waveform by many of the designed inverter possess potential risk to sensitive equipment such as medical monitors. Conversely, some low-cost inverters generate square waves or slightly modified versions, maintaining the correct RMS voltage and approximate frequency but not highly effective.

This drawback formed the bedrock for Design and Implementation of a DC to AC power electronics-based inverter that produces pure sine wave output for Critical Engineering Applications. The primary aim of this research paper is to design a DC to AC power electronics-based inverter that produces pure sine wave output that is cost-effective and reliable without using the transformer-based approach of designing power inverters with minimal or no switching harmonics.

3. Methodology

3.1. Materials Used

- **Metal Oxide Semiconductor Field-Effect Transistor**

Metal Oxide Semiconductor Field-Effect Transistor (MOSFET) is used to switch or amplify voltages in circuits [28]. It is a current-controlled device that is constructed with 3 terminals known as Source, Gain and Drain. A sine wave centered on zero volts requires both a positive and negative voltage across the load for positive and negative parts of the wave respectively. This can be achieved from a single source through the use of four MOSFET switches arranged in an H-Bridge configuration. To minimize power loss and utilize higher switching speeds, N¬-Channel MOSFETs will be used as switches in the bridge. Level translation between PWM signals and voltages required to forward bias high side N Channel MOSFETS, the IR2110 MOSFET driver integrated circuit was used. Figure 1 is a typical diagram of a MOSFET.

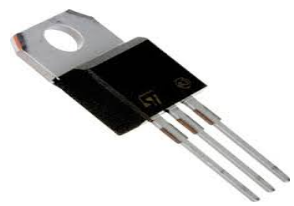

Figure 1. MOSFET

- **H-Bridge Configuration**

A H-Bridge or a full-bridge converter is a switching configuration composed of four switches in an arrangement that resembles H [29]. By controlling different switches in the bridge, a positive, negative, or zero potential voltage can be placed across a load which corresponds to forward, reverse, and off in motor respectively. Figure 2 is a typical diagram of H-bridge.

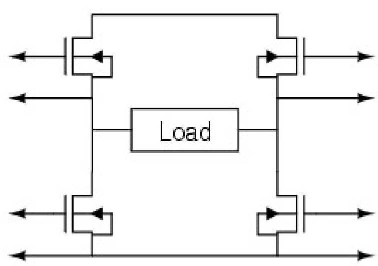

Figure 2. H-Bridge Configuration [29][30]

The H-Bridge circuit consists of four switches corresponding to high side left, high side right, low side left, and low side right. Four possible switch positions can be used to obtain voltages across the load as shown in Table 1.

Table 1. The valid H-Bridge Switch States

High Side Left	High Side Right	Low Side Left	Low Side Right	Voltage Across the Load
ON	OFF	OFF	ON	Positive
OFF	ON	ON	OFF	Negative
ON	ON	OFF	OFF	Zero potential

The switches used to implement an H-Bridge can be mechanical or built from solid-state transistors. Selection of the proper switches varies greatly. The use of P-Channel MOSFETs on the high side and N-Channel MOSFETs on the low side is easier, but using all N-Channel MOSFETs and a FET driver, lower on resistance can be obtained resulting in reduced power loss. The use of all N-Channel MOSFETs requires a driver, since turning ON a high side N-Channel MOSFET, leads to a voltage higher than the switching voltage (in the case of a power inverter, 170V). This difficulty is often overcome by driver circuits capable of charging an external capacitor to create additional potential.

- **Battery**

Battery was used to supply input voltage and power [31], since the voltage need to be inverted from DC to AC. A 7AH, 12VDC battery as shown in figure 3 was used to supply power to the system.

Figure 3. Diagram of 12V, 7AH DC Battery [31]

- **Capacitors**

A capacitor or condenser is a passive electronic component consisting of a pair of conductors separated by a dielectric. Capacitors in filter networks was used for smoothening the output of power supplies and are also used for blocking direct current while allowing alternating current to pass [32][33]. The typical diagram of capacitor is shown in Figure 4.

