Modern Environmental Science and Engineering (ISSN 2333-2581)
November 2017, Volume 3, No. 11, pp. 789-795
Doi: 10.15341/mese(2333-2581)/11.03.2017/006
Academic Star Publishing Company, 2017
www.academicstar.us

Application of Square Wave Inverter Circuit in Photovoltaic System: An Analysis of Output 240 V, 50 Hz Chop and Transform Topology Type Inverter Circuit

Rama Rao Lachanna, and Ananthi Jeyaraju

Department of Mechanical Engineering, Polytechnic Mukah, Sarawak, Malaysia

Abstract: Photovoltaic (PV) system is categorized as one of the renewable energies that have a great potential compared to its counterparts. An experimental model "Stand Alone Photovoltaic AC/DC Supply System" unit has been developed to understand the operational principle of photovoltaic system. In order to drive the AC appliances; inverter circuit is added to this unit to invert the direct current (DC) battery voltage to the alternative current (AC) at 240V, 50Hz. Chosen topology of this inverter is "chop and transform" and output waveform is square wave. The paper is an attempt to understand the working principle of this inverter circuit by analyzing the output waveform of the circuit's main components.

Key words: photovoltaic system, inverter circuit

1. Introduction

Fig. 1 shows a block diagram of the "Stand-Alone Photovoltaic AC/DC Supply System" unit. The selected type of PV system is Stand-Alone AC-DC System. This system is same as stand-alone DC system except contain inverter an electronic device which converts direct current into alternating current [1]. Each component in this unit has several functions. The PV generator consists of PV module (panel) to generate direct current (12V DC); when there is sufficient solar radiation incident on the module. Generated 12V DC will receive by solar power center. The solar power center contains a photovoltaic charge controller and low voltage load disconnect circuits. Function of charge controller is to turn on power to the rest of the charge controller circuitry when the PV module input exceeds 12 V. The low voltage disconnect has a load on-off switch and a battery low voltage indicator. Low voltage disconnects circuit used to turn off the supply to connected load; at the same time connect the circuit to PV generator for recharge the battery. This will happen when the battery voltage is lower than low voltage disconnecting (LDV) set point. Captive electrolyte lead acid battery was included on this system to buffer the energy between the varying supplies from the PV generator to a varying load demand. In order to drive the AC appliances, a stand-alone inverter was added on this unit to invert the direct current (DC) battery voltage to the alternative current (AC) at 240 V 50 Hz.

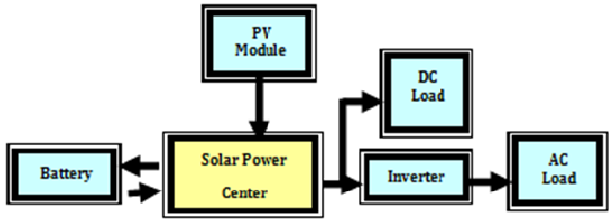


Fig. 1 Block diagram of "stand-alone photovoltaic AC/DC supply system".

Corresponding author: Rama Rao Lachanna, Head of Department of Mechanical Engineering, Polytechnics Mukah; research areas/interests: green technology, automation control system, quality in education. E-mail: ramarao@pmu.edu.my.

1.1 Inverter Circuit Design

Direct Current (DC) to Alternative Current (AC) inverter has been broadly applied to vehicle information facilities, portable computers, various power tools a variety of daily electric appliances. It has also been widely used as AC power to field operation apparatus or instruments. However, the common DC to AC inverter, as its circuitry is complicated. Due to reduce cost of this project; chosen output waveform for this inverter is square wave. This type of inverter is the simplest and least expensive compare to sine wave and modified square wave type inverters [2]. Event square wave inverter has a harmonic content; however it is enough to operate heaters and light the bulbs. Chop and transform topology was selected to design inverter circuit of this photovoltaic system (refer to Appendix A). This type of inverter circuit will convert 12 V DC into around 9V AC first and then converts the low voltage AC into 230 V AC, 50 Hz. Main advantage of this topology is low voltage (= safe) operation and the insulation to load after the inverting system. Another important aspect of this topology is reliability due to the low number of semiconductors in the power path [3].

