DESIGN PWM SINUSOIDAL ANALOG SINGLE PHASE INVERTER BASED OP-AMP

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ABSTRACT

One of the electronic components that are widely used in the fields of control, power electronics, audio and video electronics are operational amplifiers (Op-Amp). In this study designed a PWM signal generator using basic components Op-Amp. PWM signal is raised is used to control the phase of the inverter output frequency. Having a frequency inverter output can be set normally used to control the speed of electric motors. One of the single-phase inverter applications that are widely used in home appliances stay is the air-conditioning equipment. PWM technique used in the inverter generates output voltage with low harmonics. To strengthen the PWM signal is done by using a driver amplifier circuit does not reverse the amount of reinforcement can be arranged according to voltage full wave bridge inverter driver. Harmonic distortion (% THD) that appears at the inverter output waveform occurs at frequencies greater reference is 1761, but lower output currents of 41A. Therefore, the efficiency of the inverter with great value occurs in the lower reference frequency setting is 74.56%.

Keywords: *Op-Amp, PWM unipolar, inverter*

Introduction

The development of electronics continues to progress very quickly. The development is based on the needs of the community, both industrial community and society in general. The development of electronics can seen from the size of components and speed. One of the electronic components that are widely used in the fields of control, power electronics, audio and video electronics are operational amplifiers (Op-Amp). This study designed a PWM signal generator using basic components Op-Amp. PWM signal is raised to control the phase of the inverter of output frequency. The frequency of inverter output can be set normally by controlly the speed of electric motors. One of the single-phase inverter applications that are widely used in home appliances is the air-conditioning equipment. PWM technique uses in the inverter to generate output voltage with low harmonics.

Basic Theory

a. Op-Amp[5]

Operational amplifiers (Op-Amp) are electronic components in the form of analog ICs and it is a response to strengthen dc or ac input signal. Operational amplifier was originally used to carry out arithmetic operations in analog computers by division multiplication, addition, subtraction, differential and integral. Operational amplifier which consists of several amplifiers are connected in a row. In the operational amplifier there are three parts: (a) the differential amplifier having a very large input impedance, (b) the voltage amplifier with very large gains, and (c) the amplifier output impedance that is very small.

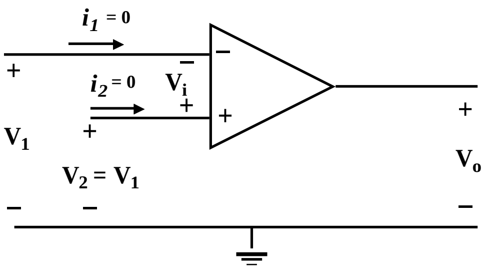

Figure 2.1 Ideal Op-Amp

In ideal conditions, V_1 is equal to V_2, ideal properties owned operational amplifier open-loop voltage gain is infinite, infinite input prisoners, but prisoners output is zero, infinite bandwidth, infinite CMRR, and operational characteristics of the amplifier is not temperature dependent. Op-Amp can be used as a comparator for comparing the input signal, as an inverting amplifier and amplifier does not reverse as a signal generator or oscillator.

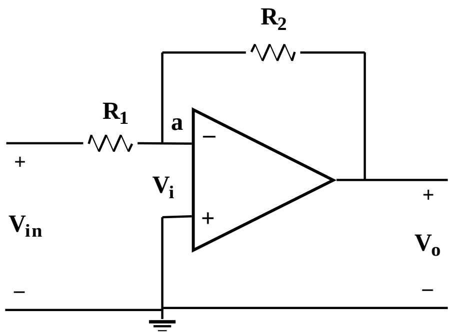

Figure 2.2 Inverting amplifier

Based on the current picture above equation knot, voltage V_i can be expressed by $\frac{(V_{in}+V_i)}{R_1} = -\frac{(V_i+V_o)}{R_2}$

$$V_0 = \frac{-R_2}{R_1} V_{in}$$

Reversing the voltage gain of the circuit is the ratio between the output voltage to the input voltage and ii can be expressed as follows:

$$A_v = \frac{-V_0}{V_{in}} = \frac{-R_2}{R_1} \quad \text{...........(2.1)}$$

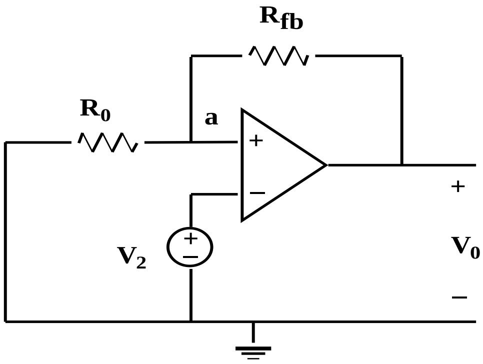

Figure 2.3 Non-Inverting amplifier

Equation output voltage of the amplifier circuit is not flipped, it can be described as follows $\frac{V_2}{R_0} + \frac{(V_2 - V_0)}{R_{fb}} = 0$

$$\frac{V_0}{R_{fb}} = V_2\left[\frac{1}{R_0} + \frac{1}{R_{fb}}\right]$$

$$V_0 = \left(1 + \frac{R_{fb}}{R_0}\right)V_2$$

Voltage gain (A) on the amplifier circuit is not flipped

$$A_v = \frac{V_0}{V_2} = \left(1 + \frac{R_{fb}}{R_0}\right) \quad \text{...........(2.2)}$$