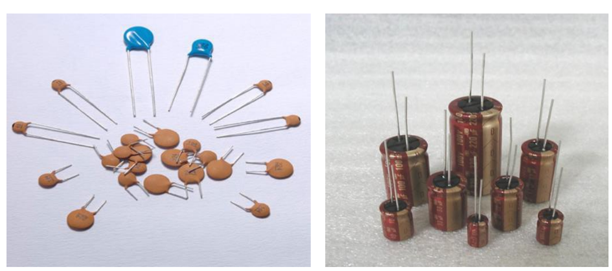

Figure 4. Typical Diagram of Capacitors

- **KA3525A**

KA3525A is a monolithic integrated circuit that includes all of the control circuits necessary for a pulse width modulating regulator. There is a voltage reference, an error amplifier, a pulse width modulator, an oscillator, an under-voltage lockout, a soft start circuit, and the output driver in the chip. The block diagram in Figure 5 shows the external and the internal components of the KA3525A IC that produces PWM signal.

- **Resistors**

A resistor is a two-terminal electronic component designed to oppose an electric current by producing a voltage drop between the terminals in proportion to the current as opined by Ohm's law (V = IR). Where; V is applied voltage across the terminals of a resistor, I is current and R is the resistance [32][33]. The typical diagram of resistor is as shown in figure 6.

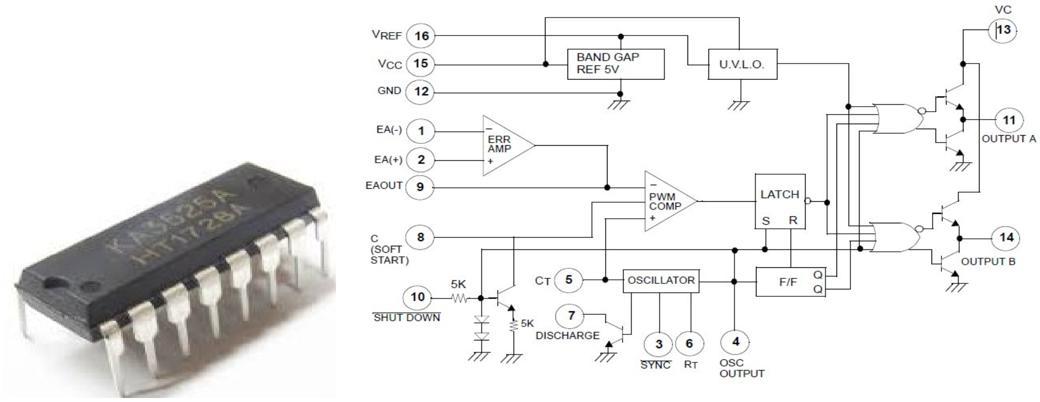

Figure 5. Block Diagram External and Internal Structure of KA3525A IC

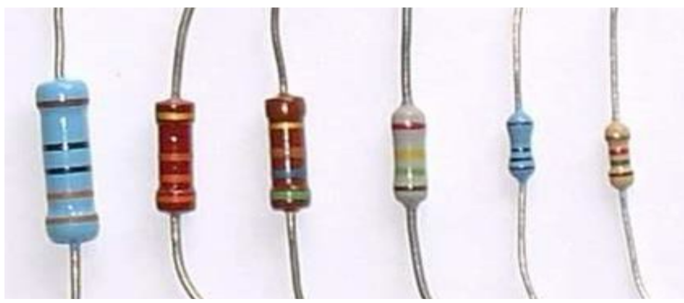

Figure 6. Typical Diagram of Resistors

- **Zener Diode**

The Zener Diode is a voltage regulator device that ensures a constant voltage output regardless of the fluctuations that may occur in the circuit [34]. In this research project the Zener diode was connected in parallel with an 82 Ohms resistor to the MOSFET terminal to ensure and regulate the signal to the gate of the MOSFET. Figure 7 is the diagram of Zener diode

Figure 7. Diagram of Zener Diode

3.2. Methods

The first step taken in this research design is creating an accurate pulse width modulation signal using analog circuitry as shown in Figure 8, to ensure an accurate representation of the signal that is to be duplicated. In the case of a pure sine wave inverter, the 50 Hz sine wave output is required. Therefore, an oscillator will be used to produce a stable 50 Hz. The KA3525a IC produces a signal from its output pins of 12 and 14 as shown in Figure 5 that act as the inputs for the MOSFETs to generate AC signal at the source terminal of the MOSFET.