2. Operational Principle of Inverter Circuit

The inverter circuit schematic shows in Appendix A. The inverter chops the 12 volt DC Battery voltage into a square wave voltage of 50 cycles per second and duty cycle of 50%. When around 12 V DC exceed the input terminal; rest of circuit start to work, mainly oscillation part which consist of crystal oscillator (CR1) and the 14-stage ripple carry binary divider and oscillator (IC1). The Oscillator configuration of IC1 is controlled by external crystal oscillator. Selected crystal oscillator design for this circuit is parallel resonant crystal because this type of oscillator specified to operate with a specified value of load capacitance, at the desired frequency and with the desired frequency tolerance and stability. Considered frequency value for CR1 is 3.2768 MHz, because output frequency of this circuit is not much larger. Higher frequencies value of CR will difficult the frequency divider stage. Selected feedback resister (R1) value for oscillator is 10Mohms and also the input capacitor (C1) and the output capacitor (C2) value are 22pF. As the value of the load capacitance is changed, so is the output frequency of the oscillator. Therefore, this circuit does provide a convenient means of adjusting the output frequency by exist the variable capacitor (CX), parallel with the C1. To ensure the regulation of frequency, point P1 will emit 204.8 KHz and this frequency is obtained by adjusting the CX. Output waveform from crystal oscillator is shall sinusoidal with frequency 3.2768 MHz.

The frequency emitted by the crystal oscillator is applied to IC1 as an input clock (Pin 11). This pin (Pin 11) is a negative-edge triggering clock input. A high-to-low transition on this input advances the state of the counter. The oscillator’s output 1 (Pin 10) is connected to the other side of crystal oscillator and oscillator output 2 (Pin 9) must be left open circuit due to the application of the crystal oscillator configuration. If the RC configuration is used; pin 9 will be connected with an external capacitor. Output from IC1 (Q4-Q10) and (Q12-Q14) is the active-high outputs. Each QN output divides the clock input frequency by 2N. The output frequency from pin 7 (Q4) and pin 3 (Q14) can be calculated as bellow:

Output Frequency Pin 7 = Input Frequency/24
= 3.2768 MHz / 16
= 204.8 KHz

Output Frequency Pin 3 = Input Frequency/214
= 3.2768 MHz/16384
= 200 Hz

Output frequency from IC1 (Pin 3) was applied as an input clock to the Dual-D type Flip-Flop (IC2). Main function of IC2 is to divide the input 200 Hz to 50 Hz to feed to the rest of circuit. The clock source for second flip-flop (IC2B) is produce by the IC1 which is 200 Hz with a cycle of 5 ms. Hence the output of the flip-flop IC2B is obtained at 100 Hz with a 10 ms cycle. This signal is then feed to the first flop-flop (IC2A) as the main clock input to produce a signal which 50 Hz with a 20 ms cycles at the IC2A output. Fig. 2 shows the timing diagram of frequency dividing process of IC2. The 50 Hz square wave output frequency from IC2 is used as input pulse for IC3. IC3 is a monostable multivibrator which is used in this circuit as a single positive edge-trigger by applying a leading-edge pulse from IC2 to the positive trigger (Pin 8). This type of multivibrator produces a single pulse that stays high for a fixed amount of time. The positive pulse of this signal is feed at pin 10 and its inverse the negative pulse is feed to the pin 11. The output pulse width from IC3 is determined by the configuration of external capacitor (between pin 1 and 3) and an external resister (between pin 2 and 3). The calculation of output pulse width from pin 10 and 11 as shown as bellow:

Output Pulse Width (tM) = 2.48 × Rt × Ct

= 2.48 × 560 KΩ× 8.2 nF

= 11.388 ms

Output pulse from IC3 is used as an input for push-pull modulator section, which consist of MOSFET Q1-Q2 as buffer stage, followed by the drive stage Q3-Q4 and the power stage Q5-Q6 When Q1 get positive input pulse from IC3 (Pin 10) Q3 and Q5 switch on but Q2, Q4 and Q6 is off. Current flows through the “upper” half of T1’s primary and the magnetic field in T1 expands. The expanding magnetic field in T1 induces a voltage across T1 secondary. When Q1, Q3, Q5 turns off, the magnetic field in T1 collapses and after a period of dead time (dependent on the duty cycle). If Q2 get negative input pulse from IC3 (Pin 11) Q4 and Q5 conducts, and causing the current to flow through the “lower” half of T1 primary and the magnetic field in T1 expands. Now the direction of the magnetic flux is opposite to that produced when Q1 conducted. The expanding magnetic field induces a voltage across T1 secondary. After a period, Q1 conducts and the cycle repeats. There are two important considerations to be made when it comes to the design of the push-pull modulator:

(i) Both transistors must not conduct simultaneously,

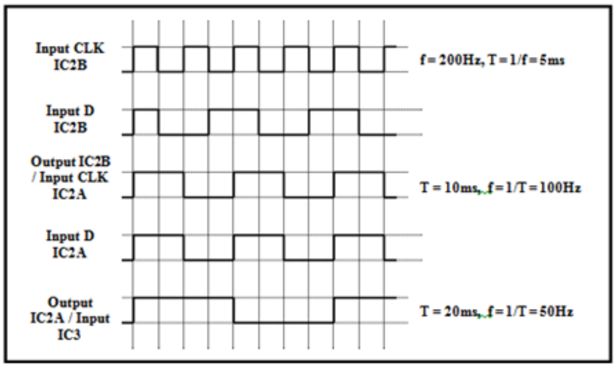


Fig. 2 Timing Diagram of Frequency Divided in IC2.

as this would effectively short-circuit the supply. Hence, the conduction time of each transistor must not exceed half of the total period for one complete cycle; otherwise, the conduction will overlap.

(ii) The transformer magnetic flux must be bi-directional; otherwise the transformer may saturate, and cause destruction of Q1 and Q2. This requires that the individual conduction times of Q1 and Q2 are exactly equal and the two halves of the center-tapped transformer primary be magnetically identical.

The diode zener D2-3 used to protect the power transistor from voltage peaks, which are produced by the transformer T1. The power transistor Q5 and Q 6 should place in heat sink. Transformer T1 is a simple center tap power transformer, with intermediate reception, which is connected in the contacts of CO1. The transformer T1, is placed in reverse with secondary convolution used as primary, with the intermediate reception is connected in the positive point of battery 12 volt and the two other contacts are connected in the emitters of Q5 and Q6, that are connected in the potential of ground alternately. By using this method while in being primary flow AC current, in secondary is created 230 V AC, 50 Hz square wave voltage. As a general rule, the input lines to any power converter should be fused. The fuse used to limit the input power in the event of a catastrophic failure within the converter or the system the converter is supplying power to. The chosen fuse rating for input DC voltage is 5A and for output AC voltage is 0.25A.

3. Inverter Circuit Analysis Result

As shown in Fig. 3, the 12.6 volt direct current (DC) from battery is used as an input for this inverter circuit. The 12.6 volt input is not fixed for this inverter circuit because the input voltage for inverter circuit is determined by the battery nominal voltage. Nevertheless the 12.6 volt is used as the input for this analysis. Referring to Fig. 4, output frequency of the crystal oscillator (CR1) is 3.283 MHz which generates a sinusoidal waveform. Even though this output frequency is over then actual value (3.2768 MHz) but it's still in the 5% tolerance range. The frequency emitted by the Crystal oscillator is applied to IC1 as an input clock. To ensure the frequency regulation of this inverter circuit, pin 7 in IC1 (point P1) will emit a square wave output with the frequency of 204.8 KHz as shown in Fig. 5. This reference frequency is obtained by adjusting the adjustable capacitor (CX).