The comparator is used to compare the two voltages at both input and produces a high voltage level / saturation voltage positive (+ Vsat) or low voltage level / negative saturation voltage (-Vsat) depending on the input voltage level. There are two types of comparators, namely: (a) Comparator Not Flipping (Non-Inverting Comparator), and (b) Reversing comparator (Inverting Comparator). Figure 2.5 shows the comparator does not reverse, if V_{in} is greater than V_{ref}, the output voltage comparator is + V_{sat} (+ Vcc). If Vin is smaller than Vref, the output voltage is -V_{sat} (-Vcc).

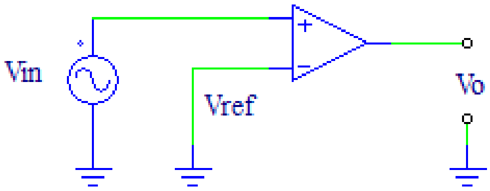

Figure 2.4 Non-inverting comparator

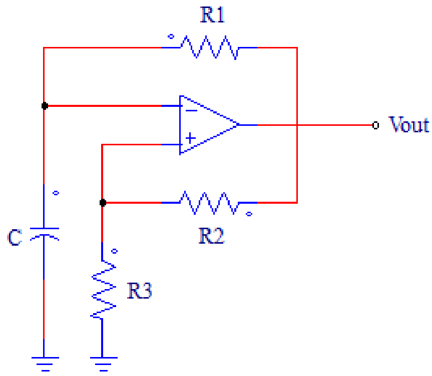

Figure 2.5 Square wave oscillator circuit

Op-Amp can be used as an oscillator to generate a triangular wave, a square, and a sinusoid. Figure 2.5 shows the chain of square wave generator. If the price of R_3 is equal to 86% of the price of R_2, the output frequency is determined by the equation

$$f = \frac{1}{2R_1C} \qquad \text{.....(2.3)}$$

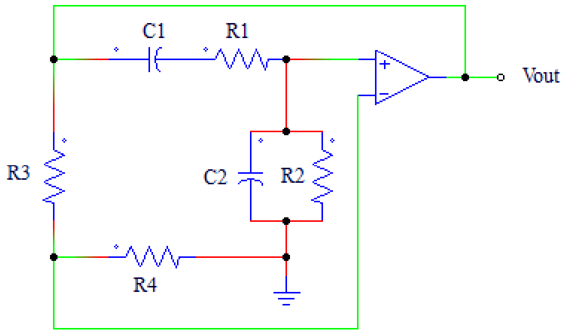

Figure 2.6 Wien bridge oscillator

Wien bridge oscillator generates sinusoidal waves with feedback given to the second input. Frequency selector network consisting of R_1, C_1 and R_2, C_2 provides positive feedback on the inputs tratare not flipped. If R_1 together with R_2 and C_1 equal to C_2, the output frequency is determined by the following equation

$$f = \frac{1}{2\pi\sqrt{R_1R_2C_1C_2}}$$

$$f = \frac{1}{2\pi RC} \quad \text{.......(2.4)}$$

b. Inverter[3]

Based on the resulting voltage, inverter is divided into three-phase inverter and inverter single phase, where as generated inverter output waveform is divided into a half-wave inverter (halfwave) and full-wave bridge inverter (fullwave). The forms of ideal inverter output waveform is sinusuida. But in reality, the inverter output waveform is not sinusuida and it has harmonics. Harmonics that occur at the inverter output waveform can affect the performance of the equipment. The use of inverters in the industrial world is widely used to control the speed of induction motors. Inverter type is known as the VSD (variable speed drive). Besides, inverters are also used for backup power source provider (UPS). Figure 2.7 shows the full wave bridge inverter single phase that uses switches in the switching process. In the first half period (T/2), switch is actively working simultaneously and, current will flow from the source of positive voltage Vs, then passes through S_1, load, and S_4. In the second half period (T/2), switch is active and working simultaneously, current will flow from the negative voltage source Vs, and then pass S_3, load, and S_2.

