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SPWM Inverter with Closed Loop Control System to Maintain Constant Load Voltage at Variable Load Condition

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Abstract— AC is the predominant form of electrical power consumption, inverters have been widely used for residential, commercial and industrial applications such as uninterruptible power supply (UPS) and AC motor drives etc. Reliable conversion of electric power is very important in these various applications. This project, "Design and Fabrication of SPWM Inverter with Closed Loop Control System to Maintain Constant Load Voltage at Variable Load Condition" aims to build a closed loop SPWM inverter to provide a reliable conversion of electric power by providing constant load voltage at variable loading conditions. This is done by constantly monitoring the output voltage of the inverter. The change in load either increases or decreases the voltage at the output side of the inverter. This change in output voltage is monitored through a feedback mechanism. The inversion of electric power is controlled through the SPWM mechanism so that the monitored effect in the output voltage is considered and essential actions are taken to keep the output voltage of the inverter constant. The design and tuning of the system are done through simulation software MATLAB Simulink and Proteus 8 professional.

Keywords— Inverter, PWM, SPWM, Closed loop system, MI, Output voltage

Introduction

AC is the most widely used form of electric power consumption so it is expected to get a reliable output of electricity through the inverters. The quality of output voltage is dependent on the technique of conversion of electric power. The Pulse Width Modulation (PWM) is a very advance and useful technique in which, the width of the gate pulses is controlled by various mechanisms [3]. SPWM, or Sinusoidal Pulse Width Modulation, is a widely used PWM technique in power electronics and inverters for generating high-quality sinusoidal waveforms. It involves modulating the width of square wave pulses to approximate a sine wave.

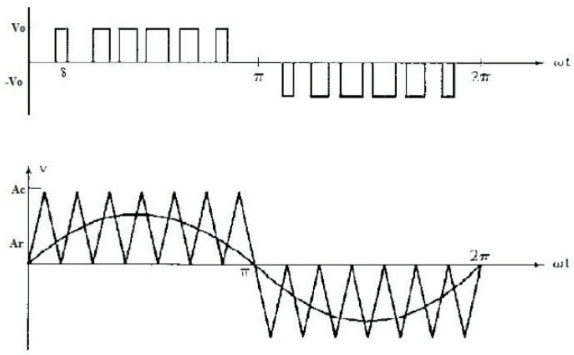

Fig. 1 Sinusoidal pulse width modulation [3].

The SPWM technique is carried out by using two types of waveforms, one is reference waveform and the other is carrier waveform. The reference waveform is the sinusoidal waveform with fundamental frequency and the carrier waveform is a triangular waveform with high frequency [3]. The idea behind SPWM signal generation is that output is generated by comparing reference wave with the carrier wave and when the value of the reference sine wave is greater than that of the carrier triangular wave signal is generated.

The fundamental frequency component of output voltage can be controlled by the modulation index [3]. The MI of a SPWM signal represents the amplitude of the modulating sine wave relative to the amplitude of the carrier waveform.

$$MI = \frac{\text{Amplitude of reference sine wave (Ar)}}{\text{Amplitude of carrier triangular wave (Ac)}}$$

It is a crucial parameter in SPWM as it controls the output voltage magnitude. When MI is increased the time period for which the reference sine wave is greater than the carrier

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triangular wave increases thus increasing duty cycle of each PWM and vice versa. Increasing or decreasing duty cycle relatively increases or decreases the average output voltage of the inverter.

Problem Statement And Objectives

In the inverter with open loop system, there is no direct feedback from the output to adjust the input or the operating parameters. This lack of feedback can result in voltage fluctuations under variable loading conditions.

The objective of this project is to design and fabricate a Sinusoidal Pulse Width Modulation (SPWM) inverter with a closed-loop control system that ensures the maintenance of a constant load voltage even under variable load conditions.

Proposed Approach

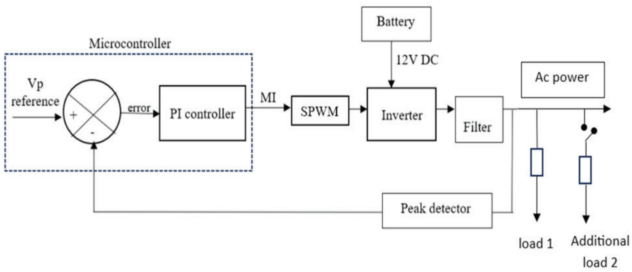

Fig. 2 Proposed system

The Inverter used in this project is a half bridge inverter. This inverter utilizes two MOSFETs, one MOSFET acts as the high-side switch and other acts as a low-side switch. Gate driver circuit controls the switching of the MOSFETs.

