SELECTIVE HARMONIC ELIMINATION(SHE) OF SINGLE-PHASE INVERTOR

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ABSTRACT

- To explore technique of selective harmonic elimination.
- The challenge of eliminating harmonics in a switching converter is addressed.
- The goal is to find switching angles that produce the desired fundamental output voltage while avoiding specific harmonics.

INTRODUCTION

Harmonic elimination is a technique that reduces or removes harmonics from a converter's current spectrum. It's used in power inverters, which convert DC input to AC output, to control low-order harmonics in voltage and current waveforms.

Selective Harmonic Elimination (SHE) is a Pulse Width Modulation (PWM) technique that removes specific harmonics from the output waveform. SHE is used to reduce odd harmonics in the output of a single-phase inverter.

How it works

SHE calculates a series of nonlinear equations to find the ideal gate switching angles that eliminate the desired harmonics.

SHE works by optimizing and pre-computing switching angles. The optimization process can be time-consuming, so the optimized angles are often stored in a look-up table (LUT) for real-time use.

Methods

Harmonic elimination can be done using following techniques:

1.Carrier Based PWM

2.Space Vector PWM

3.Third Harmonic Injection

4.Selective Harmonic Elimination PWM

Traditional approaches have limitations; this research explores complete solutions.

Benefits

SHE is effective at controlling low-order harmonics in voltage and current waveforms. It also results in lower switching losses, making it beneficial for high-power applications.

Commonly used in power converters to enhance efficiency and reduce harmonic distortion.

SHE is a useful technique for: High-power motor drives, Active rectifiers, and Grid-connected converters.

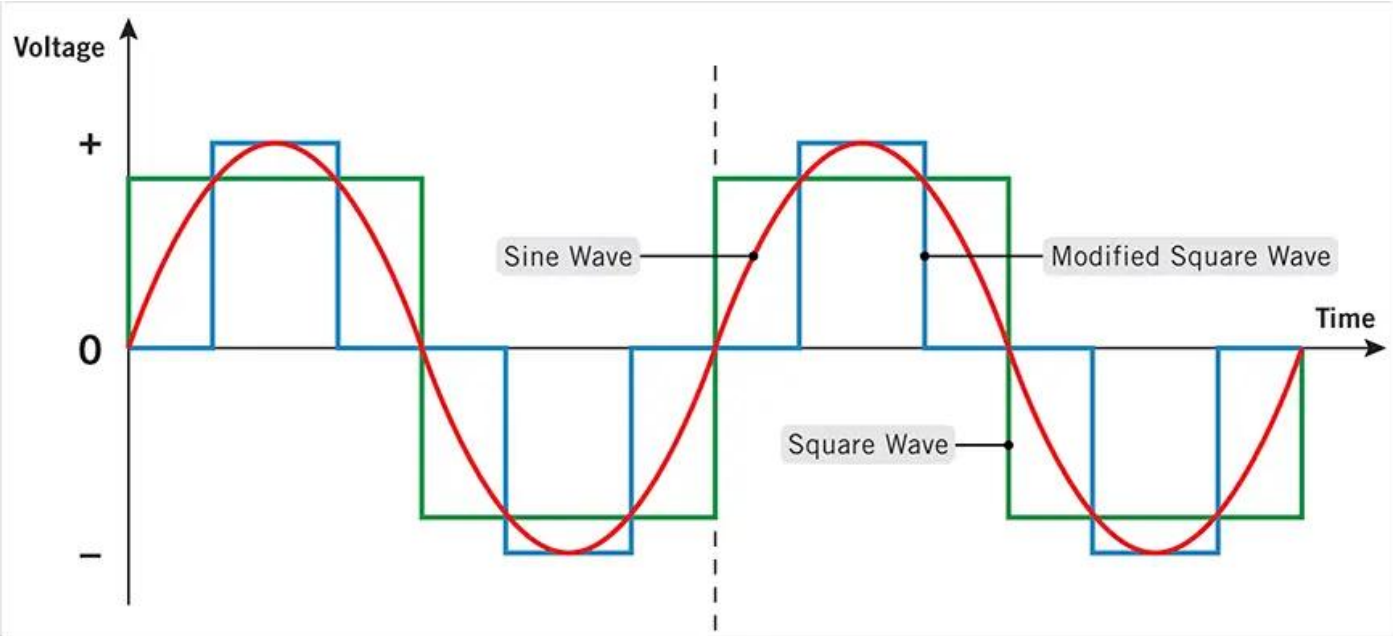


Fig1. Waveform pattern for invertor output.