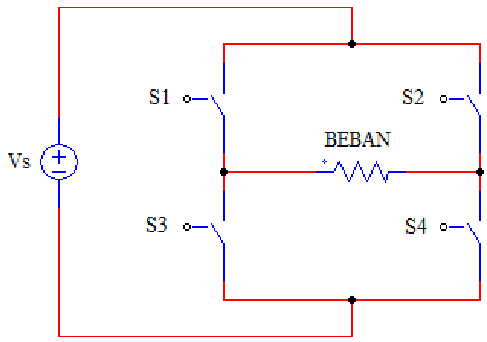

Figure 2.7 The working principle inverter

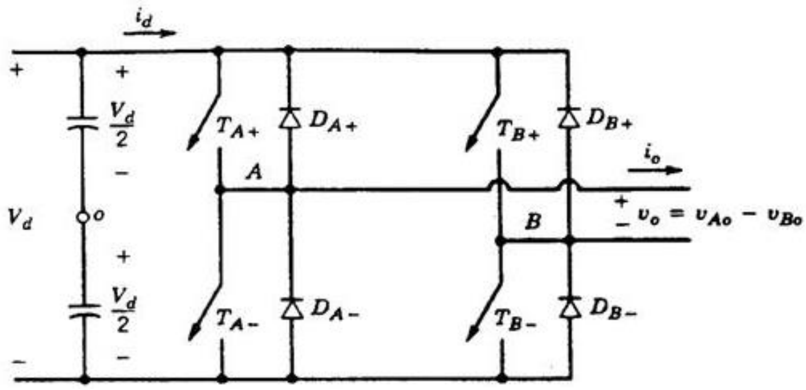

Figure 2.8 Full wave bridge inverter

To minimize harmonics at the inverter output waveform, PWM method is used (pulse width modulation). It forms a full wave bridge inverter circuit that uses a PWM technique shown in figure 2.8 In the first half period of the inverter output voltage of + $V_d/2$ is $V_{AO}(t)$ and in the second half period of the inverter output voltage $-V_d/2$ is the $V_{BO}(t)$, with the $V_{BO}(t) = -V_{AO}(t)$. Inverter output voltage is

$v_o(t) = v_{Ao}(t) - v_{Bo}(t) = 2v_{Ao}(t)$ ....(2.5)

The PWM method is divided into two PWM method with bipolar switching voltage and PWM with unipolar voltage switching.

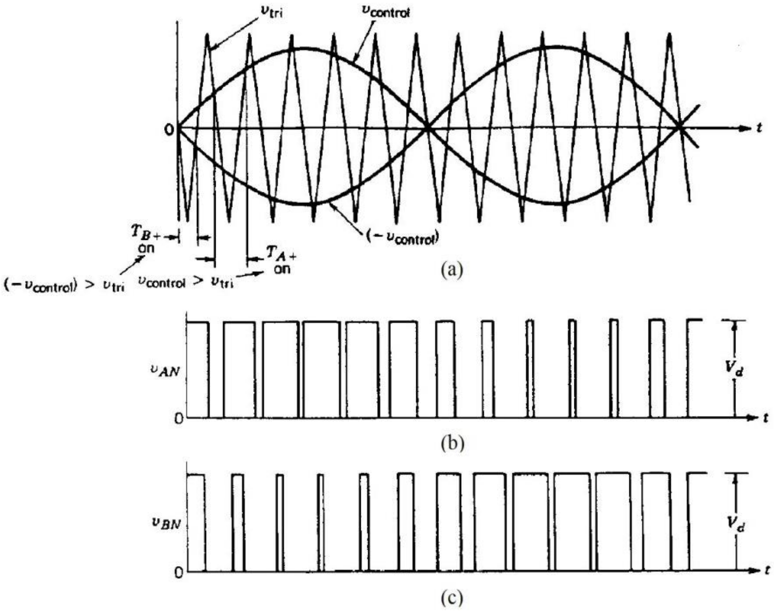

Figure 2.9 PWM with unipolar voltage switching single phase

In this method the output voltage V_{o1} with the fundamental frequency component is

$V_{o1} = m_a V_d \qquad (m_a \leq 1.0)$

$V_d < V_{o1} < 4/\pi\, V_d \qquad (m_a > 1.0)$

Waveform in PWM inverter with unipolar switching voltage method is produced by comparing the triangular wave (V_{tri}) with a sinusoidal wave ($V_{control}$). Fixed frequency triangular wave and sinusoidal wave frekusensi made variable. At the time of a positive period $V_{control} > V_{tri}$ the T_A + on generating $V_{AN} = V_d$ and $V_{control} < V_{tri}$ then hands on to produce $V_{AN} = 0$. When the negative period $-V_{control} > V_{tri}$ then T_B + on generating $V_{BN} = V_d$

and -$V_{control}$ <V_{tri} then on generating V_{BN} = 0.