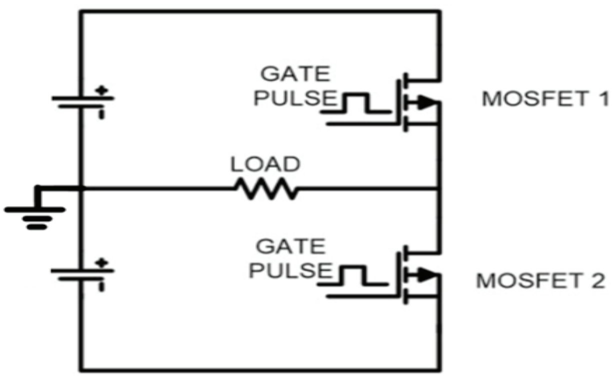

Fig. 3 Half bridge inverter circuit

When MOSFET 1 (M1) is turned on and MOSFET 2 (M2) is turned off, current flows from the positive terminal of the DC supply through M1, through the load, and back to the negative terminal of the supply. Similarly, when M2 is turned on and M1 is turned off, current flows from the positive terminal of the DC supply through M2, through the load, and back to the negative terminal of the supply. This way the direction of current through the load alternates and AC voltage appears across the load. This is the operation of the inverter circuit.

The gate signals provided to the MOSFETs of the inverter are SPWM signals. SPWM signal is generated by constantly comparing the triangular carrier wave with the modulating sine wave. The SPWM signals are produced on the two separate pins of the Arduino alternatively, which when connected to the gate terminals of the MOSFETs of the inverter, the inverter produced an AC voltage on the output end. The logic of gate signal generation can be described below.

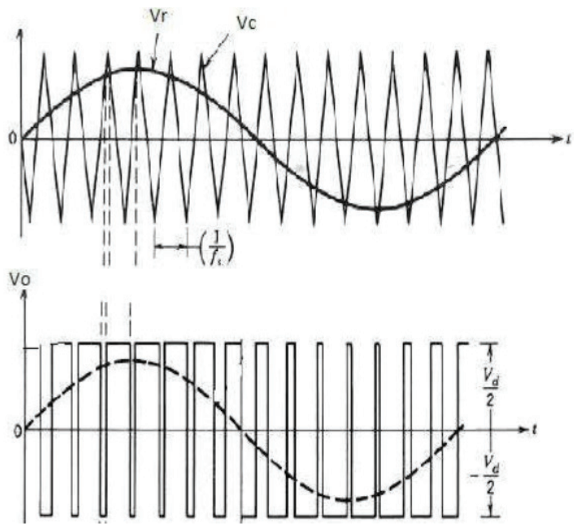

Fig. 4 Generation of SPWM signal

When Vr > Vc, Gate signal = High

When Vr < Vc, Gate signal = Low

When load is added to the system, the output voltage of the system decreases, in response the system increases the MI of the SPWM gate signal generated. Now on increasing MI, the amplitude of sine wave increases which in turn increases the time for which the value of reference signal is greater than the carrier wave. Which means the gate signal will be high for a longer time increasing the average value of the output signal. Similarly, when the load is decreased the output voltage increases and in response of MI is decreased by the system keeping the load voltage of the system constant.

Methodologies

- Simulation of the open loop inverter in MATLAB
- Simulation and tuning of the closed loop system in MATLAB
- Simulation of the system in Proteus software
- Fabrication of hardware according to Proteus simulation

Discussion

The main purpose of the project was to fabricate a hardware model of an SPWM inverter capable of maintaining a constant output voltage while varying the load. This project successfully kept the output voltage of the inverter constant at 26V by the use of the PI control mechanism, while varying the load. Through this project we were able to fully utilize the concept of Modulation Index (MI). With the help of an Arduino, it is able to continuously monitor the output voltage, calculate the error, and adjust the modulation index to keep the output voltage constant. During the project, different circuit designs and logics were tried, which helped to improve the performance of the inverter as well as learn deeply about the working of the closed loop inverter system.