Output waveform;

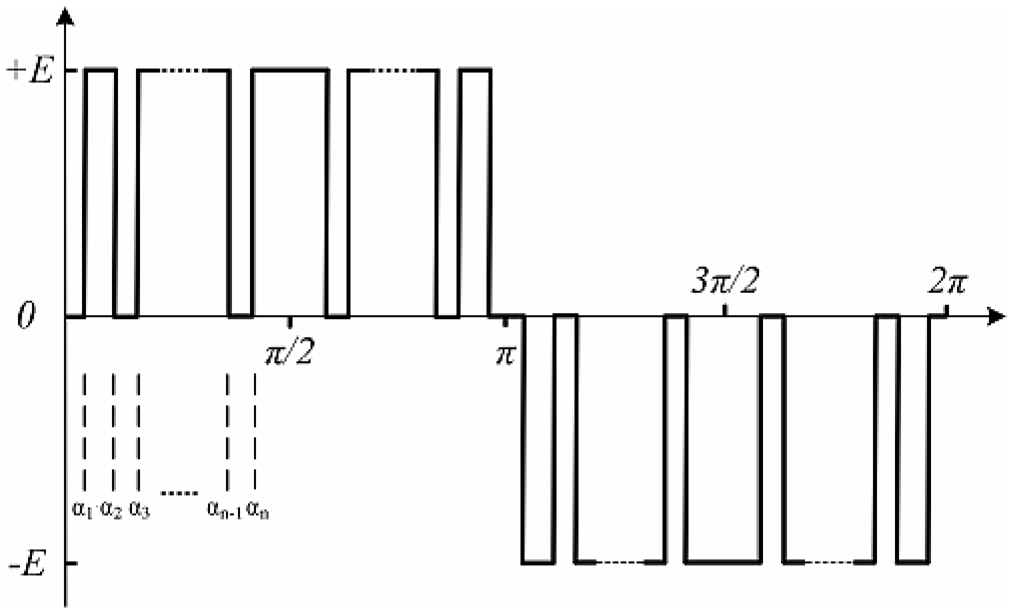


Fig2. Shows the switching pattern for different angles (α1, α2, α3) to control harmonic content.These angles define the inverter’s switching points to selectively cancel harmonics.

Equation for Harmonic Content of Output Voltage:

$$V(\omega t) = \sum_{n=1,3,5,\ldots}^{\infty} \frac{4V_{dc}}{n\pi} \times (\cos(n\theta_1) - \cos(n\theta_2) + \cos(n\theta_3)) \sin(n\omega t)$$

This equation represents the inverter's output voltage as a Fourier series.

By adjusting angles, unwanted harmonics can be minimized.

Switching Angle Equations

Equations to Eliminate Specific Harmonics

For Fundamental: $\cos(\alpha 1) - \cos(\alpha 2) + \cos(\alpha 3) - \cos(\alpha 4) + \cos(\alpha 5) = m*pi/4$

For 3rd Harmonic Elimination: $\cos(3\alpha 1) - \cos(3\alpha 2) + \cos(3\alpha 3) - \cos(3\alpha 4) + \cos(3\alpha 5) = 0$

For 5th Harmonic Elimination: $\cos(5\alpha 1)-\cos(5\alpha 2) + \cos(5\alpha 3) - \cos(5\alpha 4) + \cos(5\alpha 5) = 0$

For 7th Harmonic Elimination: $\cos(7\alpha 1) -\cos(7\alpha 2) + \cos(7\alpha 3) - \cos(7\alpha 4) + \cos(7\alpha 5) = 0$

For 9th Harmonic Elimination: $\cos(9\alpha 1) - \cos(9\alpha 2) + \cos(9\alpha 3) - \cos(9\alpha 4) + \cos(9\alpha 5) = 0$

CODE:

```
clc;
clear all;


m1=0:0.01:1;                % Modulation Index


for ii=1:101                %
a1=20*pi/180;           % Initial angles
a2=30*pi/180;
a3=50*pi/180;
a4=70*pi/180;
a5=80*pi/180;


for i=1:100                 %


T=[m1(ii)*pi/4 0 0 0 0]';

F=[cos(a1)-cos(a2)+cos(a3)-cos(a4)+cos(a5);
    cos(3*a1)-cos(3*a2)+cos(3*a3)-cos(3*a4)+cos(3*a5);
    cos(5*a1)-cos(5*a2)+cos(5*a3)-cos(5*a4)+cos(5*a5);
    cos(7*a1)-cos(7*a2)+cos(7*a3)-cos(7*a4)+cos(7*a5);
    cos(9*a1)-cos(9*a2)+cos(9*a3)-cos(9*a4)+cos(9*a5)];

dF=[-sin(a1) +sin(a2) -sin(a3) +sin(a4) -sin(a5);
    -3*sin(3*a1) +3*sin(3*a2) -3*sin(3*a3) +3*sin(3*a4) -3*sin(3*a5);
    -5*sin(5*a1) +5*sin(5*a2) -5*sin(5*a3) +5*sin(5*a4) -5*sin(5*a5);
    -7*sin(7*a1) +7*sin(7*a2) -7*sin(7*a3) +7*sin(7*a4) -7*sin(7*a5);
    -9*sin(9*a1) +9*sin(9*a2) -9*sin(9*a3) +9*sin(9*a4) -9*sin(9*a5)];


deriv_a=(inv(dF))*(T-F);

alpha=[a1;a2;a3;a4;a5]*180/pi;