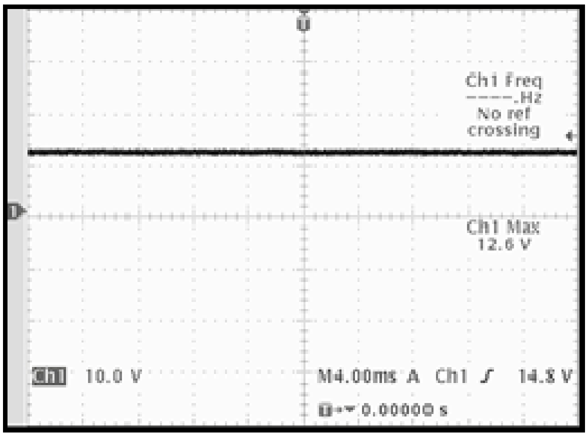


Fig. 3 Input voltage of inverter circuit.

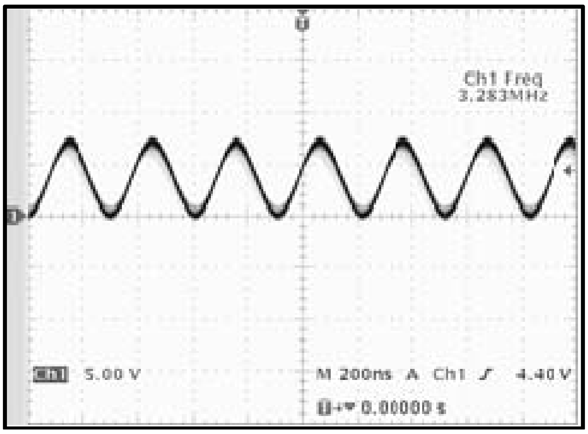


Fig. 4 Output frequency of crystal oscillator (CR1).

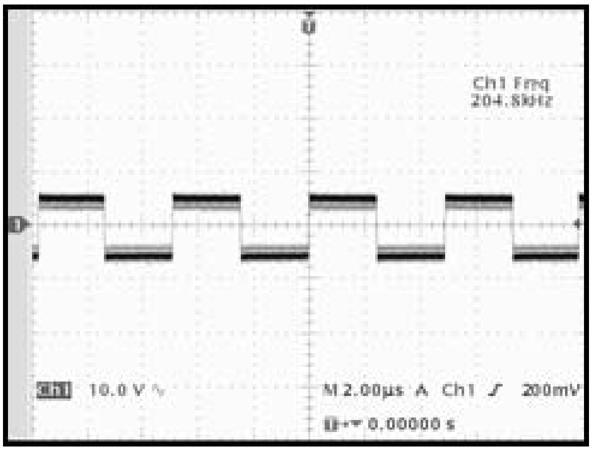


Fig. 5 Output frequency from reference pin (P1).

Fig. 6 shows the output signal of IC1, which is used as an input clock for dual D-type flip-flop (IC2). The input signal for IC2 generates a square wave with frequency of 200 Hz. The main function of IC2 in this circuit is to divide the 200 Hz output frequency of IC1 to 50 Hz to be feed to the rest of the circuit. Output signal of IC2 is as shown in Fig. 7. The 50 Hz square wave output frequency from IC2 is used as input pulse for IC3. IC3 function as a monostable multivibrator which generates a single cycle of signal where the positive and the negative pulse are set to stay high in certain amount of time. The positive pulse is then separated from the negative pulse and both of these pulses can be obtained from pin 10 and pin 11 of the IC3. As stated above the main function of monostable multivibrator in this circuit is to increases the duty cycle of these pulses thus reducing the amplitude voltage.

