Small Scale Two Level PWM Driver Design for Single Phase Sine Wave Inverter and Total Harmonic Distortion Mitigation

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Abstract
Inverter is necessary for DC to AC conversion for uninterrupted AC power supply and utilization of many types of AC electrical equipment in our day to day life. Square wave inverter and modified sine wave (actually a cascaded square wave) inverter is available which includes total harmonic distortion (THD). In fact the generation of a pure sinusoidal AC voltage is a big challenge with minimum amount of total harmonic distortion. This paper deals with the design of a project which is the hardware implementation of a two level PWM driver to achieve close approximated sinusoidal waveform for DC to AC conversion with low harmonic distortion in unloaded condition.

Keywords
Inverter, DC to AC Conversion, Total Harmonic Distortion (THD), Pulse Width Modulation (PWM)

I. Introduction

An inverter is a DC to AC converter. In real life, for numerous applications DC to AC conversion is required. Uninterruptible Power Supply (UPS), AC motor drives, grid-connected wind energy or photovoltaic system are few of such fields where inverter is widely used.

At present three types of single phase inverters are available in the market. These are

1. Square wave inverter
2. Modified sine wave inverter
3. Pure sine wave inverter

Among those square wave inverter and modified sine wave inverter suffers from high harmonic contents. These are inefficient and not suitable for a large number of applications like clock and timers. But pure sine wave inverter provides output very close to the output generated by an AC generator.

Inverter can also be classified as voltage source inverter (VSI) where the output is AC voltage and as current source inverter (CSI) where the output is AC current.

As switch BJT, Thyristor, IGBT, MOSFET etc. can be used. In our project MOSFET switches have been used due to the following advantages-

1. MOSFET contains an anti-parallel Schoktty diode
2. Fast switching characteristics
3. High efficiency

Common topologies used by an inverter are half bridge and full bridge topologies in conjunction with Pulse Width Modulation (PWM) switching schemes. Three basic PWM techniques are available-

1. Single pulse width modulation
2. Multiple pulse width modulation
3. Sinusoidal pulse width modulation

This paper deals with a VSI type pure sine wave inverter in conjunction with analog sinusoidal PWM techniques implemented by half bridge topology.

II.OBJECTIVES

Our aim is to design a close approximation of pure sine wave with low total harmonic distortion on no load condition.

III. SOFTWARE USED

TINA-TI is simulator software of Texas Instrument. Tina90-TIen.9.3.150.4 version is used for simulation.

IV. SINGLE PHASE HALF BRIDGE PURE SINE WAVE INVERTER

From Fig. 1 it is clear that, two semiconductor switches are employed with freewheeling diodes. By operating these switches simultaneously using PWM technique, desired AC output is generated.

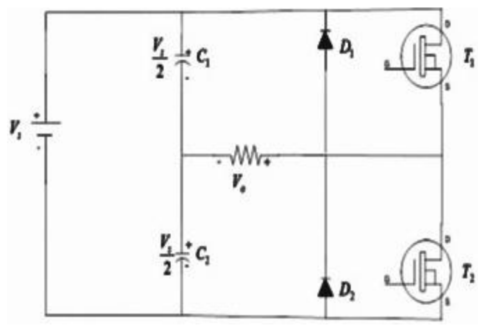


Fig.1Half bridge inverter topology

V. SINUSOIDAL PULSE WIDTH MODULATION (SPWM) TECHNIQUE

This type of control generates constant amplitude pulses by modulating the pulse duration by varying duty cycle. Here a reference sine wave with desired AC output frequency and a high frequency triangular or saw tooth carrier wave is compared using a comparator circuit.

A. Wien Bridge Oscillator

A Wien bridge oscillator is a type of electronic oscillator that generates sine waves. The oscillator is based on a bridge circuit that comprises four resistors and two capacitors. The oscillator can also be viewed as a positive gain amplifier combined with a band pass filter that provides positive feedback. [1]