Observation And Results

MATLAB Observation and Results

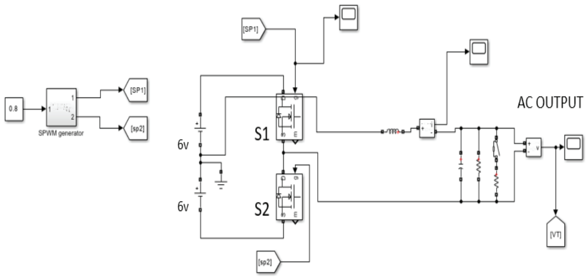

Fig. 5 Simulation of open loop system in MATLAB Simulink

The simulation of open loop system allowed us to analyse the behaviour of the output voltage when additional load is connected to the output terminal at 7s.

Fig. 6 Waveform of AC output voltage showing voltage drop with increase in load

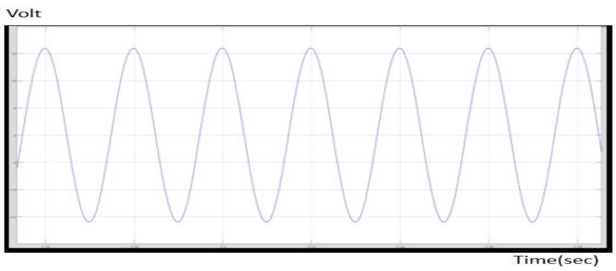

Fig. 7 Magnified view of AC voltage output

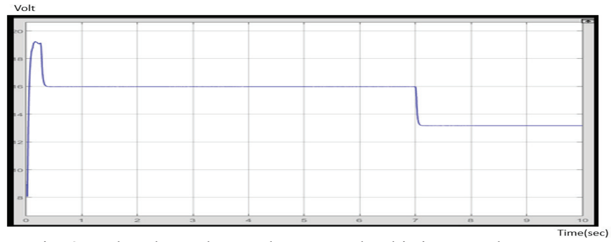

Fig. 8 Peak voltage drops when a step load is increased at 7sec

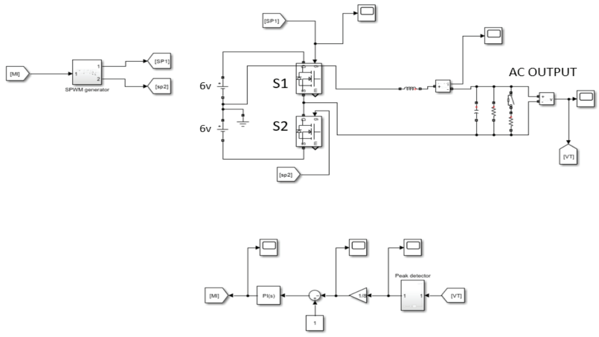

Fig. 9 Simulation model with closed loop system.

feedback is added, which detects the peak value of the output voltage and creates a closed loop.

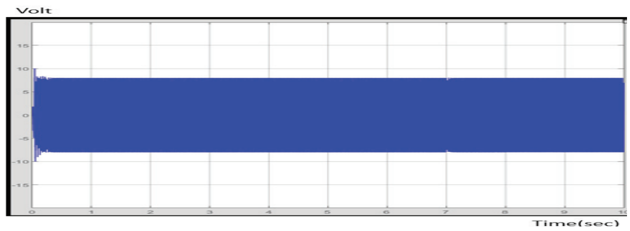

Fig. 10 Waveform of output voltage with a step load increased at 7 sec

Fig. 11 Peak value of output voltage with a step load increased at 7 sec

Here, from above results of the open loop system it is observed that when additional load is connected to the output terminal of the inverter at 7s of simulation there is a significant drop in the output voltage of the inverter and thus the drop in peak voltage value is also observed.

When using a closed loop system, the system detects the drop in peak voltage when an additional load is added. This generates an error, which is fed to a PI control mechanism that generates the value of MI according to the error generated. This MI is used to generate a new SPWM gate signal, which, when provided to the inverter circuit, changes the output voltage of the system keeping it constant, as shown in the waveform.