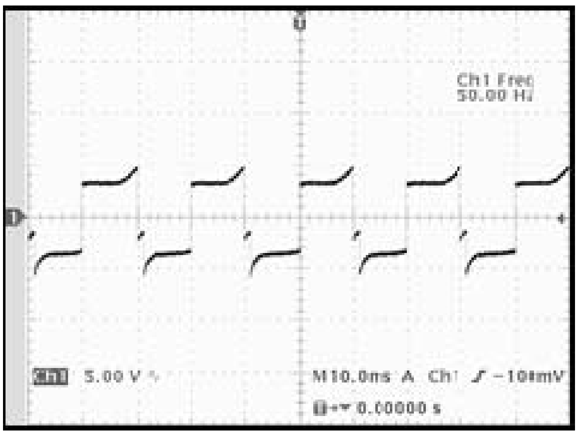


Fig. 6 Input signal of IC2.

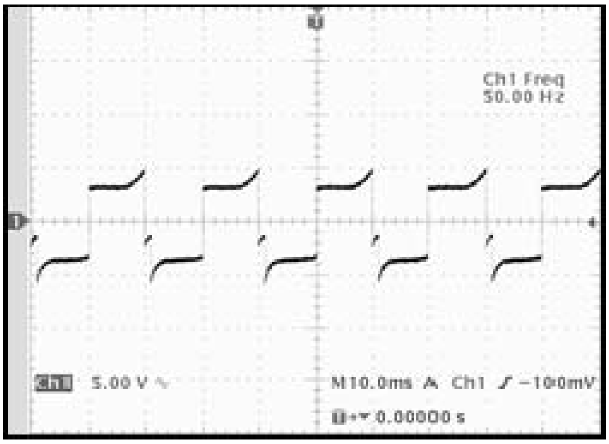


Fig. 7 Output signal of IC2.

As shown in Fig. 8 the input amplitude in channel 1 reveals that input voltage of IC3 is 7.60 v with 10 ms duty cycle while channel 2 of the oscilloscope shows that the output voltage of positive cycle at pin 10 of IC3 had been reduced to 6.8V but at the same time duty cycle of this output increase to 11.3 ms. Notice that the frequencies of the positive pulse are still maintained at 50 Hz even though the duty cycle of the pulse had been increased from 10 ms to 11.3 ms. Fig. 9 shows that the input amplitude in channel 1 reveals that input voltage of IC3 is 7.60 v with 10ms duty cycle while channel 2 of the oscilloscope shows that the output voltage of negative cycle at pin 11 of IC3 had been reduced to 6.1 V. While the duty cycle of this output increase to 11.3 ms from 10ms but frequency of this output signal still remain at 50 Hz. Both positive and negative outputs pulse of IC3 is shown in Fig. 10.

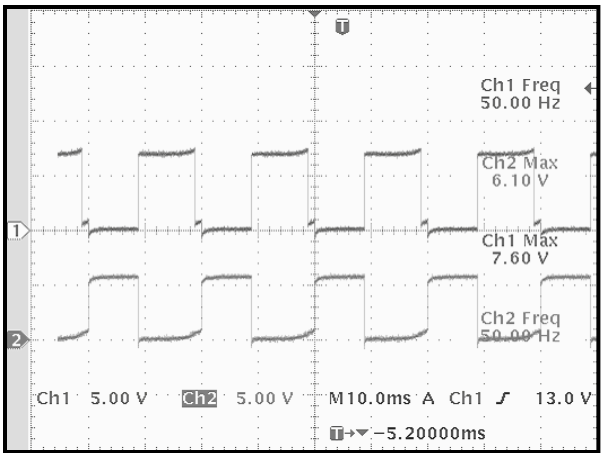


Fig. 8 Comparison between input signal and positive output signal of IC3.