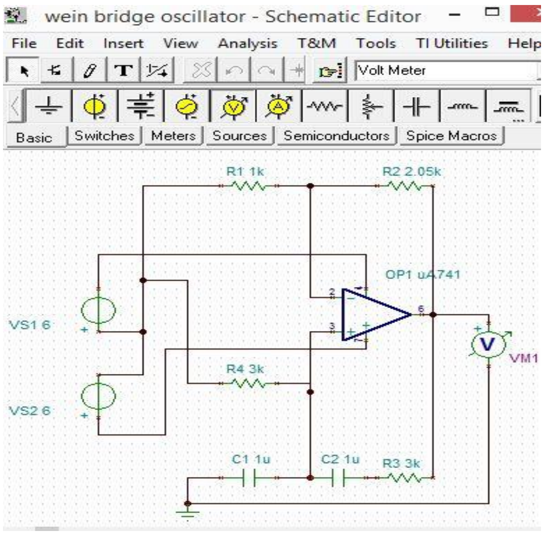


Fig. 2Wien Bridge Oscillator Design [1]

The condition for stable oscillation is given by $2R_1=R_2$

With the Condition $R_3=R_4=R$ and $C_1=C_2=C$, the frequency of oscillation is given by:

$$f = \frac{1}{2\pi RC}$$

For $R_3=R_4=3k\Omega$, $C_1=C_2=1uF$, $R_1=1k\Omega$ and $R_2=2.05k\Omega$

$$f = \frac{1}{2\pi RC} = \frac{1}{2\pi \times (3E3) \times (1E-6)} = 53.052 \text{ Hz}$$

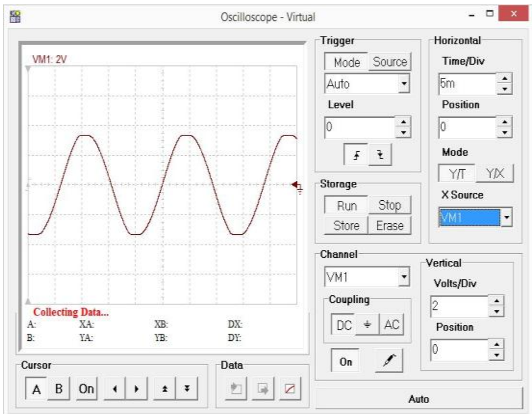


Fig. 3Reference Sinusoidal Voltage Oscillation

From the figure period T=19ms, amplitude 3.5V

B. Triangular Wave Generator

It consist of two stages

1. Square wave generator
2. Integrator

We can get triangular waveform after integrating a square wave. An OP Amp based AstableMultivibrator is used to generate square wave as shown in the simulation.

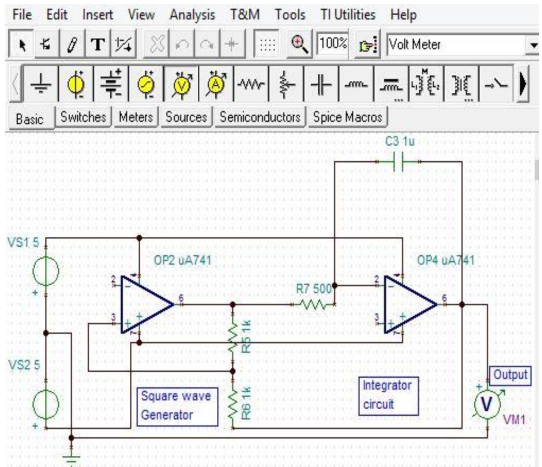


Fig. 4 Integrator Circuit followed by Square wave Oscillator Simulated by TINA.

If we vary the value of R7 and C3 we can vary the frequency of the carrier signal.

