**TRIBHUVAN UNIVERSITY**

**INSTITUTE OF ENGINEERING**

**PULCHOWK CAMPUS**

**DEPARTMENT OF ELECTRICAL ENGINEERING**

A FINAL YEAR PROJECT REPORT
ON

# "SELECTIVE HARMONIC ELIMINATION"

(A Project Report submitted in partial fulfillment of the requirements for the Bachelor's Degree in Electrical Engineering)

**EE755**

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*APRIL 25, 2023*

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The undersigned certifies that they have read and recommended to the Institute of Engineering for acceptance, a project progress report entitled **"SELECTIVE HARMONIC ELIMINATION"** submitted by **Jibalal Kunwar, Prakash Paudel, Ramesh K.C.** and **Sanil Bista** in the partial fulfillment of the requirements for the Bachelor's Degree in Electrical Engineering.

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# ACKNOWLEDGEMENT

We wish to extend our heartfelt gratitude to the Department of Electrical Engineering, acknowledging their generosity in granting us the chance to undertake a project centered around "Selective Harmonic Elimination." This endeavor provided us with a tangible insight into the practical functioning of an inverter, thereby enriching our theoretical understanding.

Our deep appreciation goes to our esteemed mentors, Sahabuddin Khan and Akhileshwor Mishra, for their consistent provision of invaluable insights and guidance throughout the entirety of our project's execution.

Furthermore, we would like to express our thankfulness to both our educators and companions who, whether directly or indirectly, contributed to the triumphant culmination of this project.

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# ABSTRACT

Selective Harmonic Elimination (SHE) is a widely used technique in power electronic converters to mitigate the detrimental effects of harmonics on system performance. Harmonics, which are undesired sinusoidal components occurring at frequencies that are multiples of the fundamental frequency, can lead to waveform distortion, increased losses, and interference with other electronic devices. The SHE technique selectively eliminates specific harmonics from the output waveform by precisely controlling the switching instants of the converter. This research project focuses on investigating the theory and implementation of Selective Harmonic Elimination for square wave inverters, which commonly produce harmonically rich waveforms due to the abrupt transitions in the output voltage.

The primary objective of this study is to design a selective harmonic elimination pulse width modulation (SHE PWM) controller for square wave inverters to reduce the Total Harmonic Distortion (THD) present in the output waveform. The research project aims to develop an effective SHE algorithm capable of selectively eliminating specific harmonics while preserving the desired characteristics of the output waveform.

The project encompasses several stages, including algorithm design, simulation, validation, implementation, and testing. In the algorithm design phase, the fundamental principle of SHE is explored, which involves determining a set of switching angles that result in the elimination of a particular harmonic. The SHE equations, a set of nonlinear equations, are solved to find the optimal solutions for these switching angles. The obtained solutions are then utilized by the SHE PWM controller to determine the precise switching instants required for the elimination of specific harmonics, resulting in a cleaner and more efficient output waveform.

The simulation and validation stage involves creating a power electronic system model using software tools like MATLAB/Simulink. The developed SHE algorithm is implemented in the simulation, and the elimination of targeted harmonics is verified. Once validated, the algorithm is implemented in hardware, where control circuitry is designed and interfaced with the power electronic system. Rigorous testing is conducted under real-world conditions to ensure the successful elimination of harmonics. Performance evaluation is performed to assess the effectiveness of the system in

reducing harmonic distortion across various operating conditions.

While Selective Harmonic Elimination offers significant benefits in terms of harmonic reduction and system performance enhancement, it does have limitations. The complexity of the SHE algorithm, which involves solving nonlinear equations, can present computational challenges and require time-consuming calculations. Additionally, the effectiveness of the technique relies on factors such as load impedance and switching frequency, and deviations from these parameters may impact the algorithm's performance.

Overall, this project aims to contribute to the field of power electronics by developing a robust and efficient Selective Harmonic Elimination technique tailored for square wave inverters. The successful implementation of the SHE PWM controller has the potential to significantly enhance the performance of power electronic systems by minimizing harmonic distortion, reducing losses, and improving the overall quality of the output waveform. The findings of this research can benefit various applications, including inverters, rectifiers, and DC-DC converters, where the elimination of targeted harmonics is crucial for achieving optimal system performance.

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# LIST OF ABBREVIATIONS

AC = Alternating Current

DC = Direct  Current

MOSFET = Metal-Oxide Semiconductor Field-Effect Transistor

PWM = Pulse Width Modulation

SHE = Selective Harmonic Elimination

THD = Total Harmonic Distortion

# CHAPTER ONE
# INTRODUCTION

## 1.1 Background

Selective Harmonic Elimination (SHE) is a technique used to eliminate specific harmonics in the output waveform of power electronic converters. Harmonics are unwanted sinusoidal components that occur at frequencies that are multiples of the fundamental frequency of the input waveform. These harmonics can cause problems such as distortion of the voltage and current waveforms, increased losses in the system, and interference with other electronic devices.

SHE works by selectively eliminating specific harmonics from the output waveform by controlling the switching instants of the converter. This technique has been widely used in various applications such as inverters, rectifiers, and DC-DC converters. It is particularly useful in applications where the elimination of certain harmonics is critical for the proper functioning of the system.

The basic idea behind SHE is to find a set of switching angles that will result in the elimination of a specific harmonic. This is achieved by solving a set of nonlinear equations, known as the SHE equations. The solution of these equations gives the switching angles that will eliminate the desired harmonic.

Overall, selective harmonic elimination is a powerful tool for controlling the harmonics in power electronic systems, which can help improve the efficiency and reliability of these systems.

## 1.2 Problem statement

The problem addressed by Selective Harmonic Elimination (SHE) is the presence of unwanted harmonics in the output waveform of power electronic converters. These harmonics can cause distortion of the voltage and current waveforms, increased losses in the system, and interference with other electronic devices.

The square wave inverter generates a square wave output which also contains odd harmonics. If the generated square wave is of 50Hz, then it contains a fundamental sine wave of 50Hz and higher harmonics of 100Hz, 150Hz, and so on. For normal operations, we only require the sine wave of 50Hz. Higher frequency harmonics present in the square wave create currents, which cause unwanted overheating of load. Harmonics also distort the required ideal fundamental sine wave. Overall, harmonics increase losses in the system.

## 1.3 Objective

The objectives for our project are:

- To design a selective harmonic elimination pulse width modulation (SHE PWM) controller for square wave output of a square wave inverter.
- To reduce total harmonic distortion (THD) present in the square wave output and hence reduce unwanted losses.

## 1.4 Scope and limitations of project

The proposed system has some scopes and limitations:

➢ **Scopes**

The scope of our project "Selective Harmonic Elimination" involves the following:

- Design of the SHE algorithm: An algorithm needs to be developed that can selectively eliminate specific harmonics while maintaining the desired characteristics of the output waveform.
- Simulation and validation: The effectiveness of the SHE algorithm needs to be tested through simulation and validation using software tools such as MATLAB/Simulink. The simulation would involve modeling the power electronic system and

implementing the SHE algorithm to verify that the targeted harmonics are eliminated.

- Implementation and testing: Once the algorithm has been validated through simulation, it needs to be implemented in hardware and tested under real-world conditions. This involves designing the control circuitry and interfacing with the power electronic system to ensure that the desired harmonic elimination is achieved.
- Performance evaluation: The final step is to evaluate the performance of the system under different operating conditions and validate the effectiveness of the SHE algorithm in reducing harmonic distortion.

➢ **Limitations**

Limitations of Selective Harmonic Elimination technique are:

- Complexity: The SHE technique involves solving a set of nonlinear equations to determine the optimal switching angles for harmonic elimination. This process can be computationally intensive and time-consuming, particularly for systems with a large number of harmonics. As a result, implementing SHE in real-time applications with stringent timing constraints may pose challenges.

- Dependence on system parameters: The effectiveness of the SHE technique is highly dependent on various system parameters, such as the load impedance, switching frequency, and component tolerances. Changes in these parameters can impact the performance of the algorithm and may require the SHE equations to be recalculated or optimized for the new system configuration.

- Sensitivity to switching delay: SHE relies on precise control of the switching instants of power electronic devices to eliminate specific harmonics. Even a small delay in the switching transitions can result in the failure to eliminate the targeted harmonic effectively. Therefore, minimizing switching delays and ensuring accurate timing control are critical for achieving optimal harmonic elimination.

- High switching frequency: While SHE is effective in reducing harmonic distortion, it can lead to an increase in the switching frequency of power electronic devices. Higher switching frequencies can result in increased power losses due to switching losses and higher demands on the design of power devices and heat dissipation mechanisms. Consequently, the efficiency of the overall system may be compromised.

## 1.5 Report Organization

This project consists of following chapters:

- This project encompasses five sections, including the present one. This section delineates the Selective Harmonic Elimination technique, outlining its objectives, scopes, and limitations.

- The second section presents an extensive review of relevant literature, encompassing theoretical materials, articles, and publications from IEEE conferences or transactions, as well as books published by prominent publishers. The principal aim of this review is to extract available information and findings from prior research endeavors.

- The third section elucidates the work methodology for Selective Harmonic Elimination, expounding on the operational principles of components such as the H-bridge inverter, optocoupler, MOSFET, and Arduino microcontroller.

- Moving on to the fourth section, it showcases both simulation and hardware outcomes, coupled with discussions about the manipulation of switching angles to generate the PWM control signal for the H-bridge inverter.

