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DESIGN, CONSTRUCTION AND TESTING OF A BASE DRIVEN STATIC INVERTER

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ABSTRACT

Based on the active circuit of a 50Hz astable multivibrator, a base driven static inverter has been designed, constructed and tested. Design is able to convert small amounts of dc current to their amplified ac equivalents. A conversion of 12V dc input to the usual domestic range of 220-240V ac is also derivable from the inverter. Therefore this design is recommended for use in mounting of photovoltaic (PV) generators in rural areas.

KEYWORDS: inverter, dc-current, ac-current, photovoltaic generator.

INTRODUCTION

Hydroelectric power (HEP) has been the major source of power for many developing countries. Presently nuclear reactors though most promising are power sources for a few privileged developed countries. The attendant problems of HEP in places like Nigeria include seasonal water fluctuations affecting water levels of dams and consequently power generation. Other technological problems arise due to outdated equipment and lack of expertise in terms of personnel. Furthermore, the impact of the growing population and modernization has imposed demands over and above installed capacity. The result is dwindling, epileptic and insufficient supply of power to the populace.

Attention is therefore being given to other renewable resources both to supplement and complement the national grid.

Solar modules and solar arrays as obtained in a photovoltaic (PV) generator primarily produce dc currents, which cannot be stepped up or down (Oparaku, 2002). This has to M N N be converted into a manageable ac form. Inverter circuits are used to do this.

An inverter is a circuit that converts dc current to its ac version. It carries out the reciprocal function of rectification (Cluley, 1984). In general the term inverter is used for an oscillator whose frequency is less than 100KHz and its primary function is to provide ac power for some other circuits. They are therefore special types of oscillators. According to Gottlies (1980) the emphasis is on efficiency, regulation, load capability with operation targeted at audio or low hypersonic frequency.

THEORETICAL BACKGROUND

The active circuit of the inverter of this work is the astable multivibrator, which is one of the most versatile classes of circuits used for wave generation. A multivibrator circuit produces composite rectangular waveforms by a combination of many harmonics (Plant, 1990). Its period and frequency can be varied with ease.

Fig 1 is a typical multivibrator circuit with two-cascaded RC coupled stage. According to Woollard (1984) when given 100% positive feedback one stage becomes fully conducting while the other is in off state and conduction is transferred from one state to the other by the discharge of a capacitor through a transistor.

In fig 1, the maximum value of R_1 and R_2 is determined from the requirement that transistor Q_1 and Q_2 must saturate when in the "on state". Thus:

$$R_{max} = hfe_{min}, R_L \qquad (1)$$

where the current gain, $hfe = 1_C/1_B$

From the circuit both Q_1 and Q_2 can be saturated simultaneously with the base drive furnished by the resistor R_1 and R_2. When Q_2 is saturated, the charge on C_2 causes Q_1 to be cut-off until V_{EB1} rises to zero, when Q_1 saturates, the drop in potential at the collector of Q_1 then causes Q_2 to be cut-off. The circuit remains in the second questable state until V_{EB2} rises to zero when Q_2 saturates and the cycle is once again repeated.

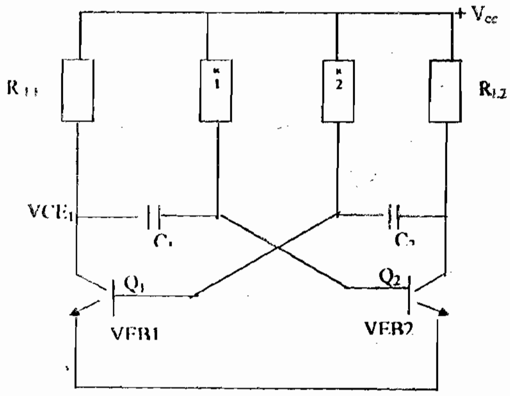

Fig1: Astable multivibrator circuit

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The period of time for which Q_1 is cut-off is given as T_1 and for Q_2, T_2. This time or period can be determined from the time taken for the voltage across the capacitor to charge from $-V_{cc}$ to zero. The voltage across the capacitor can be expressed as:

$V_{c1} = V_{i1} + (V_{t1} - V_{i1})(1\text{-}e\text{-}t/R_1C_1)$ ------------------------(2)

where V_{i1} = the initial voltage of the capacitor at $t = 0$

V_{t1} = the final voltage to which the capacitor charges.