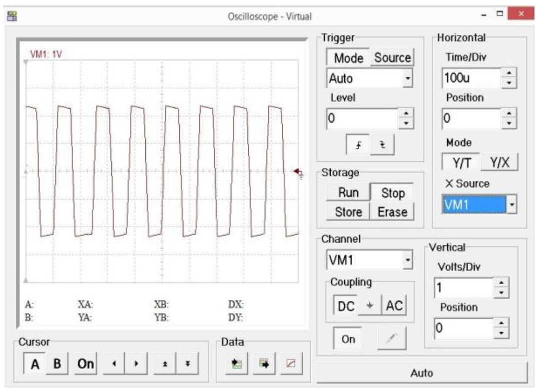


Fig. 5 Square wave simulated output

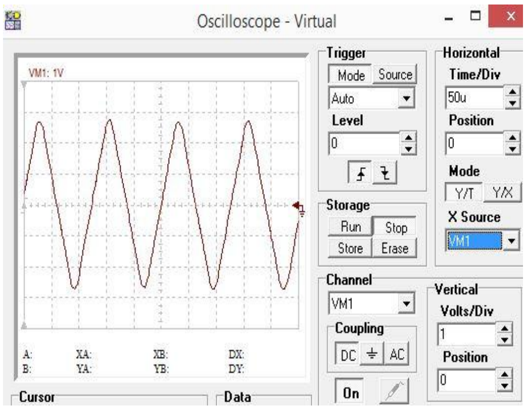


Fig. 6 Triangular carrier wave after the integration of square wave

C. Comparator Circuit: Basic PWM Gate Pulse Generation

We have designed a comparator circuit by op amp where V_{in} is the carrier triangular wave and V_{ref} is the sine 50-60 Hz oscillation wave.

After comparision of this two signals output gives us PWM signal which can be used as gate pulse.

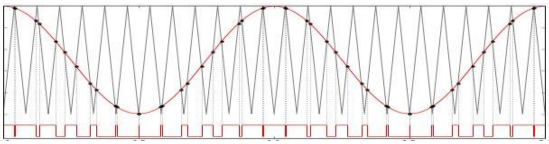


Fig. 7 Compared PWM output where, V_{ref} is modulating sine wave oscillation and V_{in} is carrier Triangular wave [2]

D. Complete Design of PWM Driver Circuit

By assembling wein bridge oscillator, triangular wave generator and comparator circuit the complete PWM driver circuit is built which is shown in Fig. 8 below.

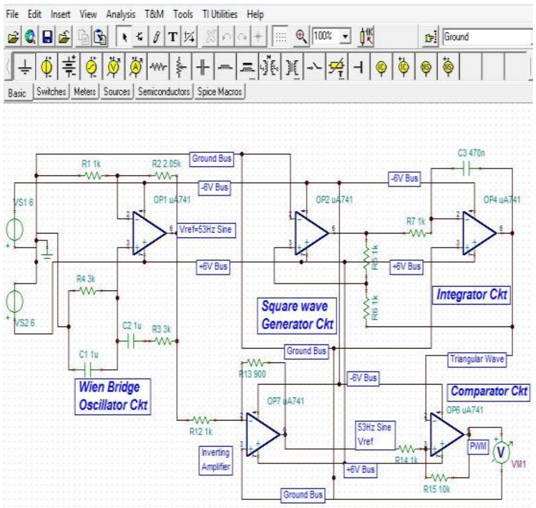


Fig. 8 PWM driver circuit schematic design

VI.INVERTING AMPLIFIER AND BUFFER CIRCUIT

Inverting amplifier is used for gain maintaining of sine wave from attenuation. Another inverting amplifier is used for the generation of complimentary PWM gate pulse [1].

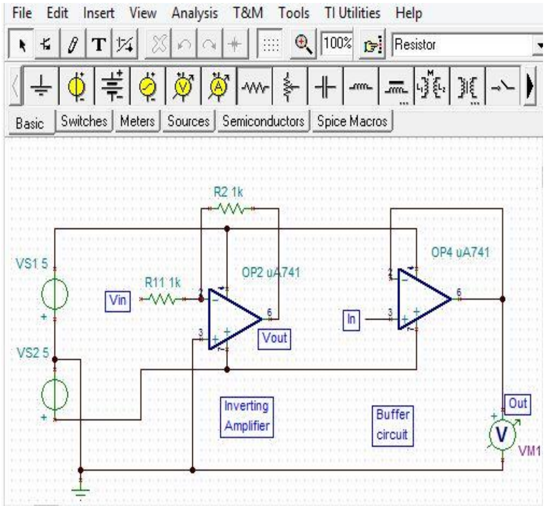


Fig. 9 Inverting Amplifier and Buffer circuit schematic by TINA.

Where, $V_{out} = - V_{in} (R_2/R_1)$
When $R_2=R_1$
Then $V_{out} = - V_{in}$

Voltage follower mitigates the distortion of a voltage from loading effect.Here it works as a perfect voltage source.It saves Op-Amp from bruning out in loading condition.
Where $V_{in}=V_{out}$

Two buffer circuits are practically implemented after two PWM gate pulse circuit. Buffer circuit is also used after sine wave oscillator circuit and carrier wave circuit although buffer circuit is withdrawn from schematic design here.

