IJAREEIE

e-ISSN: 2278-8875
p-ISSN: 2320-3765

International Journal of Advanced Research

in Electrical, Electronics and Instrumentation Engineering

Volume 13, Issue 8, August 2024

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

Impact Factor: 8.514

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 8.514|| A Monthly Peer Reviewed & Referred Journal |

||Volume 13, Issue 8, August 2024||

|DOI:10.15662/IJAREEIE.2024.1308010|

Study of Harmonics Content in Single Phase Inverter with Square PWM and Sinusoidal PWM

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ABSTRACT: This paper focuses on the study of harmonic content present in single-phase square wave and sine wave inverters using R and RL type series loads, analysing both current THD and voltage THD. The model is implemented using MATLAB SIMULINK software with the Sim Power Systems block set. To determine the harmonic content and total harmonic distortion (THD), Fast Fourier Transform (FFT) analysis is utilized in MATLAB SIMULINK. The study results indicate effective harmonic reduction in RL type loads compared to R loads.

KEYWORDS: THD, FFT, R and RL series Load.

I.INTRODUCTION

Current is defined as the flow of electrons. There are mainly two types of currents, alternating current (AC) and Direct current (DC). In AC , the electrons flow back and forth in regular cycles ,with the voltage periodically changes from positive to negative and back again. AC is used to deliver electricity to homes and businesses through power transmission lines. It's also the type of current that flows in normal household electricity from a wall outlet. In DC, the electrons flow consistently in one direction. The voltage is always constant. DC is often used in electronic devices and comes from batteries, solar cells, or AC/DC converters. It's also the type of current that flows in a flashlight or other appliance running on batteries.

An inverter is a device that is used to convert Direct current to Alternating Current. However, the output is not a sine wave. It can be square wave, quasi square wave or PWM. But in most scenarios the value of DC power is low. But we require high Alternating Currents. First, we need to step up the DC power. Then we can make use of inverter to convert DC to AC. Secondly, we convert low powered DC to low powered AC. Then we increase the power of Alternating current by stepping it up.

Harmonics in power systems originate primarily from non-linear loads. These loads do not have a linear, direct relationship between their voltage and current. Non-linear loads include fluorescent lighting, adjustable speed drives, computers, and other electronic devices. These devices distort the sinusoidal wave of the current due to their switching power supplies, leading to the creation of harmonics. Power electronic devices such as inverters and converters are also significant sources of harmonics. These devices often operate by rapidly switching the voltage or current between different states, resulting in waveforms far from sinusoidal. The sharp, abrupt changes can produce a broad spectrum of harmonic frequencies.

II.THEORY

An inverter is a digital device that converts direct Current (DC) power into alternating contemporary (AC) energy. This conversion is critical in diverse programs, inclusive of renewable power structures, uninterruptible strength materials (UPS), and electric-powered automobile powertrains. The number one function of an inverter is to supply AC power. Inverters convert direct contemporary (DC) from a electricity source (consisting of batteries or sun panels) into alternating cutting-edge (AC), which is generally used in household home equipment and business gadget. Many inverters use Pulse Width Modulation to generate an AC output. In PWM, the width of the pulses of the output waveform is varied to manipulate the common strength delivered to the weight. Inverters use switching gadgets like transistors or insulated gate bipolar transistors (IGBTs) to swiftly transfer the DC input on and off. This switching movement creates the AC output waveform. Some inverters contain transformers to step up or step down the voltage of the AC waveform, depending at the utility.

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Inverters can be classified based on output characteristics as square wave inverter, modified sine wave inverter and and pure sine wave inverter.

For square wave inverter, it is said to be One of the only forms of inverters is the square wave inverter. As the name suggests, it produces a rectangular wave AC output. While these inverters are price-powerful and clean to layout, they are no longer appropriate for many packages due to the presence of harmonics and their potential to harm touchy electronics. Square wave inverters operate with the aid of switching the direct current (DC) enter into a sequence of square pulses, creating an output waveform that approximates a rectangular wave. While these inverters are simple and fee-powerful, their output waveform might not be as ideal as that of modified sine wave or pure sine wave inverters.