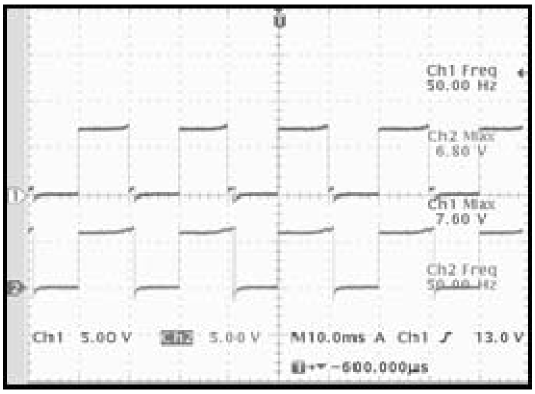


Fig. 9 Comparison between input signal and negative output signal of IC3.

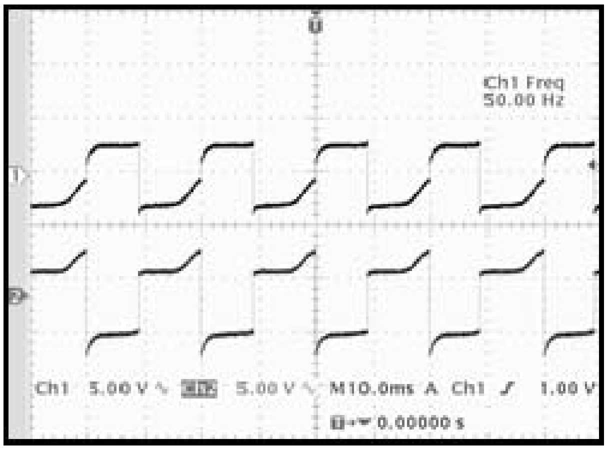


Fig. 10 Positive and negative outputs pulse of IC3.

Fig. 11 shows that input signal for primary side of center tape transformer. Channel 1 reveals that output signal from power transistor Q5. Otherwise the channel 2 shows the output signal from power transistor Q6. Both of signals still maintained the same frequency level which is 50 Hz and input voltage for transformer is around 9 V square wave. The 9 V amplitude will either increase or decrease depending to the input voltage level for this inverter circuit from battery.

Figs.12 and 13 show the waveform of the 9 watt/5 watt with 1 Ampere rating center tap transformer output. This waveform is obtained during the operation where no load is fixed at the output. The output also is influenced by the output from the battery. According to the principles the waveform produced should be the 230 volts square wave alternating current. Notice that the waveform is distorted due to no filter circuit at output of transformer and internal noise of the circuitry. It is determined that the output voltage of the transformer is influenced by the output load watts. The higher watts load will produce a higher transformer output voltage while a lower watt load produces a lower transformer output voltage (refer to Table 1). However the highest watt rating supported by this circuit is only 50 watts.

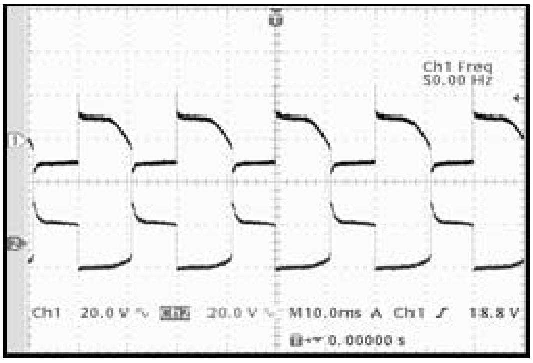


Fig. 11 Input signal for primary side of centre tap transformer.

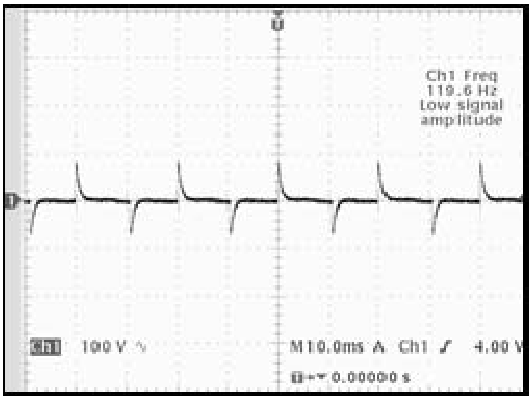


Fig. 12 Waveform of the 9 watt with 1 ampere rating transformer output for no load condition.