VII.APPLICATION OF PWM TECHNIQUE TO HALF BRIDGE SINE WAVE INVERTER

It consists of PWM gate pulse circuit from where gate pulses are applied in the gate pin of two MOSFETs. In this case push pull technique is applied in the drain terminal by two low valued resistances. Second order low pass RC filter is used across the push pull resistors (R12 and R13) to get smooth sinusoidal AC voltage.

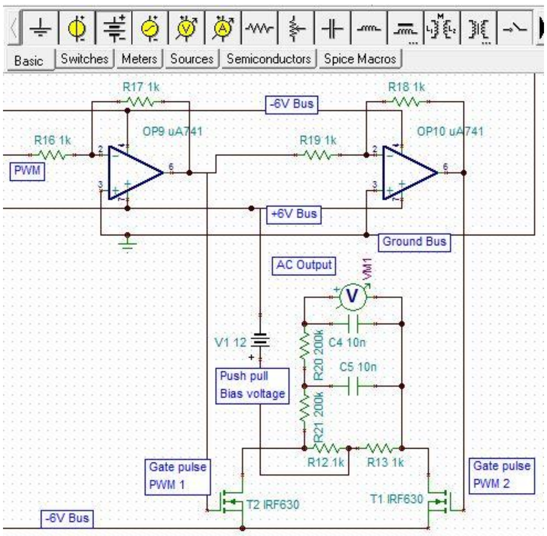


Fig. 10 Schematic of Half bridge MOSFET with push pull resistor by TINA.

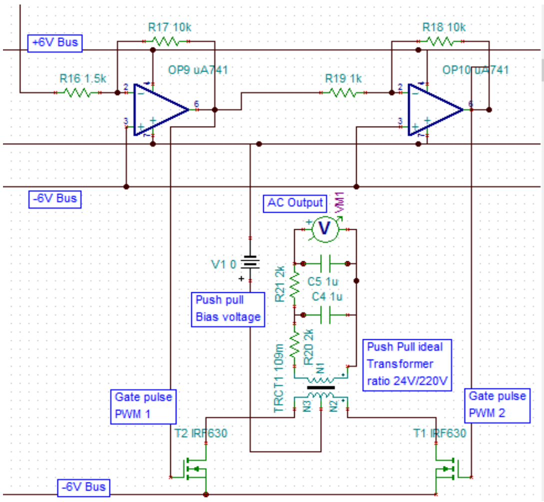


Fig. 11 Schematic of Half bridge MOSFET with push pull transformer by TINA

A. *Output Waveform*

All these output waveshapes have been found by simulation in TINA software.