The square wave inverter has the following advantages: (1) Cost-Effective: Square wave inverters are often the most price range-pleasant choice among inverter kinds. This affordability makes them available for customers with basic power wishes and restricted budgets. (2) Ease of Maintenance: With fewer additives and a simple layout, rectangular wave inverters are generally easier to hold. This can result in lower renovation fees and decreased complexity for users who prioritize simplicity. (3) Quick Response Time: Square wave inverters have a fast response time due to their easy design. This quick response may be advantageous in packages. (4) Compatibility with Some Appliances: Certain home equipment, specifically those with easy designs and much less sophisticated electronics, are well suited with square wave strength. This can encompass a few older or less touchy gadgets. (5) Suitable for Non-Critical Applications: Square wave inverters are properly applicable for non-critical programs in which the pleasant of the electricity deliver is less essential. In situations in which the primary goal is primary strength provision, such as in tenting or emergency situations, rectangular wave inverters can be enough.

Some of the disadvantages of square wave inverter are as follows: (1) Harmonic Distortion: One of the number one drawbacks of square wave inverters is the presence of significant harmonic distortion in the output waveform. This distortion can adversely affect the performance and lifespan of sensitive electronic gadget. (2) Limited Appliance Compatibility: Square wave inverters aren't suitable for gadgets with complex electronics, which includes modern-day computer systems, audio equipment, or variable pace cars. The distorted waveform can also cause malfunctions or harm. (3) Noise and Heat Generation: The abrupt changes in voltage in rectangular wave inverters can lead to elevated noise and heat generation. This can be unwanted in sure packages, particularly the ones where quiet operation or minimal warmness dissipation is essential. (4) Inefficient for Some Loads: While square wave inverters may be green for positive hundreds, they may be inefficient or incompatible with devices that require a cleaner strength source. This trouble restricts their use in many modern-day electronic programs. (5) Potential for Equipment Damage: Due to the distorted waveform, square wave inverters have the capacity to harm touchy digital equipment through the years.

For pure sine wave inverters, it is considered as the gold well known within the industry, pure sine wave inverters produce a smooth and easy AC waveform that carefully resembles software-supplied electricity. These inverters are relatively versatile and may power a extensive range of gadgets, making them best for touchy electronics, such as clinical system, audio systems, and variable velocity automobiles. The features of pure sine wave inverter are, High-Quality Output: Generates a clean and stable AC waveform, just like utility electricity. Compatibility: Suitable for all styles of electronic devices, along with touchy equipment like laptops and medical gadgets. Low Harmonic Distortion: Produces minimal harmonic distortion, making sure green and noise-unfastened operation. Versatility: Compatible with a extensive variety of appliances and gadgets, making it flexible for various programs. Efficiency: Offers high performance in converting DC strength to AC, minimizing energy loss in the procedure.

The pure sine wave inverters start with a direct contemporary (DC) input, typically sourced from batteries or renewable strength structures. The inverter circuit employs superior electronics, inclusive of exceptional transistors (e.g., IGBTs), arranged for precise manage. PWM is used to shape the DC enter into a chain of managed pulses, supplying the idea for the AC output waveform. The pulse train undergoes filtration via a low-pass LC filter out, such as inductors and capacitors, to dispose of excessive-frequency additives and harmonics. The result is a pure sine wave output that carefully resembles the easy and continuous waveform of preferred grid energy, making it appropriate for powering sensitive digital gadgets and appliances.

The Pulse Width Modulation (PWM) is a technique which is characterized by the generation of constant amplitude pulse by modulating the pulse duration by modulating the duty cycle. Analog PWM control requires the generation of both reference and carrier signals that are feed into the comparator and based on some logical output, the final output is

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generated. The reference signal is the desired signal output maybe sinusoidal or square wave, while the carrier signal is either a sawtooth or triangular wave at a frequency significantly greater than the reference. There are various types of PWM techniques and so we get different output, and the choice of the inverter depends on cost, noise and efficiency. There are three basic PWM techniques: 1. Single Pulse Width Modulation 2. Multiple Pulse Width Modulation 3. Sinusoidal Pulse Width Modulation.