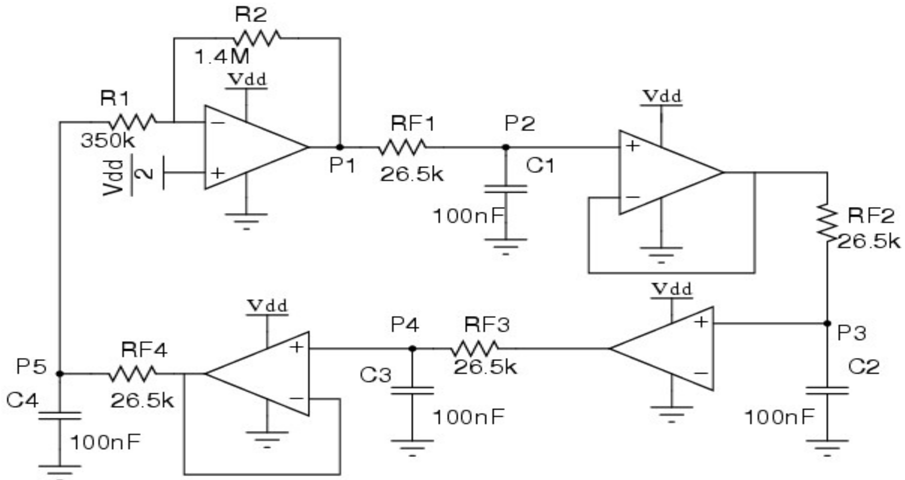

Figure 8. Diagram of an Oscillator Circuit

An internationally recognized pure sine wave driver in conjunction with MOSFETs to generate 170VAC power from a 12V DC power source was employed in this research. The inclusion of an N coefficient temperature sensor facilitates the detection of heated components thereby triggering the fan ON to effectively cool the system. To streamline this research construction, it was organized into distinct sectors: DC to AC inversion for converting battery power (DC) to electricity (AC), a temperature sensing system to regulate internal component heat, and a feedback monitoring system [19][20]. This monitoring system assesses the inverter output, ensuring its correctness. In cases where the output deviates from the design specifications, the control circuit adjusts settings to achieve a sinusoidal waveform for the output feedback voltage Root Mean Square (RMS).

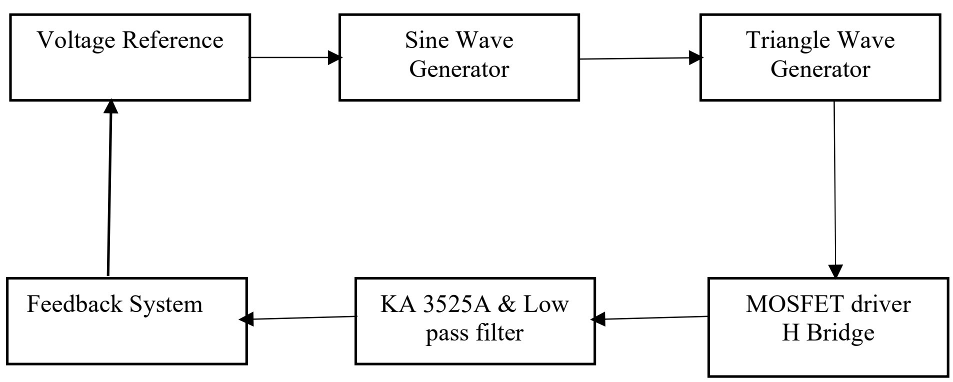

Figure 9. Block Diagram of a DC to AC Power Electronics-Based Inverter that Produces a Pure Sine Wave Output for Critical Engineering Applications

A MOSFET drive integrated circuit and a low pass filter were used to generate a 60Hz, 240V AC sine wave across a load in this research paper. The block diagram shown in Figure 9 shows the control circuit which comprised of three basic blocks known as the voltage reference, sine wave generator, and triangle wave generator blocks. When these three blocks are implemented with comparators and other small analog circuitry, they control the Pulse Width Modulation (PWM) signals that the two MOSFET drivers send. The PWM signals is being fed into these MOSFET drivers that perform level translation to drive four N-¬Channel MOSFETs in an H¬-Bridge configuration. From here the signal is sent through a low¬ pass (LC) filter so that the output delivers a pure sine wave.