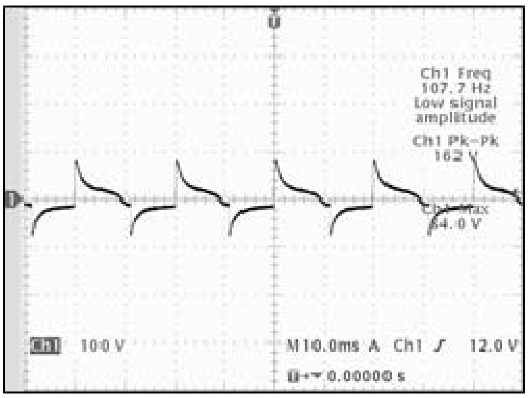


Fig. 13 Output Waveform of Transformer Connected To 5 Watt Bulb.

Table 1 Comparison of output voltage according to transformer rating and size of output load.

Transformer Rating	Maximum Output Amp.	Maximum Output Voltage
- input voltage = 9 V, 50 Hz - output voltage = 230 V - output power = 9 VA	9 watt / 230 V = 0.0391 A	**For 5 watt load** :5 watt / 0.0391 A = **127.88 V**
- input voltage = 9 V, 50 Hz - output voltage = 230 V - output power = 27 VA	27 watt / 230 V = 0.1174 A	**For 5 watt load :** 5 watt / 0.1174 A = **42.59 V** **For 25 watt load :** 25 watt / 0.1174 A = **212.95 V**

4. Conclusion

Efficiency and reliability of this inverter circuit is slightly lower compared to DC part. According to the principles, the inverter should produce 240 volts square wave alternating current. Based on the analysis, the inverter circuit was only capable of producing 162 V AC when connected with 5 watt tungsten bulb (load). It is noticed that the output waveform is distorted due to no filter circuit at the transformer output and internal noise of the circuitry. It is determined that the output voltage of the transformer is influenced by the output load watts. The higher the load watts, a higher transformer output voltage is produced, while a lower watts load produces a lower transformer output voltage. Problem occurred to find out the best transformer rating to this system. Discharging duration of AC load is too short because of lower battery capacity.

5. Recommendation

Efficiency and reliability of this inverter circuit is slightly lower compared to DC part. According to the principles, the inverter should produce 240 volts square wave alternating current. Based on the analysis, the inverter circuit was only capable of producing 162 V AC when connected with 5 watt tungsten bulb (load). It is noticed that the output waveform is distorted due to no filter circuit at the transformer output and internal noise of the circuitry. It is determined that the output voltage of the transformer is influenced by the output load watts. The higher the load watts, a higher transformer output voltage is produced, while a lower watts load produces a lower transformer output voltage. Problem occurred to find out the best transformer rating to this system. Discharging duration of AC load is too short because of lower battery capacity.