Single pulse width modulation is employed in single phase square wave inverter. In single pulse width modulation, there is an only one output pulse per half cycle. The output is changed by varying the width of the pulses. The gating signals are generated by comparing a rectangular reference with a triangular reference. The frequency of the two signals is nearly equal.

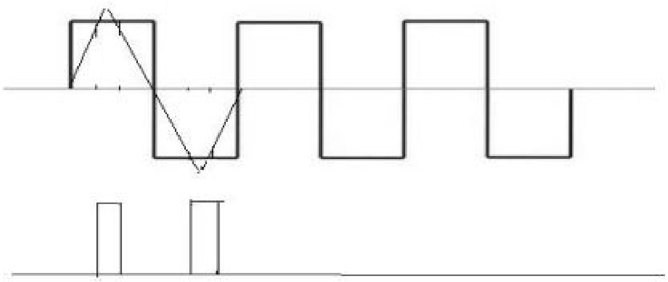

Fig1: Single Pulse Width Modulation

The rms ac output ,

$$Vo = Vs\sqrt{2\frac{ton}{T}} = Vs\sqrt{2\alpha}$$

Where,

α = duty cycle = $\frac{ton}{T}$,   Modulation Index (MI) = $\frac{Vr}{Vc}$.

Where,

Vr = Reference signal voltage,   Vc = Carrier Signal Voltage.

By varying the control signal amplitude Vr from 0 to Vc the pulse width ton can be modified from 0 secs to T/2 secs and the rms output voltage Vo from 0 to Vs.

Sinusoidal Pulse Width Modulation technique are multiple numbers of output pulse per half cycle and pulses are of different width. The width of each pulse is varying in proportion to the amplitude of a sine wave evaluated at the centre of the same pulse. The gating signals are generated by comparing a sinusoidal reference with a high frequency triangular signal.

The rms ac output voltage

$$Vo = Vs\sqrt{\frac{p\delta}{\pi}} = Vs\sqrt{\sum_{n=1}^{2p}\frac{\delta m}{\pi}}$$

Where,
p=number of pulses and δ=pulse width.

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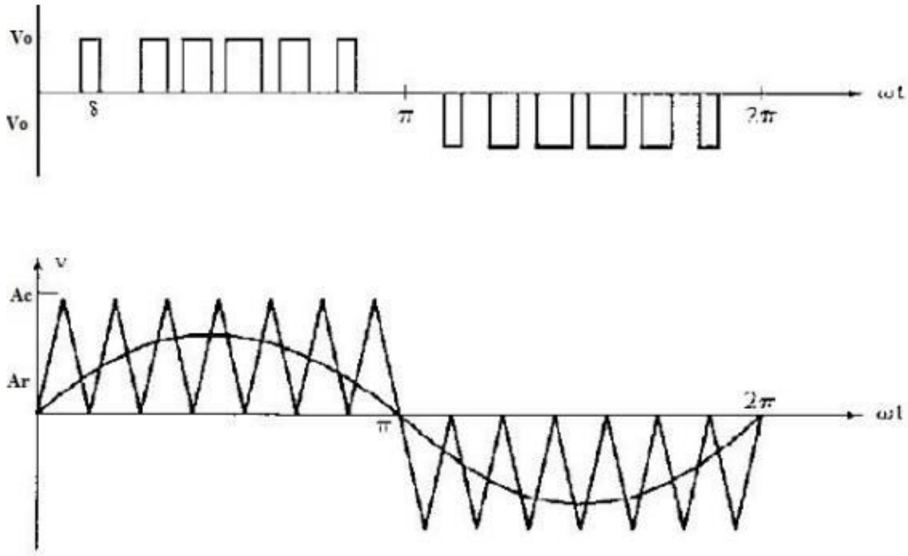

Fig2: Sinusoidal Pulse Width Modulation

III.HARMONICS

Harmonics are disturbances that occur in an electrical system due to distorting current and voltage waves. If the basic frequency of an electric power system is 50 Hz, the second, third and next harmonics have a frequency with 100 Hz, 150 Hz and its multiples. The harmonics wave hitched a ride on original wave so that it produced a defective wave.