Method

In this study, it uses a power simulator 9 in designing the circuit. In the circuit design the stage of studies uses operational amplifiers (Op-Amp) as follows:

1. The series of sinusoidal wave generator

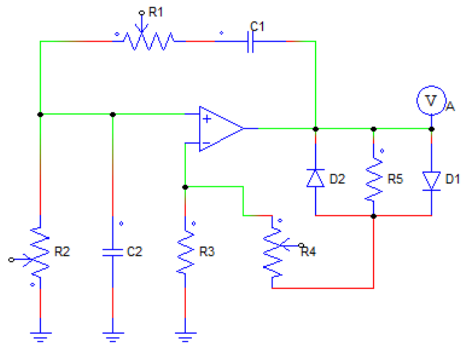

Figure 3.1 Wien bridge oscillator circuit

In designing a sinusoidal wave generator, wien bridge oscillator circuit is used the amount of V_A output frequency is set using a variable prisoners R_2 or R_1.

2. The series of triangular wave generator

In generating a triangular wave, it is conducted in two phases. The first stage was raised square wave of the first Op-Amp circuit with a fixed frequency of 2,500 Hz magnitude. Square wave is then input into the integrator Op-Amp second, so that the output VB is a triangular wave.

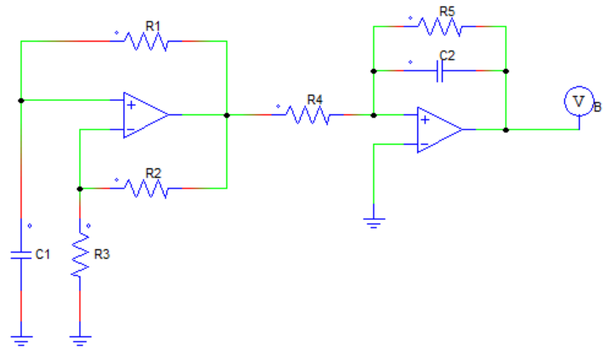

Figure 3.2 Triangular wave generator circuit

3. The comparator circuit

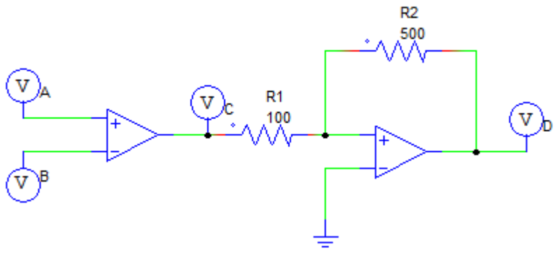

Figure 3.3 Circuit comparator

V_A sinusoidal wave and triangle wave V_B can be input to comparator circuit. V_C comparator circuit output is PWM wave with an amplitude of 1V. PWM waveform is amplified by 5 times with no reverse amplifier circuit with output V_D.

4. The series of phase separator

Phase separator circuit serves to generate two PWM signals with different logic level, NAND gates are used in the design of IC 7400. In addition, in a series of phase separators it uses optocoupler which serves to separate the PWM control circuit with a power circuit with a large voltage.

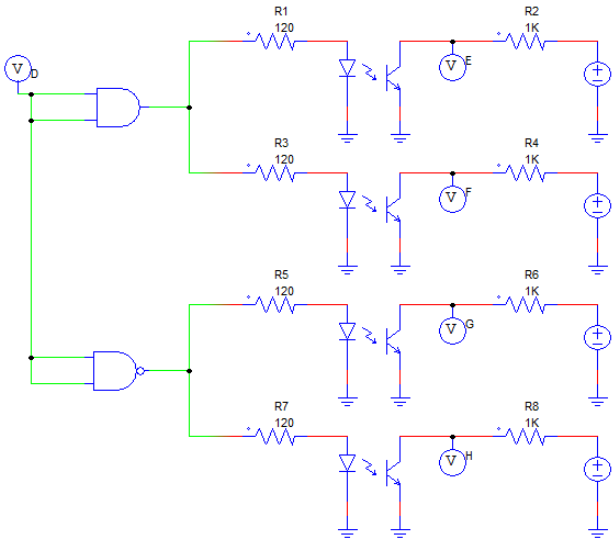

Figure 3.4 The series of phase separator

5. The PWM amplifier circuit

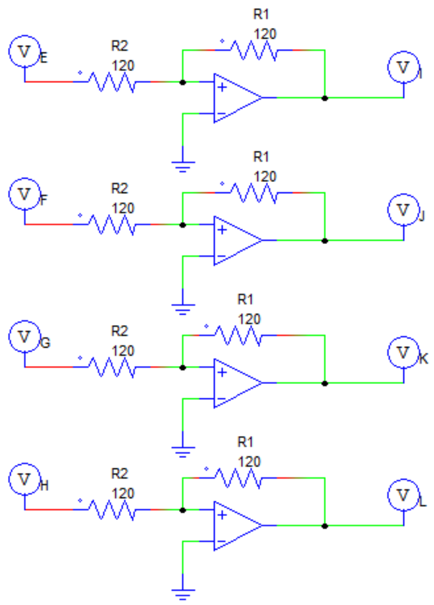

Figure 3.5 PWM amplifier circuit

PWM amplifier circuit serves to amplify the output signal for one optocoupler so it has the level of voltage of 5 V. The amplifier circuit using the PWM amplifier circuits do not flipped.