```

```
    deriv_a*180/pi;
    a1=a1+deriv_a(1);
    a2=a2+deriv_a(2);
    a3=a3+deriv_a(3);
    a4=a4+deriv_a(4);
    a5=a5+deriv_a(5);
    if deriv_a>-1e-15 & deriv_a<1e-15
        break;
    end
    end

    a11(ii)=a1*180/pi;
    a22(ii)=a2*180/pi;
    a33(ii)=a3*180/pi;
    a44(ii)=a4*180/pi;
    a55(ii)=a5*180/pi;
    end
    plot(m1,a11,'b',m1,a22,'r',m1,a33,'g',m1,a44,'k',m1,a55,'m');
    legend('alpha1','alpha2','alpha3','alpha4','alpha5')
    grid on;
    title ('Selective Harmonic Elimination - Angles Vs Modulation Index')
    xlabel('Modulation Index (m)');
    ylabel('Angles (deg)');


    clc
    % To choose  the modulation Index---> do ii = (m)*100 + 1
    ii = 76;
    m = 0.75;

    a1 = a11(ii);
    a2 = a22(ii);
    a3 = a33(ii);
    a4 = a44(ii);
    a5= a55(ii);
    fprintf('Modulation Index =%.2f\n',m);
    fprintf('Harmonic Order = 5');
    ang = [ a1 a2 a3 a4 a5]';
```

OUTPUT: For M=0.75 and Harmonic Order=5

```
Command Window
Converged alpha (degrees) for M = 0.75:
 a1=23.5980:
a2=33.7772:
a3=48.6998:
a4=68.2649:
a5=77.6321:
fx >>
```

SIMULATION:

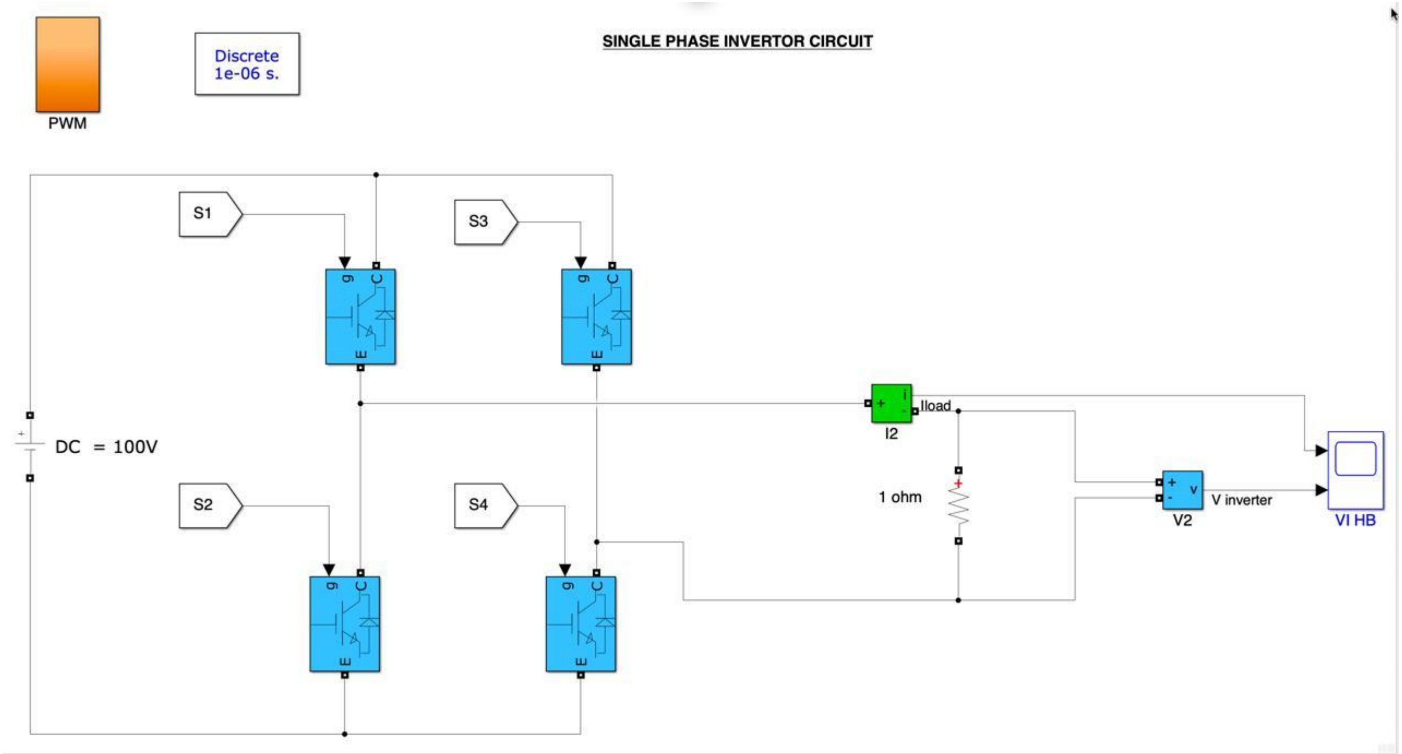
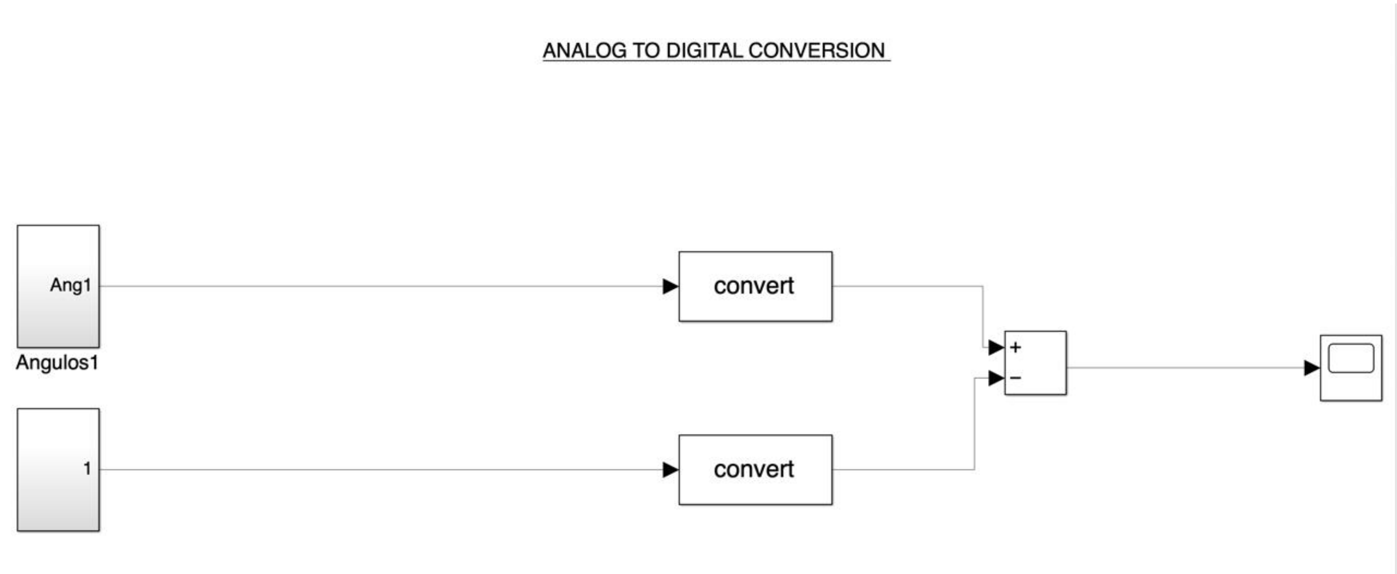


Fig3. The system is Single phase invertor using IGBT built in Simulink



SUB-BLOCK A:

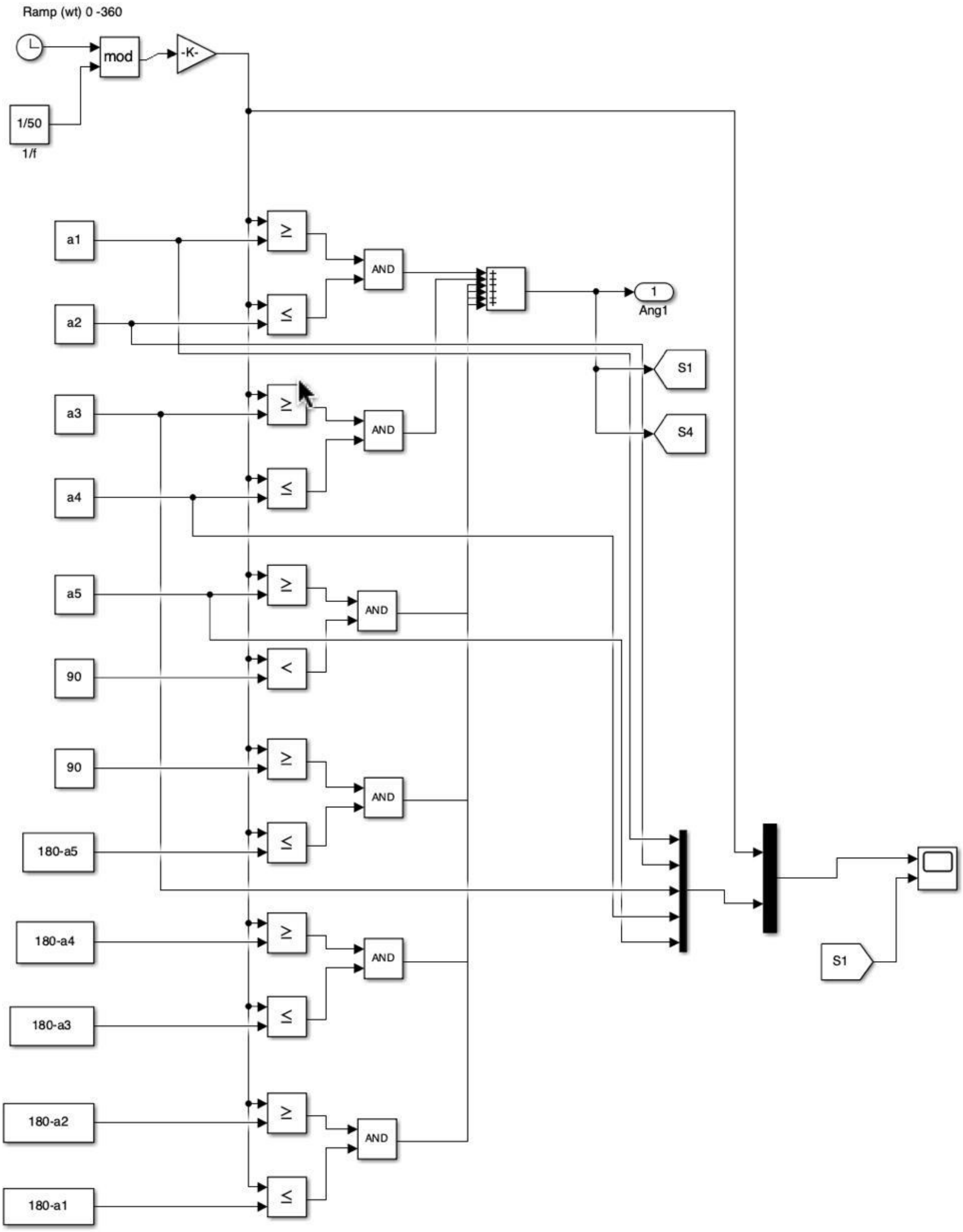


Fig4. This sub-block helps to compare initial angle with sawtooth waveform and provides positive half - cycle and negative half cycle with required switching angles.

WAVEFORM:

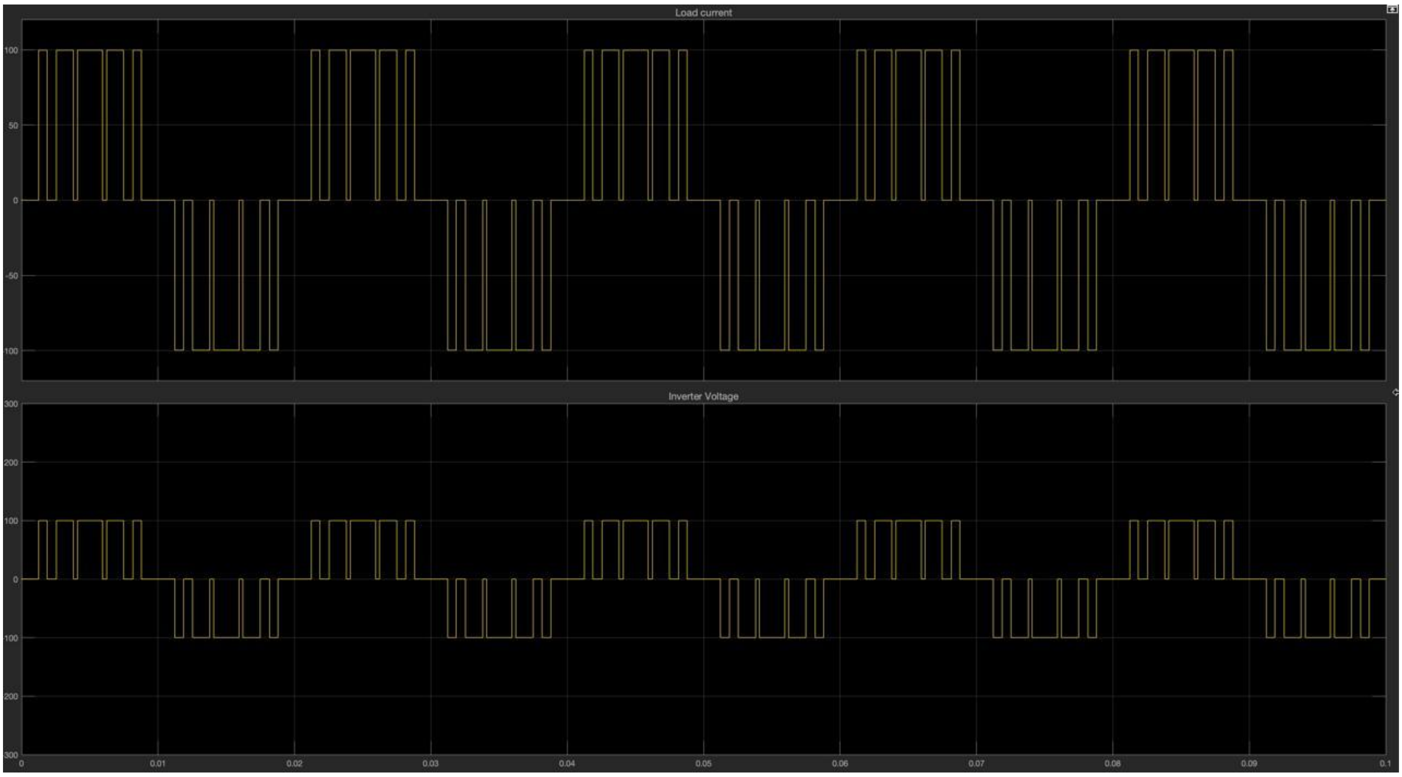


Fig5. Output waveform of Current and Voltage with harmonics.