The Total Harmonic Distortion (THD) can be analysed using Fourier series approach. The voltage and current in time function are formulated through (1) and (2) below.

$$v(t) = Vo + \sum_{n=1}^{\infty} V_n \cos(n\omega t + \theta_n) \qquad (1)$$

$$i(t) = Vo + \sum_{n=1}^{\infty} I_n \cos(n\omega t + \theta_n) \qquad (2)$$

The rms voltage and current of sinusoidal wave is wave peak value divided by 2 as shown in (3) and (4).

$$V_{rms} = V_0^2 + \sqrt{\sum_{n=0}^{\infty} \left(\frac{V_n}{\sqrt{2}}\right)^2} \qquad (3)$$

$$I_{rms} = V_0^2 + \sqrt{\sum_{n=0}^{\infty} \left(\frac{I_n}{\sqrt{2}}\right)^2} \qquad (4)$$

The value of THD can be found using the following equation in (5).

$$THD = \frac{\sqrt{\sum_{h>1}^{h\,max} M_h^2}}{M_1} \times 100 \qquad (5)$$

M_h is the rms value of harmonic h of the quantity M.

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The main components of passive filter are inductor (L) and capacitor (C), both connected in series or parallel. At certain frequency, filter circuit can be tuned. Passive filter which is used as harmonic filter serves to reduce amplitude of one or more specific frequencies of voltage or current. To determine the value of inductor and capacitor components, the cut-off frequency value must be determined previously. The multiplying result of system basic frequency with the nth harmonic will produce a cut-off frequency. Meanwhile, the resonance frequency of the AC circuit is determined by (6) as shown below.

$$f_r = \frac{1}{\sqrt{LC}} \text{Hz}$$

In non-linear loads, the output waveform is not same with input waveform. This is due to absorption of current waves that are not sinusoidal. Examples of linear loads include rectifiers, inverters, chargers and variable speed drives.

IV.SIMULATION AND RESULTS

The inverter circuit used in the simulations is a voltage source inverter in full bridge or H-bridge topology. The input is DC voltage source. The inverter uses four MOSFET switches for the switching function, to produce an AC output signal. The simulation design use pulse generator for the square wave inverter design and SPWM technique is used for PWM generation in sine PWM inverter design. The parameters in the PWM controller for the SPWM are as follows: modulation index ($m_{i)}$ =1; frequency (f) = 50Hz; Switching frequency for the triangular carrier waves (s)=10kHz. The input DC Voltage is 12 V. Output Voltage is measured using voltage measurement with rms block via a display block and Output Current is measured using current measurement with rms block via a display block. THD is measure using THD block and FFT analysis tool. The Output waveforms are obtained through the scope.

In square wave inverter the output is a alternating square wave. The harmonic content in this wave is very large. This inverter is not efficient and can give serious damage to some of the electronic equipment. But due to low cost, it has some limited number of applications in household appliances.

