Performance Analysis of Unipolar SPWM Inverter: Resistive load and Inductive load

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Abstract – This paper presents the performance analysis of the Unipolar SPWM Inverter for the resistive and inductive load testing. The common criteria reported in various technical papers where the resistive load will produce a unity power factor correction and lagging power factor behaviour for inductive load. This paper is to demonstrate the performance of both loads that are tested to the single phase Unipolar SPWM inverter under the modulation ratio of 0.8. The performances will be covered in term of the waveform behavior and THDv performance. The project are carried out through the simulation using PSIM software and real implementation to the real hardware. The selection of filter for this paper is the low pass passive LC filter.

1. Introduction

Inverter is an electrical device that converts D C power into A C power at coveted yield voltage and frequency [1]. The classification of inverters based on electrical isolation between load and source as isolated and also non-isolated inverters [2]. An existing power supply network or from a rotating alternator through a rectifier or a battery, fuel cell, photovoltaic array or magneto hydro dynamic generator is gained from D C power input to the inverter. Constant D C link voltage is the result of the filter capacitor across the input terminals of the inverter. D C link converter is the configuration of A C to DC converter and D C to A C. The classification of inverter is divided by two types which is voltage source and current source inverters [3].

This project mainly focused on the performance analysis of the inverter for the cases of resistive load and inductive load. The waveform of resistive load and inductive load will face whether unity power factor, lagging or leading effect. Leading power factor will occur at capacitive load but for some cases, it will appear at resistive load or inductive which discussed later on this paper. A proper switching in the inverter are important as to avoid any probability of generating the wrong pattern of waveform which later could impose the appearance of harmonic [4]. The input system power for this inverter is from the single unit of sealed lead acid battery with the capacity of 12 V DC and 7.2Ah and will be convert into 230 V rms voltage to power up the real resistive and inductive load. During the performance testing, a digital oscilloscope of Tektronix TPS2014 will be connected as to measure the
waveform pattern and observing the performance of THD through the FFT windows inside the digital scope.

The loads that use in this project are divided into resistive load and inductive load in the rating of 25W application. The selected resistive load are the normal table lamp and for the inductive load will be the table fans that using induction motor with variables speed. The results will discussed on Total Harmonic Distortion (THD) performance for both resistive and inductive load as both types of load have its own THD disturbance [5]–[7].

2. Proposed Topologies and Operating Principles

2.1. Inverter Design

The selected topology for this paper is the normal full bridge inverter topology with four units of power MOSFETs in configuration. The circuit arrangement are separated into three main parts where the inverter circuit design, the development of LC filter and the load section [8]–[11]. The circuit topology used in this paper are the normal full bridge inverter as shown in Figure 1.

During the simulation stage, the highest concern is on developing the inverter with sinusoidal output voltage. For this case, the value of inductor and capacitor are the most crucial part as it will not generating a good sinusoidal voltage if the value is not suitable. A good sinusoidal waveform should in align with the right axis and will not affected by lagging or leading effect for open load testing.

For unipolar cases, the MOSFETs in Figure 1 are controlled from two set of controller where \(+V_{\text{ref}}\) and \(-V_{\text{ref}}\) or known as \(V\) will intersect with the \(V_{\text{carrier}}\) or known as \(V_{\text{triangular}}\) in order to generate the alternate unipolar switching wave pattern.

![Figure 1. The full bridge inverter topology](image)

The input stages for this project can be either from DC power supply or DC battery with a good rated power so that it can power up the load normally otherwise it cannot run at the optimum power. PWM controller that used in this project are mainly came from the generated pulses from the microcontroller and will be connect to the MOSFET gate driver before it can trigger the MOSFET gate pin as most power MOSFET need \(\pm 15V_{gs}\) to conduct the connection between the leg of drain and source.
2.2. Operating Principles
This inverter scope are set to be conversion from 12 V_{DC} into 230 V_{AC} and will tested to the real load under the switching state of 5 kHz and the fundamental frequency is 50 Hz according to Malaysia electric socket types. The circuit consist of four units of MOSFETs, which work alternately in a pattern as to avoid the short circuit occurrence at the inverter leg.

The generated switching before LC filter is in the form of Unipolar switching state that high in pulses alternately between positive and negative side. The waveform of unipolar inverter before LC filter need to be properly observed as to see the switching is correct or sometimes it is in switching overlap. These criteria are important as switching will resulting the next conversation of sinusoidal A_{C} voltage as it might produce some voltage spike at the point of overlapping.

2.3. Inverter Parameters
The parameters used for the develop inverter are mention in Table 1. In the beginning, the inverter is tested with the wire wound resistor as load in order to observe the result of the develop LC filter are successfully achieved or need to be tune. Wire wound resistor are very good example for measuring the high current before test it at the real load.

| Parameters          | Value          |
|---------------------|----------------|
| Input voltage, V_{in}| 12V_{DC}       |
| Output voltage, V_{out}| 230 V_{AC}    |
| Output current, V_{out} | Before Transformer | 4.9A |
|                      | After Transformer | 0.26A |
| Switching frequency, f_{sw}  | 5 kHz         |
| Fundamental frequency, F   | 50 Hz          |

3. Hardware Implementation
In order to ensure this project run properly and not forming any damages to the real load, the inverter is installed with safety fuse after the transformer as to break the circuit if got overshoot reverse current.