- Chapter five concludes the result.

# CHAPTER TWO
# LITERATURE REVIEW

## 2.1 Review of Published Papers

One of the earliest works on SHE using PWM was published by R. Krishnan in 1991. In this work, Krishnan proposed a method for selectively eliminating low-order harmonics in a single-phase inverter. The proposed technique used a nonlinear equation to determine the switching angles for the inverter. The method was shown to be effective in eliminating harmonics while maintaining a sinusoidal output voltage.

Since then, numerous works have been published on SHE using PWM. One of the most common methods for implementing SHE using PWM is through the use of iterative algorithms. These algorithms are used to determine the optimal switching angles that will eliminate specific harmonics. This approach has been used in various power electronic systems, including inverters, rectifiers, and active power filters.

Another approach to SHE using PWM is to use artificial intelligence techniques, such as neural networks and fuzzy logic systems. These techniques have been shown to be effective in determining the optimal switching angles for eliminating specific harmonics. For example, in a work by H. S. Shriram et al., a fuzzy logic controller was used to control the switching angles of a three-phase inverter for SHE.

In recent years, there has been a growing interest in SHE using PWM for grid-connected renewable energy systems, such as wind turbines and solar PV systems. This is due to the increasing penetration of these systems in the power grid, which can introduce harmonic distortions. A number of works have been published on SHE using PWM for renewable energy systems, including works by A. M. Eltamaly and A. M. Massoud.

In conclusion, SHE using PWM is an effective technique for reducing or eliminating specific harmonic frequencies in power electronic systems. Various methods, including iterative algorithms and artificial intelligence techniques, have been proposed for implementing SHE using PWM. The application of SHE using PWM has been extended to grid-connected renewable energy systems, which have become increasingly important in the modern power grid.

## 2.2 Theory

### 2.2.1 Total Harmonic Distortion

Total Harmonic Distortion (THD) is a vital concept in electrical engineering and signal analysis. It measures the distortion caused by harmonics in a waveform, which are additional frequency components that appear as integer multiples of the fundamental frequency. THD quantifies the level of distortion relative to the fundamental frequency and is crucial for assessing signal quality. By minimizing THD, we can ensure efficient and reliable operation of electrical systems, reducing power losses and interference with other devices. Techniques like harmonic filtering and selective harmonic elimination are employed to mitigate THD and maintain signal integrity.

### 2.2.2 Arduino Uno

Arduino Uno is a popular microcontroller board widely used in electronic prototyping and project development. Based on the ATmega328P microcontroller, it offers a user-friendly platform for programming and interfacing with various electronic components. The board features digital input/output pins, analog inputs, a USB interface, and a power jack, making it versatile for a range of applications. Arduino Uno is programmed using the Arduino IDE, which simplifies the coding process for beginners and professionals alike. With its extensive library support and a vast community, Arduino Uno enables users to easily create interactive projects, control sensors, motors, and actuators, and explore the world of electronics and programming.


**Fig 2.1 : Arduino Uno Board**
**[https://commons.wikimedia.org]**

### 2.2.3 IRFZ44N MOSFET

The IRFZ44N MOSFET is a widely used N-channel power transistor in various electronic applications. It is designed to handle high-voltage and high-current loads while offering low on-state resistance. With a maximum voltage rating of 55V and a maximum current rating of 49A, the IRFZ44N is suitable for power electronics projects. Its low gate-to-source threshold voltage of 2V allows for easy integration with microcontrollers and digital circuits. The IRFZ44N MOSFET finds applications in motor control circuits, power supplies, and switching applications. Its reliability, high performance, and ease of use have made it a popular choice among electronic enthusiasts and professionals alike. With its ability to handle significant power loads and provide efficient switching, the IRFZ44N MOSFET serves as a fundamental component in many electronic systems.

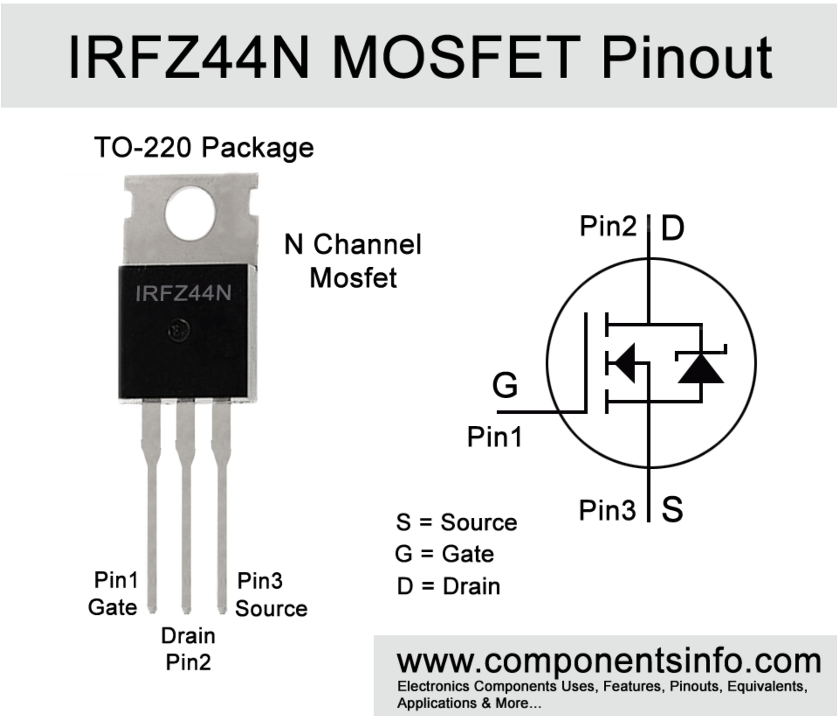


**Fig 2.2 : MOSFET [www.componentsinfo.com]**

### 2.2.4 EL4N35712 Optocoupler

The EL4N35712 optocoupler is a versatile electronic device that consists of an infrared emitting diode and a phototransistor. It is commonly employed for signal isolation and noise suppression purposes in electronic circuits. When a current is applied to the infrared emitting diode, it emits infrared light that is then detected by the phototransistor. This detection leads to the activation of the phototransistor, allowing current to flow through the output circuit. The EL4N35712 optocoupler offers galvanic isolation between the input and output circuits, providing protection against voltage spikes and ground loops. It also exhibits high noise immunity, making it suitable for various industrial and automotive applications. Widely used in power supplies, motor control circuits, and digital signal isolation circuits, the EL4N35712 optocoupler is known for its reliability, performance, and versatility in the field of electronics.

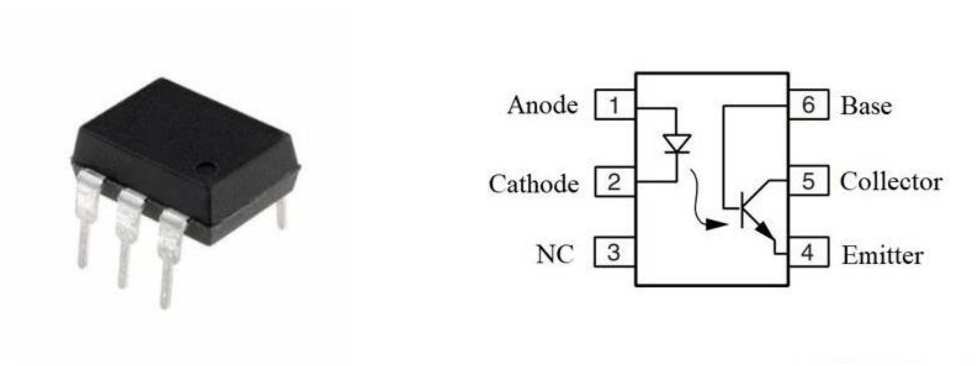


**Fig 2.3 : Optocoupler [https://www.apogeeweb.net]**

### 2.2.5 H-bridge Inverter

The H-bridge inverter is a fundamental component in power electronics that allows for the conversion of DC (direct current) power to AC (alternating current) power. It consists of four switches, typically power transistors or MOSFETs, arranged in an "H" configuration. This configuration enables the control of current flow through the load in both directions, allowing for the generation of an AC output waveform.

By controlling the switching states of the four switches, the H-bridge inverter can create a square wave or modified sine wave output. This output can be further filtered to produce a clean sine wave, suitable for powering various AC loads. The H-bridge inverter's ability to produce AC power from a DC source makes it an essential component in applications such as motor drives, uninterruptible power supplies (UPS), and renewable energy systems.

The H-bridge inverter provides several advantages, including high efficiency and precise control over the output voltage and frequency. It allows for bidirectional power flow, enabling regenerative braking in motor control applications. Additionally, its modular design allows for scalability and flexibility, making it suitable for a wide range of power levels and applications.

However, the H-bridge inverter also has some limitations. One notable limitation is the need for careful switching control to prevent shoot-through currents, which can cause short circuits and damage the switches. The high-frequency switching operation of the inverter can also introduce electromagnetic interference (EMI) that needs to be managed through proper design and filtering techniques.