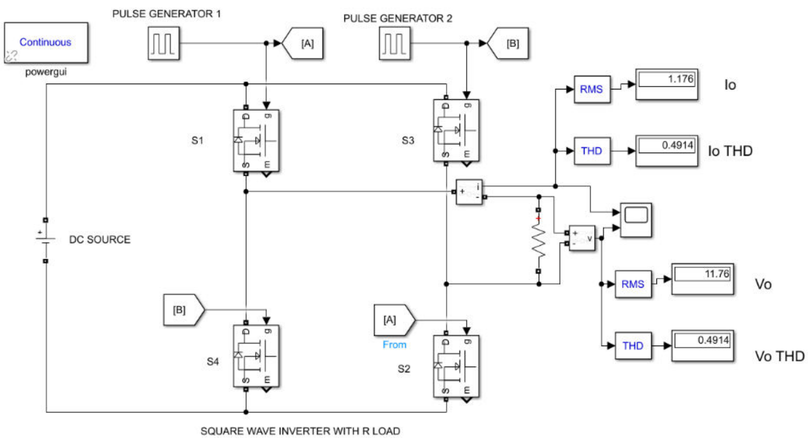

Fig.3 simulation of square wave inverter with R load

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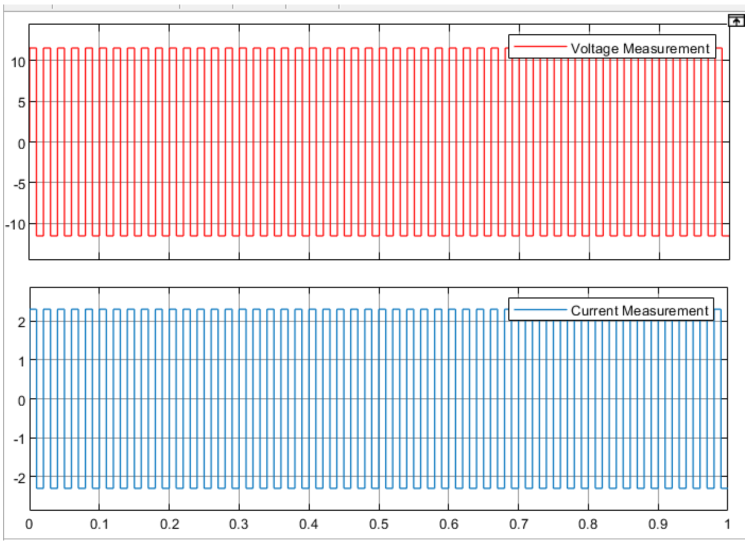

Fig.4 Square wave inverter output waveform for R load

R (ohms)	Vo (V)	Io(I)	THD of V (%)	THD of I (%)
3	7.955	2.652	49.22	49.22
5	8.15	1.632	49.22	49.22
7	8.25	1.179	49.22	49.22
10	8.31	0.8319	49.22	49.22

Table 1: Results with R load

From the above table we can conclude that the change in the value of resistance in the resistive load, does not affect the THD values of output Current and voltage. For resistive load the THD values of current and voltage are the same.

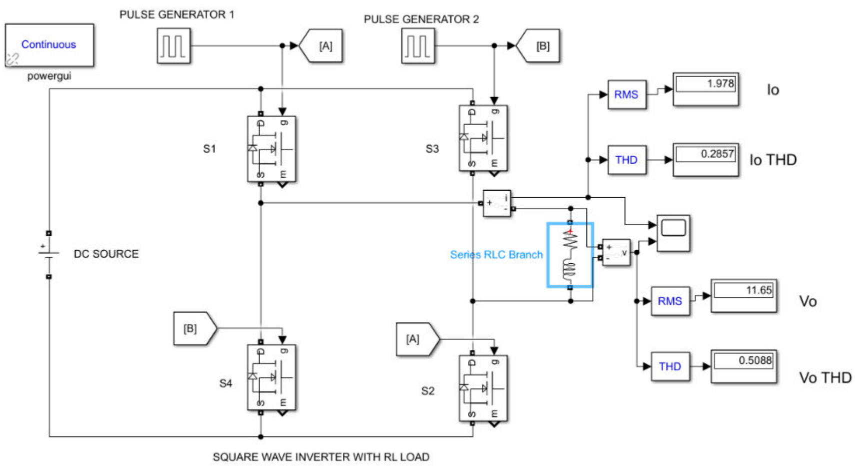

Fig.5 simulation of square wave inverter with RL load

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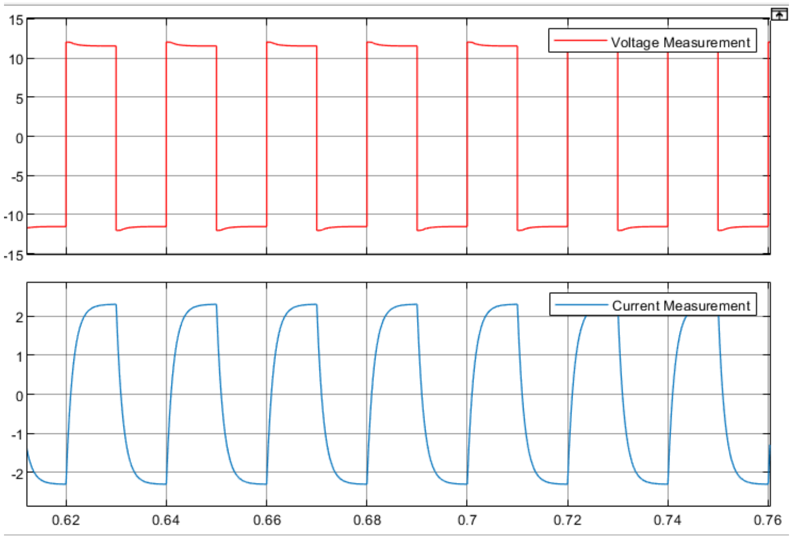