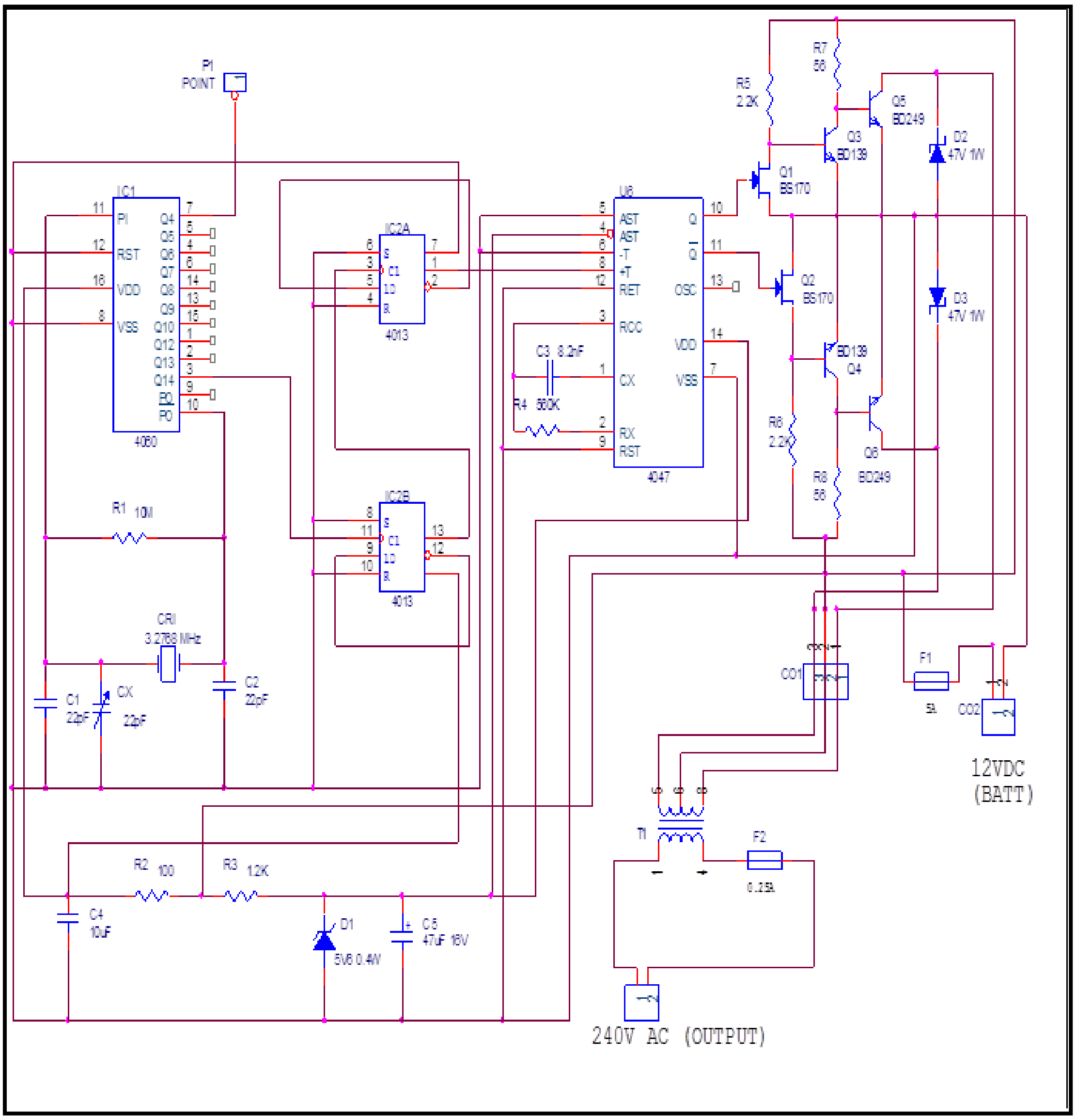
References

[1] I. Tsagas, Laboratory evolution of DC/AC inverters for stand alone & grid-connected photovoltaic system, MSc "Energy Systems & the Environment" Thesis, Energy Systems Research Unit, University of Strathclyde, 2002.

[2] F. G. Akinboro, I. A. Adejumobi and N. E. Erusiafeu, Design model considerations for grid connected Dc-Ac inverters, *Transnational Journal of Science and Technology* 2 (2012) (3) 54-65.

[3] S. Madichetty and A. Dasgupta, Modular multilevel converters part-I: A review on topologies, modulation, modeling and control schemes, *International Journal of Power Electronics and Drive System* 4 (2014) (1) 36-50.

Appendix A



Output 240 v, 50 Hz chop and transform topology type inverter circuit.