But $V_{il} = -V_{cc}$ and $V_t = +V_{cc}$

Therefore, equation (2) reduces to the following:

$V_{ci} = -V_{cc} + (V_{cc} - (-V_{cc}))(1\text{-}e\text{-}t/R_1C_1)$ ------------------------(3)

$V_{ci} + -V_{ci} + 2V_{cc}(1\text{-}e\text{-}t/R_1C_1)$ ------------------------(4)

If we let $V_{ci} = 0$ and solve for the period t, we have:

$V_{cc} = 2V_{cc}(1\text{-}e\text{-}t/R_1C_1)$

$\mathrm{Ln}(1/2) = -t/R_1C_1$

$-0.693 = -t/R_1C_1$

$t = T_1 = 0.69R_1C_1$ ------------------------(5)

Similarly.

$T_2 = 0.69R_2C_2$ ------------------------(6)

Thus the period of the astable is

$T = T_1 + T_2 = 0.69(R_1C_1 + R_2C_2)$ ------------------------(7)

The ratio T_1/T_2 is called the mark-to-space ratio or the on-to-off ratio. For this work it is made unity to give a uniform output waveform. Therefore, $R_1 = R_2 = R$ and $C_1 = C_2 = C$. Hence $T = 0.69 \times 2RC$ which is 1.38RC.

But frequency = 1/T, therefore the frequency of the astable is given as:

$F = 1/T = 1/1.38RC$ ------------------------(8)

From equation (1) $I_C = hfe\ 1_B$ ------------------------(9)

where $1_B = V_{cc}/R_1$

Equation (9) holds for Q_1 up to saturation of the transistor.

But $R_1 = R_2 = R$ ------------------------(10)

where $1_C = V_{cc}/R_L$

Also $R_{L1} = R_{L2} = R_L$ ------------------------(11)

Using equations (10) and (11) in equation (9) we have:

$V_{cc}/R_L = hfe\ V_{cc}/R$

$R_L = R/hfe$ ------------------------(12)

DESIGN AND CONSTRUCTION

For a frequency of 50Hz, equation (8) becomes:

$50 = 1/1.38RC$

C was chosen to be 3.3μf. Therefore

$R = 1/50 \times 1.38 \times 3.3 \times 10^{-6}$

$= 4.39$ or $4.4\text{k}\Omega$

However the practical value used was 4.5 kΩ. The peak value of the emitter voltage of each transistor should be twice the supply voltage in addition to a minimum of 20% of the supply voltage to account for the spike. Expected collector to emitter voltage is given as:

$V_{CE} = 2V_{cc} + 20\%\ V_{cc}$

$= 2 \times 12 + 2.4$

$= 26.4\text{V}$

Expected maximum power output of the inverter is about 15 Watts. Thus for an 80% efficient transformer, the switch circuit power output will be 15/0.8 = 18.78 Watts. For safety purposes, 10Watts dissipation was allowed. Therefore the maximum collector current will be:

$$1_C = \frac{V_{cc} - V_{CE}}{R_L} = \frac{V_{cc}}{R_L} \qquad \text{------------------------13}$$

From equation (12), we see that

$R_L + R/hfe$

$R_L = \frac{4.5\text{x}103}{64}$

≈ 72 for $hfe = 66$

Also, $R_L = \frac{4.5\text{x}103}{47}$

$= 100$ for $hfe = 47$

Hence the transistor, $Q_1 = Q_2$ with gain $h_{fe} = 47$ to 64.

DC to ac inversion is done by a switching circuit in a push-pull output stage. The one used in this work is the base driven type. This is shown in fig2. Here the output of the multivibrator is fed through the base of Q_3 and Q_4 to the transformer primary. Each transistor drives collector current through one half of the total number of windings of the output transformer primary. As 1_{c1} travels in the opposite direction to 1_{c2} through the output transformer, the two currents cause opposite polarity signals in the secondary of the transformer. When 1_{c1} is flowing, a positive going waveform appears across the secondary winding and when 1_{c2} flows, the alternate negative going waveform appears. Then the current flowing from the switching circuit is the sum of 1_{c1} and 1_{c2}. Consequently, the average dc collector current for each transistor is:

$1_c = 1_m/\Pi$ ------------------------(14)

where 1_m ⇒ peak current for the two transistors, the dc supply current $1_{dc} = 2_{LC}$

$$= 21_m / \Pi \text{ ---------------(15)}$$

Power delivered to the collector is:

$$P_{dc} = V_{cc} \times 1_{dc} = [(21_m/n) V_{cc}] \text{ Watts ---------------(16)}$$