Fig.6 Square wave inverter output waveform for RL load

R (ohms)	L (mH)	Vo (V)	Io(I)	THD of V (%)	THD of I (%)
5	3	11.59	2.17	52.53	40.66
5	5	11.62	2.08	52.14	34.94
5	7	11.65	1.98	50.88	28.57

Table 2: Results with RL load

From the above table, with value RL load inductance increase, the THD value of the output current decreases. The output voltage values increases when the increases in the inductance value.

Sine wave inverter provides output voltage waveform which is very similar to the voltage waveform that is received from the Grid. The sine wave has very little harmonic distortion resulting in a very „clean" supply and makes it ideal for running electronic systems such as computers, racks and other sensitive equipment without causing problems or noise. Things like mains battery chargers also run better on pure sine wave converters.

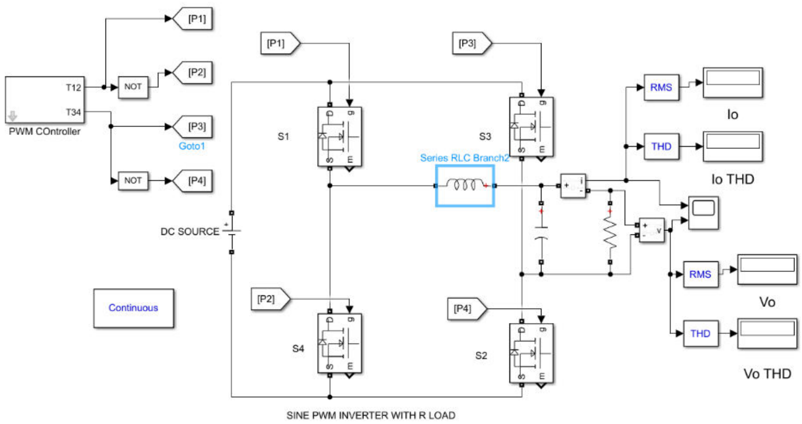

Fig.7 simulation of sine wave inverter with R load with LC filter

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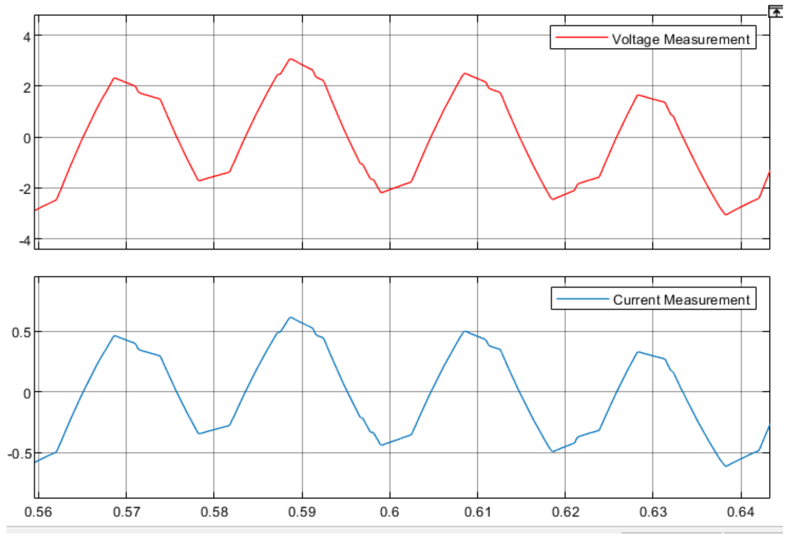

Fig.8 sine wave inverter output waveform for R load with LC filter

Filter values L=80mH, C=14μF

R (ohms)	Vo (V)	Io(I)	THD of V (%)	THD of I (%)
5	1.861	0.372	5.23	5.23
7	2.399	0.34	5.779	5.779
10	3.171	0.31	11.88	11.88

Table 3: for sine wave inverter with R load

From the above table we can observe that THD Values of current and voltage are same for resistive load and with the increase in resistance the THD value of the current and voltage increases.