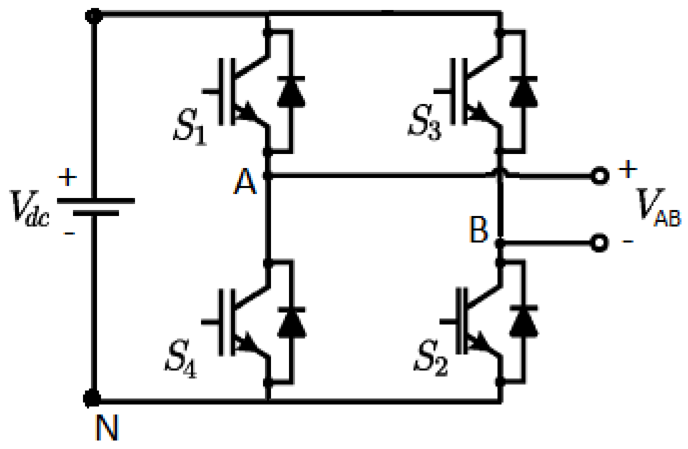


**Fig 2.4 : H-bridge Inverter [https://www.researchgate.net/]**

# CHAPTER THREE

# METHODOLOGY

## 3.1 Overview

Following is the block diagram of our proposed system

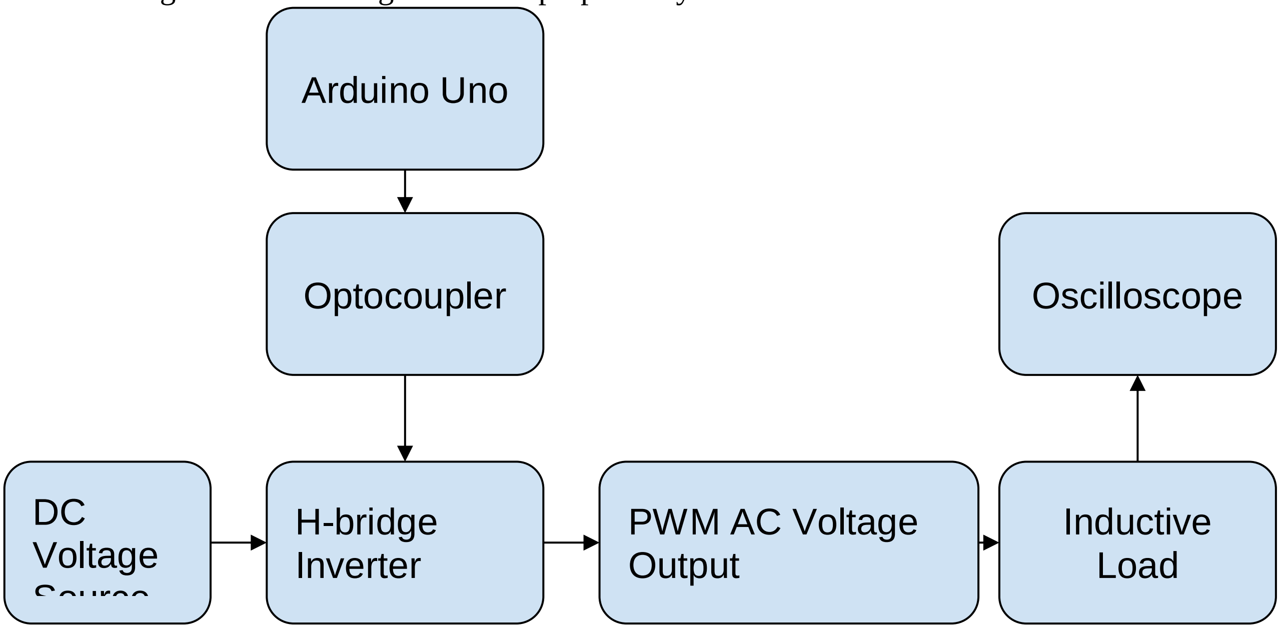


**Fig 3.1: Proposed Circuit Block Diagram**

The H-bridge inverter takes in DC voltage supply and converts it into pulse width modulated AC output. The PWM signal is generated by the Arduino Uno board. The board generates the required PWM signal by the programming code entered into based on the switching angles required to eliminate specific harmonics. There is optocoupler in between Arduino and the inverter, which isolates the two such that the high currents that may occur in the inverter circuit does not affect the arduino board circuit and damage it. The H-bridge inverter thus operates as per the PWM control signal provided by the arduino board and converts the DC supply into pulse AC. The PWM AC output signal of the inverter has specific harmonics eliminated which is then supplied to an inductive load, which further eliminates higher harmonics. Thus, the THD of the AC signal is greatly reduced, which can be observed in an oscilloscope. The arduino is programmed to generate different PWM control signals for eliminating selected different harmonics, in our case we have developed 3 arduino program codes to eliminate up to 3rd, up to 5th, and up to 9th order harmonics from the required AC signal of 50 Hz.

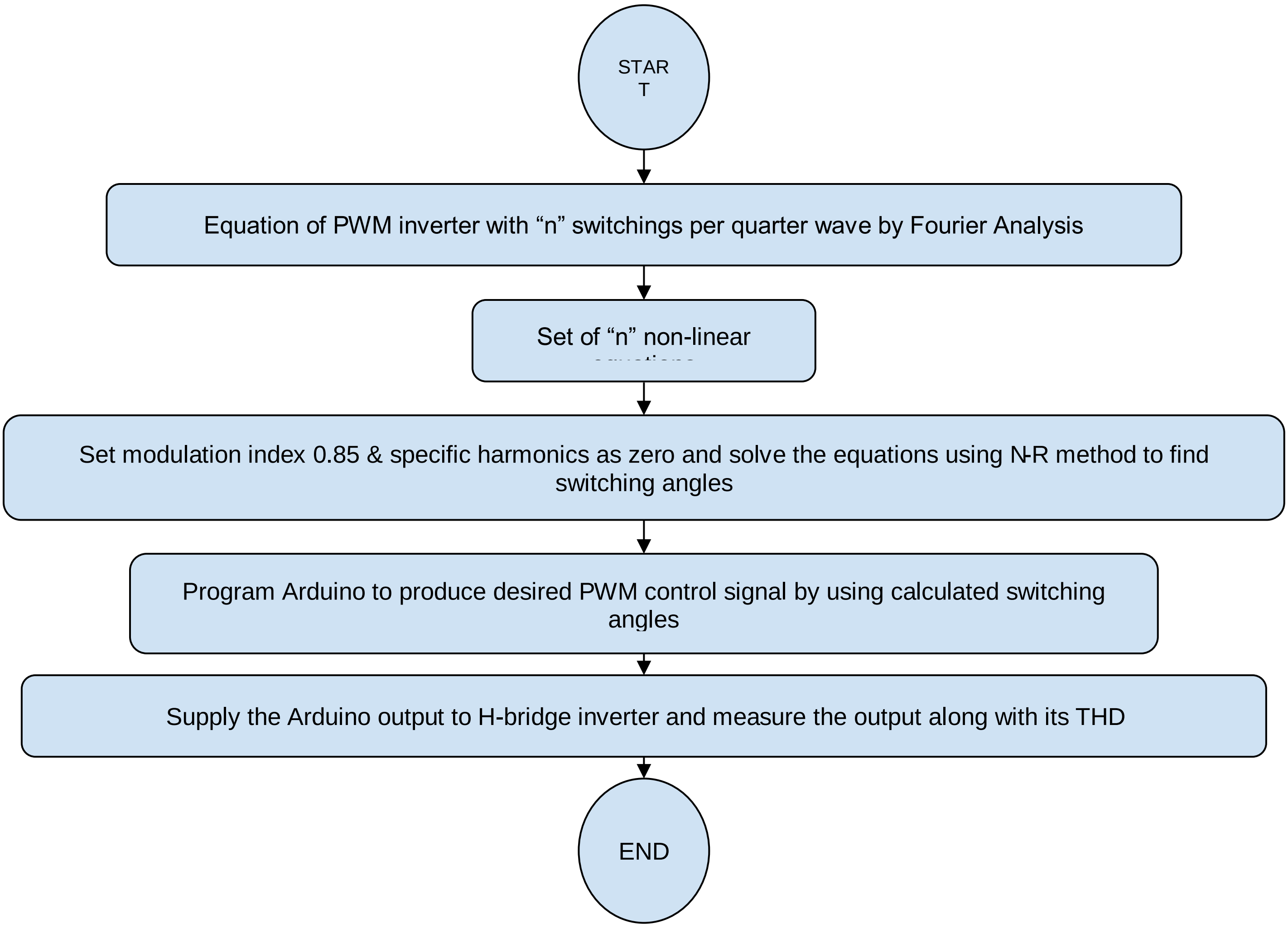


**Fig 3.2: Flowchart of Proposed System**

### 3.2 Determining Switching Angles

The PWM control signal generated by a PWM controller can be deduced through Fourier analysis. The resulting equation can then serve as the foundation for deriving a series of nonlinear equations. These equations can be effectively solved through the application of the Newton-Raphson numerical technique, programmed for this purpose. These nonlinear equations are instrumental in determining the switching angles required for the inverter's operation. The Selective Harmonic Elimination (SHE) technique is introduced to tackle undesirable harmonics. However, calculating the necessary switching angles proves intricate due to numerous available algorithms. For this endeavor, we have opted to employ Fourier Series expansion and the Newton-Raphson method. These methods are harnessed to ascertain the unknown switching angles, thus aiding in the reduction of Total Harmonic Distortion (THD).