6. The driver circuit inverter

   Driver circuit using BJT transistor that enabled the saturation and cut-off areas or as a switch. The output voltage driver circuit is used for driver inverter bridge circuit.

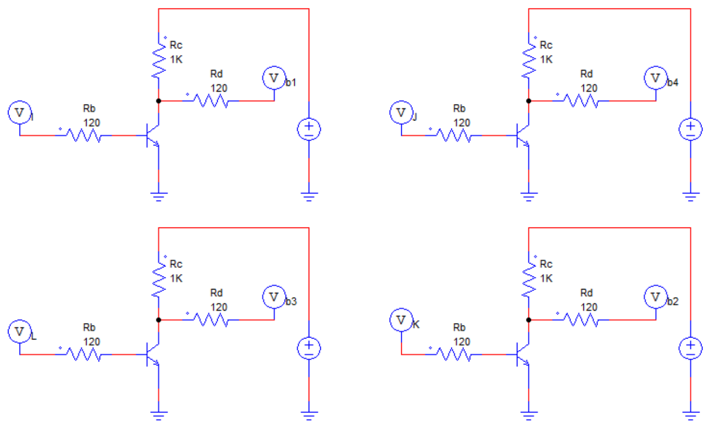

Figure 3.6 The driver circuit inverter

7. The inverter bridge circuit

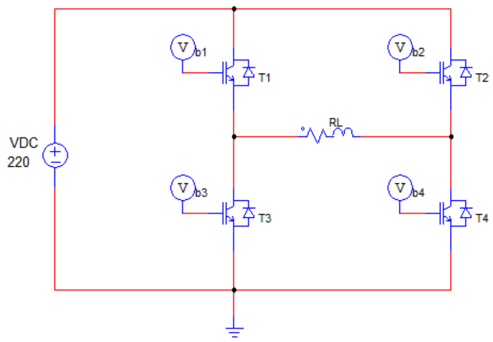

Figure 3.7 Single phase inverter bridge circuit

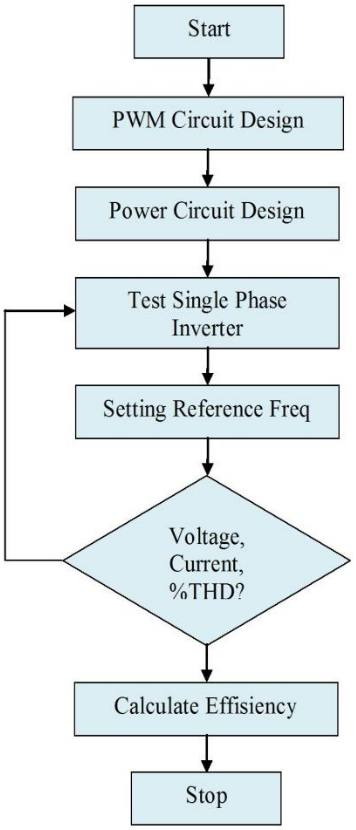

Figure 3.8 Algorithm research

Inverter bridge circuit uses a DC voltage of ± 220 V and the IGBT is as the main component of the inverter. Transistors T_1 and T_4 are working on a positive period and the transistors T_2 and T_3 are working on the current negative period.

Results and Discussion

a. Circuit Signal Generators

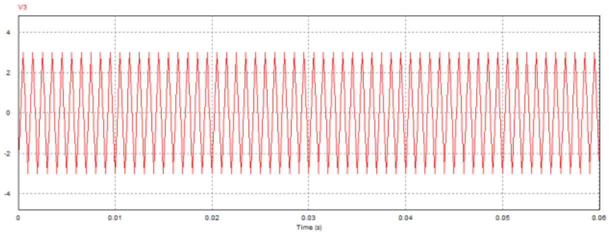

Figure 4.1 Triangle wave at a frequency of 2.500 Hz (V_B)

Triangular wave generator circuit produces output at a fixed frequency of 2.500 Hz with an amplitude of ± 3 V. The form of output wave shown in Figure 4.1. Figure 4.2 and figure 4.3 shows the sinusoidal wave that can be set the frequency, raised from wien bridge oscillator. Output frequency can be set from 0 to 50 Hz.