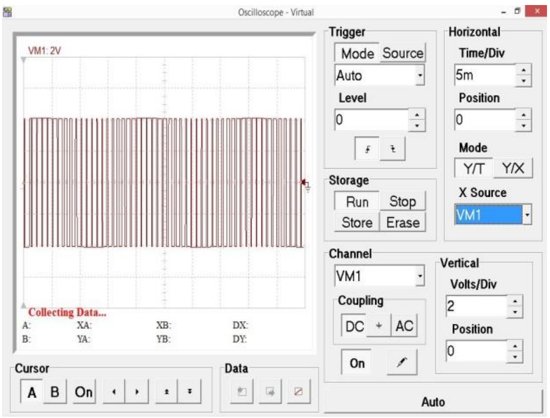


Fig. 12 PWM output from pin 6 of OP6uA74 after simulation

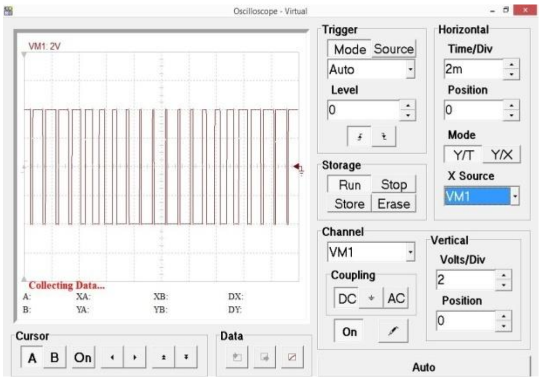


Fig. 13 PWM gate pulse1 from pin 6 of OP9uA74 after simulation

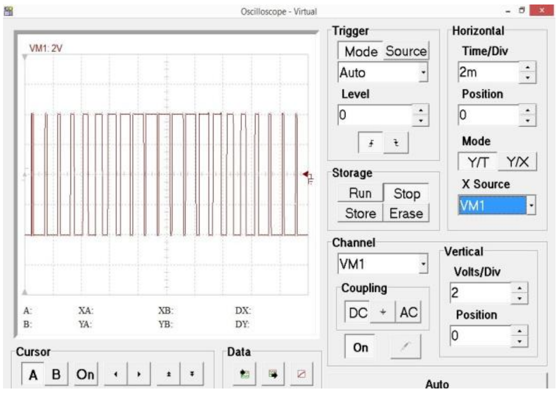


Fig. 14 PWM gate pulse2 from pin 6 of OP10uA74 after simulation

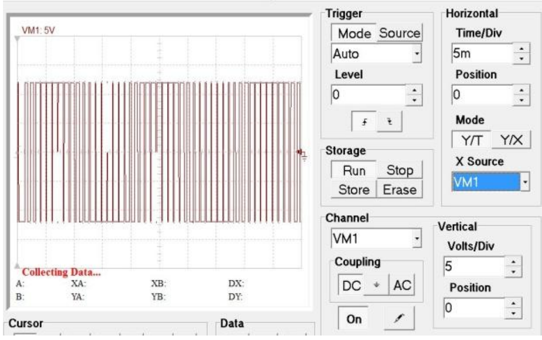


Fig. 15 12V PWM AC across push pull resistors

B. *Sine Wave AC Output And Fourier Analysis*

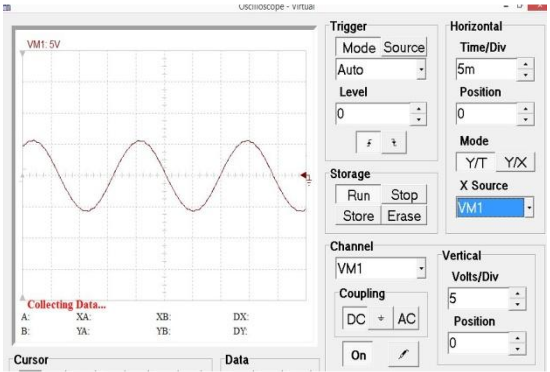


Fig. 16 5V, 53Hz AC, Output 10V peak to peak after RC filtration, When Push pull bias V1=0V DC in Fig. 10

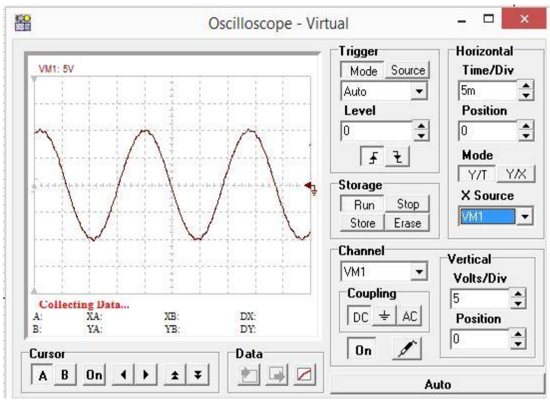


Fig. 17 10V, 53Hz sine AC, Output 20V peak to peak after RC filtration, When Push pull Bias V1=12V DC in Fig. 10