Provided the transformer turns ratio is $(n_1 + n_2)$: n_2 as shown in fig 2, the peak voltage V_m at either collector is same as the load voltage V_m. Similarly the peak load current is 1_m. Therefore

$$\text{Ac load power } P_{LCC} = \frac{V_m}{\sqrt{2}} \times \frac{1_m}{\sqrt{2}} = \frac{V_m 1_m}{2} \text{ ---------------(17)}$$

Hence the total collector dissipation for the two transistors is given as:

$$2P_c = P_{dc} - P_{lcc} = \frac{2I_m V_{cc}}{\Pi} - \frac{V_m I_m}{2}$$

$$\text{Thus} \quad 2P_c = 2I_m \left[\frac{V_{cc}}{\Pi} - \frac{V_m}{4}\right] \text{ ---------------(18)}$$

where P_c – dissipation of one transistor.

Since the supply voltage for the inverter is chosen as $12V_{dc}$ and the power output of the inverter is expected to be 15Walts, power delivered to the primary side of the inverter will be P = 15/0.8 = 18.75Watts, where the transformer efficiency is assumed to be 80%. Therefore the estimated collector current will be.

$$I_c = P/V_{cc} = P/V_s = 18.75 = \frac{1.56A}{12}$$

$$V_{CE} = 2V_{cc} + 20\%\, V_{cc} = 26.4 \text{ V}$$

For the power transistor used, $V_{CEO} = 60V$,

V_{CE} (sat) = 1.1V at I_c = 4A and maximum power dissipation is 115Watts.

$$I_{c\,(max)} = \frac{\text{Power}}{V_{CC} - V_{CC}(\text{sat})} = \frac{18.75}{12-1.1} = \frac{18.75}{10.9}$$

$$\therefore I_{c\,(Max)} = 1.72A \approx 1.7A$$

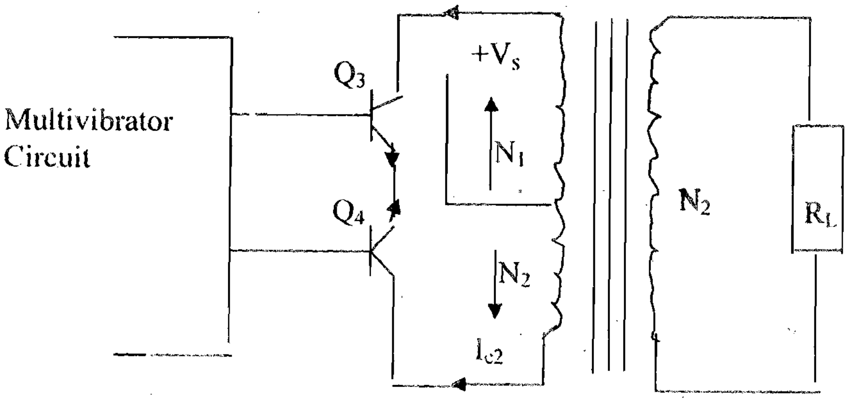

Fig 2: Switching circuit of the inverter

So far, for the design of the multivibrator, the following component values were used.

Resistors
3 x 10000, 2 x 2.5kΩ
Transistors
2 ordinary NPN transistors
2 power NPN transistors

Capacitors
2x3.3 µf, 0.1 µf
Others

1diode, 1 switch, 3A fuse, $12V_{CC}$ supply, 12V primary step up transformer with output range of 220 to 240V and connecting wires. The entire circuit was connected up as shown in fig 3.