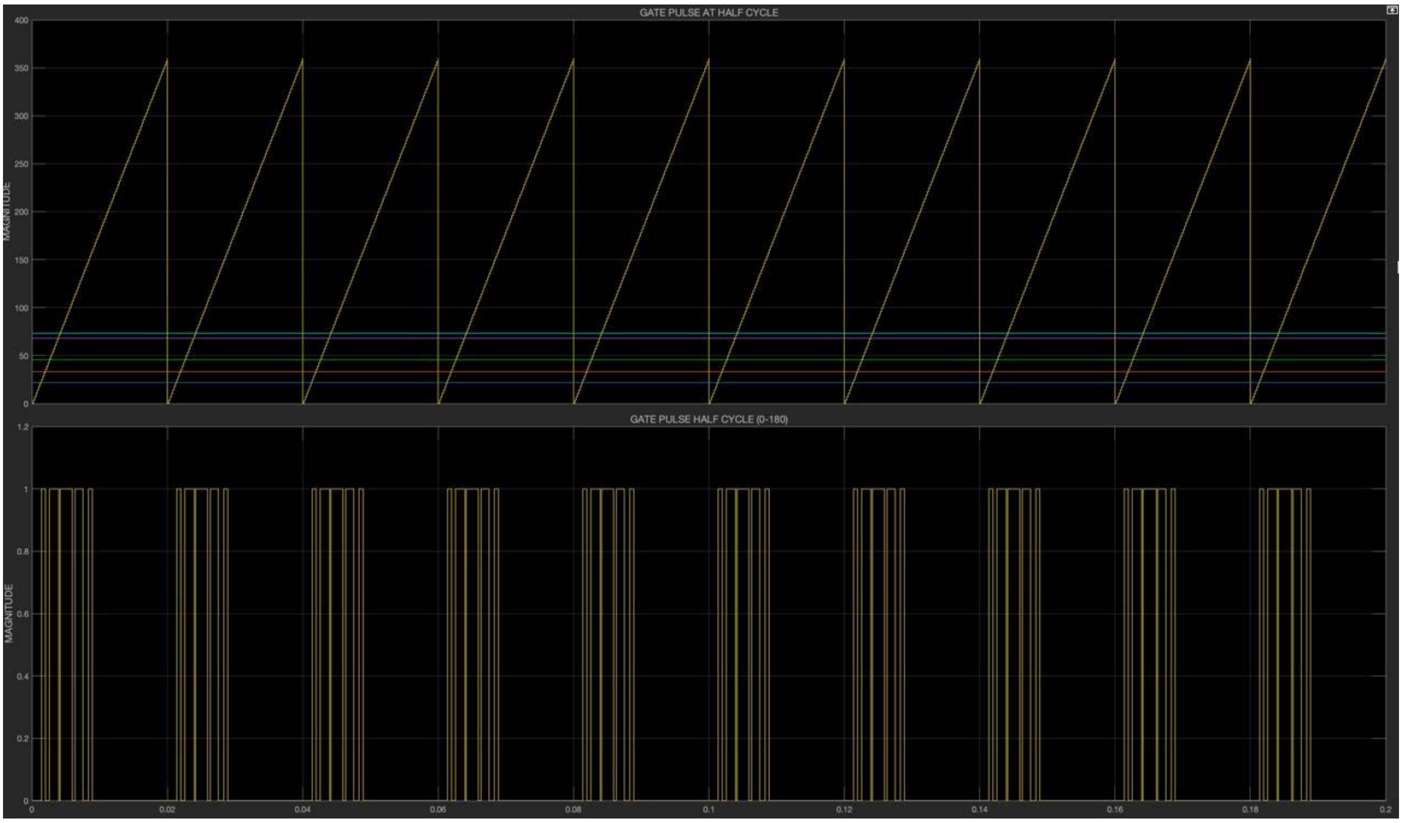


Fig6. A. Comparing initial angles with ramp signal.