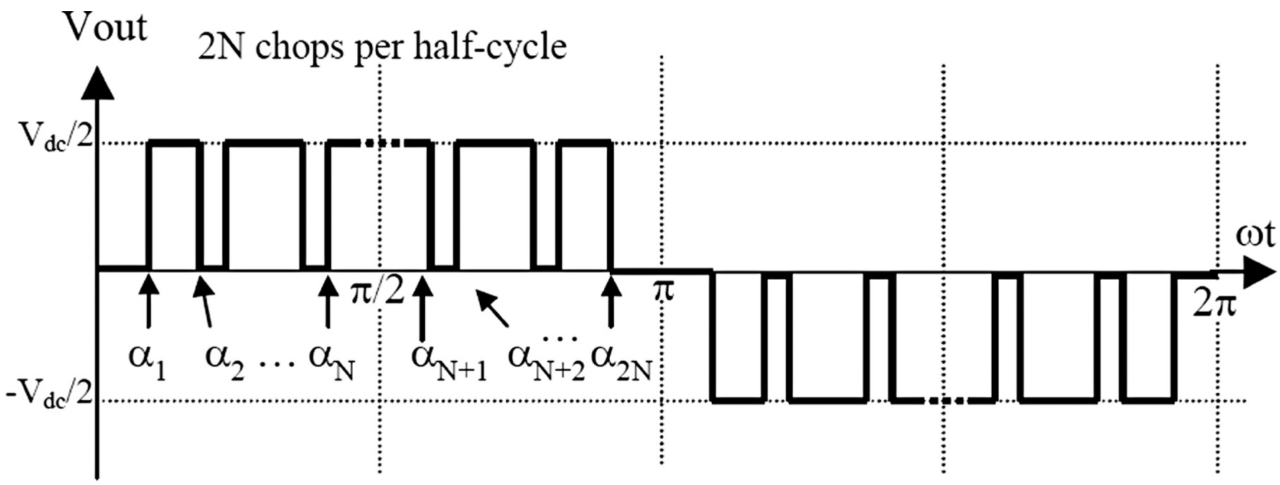


**Fig 3.3 : Pulse Width Modulation for SHE [https://ietresearch.onlinelibrary.wiley.com/]**

The equation of such waveform from fourier analysis is given by:

$$U(t) = \sum_{n=1}^{\infty} b_n \sin(n\omega t) \tag{1}$$

Where, for “m” switchings,

$$b_n = 4Vdc/n\pi(-\sum_{k=1}^{m}(-1)^k \cos(n\alpha_k)) \tag{2}$$

Let’s say there are 2 switchings per quarter wave to eliminate 3rd harmonics,

$b_n$ = 4Vdc/nπ ( cosnα1 - cosnα2)

So,

1st harmonics : $b_1$ = 4Vdc/π ( cosα1 - cosα2)

3rd harmonics : $b_3$ = 4Vdc/3π ( cos3α1 - cos3α2)

If we want to eliminate 3rd harmonics i.e. $b_3$ = 0 and retain 85% of 50hz signal i.e. $b_1$ = 0.85(π/4),

- cos(α1) - cos(α2) = 0.85(π/4) (3)
- cos(3α1) - cos(3α2) = 0 (4)

By solving equations (3) and (4) using Newton Raphson Method, we obtain switching angles α1 and α2 to eliminate 3rd harmonics.

Similarly, we can solve the equations for more switching angles to eliminate more harmonics.

By using Newton Raphson method, we obtain the switching angles to remove harmonics as:

●3rd - α1=37.33, α2=82.67

●3rd,5th - α1=30.45, α2=54.28, α3=67.09

●3rd,5th,7th,9th - α1=22.58, α2=33.6, α3=46.64, α4=68.5, α5=75.1

### 3.3 Newton Raphson Method

Newton-Raphson method is used to find out the switching angles. Let’s say we want to eliminate up to 9th harmonics, then the non-linear equations are as follows:

cos(α1)-cos(α2)+cos(α3)-cos(α4)+cos(α5)=M*π /4

cos(3*α1)-cos(3*α2)+cos(3*α3)-cos(3*α4)+cos(3*α5)=0

cos(5*α1)-cos(5*α2)+cos(5*α3)-cos(5*α4)+cos(5*α5)=0

cos(7*α1)-cos(7*α2)+cos(7*α3)-cos(7*α4)+cos(7*α5)=0

cos(9*α1)-cos(9*α2)+cos(9*α3)-cos(9*α4)+cos(9*α5)=0

Where M is the modulation index and M=h1/Vdc ( 0<=M<=1)

h1=The rms value of harmonic voltage.

Vdc=The rms value of voltage of the fundamental component.

**Step 1:**

Set the initial values of switching angles

alpha^j=[alpha1^j alpha2^j alpha3^j alpha4^j alpha5^j]

**Step 2:**

The nonlinear system can be written in matrix form as:

F(alpha^j)=[cos(alpha1^j)-cos(alpha2^j)+cos(alpha3^j)-cos(alpha4^j)+cos(alpha5^j)
cos(3*alpha1^j)-cos(3*alpha2^j)+cos(3*alpha3^j)-cos(3*alpha4^j)+cos(3*alpha5^j)

cos(5*alpha1^j)-cos(5*alpha2^j)+cos(5*alpha3^j)-cos(5*alpha4^j)+cos(5*alpha5^j)

cos(7*alpha1^j)-cos(7*alpha2^j)+cos(7*alpha3^j)-cos(7*alpha4^j)+cos(7*alpha5^j)

cos(9*alpha1^j)-cos(9*alpha2^j)+cos(9*alpha3^j)-cos(9*alpha4^j)+cos(9*alpha5^j)]

**Step 3:**

Calculate the derivative of the nonlinear system matrix:

dF/d (alpha)=[-sin(alpha1)+sin(alpha2)-sin(alpha3)+sin(alpha4)-sin(alpha5);

-3*sin(3*alpha1)+3*sin(3*alpha2)-3*sin(3*alpha3)+3*sin(3*alpha4)-3*sin(3*alpha5);

-5*sin(5*alpha1)+5*sin(5*alpha2)-5*sin(5*alpha3)+5*sin(5*alpha4)-5*sin(5*alpha5);

-7*sin(7*alpha1)+7*sin(7*alpha2)-7*sin(7*alpha3)+7*sin(7*alpha4)-7*sin(7*alpha5);

-9*sin(9*alpha1)+9*sin(9*alpha2)-9*sin(9*alpha3)+9*sin(9*alpha4)-9*sin(9*alpha5)];

**Step 4:**

Initialize a matrix T:

T=[0.85pi/4 0 0 0 0]

**Step 5:**

dTheta = inv(dF/d (alpha))*(T-F)

**Step 6:**

Theta(n) = Theta(n) + dTheta(n)

Where, n = number of switching angles

### 3.4 Hardware Implementation

We designed the simulated H-bridge inverter circuit in real life and ran the code in arduino for generating control signals to eliminate 3rd and up to 5th harmonics from the output of the square wave inverter. We observed the output of the inverter for eliminating 3rd harmonics and eliminating 3rd and 5th harmonics separately.

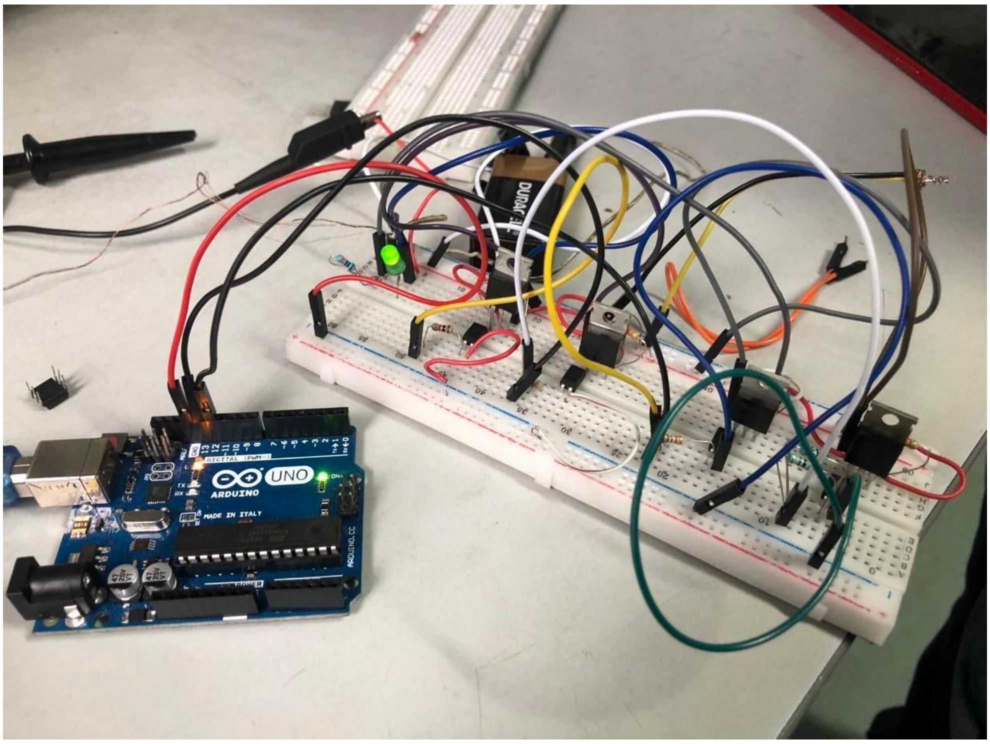

**Fig 3.3 : Hardware implementation of designed circuit**

# CHAPTER FOUR

# RESULT AND DISCUSSION

## 4.1 SOFTWARE SIMULATION

We simulated our project's circuit in MATLAB's simulation program SIMULINK. In the simulation, we have designed an H-bridge inverter which uses insulated gate bipolar transistor (igbt) as its switches, and the inverter is controlled by two controlling signals [S1S2] and [S3S4], which control the igbt switches of the inverter. The controlling signals are generated by using pulse width modulation technique for removing harmonics from the inverter output.