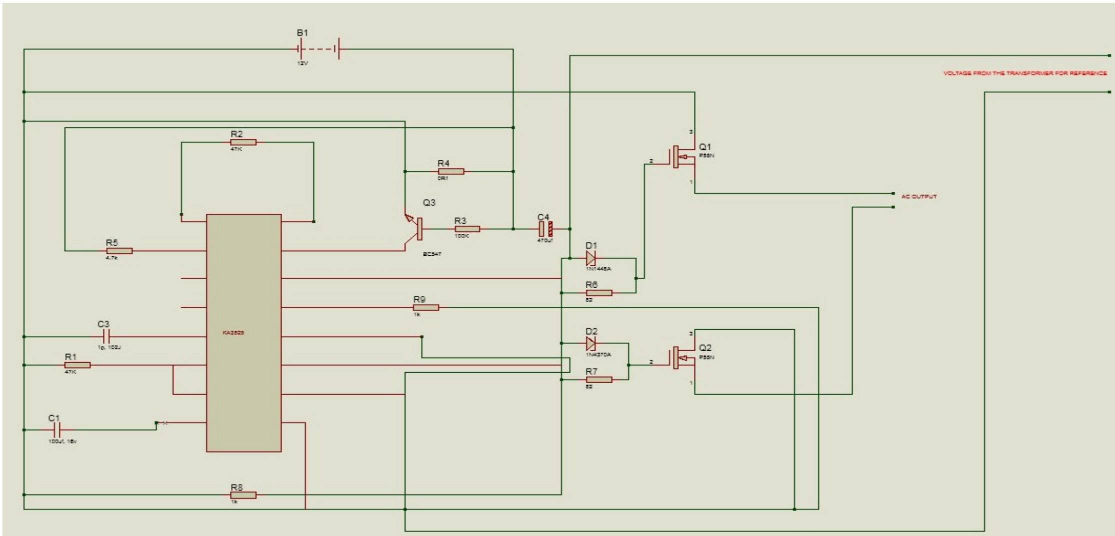

Figure 10. Circuit Diagram of a DC to AC Power Electronics-Based Inverter that Produces a Pure Sine Wave Output for Critical Engineering Applications

The circuit diagram in Figure 10 illustrates the interconnected arrangement of individual components seamlessly integrated into the overall design. The DC voltage is filtered and supplied to the KA3525 that converts reference voltage and gives the oscillated signal to the H-bridge configuration of PN55 MOSFETS which generates a pure sine wave AC output. For comprehensive monitoring, stabilization, and control of the output, a feedback transformer is required. This component provides feedback signals to the H-bridge configuration of the MOSFETs, enhancing and optimizing the output signal.

The temperature control is performed by the fan that constantly supplies and extract air to maintain optimal operating temperatures. Recognizing the inherent sensitivity of electronics to temperature, this cooling mechanism ensures a consistently low temperature environment for the circuit's efficient functioning.

4. Finding and Discussion

To optimize the efficiency, a switching frequency must be chosen which must be very low to keep the switches in line, but also high to make sure that the filter inductor is not unnecessarily large.

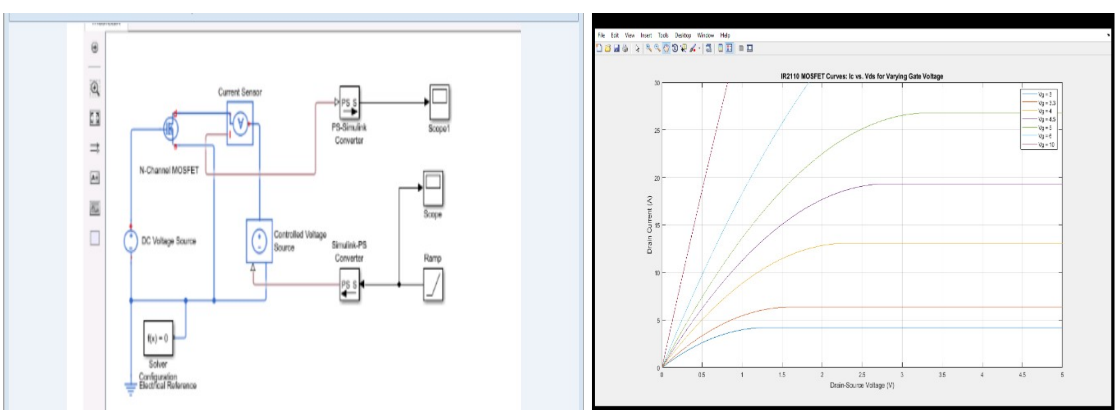

Figure 11. Block Diagram and Characteristic Curve of IR210 MOSFET

MATLAB was used to model the switching losses in the MOSFETs, based on their capacitance and switching rise times (which depends on the frequency), as well as their resistive losses (independent of frequency). Figure11 is the IR210 MOSFET characteristic curve which considered the resistive losses in the filter inductor (dependent on the inductor value/size) which is dependent on the frequency.