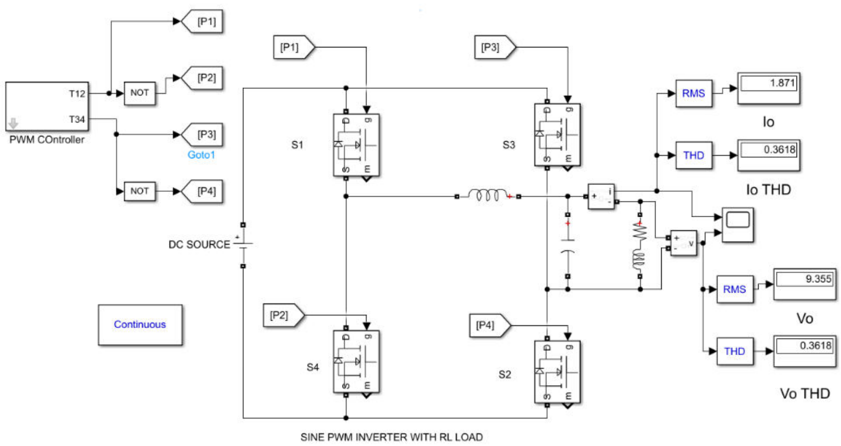

Fig.9 simulation of sine wave inverter with RL load with LC filter

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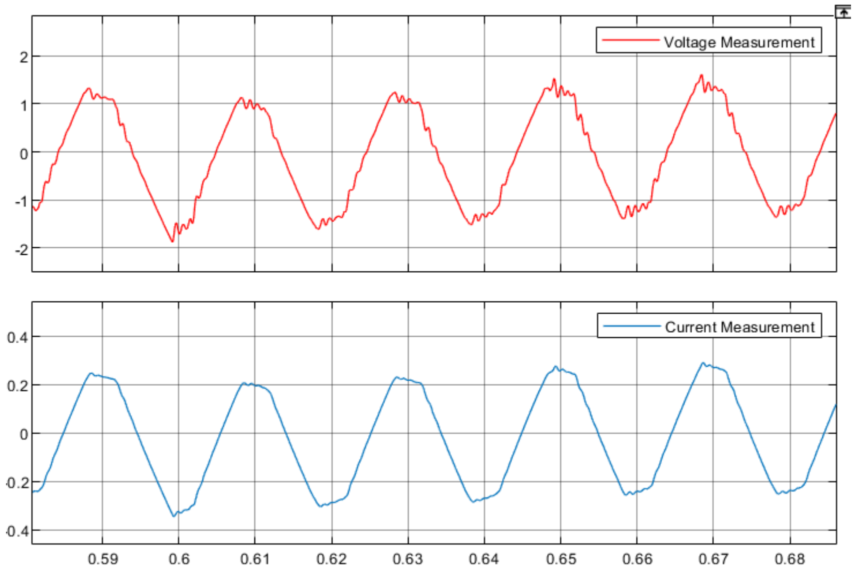

Fig.10 sine wave inverter output waveform for RL load with LC filter

Filter values L=150mH, C=7μF

R (ohms)	L (mH)	Vo (V)	Io(I)	THD of V (%)	THD of I (%)
5	1	0.9	0.191	3.837	3.288
5	2	1.002	0.195	6.741	5.011
5	5	1.07	0.2	13.81	4.696

Table 4: for sine wave inverter with RL load

From the above observations it has been concluded that type of load is very influential on the amount of THD. The Inductor load will make the output current THD decrease, and the installation of passive LC filter can reduce harmonics significantly.