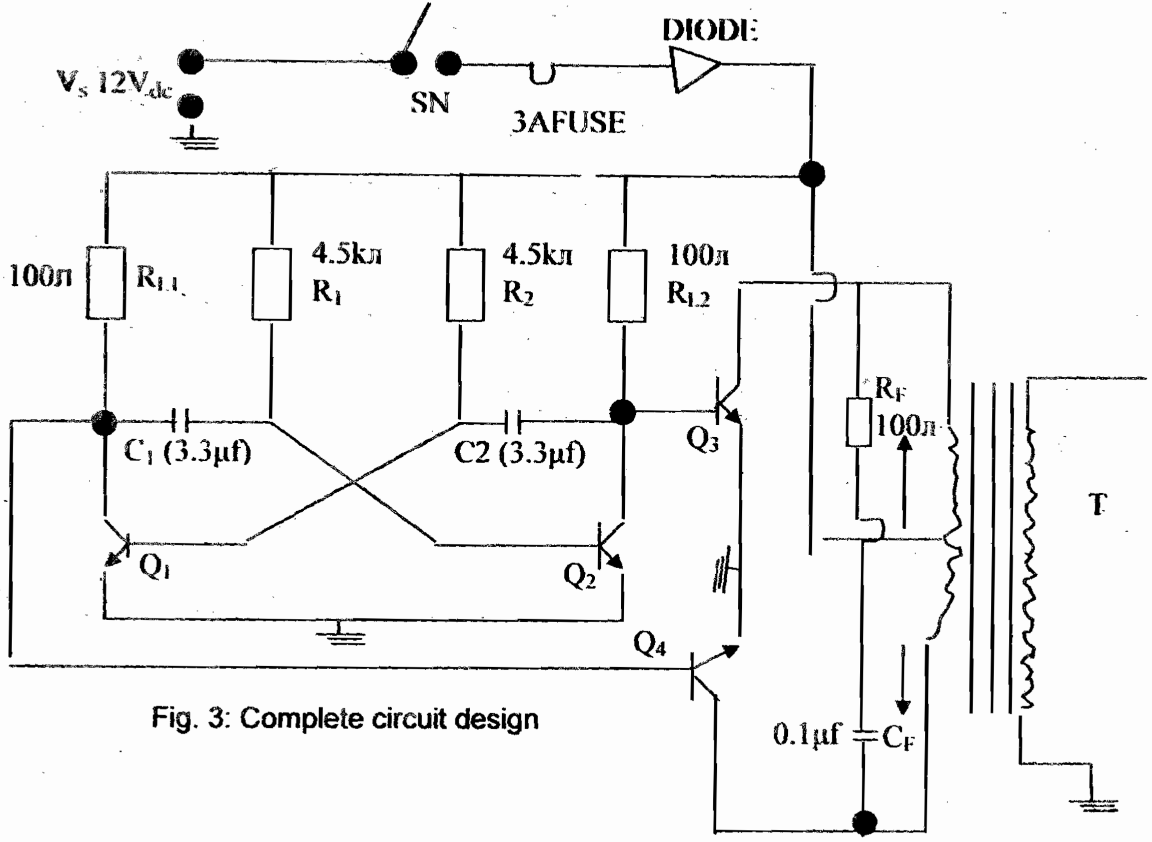

Fig. 3: Complete circuit design

TESTING OF THE INVERTER PERFORMANCE

Pure resistance variable loads were connected across the inverter circuit to test its performance. An ammeter was used to monitor the input dc current to the inverter and the corresponding output ac current from it. As the resistance load to the inverter was varied the voltage developed across the load for each case was measured. The data is shown in Table 1. From the table an output ac current of 20.2V produced a voltage of 104.2V across a 6kΩ load with an input dc current of 3.6A. Also with a small dc current input of 3.4A to the inverter, 14.2V ac output was obtained which developed a voltage of 137.8V across a load of 10kΩ.The input dc current column shows that the dc input battery fluctuated as it stayed in circuit over time. However the inverter was able to convert a small dc current into ac current of higher amplitude.

Table 1: Data obtained from experiment

Input Current Dc (Amp)	Output Current Ac (Amp)	Load (kΩ)	Voltage across Load (V)
3.92	28.4	1.0	21.5
3.82	27.1	2.0	40.2
3.72	26.3	3.0	70.2
3.69	24.6	4.0	84.3
3.65	22.1	5.0	90.6
3.60	20.2	6.0	104.2
3.56	18.1	7.0	115.2
3.51	17.2	8.0	126.1
3.48	15.9	9.0	133.2
3.43	14.2	10.0	137.8

CONCLUSION

A base driven static inverter has been designed constructed and tested. The term static implies that the design has no moving parts, as is the case with mechanical inverters. The frequency network of the inverter as well as the active current is an astable multivibrator of 50Hz frequency.

On testing it was found that the circuit was able to convert small amount of dc current to their amplified ac equivalents.

A conversion of 12V dc input to the usual domestic range of 220-240V ac is also possible with the circuit. Therefore the design is recommended for use in mounting of photovoltaic (PV) generators in rural areas.

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