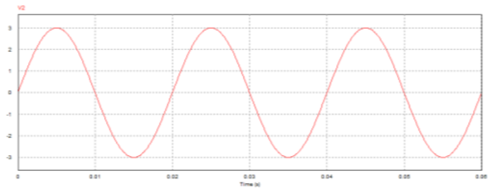

Figure 4.2 Sinusoidal wave at a frequency of 50 Hz (V_A)

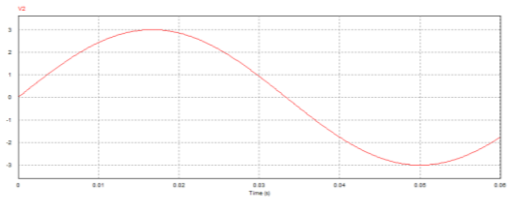

Figure 4.3 Sinusoidal wave at a frequency of 15 Hz (V_A)

b. Comparator Circuit

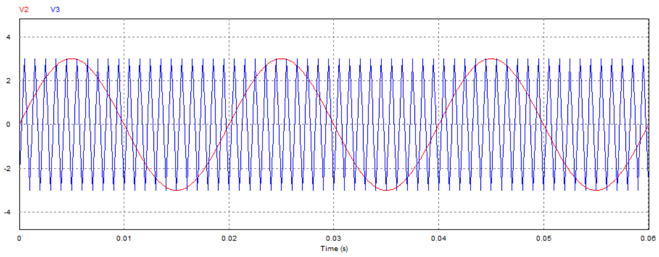

Figure 4.4 Comparator input wave at a frequency of 50 Hz V_A

Comparator circuit is used to compare the triangular wave that has a fixed frequency sinusoidal wave that has a variable frequency. The comparator output generates a PWM waveform.

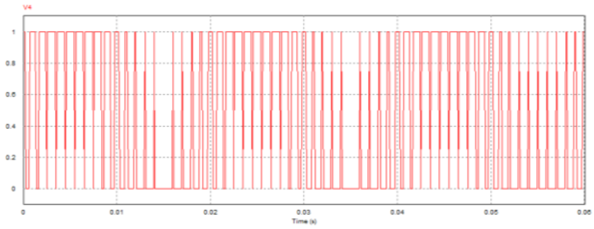

Figure 4.5 PWM wave at the comparator output frequency of 50 Hz V_A

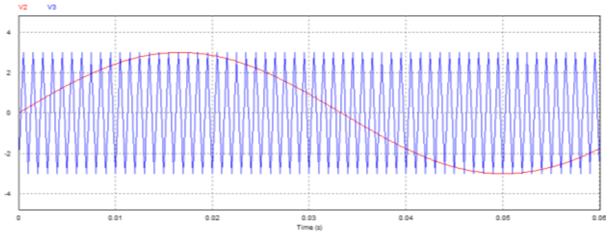

Figure 4.6 Comparator input wave at a frequency of 15 Hz V_A

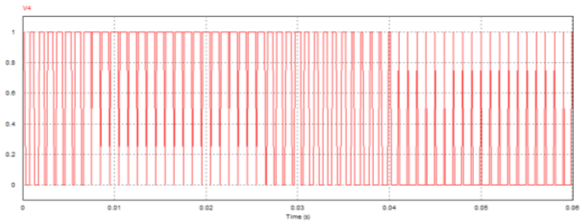

Figure 4.7 PWM wave at the comparator output frequency of 15 Hz V_A

Figure 4.8 shows the PWM waveform that has been reinforced with an amplitude of ± 5 V, PWM waveform is derived from the output of the comparator.

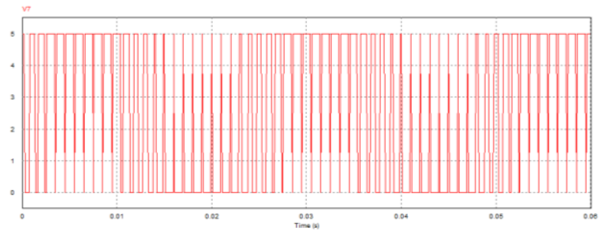

Figure 4.8 Wave PWM amplifier output

c. The series of Phase Separator

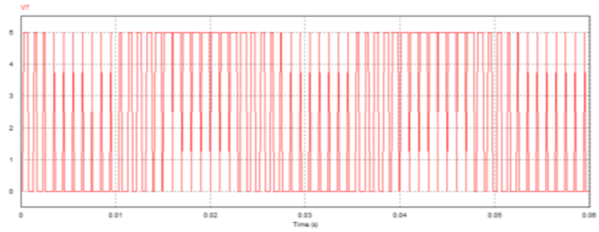

Figure 4.9 V_D phase PWM signal at a NAND gate

The series of phase separator produces two PWM waveform that has the same amplitude but have opposite logic signal. If the first phase has a logic 1, the second phase has a logic 0.