Proteus Observation and Results

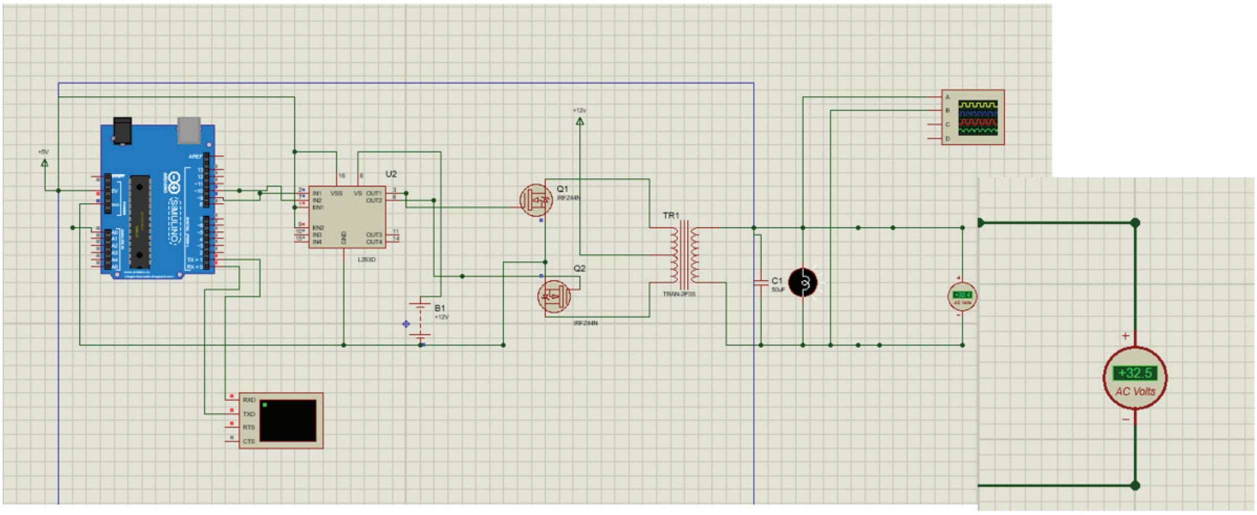

Fig. 12 Simulation model of open loop system in proteus when MI=0.5

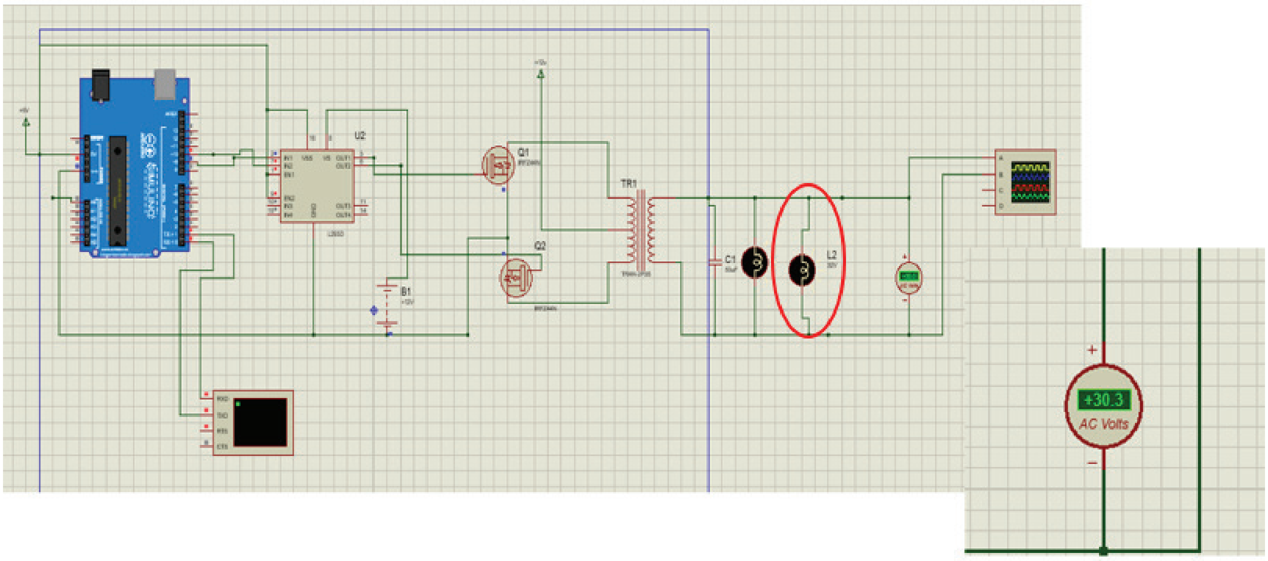

Fig. 13 When additional load is added the output voltage of the inverter drops to 30.3