V. CONCLUSION

This project deals with Harmonics analysis of single-phase inverter with both square wave & sine wave PWM techniques. The SIMULINK model of single-phase square wave inverter and sine wave inverter has been studied and stimulated in MATLAB/SIMULINK software. The THD values of output voltage and current have been studied along with the output voltage and current graphs.

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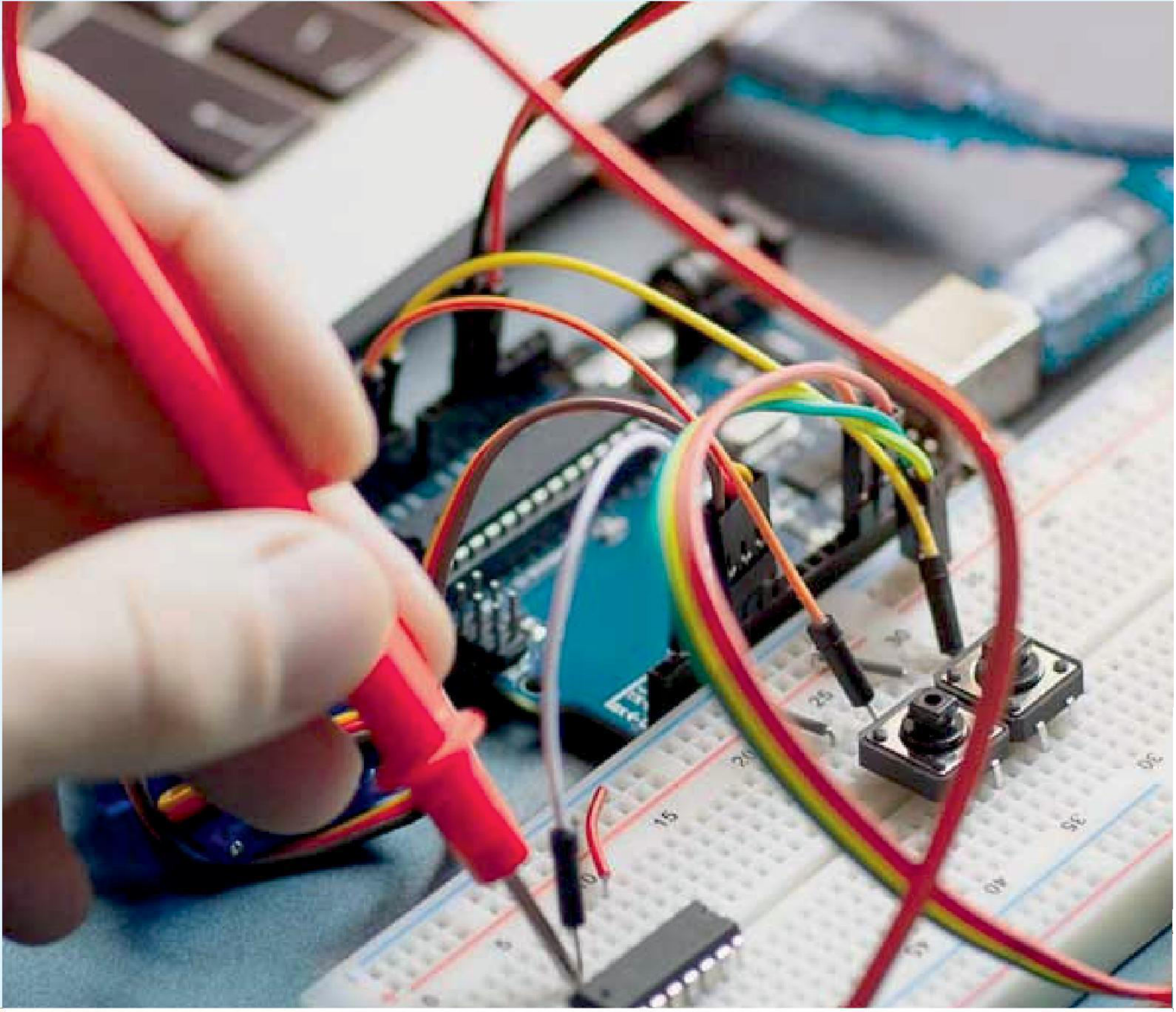

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