3.1. LC Filter Design
LC low pass filter is a circuit used to change the symmetrical unipolar output voltage into sinusoidal output voltage of the inverter. The component of inductor and capacitor play its role as it will change the standalone pulses and connect to each other near the edges of each pulses. For designing a LC filter, switching frequency is the main criteria to be referred. If 5 kHz switching frequency is impose in 50Hz reference frequency, at least 99th order of harmonic can be eliminated [12]. The value of inductance and capacitance must be reasonable as such converter size need to be considered. During the design, the value of the capacitor is decided to be fixed at 4.7 μF. For inductor design, it is made by manually winding the copper wire to the bobbin core. The value is determined by observing the output of the inverter under two criteria where the waveform is nearly sinusoidal and second criteria to get the minimum THD value [6]. The final value of the inductor is 2.2mH which brings the experimental cutoff frequency value as in equation 1.
\[ f_c = \frac{1}{2\pi \sqrt{L_f C_f}} \]  

(1)

3.2. Project Arrangement and Construction
This circuit are designed in range of 25-30W system. The main concern is to study the performance of the unipolar inverter when connected to the resistive and inductive load. Due to the low power rating, the PCB board are designed that can hold up to 10 amperes rating. The power MOSFET used in this circuit are IRFZ44N that conducting the drain to source voltage under the range of 55V before transformers connection.

The resistive load used in this paper is the normal table lamp while for inductive load is the table fans with 3 speed selection. The detail specifications of the load as in Table 2.

| Inverter Specification | Parameter    | Value  |
|------------------------|--------------|--------|
|                        | Input voltage| 12 V\text{DC} |
|                        | Output voltage| 230 V\text{AC} |
| Transformer specification | Input | 12 V\text{AC} | 2.2 A |
|                        | Power       | 26.4 W |
|                        | Output      | 230 V\text{AC} | 0.11 A |
|                        | Power       | 25.3 W |

| Load Specifications | Resistive load (Table lamp) | Input | 230 V\text{AC} | 0.1 A |
|                      | Power       | 23 W |
|                      | Inductive load (Table fan)  | Input | 230 V\text{AC} | 0.25 A |
|                      | Power       | 59 W |
|                      | Speed       | 25 W |

4. Results
In order to track the performance of the inverter, the inverter is first will undergo the no load testing as to see the performance of the transformer because sometimes at the no load testing appear to be some fault due to the faulty transformer from manufacturer itself. This kind of quality control need to be taken of before start proceeding with the load testing and data recording.

4.1. Resistive load testing
For testing purposes, the developed inverter was tested in the laboratory with the D\text{C} Power Supply as to measure the properly input voltage and input current injected to the prototype. The prototype are connected to the D\text{C} supply, and the inverter fully run on the real resistive load by using a table lamp. The measurement of the parameters was recorded in the digital oscilloscope Tektronix TPS 2014 model together with differential probe and current probe as to measure voltage and current respectively. Resistive load generates no magnetic fields. The function of resistive load will convert current into forms of energy such as heat.
Figure 2. (a) Output voltage before transformer (b) Output voltage after transformer

Figure 2. above shows that the comparison between output voltage before and after transformer with resistive load and it can be seen that the graph pattern was interrupt and not in a sinusoidal waveform. Each of the complete cycle appear to have voltage spike especially after secondary transformer side. This spike occurrence is due to many reasons. Since resistive loads are designed to optimally convert current into energy at specific voltages, resistive loads can benefit from voltage optimization, in order to conserve power and extend the life of electronics. Resistive load for some cases will change the characteristic and becoming like capacitive load characteristic where it tends to have charge and discharge effect at the peak waveform and creating a voltage spike.

Resistive load such as light bulbs and large-scale heaters with the optimal operating voltage, and ensures a consistent supply of quality power in order to prevent the effects of potentially harmful brownouts that can damage increasingly sensitive equipment. Less complex conventional resistive loads such as light bulbs can also have their consumption reduced and their operating life extended by the optimal, stable power supplied by voltage optimization.

Figure 3. (a) THDv before transformer (b) THDv after transformer

Based on the results above, it can be seen that the value of THD after transformer increase drastically from 18.7% to 27.0%. It appears to be the third harmonic increase after transformer. This is due to the waveform of output voltage after transformer appears to be high in voltage spike. This spike will give an impact towards the contribution of harmonic content especially on low order harmonic. In inverter, if the waveform pattern not resembles to sinusoidal waveform, the value of THD will increase. According to Figure 2 (b), the output voltage appears to be some spike occurrence, this will give and impact towards THD performance.
4.2. Inductive load testing
For the second cases, the inverter fully run on the real inductive load by using a table fan shown in Figure 4 below. The procedure involved same as resistive load. Inductive loads generally are those in which electricity flows through the coils normally a motor.

![Figure 4. a) Output voltage before transformer b) Output voltage after transformer.](image)

Figure 4. a) Output voltage before transformer b) Output voltage after transformer.

Figure 4. above shown the comparison between output voltage before and after transformer with inductive load and it can be seen that the graph pattern for both in a sinusoidal waveform. The output voltage after transformer higher than output voltage before transformer due to the specifications of step up transformer. The waveform produced voltage in a small ripple and this is due to the filtering design that affect the performance of the transformer itself.

![Figure 5. a) THDv before transformer b) THDv after transformer.](image)

Figure 5. a) THDv before transformer b) THDv after transformer.

Based on the result above, it can be seen that the value of THD after transformer decrease drastically after transformer from 12.8% to 5.57%. The value for $V_{rms}$ increase after transformer from 5.520V to 79.82V.

5. Conclusion
Based on the experimental results above, it is presented the result of wave pattern for both resistive and inductive load for unipolar inverter. It can be observed that the waveform of the inductive load are tend to be more sinusoidal shaped compared to the resistive load. It can be also noticeable that the result of resistive load are most likely like a capacitive load waveform. This phenomenon might be due to the element of capacitive at the table lamp which resulting the high charge and discharge rate at the resistive load forming a spike voltage. Reported in this report the value of THD for inductive load are slightly more lower than the value of THD at the resistive load side.

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