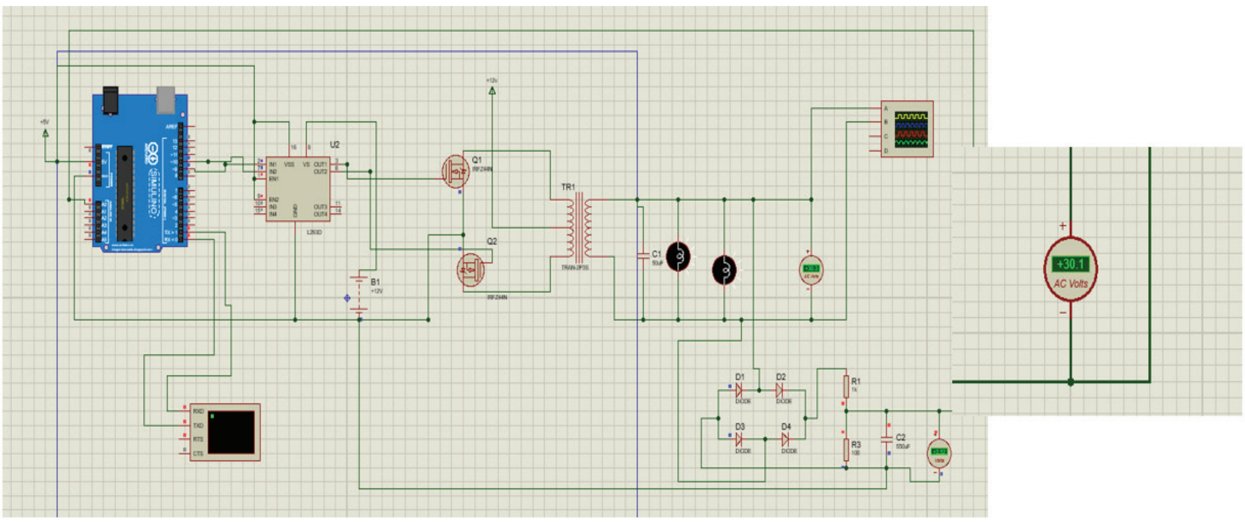

Fig. 14 Proteus Simulation with closed loop system with additional load able to keep the output voltage of the inverter constant at 30.1volts.