The controlling signals are generated from three different subsystems, which can be used one at a time to remove the desired number of harmonics from the system. The first subsystem generates the controlling signals for removing 3rd harmonics, the second subsystem generates the controlling signals for removing 3rd and 5th harmonics and the third subsystem generates controlling signals for removing 3rd, 5th, 7th and 9th harmonics from the system.

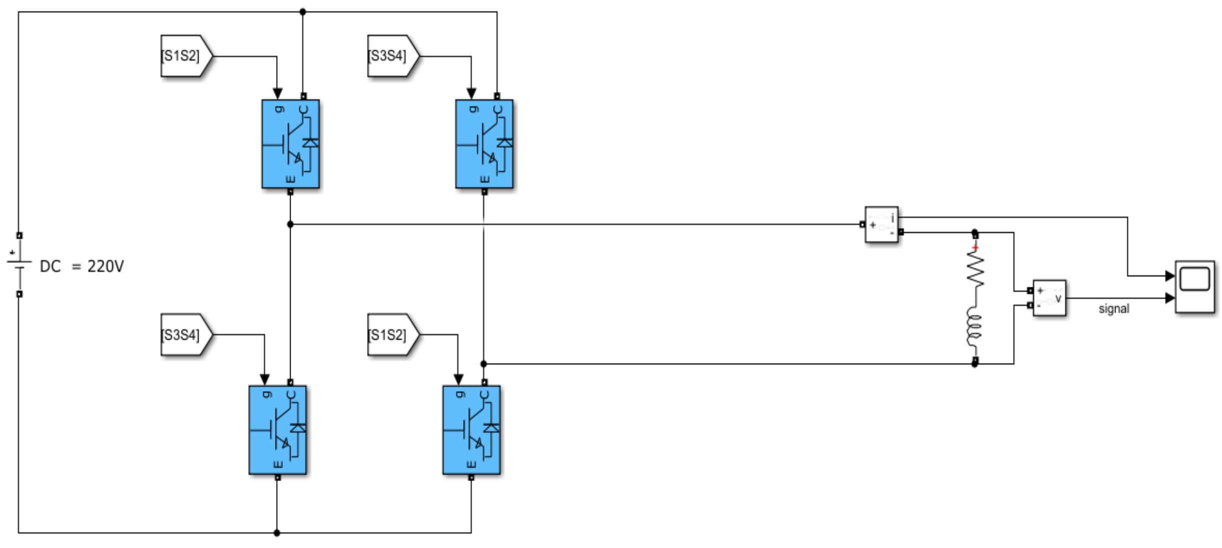


**Fig 4.1: H-bridge inverter simulation in Simulink**

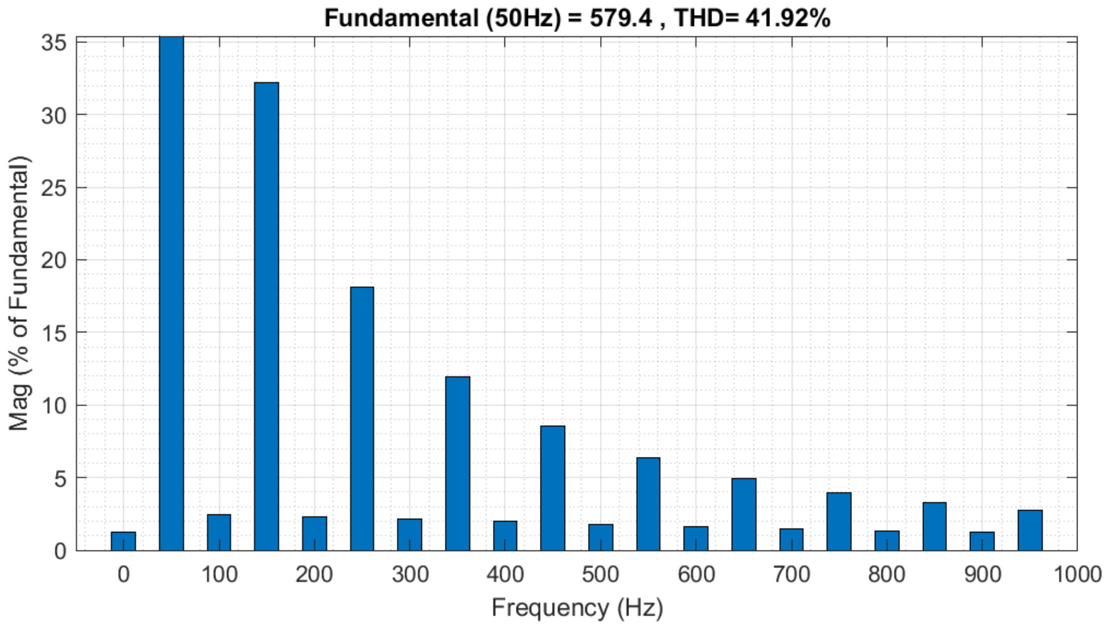


**Fig 4.2 : FFT analysis without harmonics elimination**

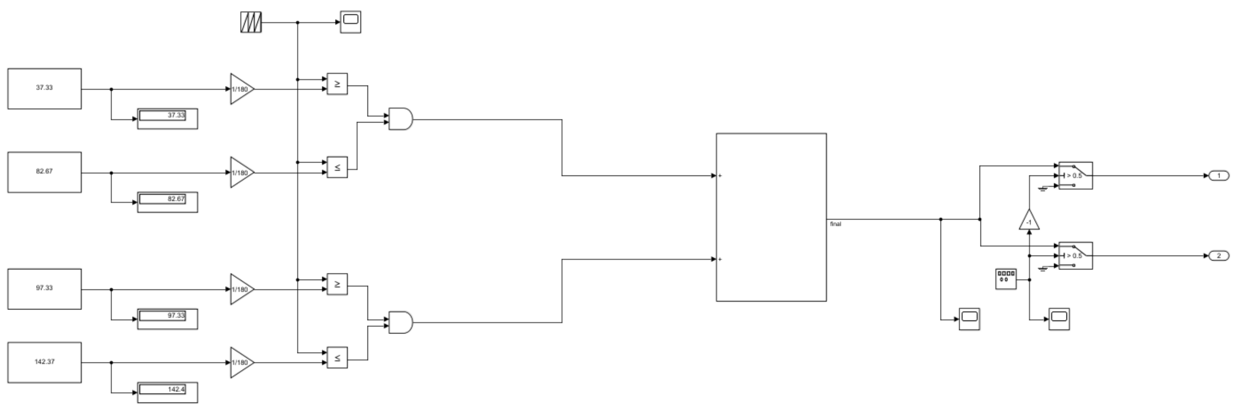

**Fig 4.3 : 1st subsystem for PWM to remove 3rd harmonics**

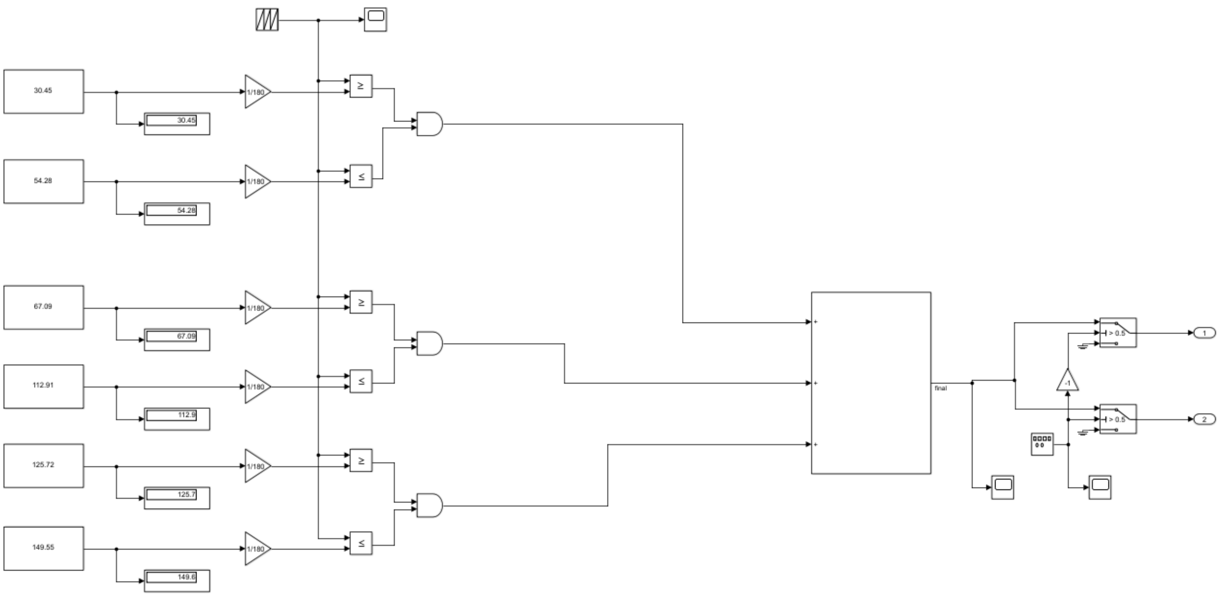