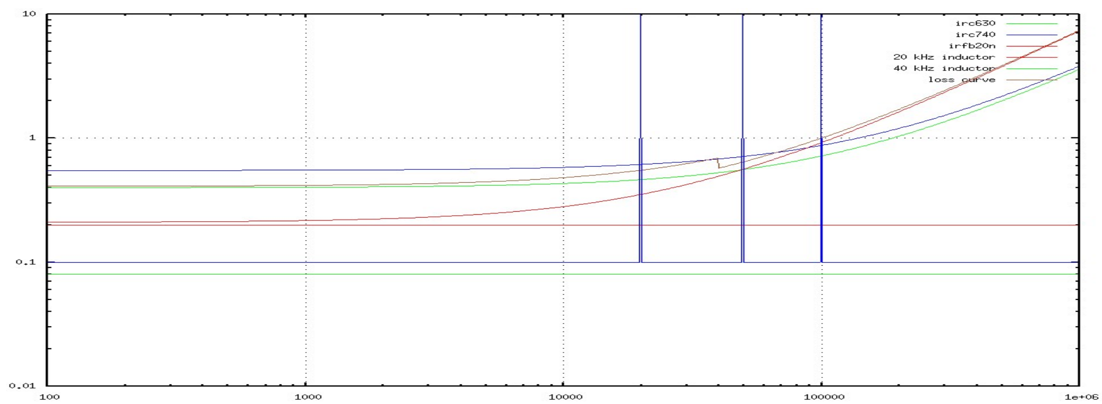

Figure 12. Graph of MOSFET Frequency Losses

Figure 12 shows the frequency losses of 3 different MOSFETs and 2 different inductors. The IRFb20n is an International Rectifier MOSFET with lower resistance than C740 and the IRC630, but has a higher capacitance. This is why the losses for this switch was significantly lower but rise drastically at higher frequencies. The curve with the 'notch' around 40 kHz shows the loss curve using the IRFb20n added to the resistive losses in the filter inductors. The notch occurs at the frequency where the required inductance value dropped. Based on the curve of figure 12, 50 kHz switching generates little extra loss over 20kHz, but have drastically improved output accuracy (less voltage ripple). This obvious observation made us to switch to 50 kHz, 2mH inductor.

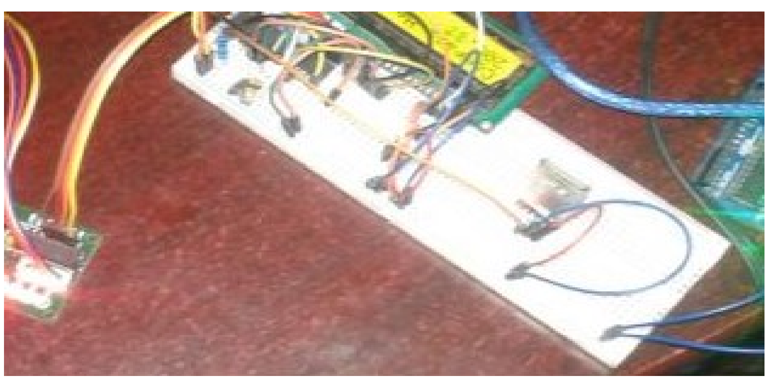

Figure 13. Breadboard Components Assembling

All components are assembled on the breadboard as shown in Figure 13, and the concept and functionality of this research work tested before transferring the components to a Printed Circuit Board (PCB). After this test the components were placed on a PCB and soldered with the aid of a soldering gun and lead.

A continuity test was carried out to check if there was current flow in the project circuitry and was aimed at finding electrical open paths in the circuitry after completing soldering and configuration. A multimeter was used to perform a continuity test on the electric circuit by measuring electric current flow as shown in Figure 14.