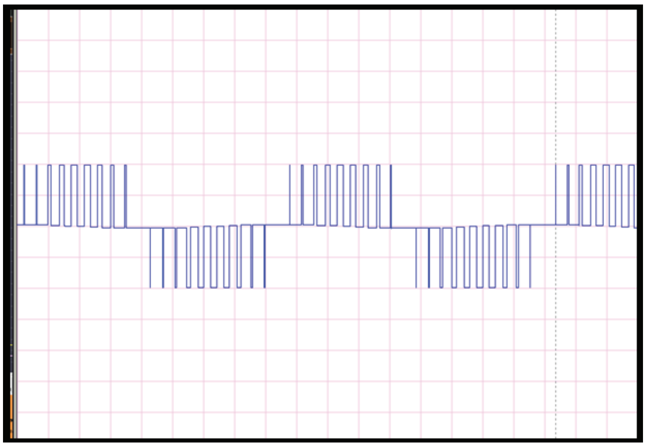

Fig. 15 Output voltage without filter

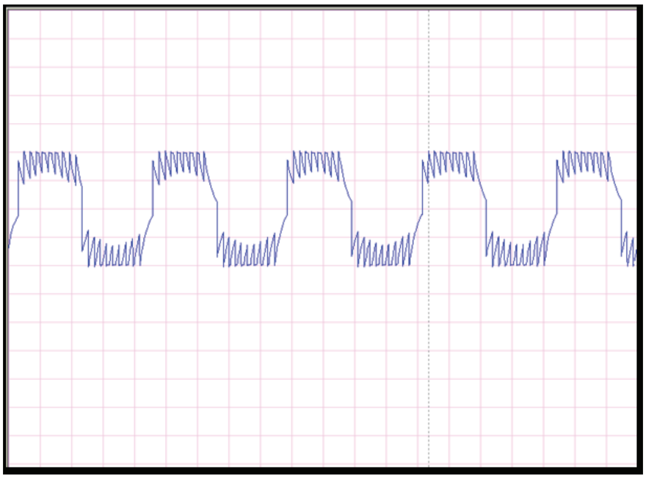

Fig. 16 Output voltage with filter

Hardware Observation and Results

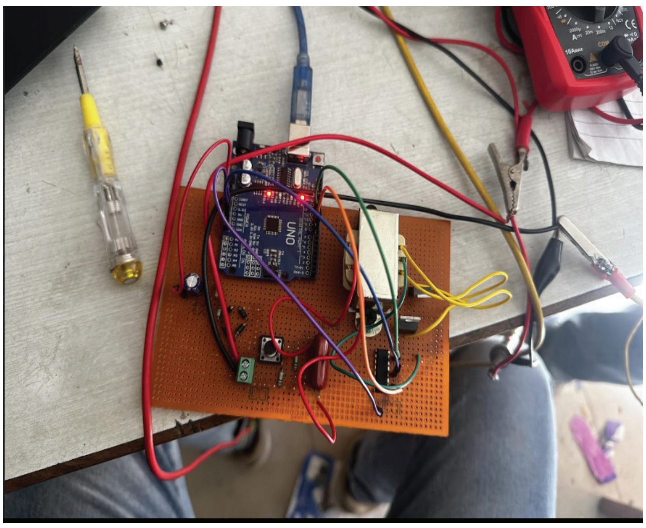

Fig. 17 Fabricated Inverter

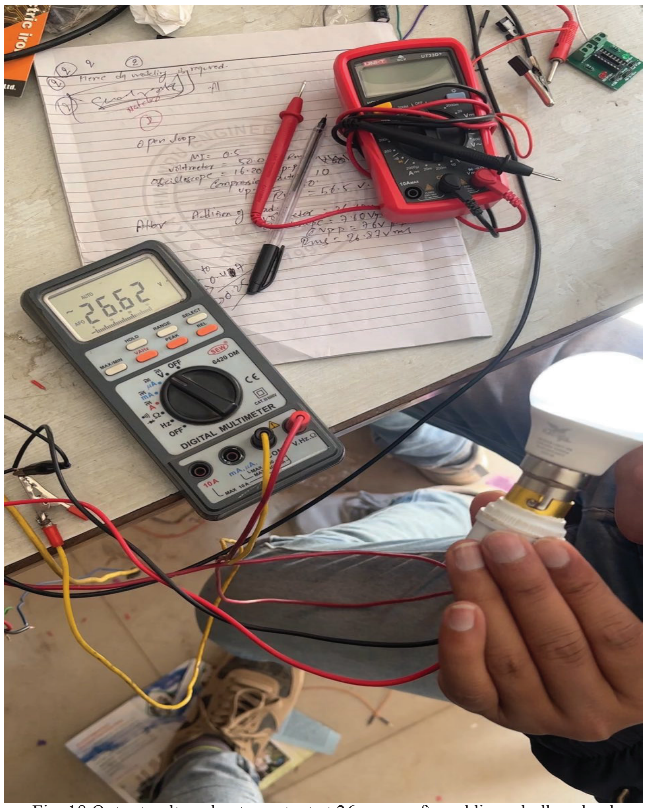

Fig. 18 Output voltage kept constant at 26v even after adding a bulb as load

Observation and Findings in Open Loop Mode of The Inverter:

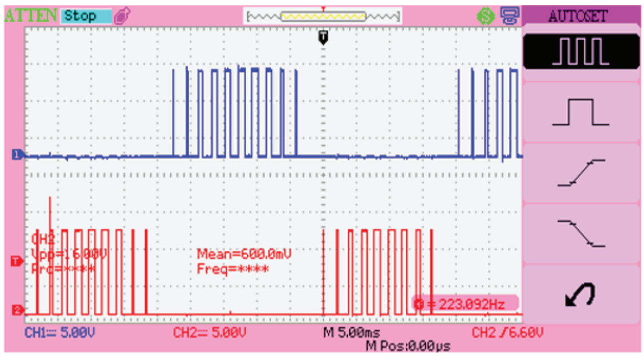

Fig. 19 Gate signal generated by microcontroller

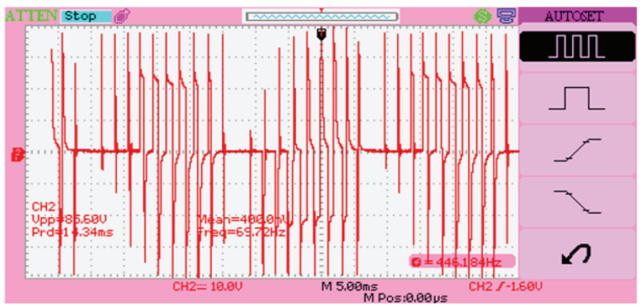

Fig. 20 Output voltage without filter

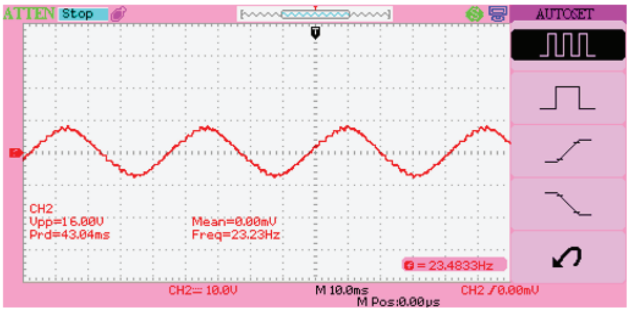

Fig. 21 Output voltage after filter before adding additional load

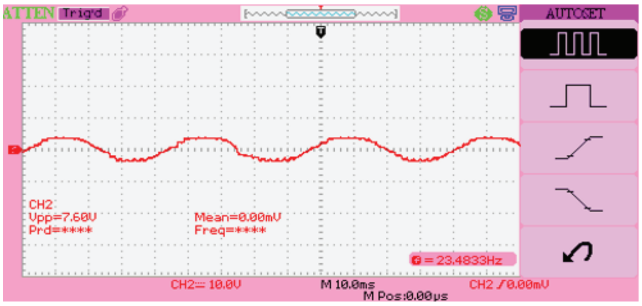

Fig. 22 Output voltage drops after adding additional load

As form observation of above waveforms, the peak-to-peak value of the output voltage before addition of the load is 16.00 v, the rms value would be 5.65v and the peak-to-peak value of the output voltage after addition of load is 7.6v, whose rms value would be 2.687v. But, to properly capture the voltage waveform, we compressed the waveform by the ratio of 1/10. Therefore, the actual rms voltage drop is from 56.6v to 26.87v. Therefore, a significant output voltage drop is observed from above waveforms when adding an additional load to the inverter.

Observation and Findings in Closed Loop Mode of The Inverter:

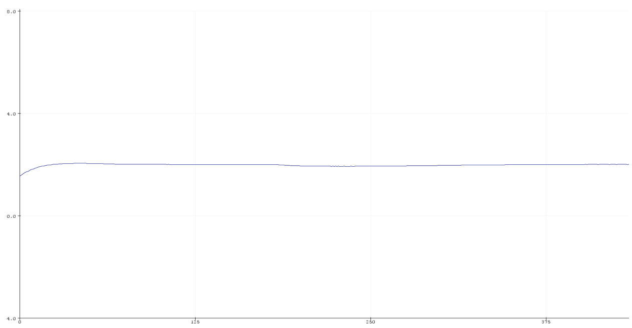

Fig. 23 Arduino's graph of peak value of output voltage with step change in load in closed loop

Here, on closed loop the peak output voltage regains itself as shown in the figure above. The reference peak voltage for Arduino is 2v for which the equivalent rms value of output voltage is 26v.

Conclusion

Thus, through the above simulation and study of the system with and implementation on hardware, we were able to fabricate a closed-loop SPWM inverter that maintained a constant output voltage of 26v even under varying load conditions.

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