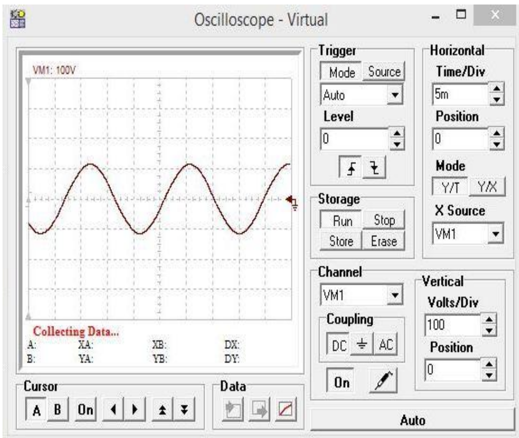


Fig. 18 110V AC when Push Pull bias voltage V1=0V DC in Fig. 11

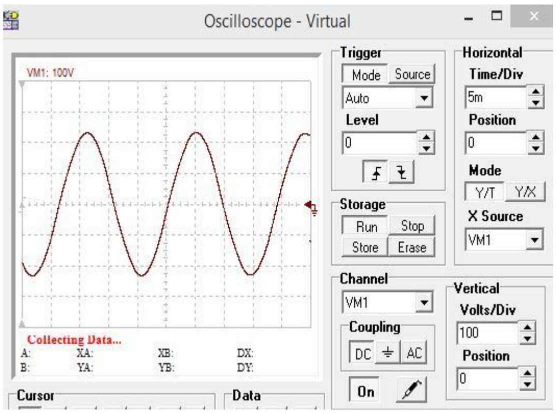
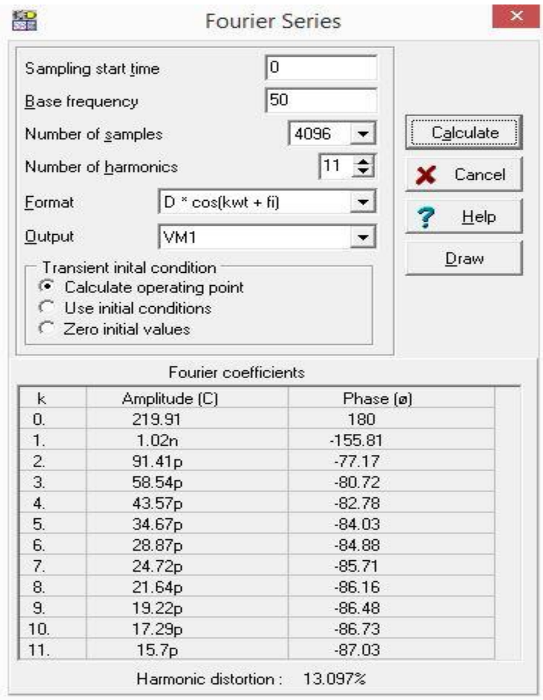


Fig. 19 220V AC when Push Pull bias voltage V1=12V DCin Fig. 11

TABLE I
FOURIER COEFFICIENTS OF SINE WAVE AC BY TINA SOFTWARE

Output is 110V AC with carrier frequency of 8kHz.



Fourier Series

Sampling start time: 0
Base frequency: 50
Number of samples: 4096
Number of harmonics: 11
Format: D * cos(kwt + fi)
Output: VM1
Transient inital condition: Calculate operating point / Use initial conditions / Zero initial values
Calculate / Cancel / Help / Draw

Fourier coefficients

k	Amplitude (C)	Phase (ø)
0.	219.91	180
1.	1.02n	-155.81
2.	91.41p	-77.17
3.	58.54p	-80.72
4.	43.57p	-82.78
5.	34.67p	-84.03
6.	28.87p	-84.88
7.	24.72p	-85.71
8.	21.64p	-86.16
9.	19.22p	-86.48
10.	17.29p	-86.73
11.	15.7p	-87.03

Harmonic distortion : 13.097%

Amplitude and phase versus frequency plotof Fourier coefficients is shown below.

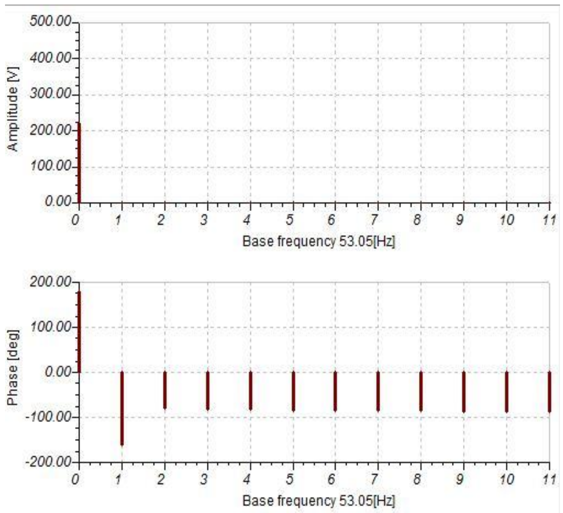


Fig. 20 Amplitude and phase versus frequency plot of Fouriercoefficients, for fc=8 kHz

VIII. HARDWARE IMPLEMENTATION

DC source: Two 6V and two 12V Lead Acid Battery.

Resistors: 680,1K,10K,12K,22K,100K, 10K (variable) Ohm resistors.