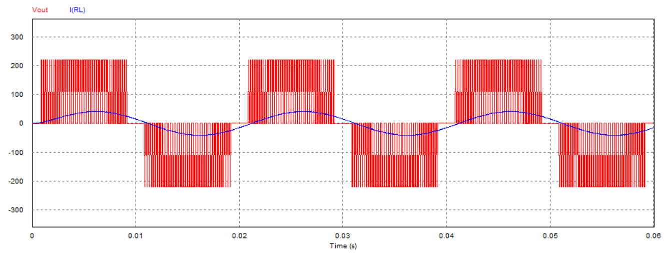

Figure 4.10 Inverter output waveform at a frequency of 50 Hz

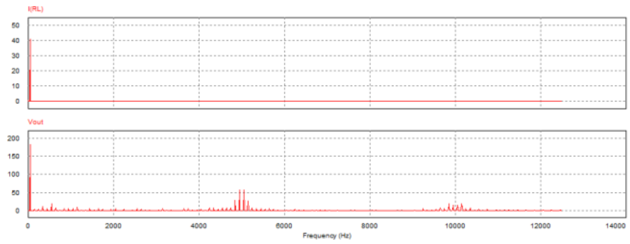

Figure 4.11 Harmonics in the inverter output frequency of 50 Hz

Inverter output waveform with a load R = 10 Ω and L = 5 mH with 50 Hz frequency sinusoidal wave generate unipolar PWM waveform with the greatest harmonics and a low output current is 41 A.

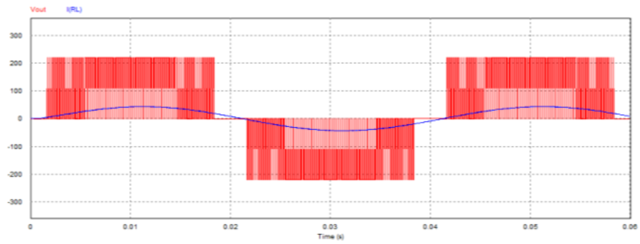

Figure 4.12 Inverter output waveform at a frequency of 25 Hz

In the settings 25 Hz frequency, sinusoidal wave generates load currents greater than the frequency of 50 Hz setting that is 42 652 A.

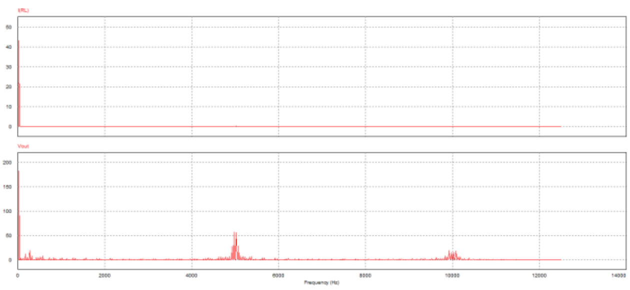

Figure 4.13 Harmonics in the inverter output frequency 25 Hz

At frequencies lower sinusoidal wave 15 Hz, harmonics appears at the inverter output waveform that is lower when compared to the frequency of 50 Hz, but the load current is greater when compared with other fundamental frequency.

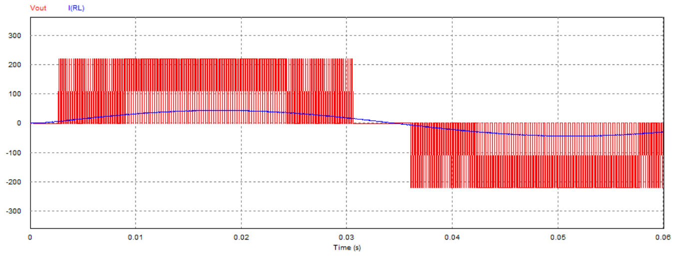

Figure 4.14 Inverter output waveform at a frequency of 15 Hz.

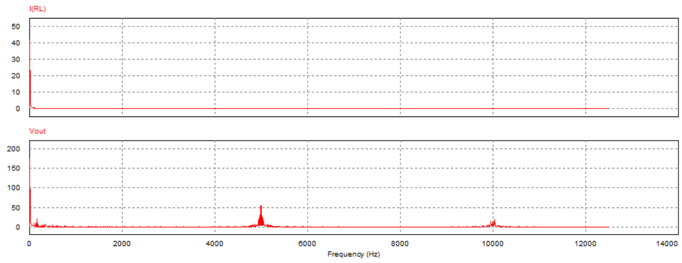

Figure 4.15 Harmonics in the inverter output frequency of 15 Hz

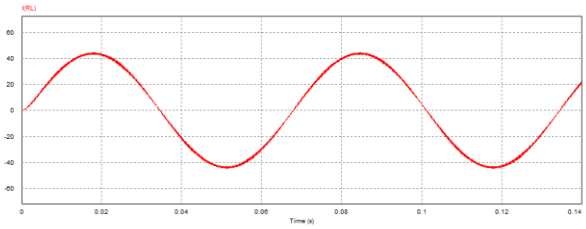

Figure 4.16 Load current at a frequency of 15 Hz.