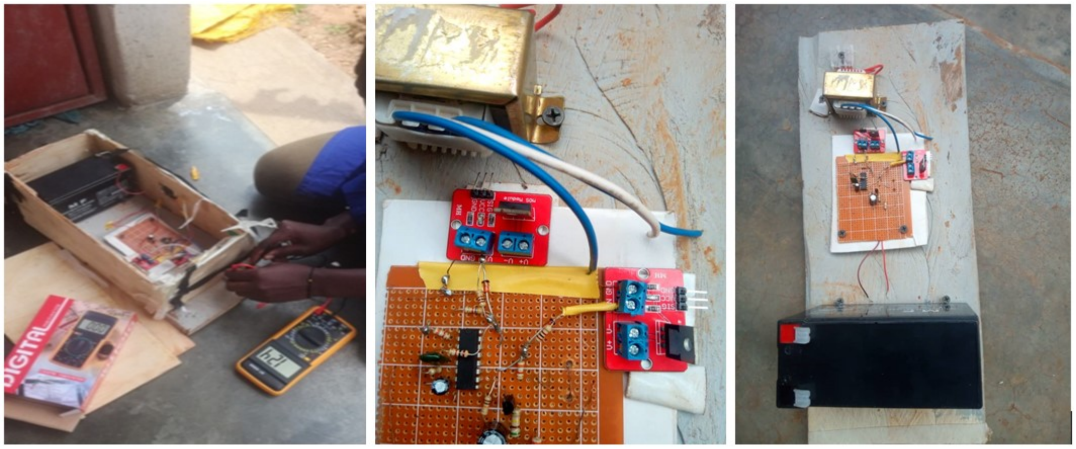

Figure 14. Testing and Implementation of the Designed a DC to AC Power Electronics Based Inverter that Produces Pure Sine Wave Output for Critical Engineering Applications

Continuity test procedures:

1. A multimeter was kept in diode mode.
2. Then it is connected to the ground terminal of the multimeter then to the ground
3. Finally, both terminals are connected across the path that needs to be checked and there is continuity in the path, a beep sound was produced by the multimeter.

Power on test was performed to check whether the voltage at different terminals is according to required or designed specifications. A multimeter was switched to voltage mode, the voltage across the source terminals of the MOSFETs was checked and measured at 170V AC voltage. The voltage across the Gate terminal measured at 0.00VAC value as shown in Figure 14.

The results obtained after tests were approximately the same as designed. Table 2 is the validation test results showing the designed data accuracy with the expected data

Table 2. Test Validation Table of the Design

Test	Expected Results	Actual Result	Comment
The voltage across the battery terminals	12Vdc	12Vdc	Correct output obtained
The voltage across the Source out pin of the MOSFET	12Vac	8Vac	Voltage drops due to internal resistance of the circuitry
Voltage Across the feedback transformer	230Vac	170Vac	Voltage drops due to less input voltage
The voltage across the source terminals of the H-bridge configuration of MOSFETs	230Vac	170Vac	Voltage drops due to internal resistance of the circuitry

The results in Table 2 were obtained after the final implementation of the research work. Due to minimize losses in the circuit, the final output that was expected out of the project was affected because some key components that were supposed to be used could not be found on the market for example EGS002 board for the production of a pure sine wave that is more efficient was replaced by KA3525a IC which can do comparably the same function with fewer effects.

5. Conclusion

In conclusion, this study focused on the conversion process of raw power to a pristine sine wave signal, crucial for powering sensitive equipment such as data switches and Remote Terminal Units (RTUs). The study utilizes the KA3525A integrated circuit (IC) in conjunction with MOSFETs of the

PN55 series, supported by capacitors and resistors for effective power filtration. The KA3525A IC serves as a monolithic solution encompassing essential control circuits for a pulse width modulating regulator. Its components include a voltage reference, error amplifier, pulse width modulator, oscillator, under-voltage lockout, soft start circuit, and output driver, all working seamlessly together. The MOSFETs act as switches synchronized with the oscillating signal from the KA3525A IC. This coordinated action, combined with filters and other signal conditioning units, enables the conversion process. The outcome of the study is the successful conversion of raw power into a stable pure sine wave signal of 170V AC at the H-bridge terminals. In conclusion, the approach involving the KA3525A IC, MOSFETs, and associated components proves effective in achieving the desired power conversion for applications demanding high stability. This research recommends for further improvement by using more MOSFETS for during design for higher power outputs as well as voltage regulator to improve the precision capacity in terms of comparing the input and the output data.

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