**Fig 4.4 : 2nd subsystem for PWM to remove 3rd and 5th harmonics**

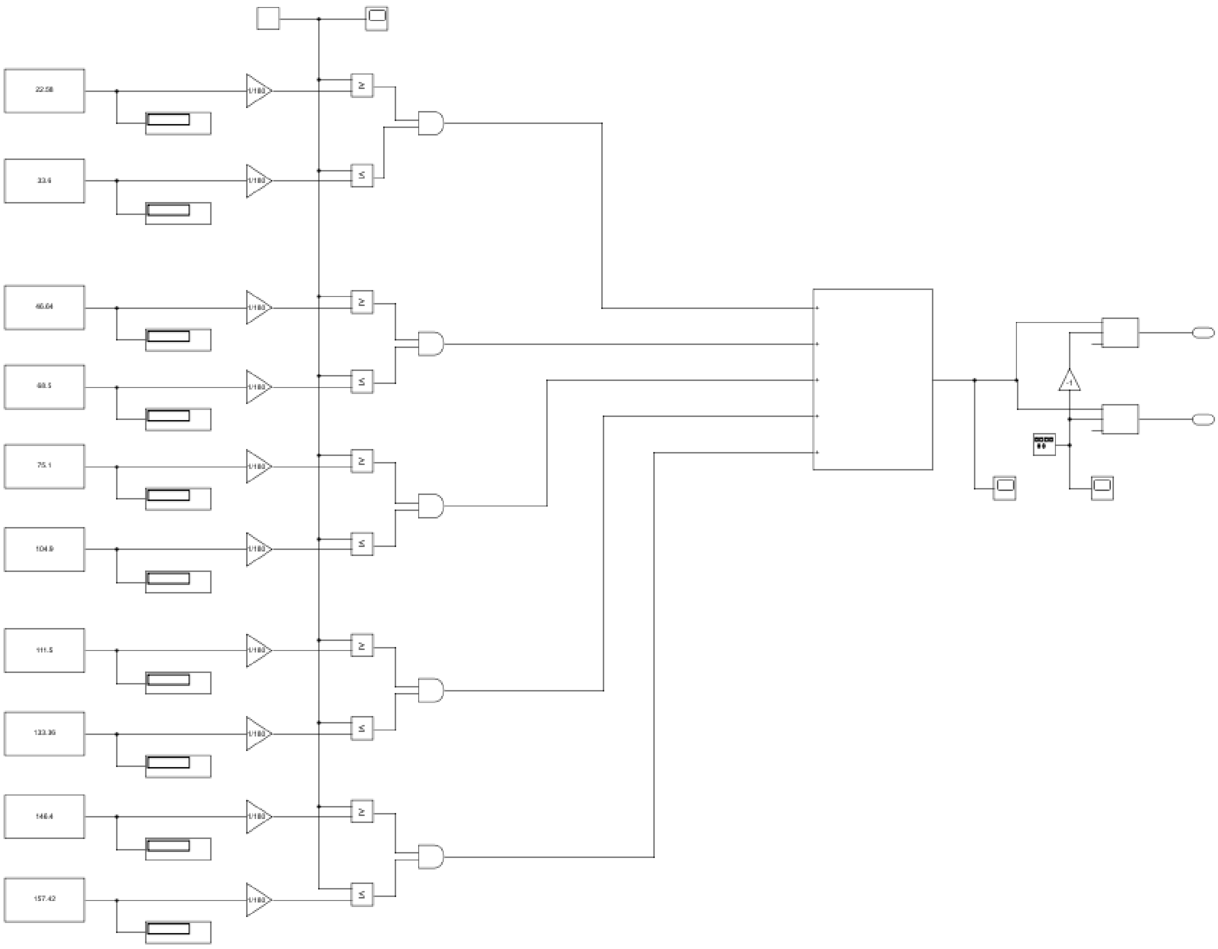


**Fig 4.5 : 3rd subsystem for PWM to remove 3rd, 5th, 7th and 9th harmonics**

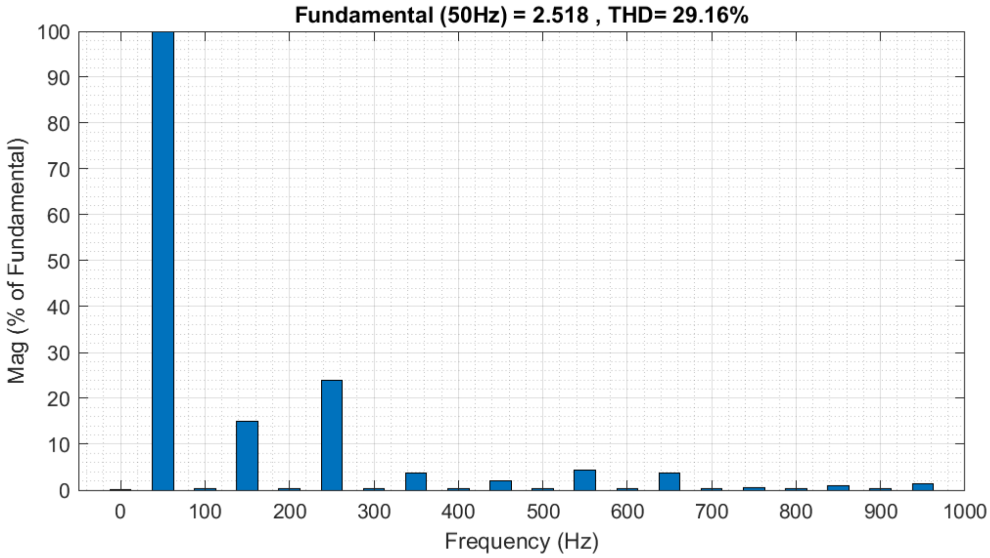


**Fig 4.6 : FFT Analysis for 3rd harmonics elimination**

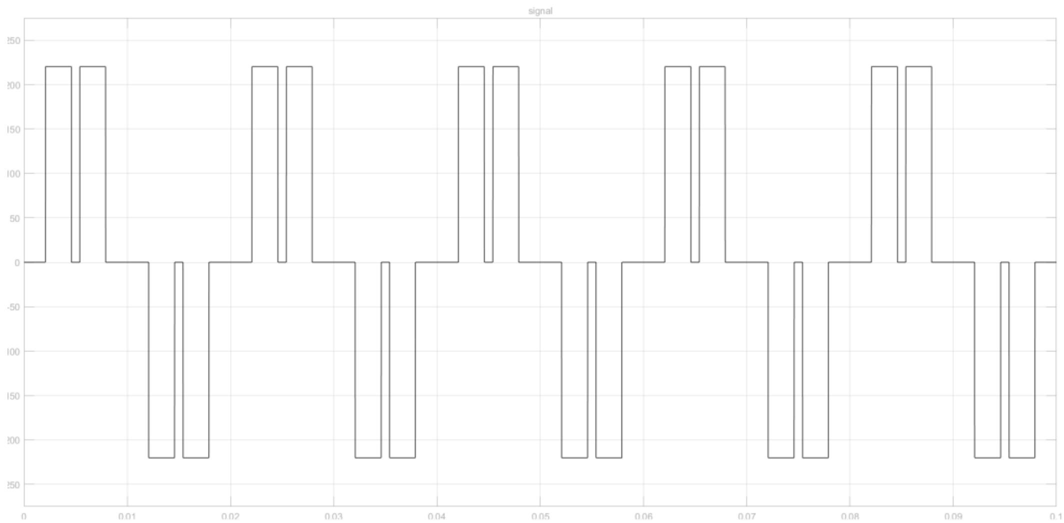

**Fig 4.7 : Inverter switching for 3rd harmonics elimination**

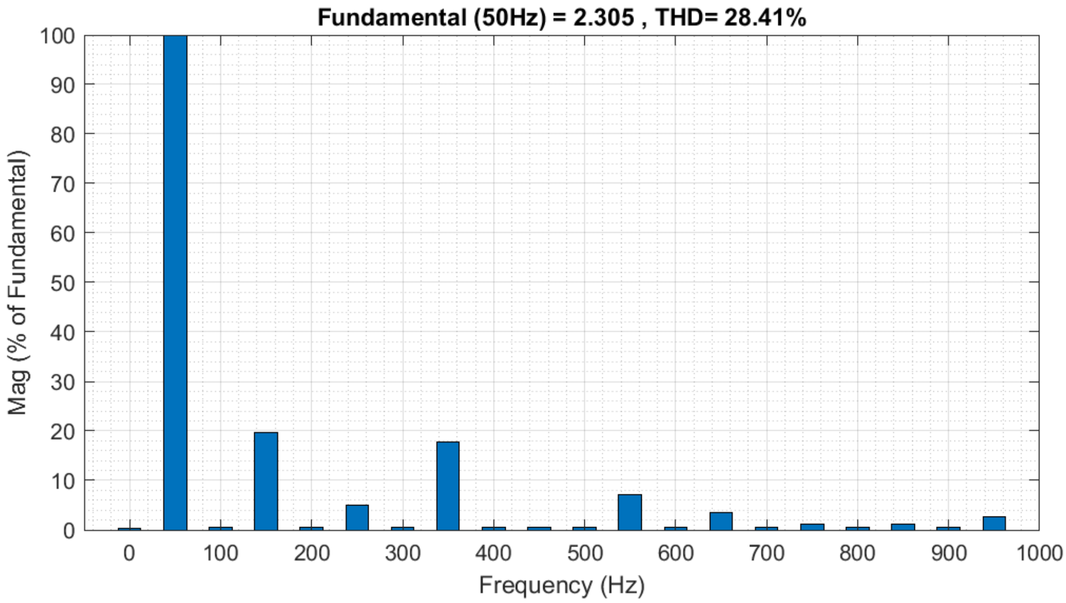


**Fig 4.8 : FFT Analysis for 3rd and 5th harmonics elimination**

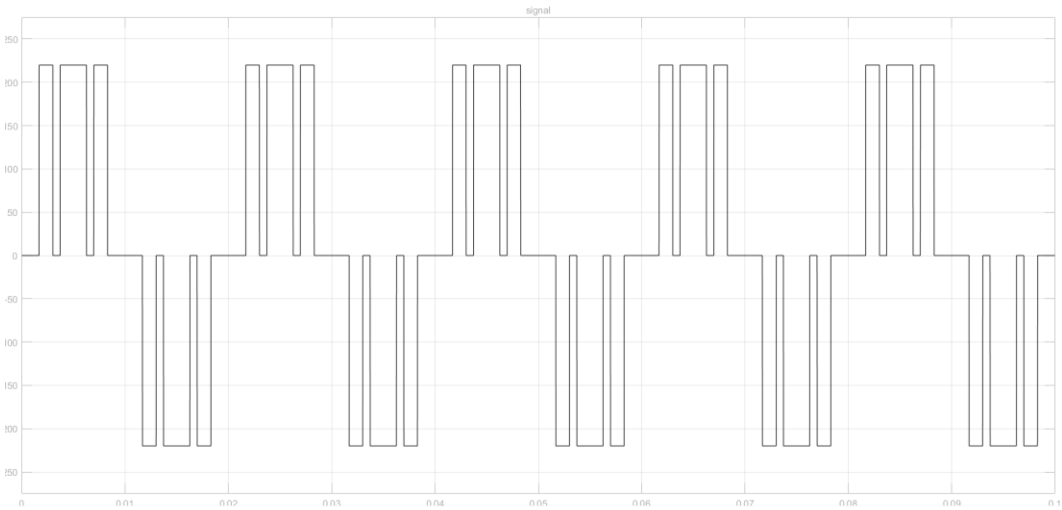

**Fig 4.9 : Inverter switching for 3rd and 5th harmonics elimination**

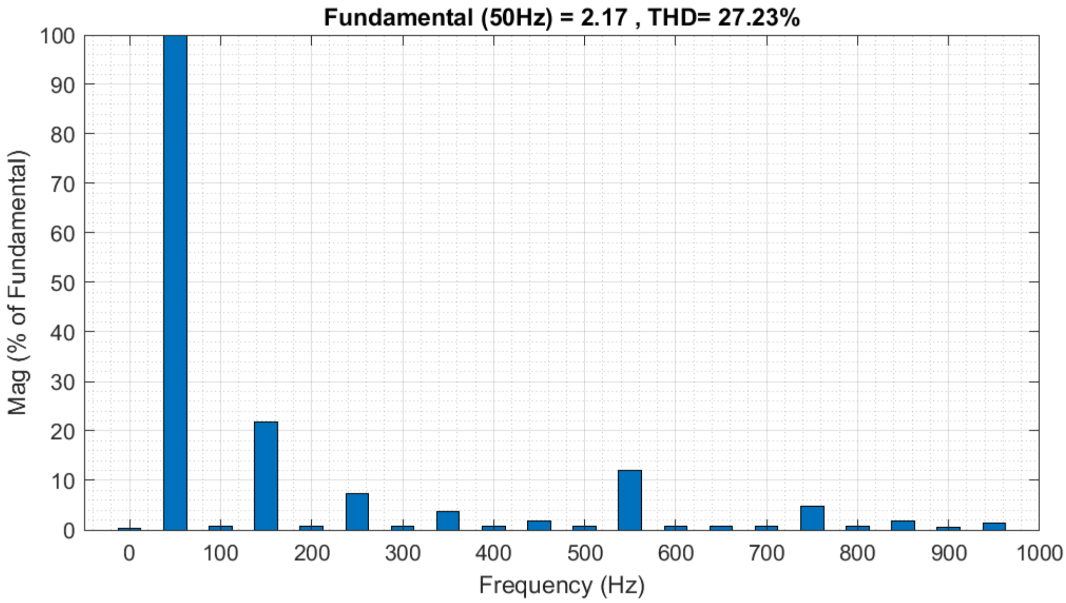


**Fig 4.10 : FFT Analysis for 3rd, 5th, 7th and 9th harmonics elimination**

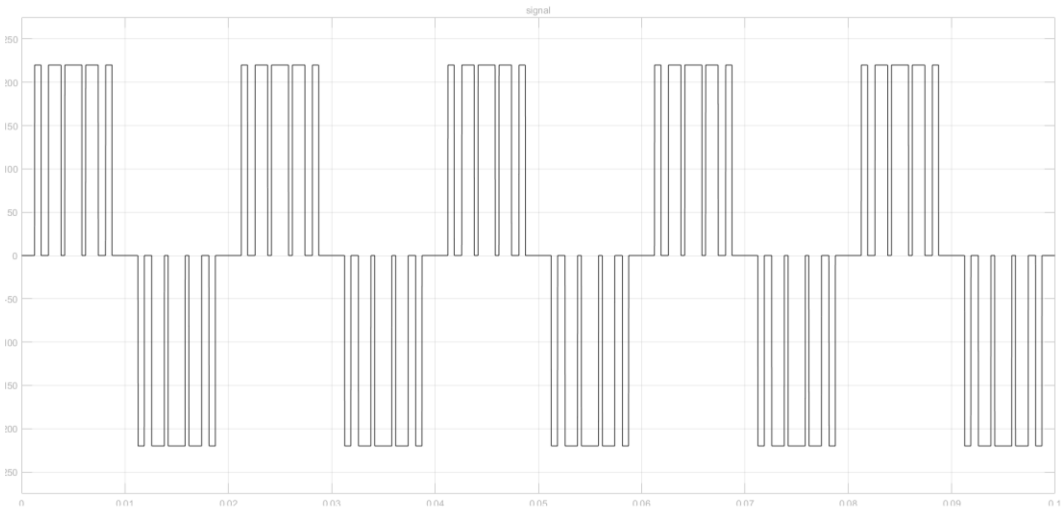

**Fig 4.11 : Inverter switching for 3rd, 5th, 7th and 9th harmonics elimination**

We have also successfully simulated the hardware in an online website called tinkercad. The coding to arduino has been generated by manually calculating time equivalents of the switching angles and using two output ports of the arduino to control the two transistor pair switches of the H-bridge.

For 50 Hz ac supply,
1 full cycle = $360^{\circ}$ = 1/50 = 0.02 sec = 20 ms
½ cycle = $180^{\circ}$ = 10 ms
Therefore, $1^{\circ}$ = 1/18 ms
So, for eliminating 3rd harmonics, the switching angles are:
$\alpha 1 = 37.33^{\circ} * 1/18 = 2.07388$ ms
$\alpha 2 = 82.67^{\circ} * 1/18 = 4.59278$ ms
$180^{\circ} - \alpha 2 = 97.33^{\circ} * 1/18 = 5.40722$ ms
$180^{\circ} - \alpha 1 = 142.67^{\circ} * 1/18 = 7.92611$ ms