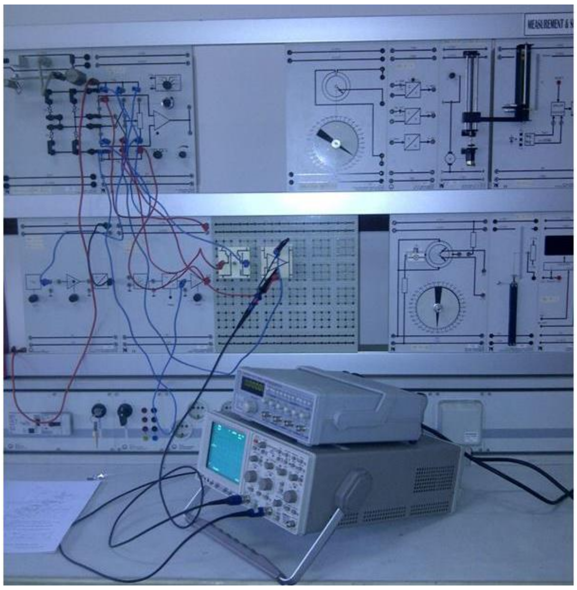

Figure 4.17 Measurement Op-Amp circuit

Based on Table 4.1 it appears that the reference frequency or fundamental frequency of 50 Hz the inverter will provide output current lower than the reference frequency 15 Hz, but the harmonic distortion (% THD) at the output of the inverter is lower in the low reference frequency. Inverter output voltage at the fundamental frequency changes give 219 999 Volt voltage stability. By changing the fundamental frequency of maximum efficiency in the single phase inverter occurs at a low frequency setting is 74.56%.

Table 4.1 Single phase output inverter variable

No	Reference Frequency (Hz)	Carrier Frequency (Hz)	Output Current (A)	Output Voltage (V)	THD (%)
1	50	2500	41.001	219.999	1.761
2	40	2500	41.608	219.999	1.698
3	35	2500	42.841	219.999	1.728
4	30	2500	42.229	219.999	1.688
5	25	2500	42.652	219.999	1.646
6	15	2500	43.824	219.999	1.622

Table 4.2 Efficiency Inverter load R-L series

No	Reference Frequency	Power Input (Watt)	Power Output (Watt)	Efisiency (%)
1	50	1.282,9036	370,1781	28,85
2	40	1.346,0247	475,9207	35,36
3	35	1.372,8937	532,4834	38,79
4	30	1.395,3506	643,4270	46,11
5	25	1.414,9666	824,1550	58,25
6	15	1.454,6842	1.084,5999	74,56

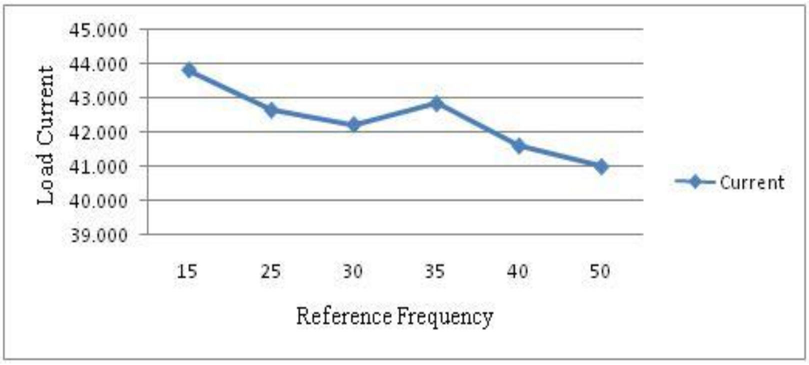

Figure 4.18 Comparison of the load current of the fundamental frequency

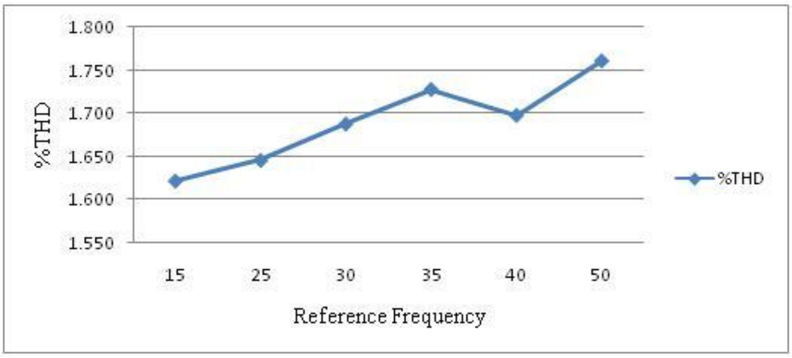

Figure 4.19 Comparison %THD against the fundamental frequency

Conclusion

First, Op-Amp is an analog electronic components that can be used to design a unipolar PWM signal with a sinusoidal wave generator to design an triangular wave.

Second, harmonic distortion (% THD) that appears most likely in the inverter output waveform at the fundamental frequency of the greatest namely 1,761, so the efficiency of the inverter with great value occurs in the setting of low fundamental frequency is 74.56%.

Third, to strengthen the PWM signal, it is done by using a driver amplifier circuit that does not reverse the amount of reinforcement that can be arranged according to voltage full wave bridge inverter driver.

Fourth, in setting the frequency or reference frequency sinusoidal wave effect on the load current. At a frequency of 50 Hz settings, it produces lower load currents when compared to the frequency setting 25 Hz or 15 Hz.

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