Capacitors: 10nF,0.47uF,1uF

Op-Amp IC: LM324N

MOSFETS: IRF630N N channel

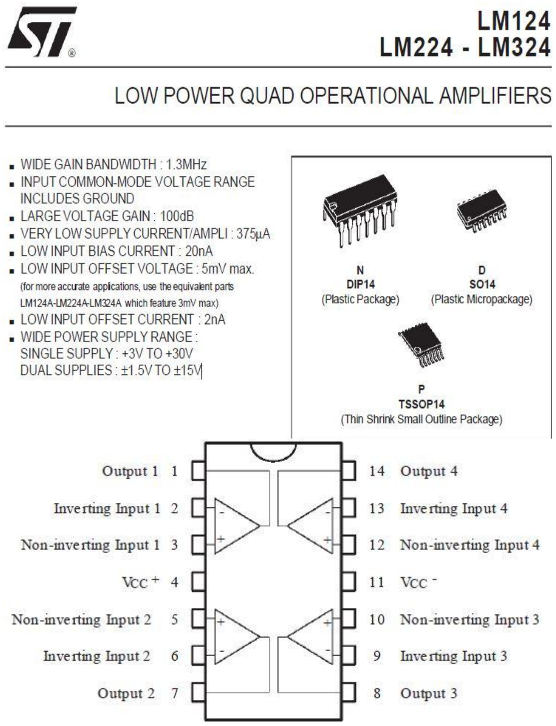


Fig. 21 Quad Op-Amp IC LM324N datasheet [3]

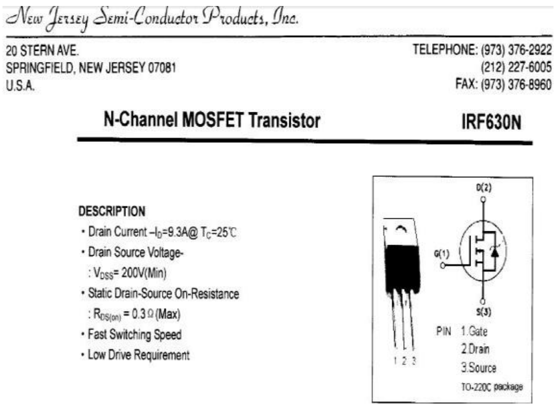


Fig. 22 N channel IRF 630N MOSFET Datasheet [4]

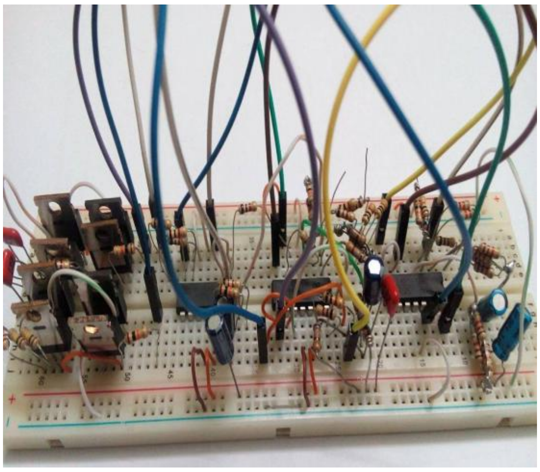


Fig. 23 Hardware Implementation of ICs

A. Circuit output waveform in Oscilloscope

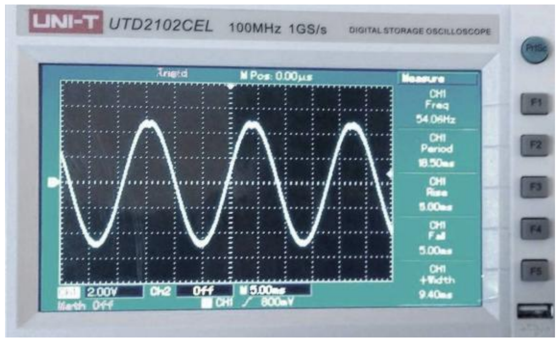


Fig. 24 Reference 53Hz sine wave form Wien Bridge Oscillator circuit.