B. Gate pulse provided to positive half cycle to eliminate harmonics.

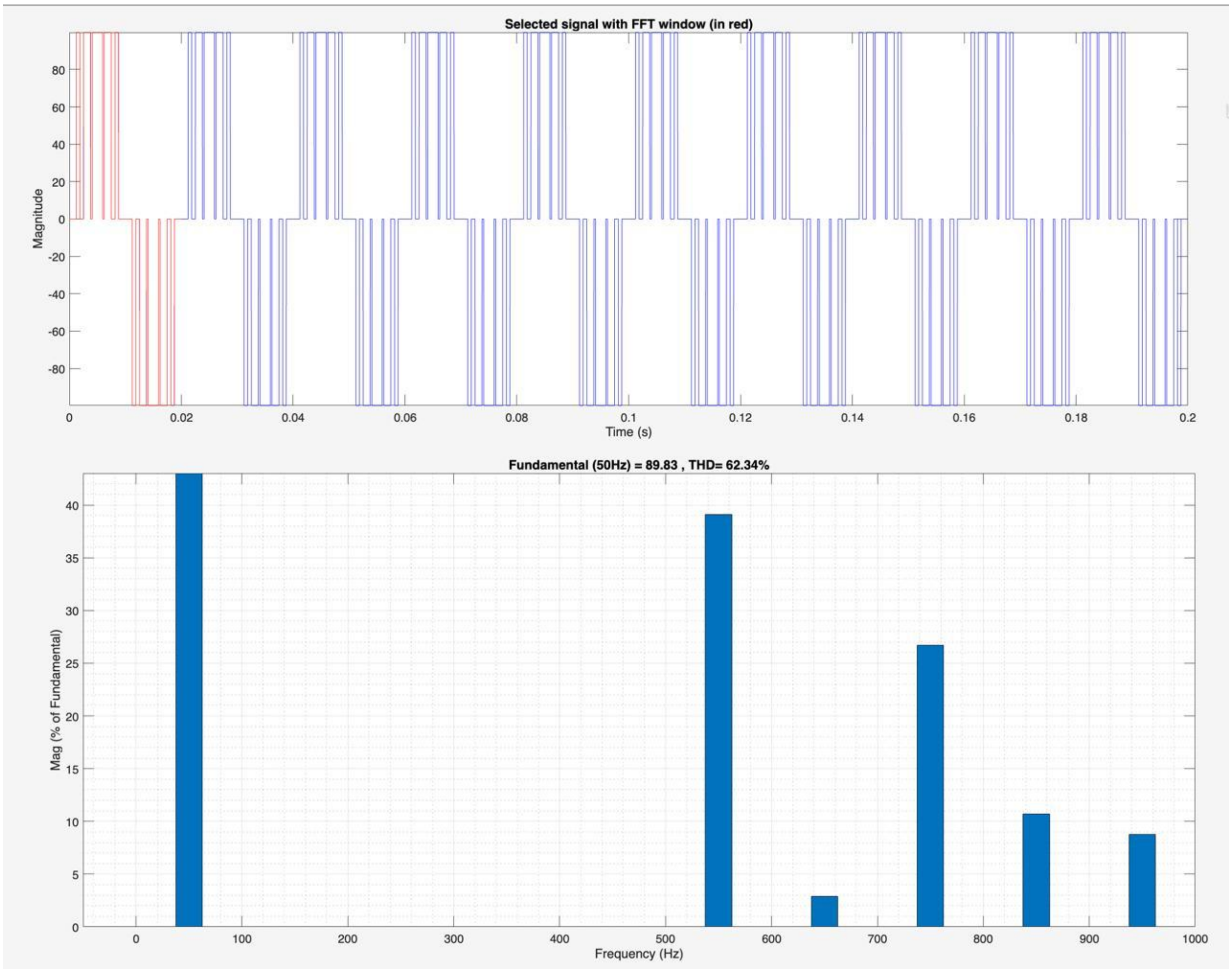


Fig7. A. Final Waveform of Output Voltage after elimination of Harmonics.

B. Elimination of 3rd ,5th ,7th and 9th harmonics.

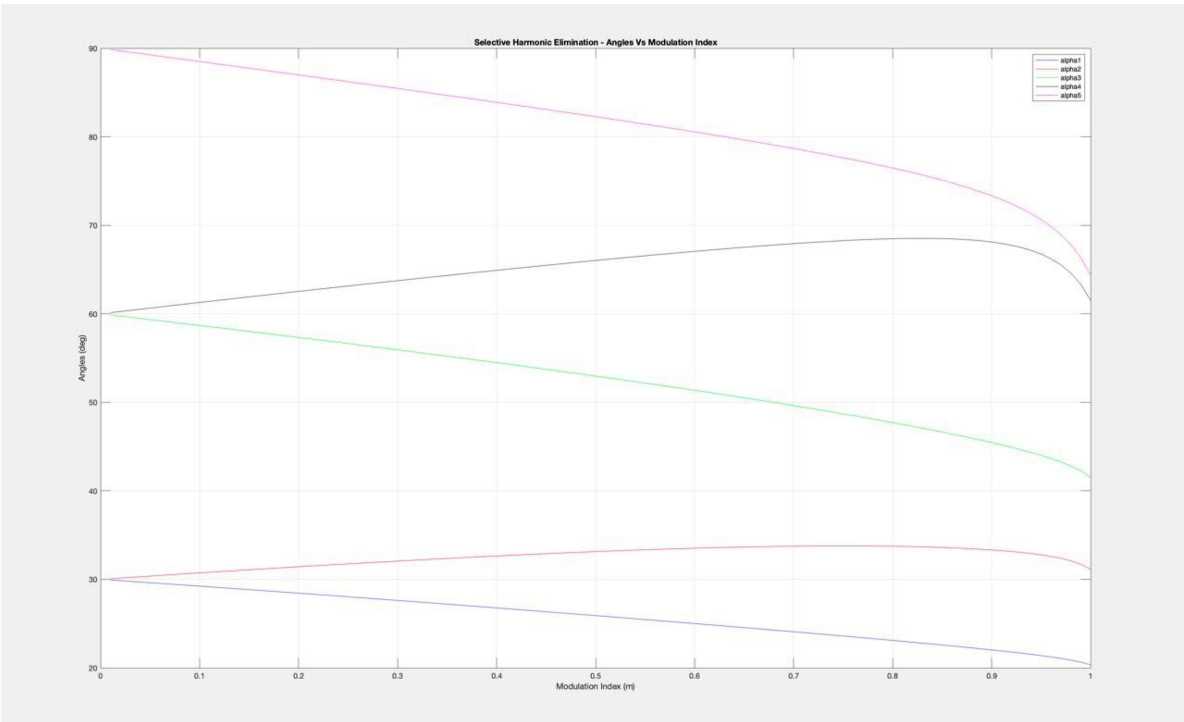


Fig8. Plot of Final angle Vs Modulation Index.

CONCLUSION:

Selective Harmonic Elimination is a valuable technique for enhancing the performance of power electronic systems. By carefully selecting and eliminating specific harmonic components, SHE enables the generation of high-quality waveforms, improves power quality, and reduces power losses. While challenges such as computational complexity and sensitivity to parameter variations exist, advancements in control techniques and computational power are continually addressing these limitations. As power electronics continue to play a crucial role in modern society, SHE will remain an important tool for optimizing system performance and efficiency.

REFERENCES:

- IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 19, NO. 2, MARCH 2004