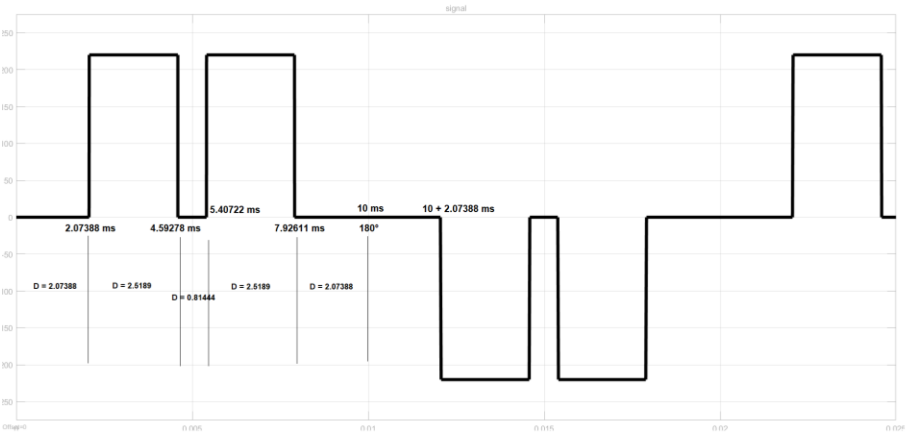


**Fig 4.12 : Calculation of time equivalent of switching angles for 3rd harmonics elimination**

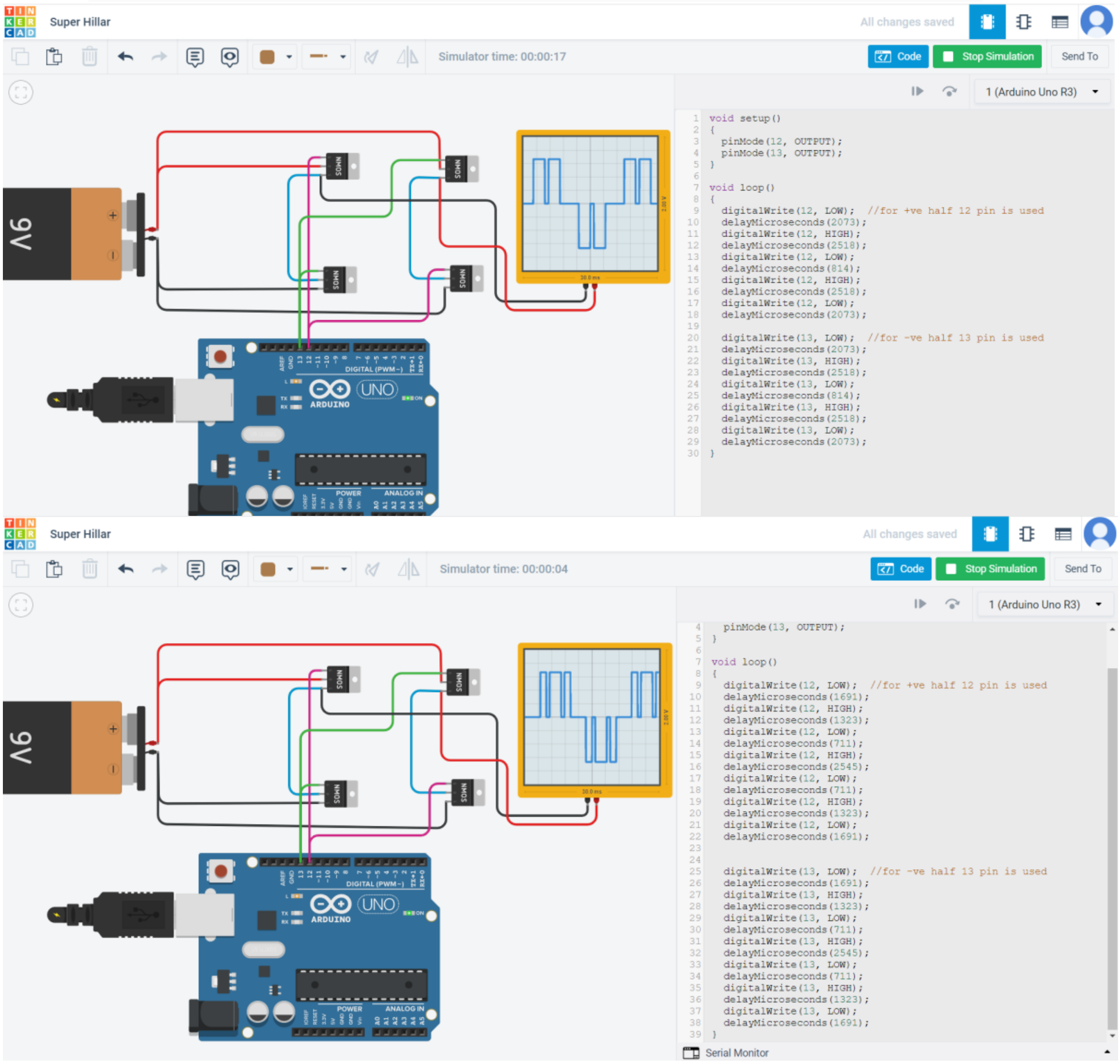


**Fig 4.13 : Hardware simulation in tinkercad website**


**Fig 4.14 : Control signal generated by arduino to eliminate 3rd harmonics**


**Fig 4.15 : Output of the inverter which has 3rd harmonics eliminated**


**Fig 4.16 : Output of the inverter which has 3rd and 5th harmonics eliminated**

As we can see the output of the inverter is as expected from the simulations and there are certain errors due to various reasons.

# CHAPTER FIVE

# CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

We studied the functioning of an H-bridge inverter and how specific lower order harmonics can be eliminated from its output by using the technique of “Selective Harmonic Elimination”. Firstly, we designed the required circuitry in a software called “Simulink” and also in the website called “Tinkercad”. Through these simulations we verified that our code is functional and we can use those codes to eliminate required lower order harmonics from the H-bridge inverter. Then we designed the circuit in real life by using breadboard and other electronic components such as arduino board, battery, mosfet, optocoupler, etc. Then we observed the output of the designed circuit in oscilloscopes and found that the lower order harmonics were eliminated as expected.

We conclude that "Selective Harmonic Elimination" is an effective technique which can be used to eliminate specific lower order harmonics from the square wave output of an inverter. By doing so, we reduce the components of lower order harmonics which contribute to the THD of the AC signal. Thus our objective of designing an H-bridge inverter and using PWM by the technique of SHE was completed. We also achieved our objective of reducing the THD from the inverter output.

## 5.2 Recommendation

- The output of the inverter can be further improved by using right filters and better components.

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# APPENDIX: A

**Specifications of Components used**

Arduino Uno

- Used as microcontroller
- Inbuilt A/D and D/A convertor
- Based on Atmega328P
- 14 digital input/output pins (of which 6 can be used as PWM outputs)
- 6 analog inputs
- A16 MHz ceramic resonator
- USB connections, a power jack, an ICSP header and a reset button

IRFZ44N

- Used as a switch
- Maximum Drain-Source Voltage (Vds): 55V
- Continuous Drain Current (Id): 49A
- Gate-Source Voltage (Vgs): ±20V
- Total Power Dissipation (Pd): 94W
- Operating Temperature Range (Tj): -55°C to 175°C
- Drain-Source On-Resistance (Rds(on)): 17.5mΩ (maximum) at Vgs = 10V and Id = 49A
- Input Capacitance (Ciss): 1470pF (typical) at Vds = 25V and f = 1MHz
- Output Capacitance (Coss): 290pF (typical) at Vds = 25V and f = 1MHz

- Reverse Transfer Capacitance (Crss): 200pF (typical) at Vds = 25V and f = 1MHz

EL4N35712

- Uses : Optocoupler
- Isolation Voltage: 5000 Vrms (minimum)
- Forward Current (If): 60mA (maximum)
- Reverse Voltage (Vr): 6V (maximum)
- Power Dissipation (Pd): 150mW (maximum)
- Collector-Emitter Breakdown Voltage (Vceo): 30V (minimum)
- Collector-Emitter Saturation Voltage (Vce(sat)): 0.2V (maximum) at If = 10mA and Ic = 0.1mA
- Current Transfer Ratio (CTR): 100% (minimum) at If = 10mA and Vce = 10V
- Rise Time (tr): 3µs (maximum) at If = 10mA and Vcc = 10V
- Fall Time (tf): 3µs (maximum) at If = 10mA and Vcc = 10V
- Operating Temperature Range (Topr): -55°C to 100°C
- Package Type: 6-Pi

# APPENDIX: B

Arduino Code:

To eliminate 3rd harmonics:

```
void setup()
{
  pinMode(12, OUTPUT);
  pinMode(13, OUTPUT);
}


void loop()
{
  digitalWrite(12, LOW);  //for +ve half 12 pin is used
  delayMicroseconds(2073);
  digitalWrite(12, HIGH);
  delayMicroseconds(2518);
  digitalWrite(12, LOW);
  delayMicroseconds(814);
  digitalWrite(12, HIGH);
  delayMicroseconds(2518);
  digitalWrite(12, LOW);
  delayMicroseconds(2073);


  digitalWrite(13, LOW);  //for -ve half 13 pin is used
  delayMicroseconds(2073);
```

```
  digitalWrite(13, HIGH);
  delayMicroseconds(2518);
  digitalWrite(13, LOW);
  delayMicroseconds(814);
  digitalWrite(13, HIGH);
  delayMicroseconds(2518);
  digitalWrite(13, LOW);
  delayMicroseconds(2073);
}
```

To eliminate 3rd and 5th harmonics:

```
void setup()
{
  pinMode(12, OUTPUT);
  pinMode(13, OUTPUT);
}

void loop()
{
  digitalWrite(12, LOW);  //for +ve half 12 pin is used
  delayMicroseconds(1691);
  digitalWrite(12, HIGH);
  delayMicroseconds(1323);
  digitalWrite(12, LOW);
```

```
delayMicroseconds(711);
digitalWrite(12, HIGH);
delayMicroseconds(2545);
digitalWrite(12, LOW);
delayMicroseconds(711);
digitalWrite(12, HIGH);
delayMicroseconds(1323);
digitalWrite(12, LOW);
delayMicroseconds(1691);


digitalWrite(13, LOW);  //for -ve half 13 pin is used
delayMicroseconds(1691);
digitalWrite(13, HIGH);
delayMicroseconds(1323);
digitalWrite(13, LOW);
delayMicroseconds(711);
digitalWrite(13, HIGH);
delayMicroseconds(2545);
digitalWrite(13, LOW);
delayMicroseconds(711);
digitalWrite(13, HIGH);
delayMicroseconds(1323);
digitalWrite(13, LOW);
```

```
  delayMicroseconds(1691);
}
```

# SELECTIVE HARMONIC ELIMINATION

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