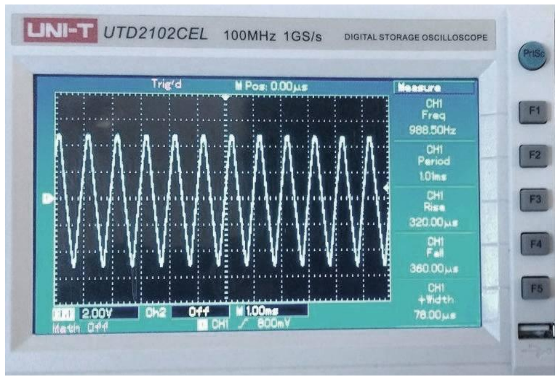


Fig. 25 Carrier triangular wave form

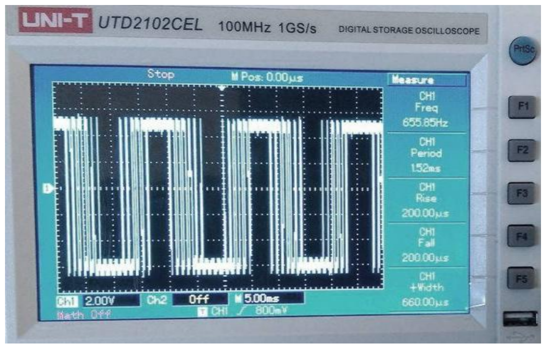


Fig. 26 PWM Wave shape

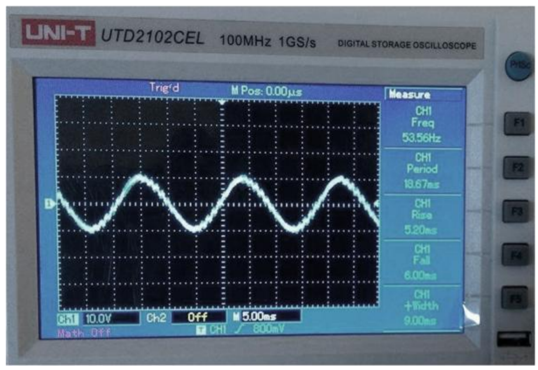


Fig. 27 Filtered 53Hz, 10V AC output from MOSFET-Push pull Network.

B. AC Wave shape Quality: A Comparison

TABLE III
TOTAL HARMONIC DISTORTION (THD) OF THE SIGNAL CALCULATED BY TINA TI.

Base frequency, f_{sin}=50Hz
Two levels PWM circuit (No load condition)

Carrier freque nc-y fc (Appr oxi-mated)	Modulat i-on Index m=fc/fsi n	Resista-nce value R7 for variable fc	THD for 10V AC	THD for 110V AC
500	10	1.75kΩ	66.54%	46.00%
750	15	1.17kΩ	58.12%	58.48%
1000	20	1.09kΩ	64.31%	53.92%
1250	25	900Ω	59.45%	57.17%
1500	30	640Ω	69.54%	68.69%
2000	40	500Ω	54.59%	64.89%
4000	80	300Ω	55.68%	45.16%
5700	114	149Ω	70.44%	24.45%
8000	160	120Ω	56.27%	13.09%

IX. DISCUSSION

From our implemented sine wave inverter, sinusoidal AC voltage has been found which has less harmonic distortion. However this sine wave AC output voltage includes 1.5V average ripple content. Wien bridge oscillator is practically implemented for carrier wave generation for better triangular wave shape. From the circuit we've designed THD is minimized to 13% by using much higher 8kHz carrier signal. The output voltage is stepped up when more push-pull bias voltage is used. For example, with push-pull bias voltage 0V output is 5V AC (10V peak to peak) but with push-pull bias voltage 12V output is 10V AC (20V peak to peak). 2V DC is lost.

X. FUTURE WORK

1. Design a feedback control system to improve the capability of PWM diver for effective implementation on inverter.
2. Hardware design of multi carrier based PWM driver to implement multilevel inverter, achieving less total harmonic distortion.
3. Improve the load capacity of the inverter.

XI. CONCLUSION

The simulated two levels PWM driver circuit is designed successfully and implemented in hardware project. The sinusoidal wave shape has been achieved (no load) with minimum total harmonic distortion and ripple. Transformer impedance matching and feedback control system design is necessary for the PWM driver to be effectively implemented in inverter. Total harmonic distortion (THD) in AC voltage would be mitigated much more when high frequency (more than 8 kHz) carrier signal would be used in the implemented circuit.

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