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Design, Fabrication and Implementation of A Modified 1kVA Sine Wave Solar Power Inverter

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ABSTRACT

The aim of this paper is to fill a niche which seems to be lacking in the power inverters market, one for a fairly efficient, inexpensive inverter with a pure sine wave output. Utilizing PWM and analog components, the output will be a clean sinusoid, with very little switching noise, combined with the inexpensive manufacturing that comes with an analog approach.

1.0 Introduction

Power electronic systems are used widely to convert electric energy from one form to the other using electronic devices. Four basic power electronics functions are AC to DC conversion, DC to AC conversion, DC to DC conversion and AC to AC conversion. These basic functions are used to build power supplies, DC transmission systems, electric drives and others. In today's scenario the demand of electricity has increased tremendously. The cause of it is increase in population day by day, economic development of a country and diminution of fossil based fuels. So alternative energy sources i.e. renewable energy sources are the best option without any harm to the nature.

With the advancement in technology in the field of power electronics more than past few years and rising crises for energy have led to increase progress in generating power using renewable energy sources like Photovoltaic (PV), Wind, Fuel cell (FC) based renewable energy technologies.

Among all renewable energy sources, solar photovoltaic (PV) electricity generation is the fastest growing source now are days throughout the world. In a PV system, a PV array converts solar power to electrical power and a grid connected inverter is required for inverting the electrical power to ac power then it is fed back to the grid. The power electronics device which converts DC power to AC power at required output voltage and frequency level is known as inverter [1]

According to the Authoritative Dictionary of IEEE Standards Terms (2000), inverter is an electrical power converter that changes direct current (DC) to alternating current (AC). The converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits[2,3].

Power inverter is an electronic device that has the ability to convert the direct current (DC) from the battery into an alternating current (AC) which is the conventional form that powers many electrical appliances.

It maintains a continuous supply of electric power to the connected loads or equipment's when the utility power is not available. Inverters are generally used in a host of applications that include variable speed drive, uninterruptible power supplies, flexible AC transmission systems, (FACTA), high voltage DC transmission systems (HVDC), active filters among the others. It is inserted between the source of power (typically commercially utility power) and the load is protecting. The inverter performs the opposite function of a rectifier[2].

For alternative energy systems, inverters are the essential step between a battery's DC power and the AC power needed by standard household electrical systems. In a grid connected home, an inverter/charger connected to a battery bank can

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provide an uninterruptible source of backup power in the event of power failures, or can be used to sell extra alternative energy power back to the utility company. Batteries produce power in direct current (DC) form, which can run at very low voltages but cannot be used to run most modern household appliances. Utility companies and generators produce sine wave alternating current (AC) power, which is used by most commonly available appliances today. Inverters take the DC power supplied by a storage battery bank and electronically convert it to AC power.

An inverter is a device that takes a direct current input and produces a sinusoidal alternating current output. An inverter needs to be designed to handle the requirements of an energy hungry household yet remain efficient during periods of low demand. The efficiency of inverter is highly dependent on the switching device, topology and switching frequency of the inverter[4]. Alternating current (AC) power is used as a power source as well for transmission purpose because it can be generated and also converted from one voltage to another. Transmission of AC power over long distance is still in use, however it results in relatively high transmission loses. The types of loses are transient stability problem and operational requirements such as dynamic damping of electrical system may also arise along the transmission line [5].

1.2 Statement of the problem

Power failure is the total loss of utility power. It may be caused by the tripping of a circuit breaker, power distribution failure, excessive demand on the power grid, effect of object on the power transmission line can cause the circuit breaker in charge to trip. In order to avoid this inconsistence, supply of electric power another means of generating electric power from other sources of energy such as solar energy can be employed and this why a Modified sine wave inverter is needed for the conversion of chemical energy into electrical energy and solar panel is needed for the conversion of solar energy into electrical energy.

2.0 Literature Review

Power electronic circuits are used to control the power conversion from one or more AC or DC sources to one or more AC or DC loads, and sometimes with bidirectional capabilities. In most power electronics systems, this conversion is accomplished with two functional modules called the control stage and the power stage [6]. Figure 1 shows the topology for a single source and single load converter application that includes a power processor (the power stage) and a controller (the control stage). The converter, handles the power transfer from the input to output, or vice versa, and is constituted of power semiconductor devices acting as switches, plus passive devices (inductor and capacitor). The controller is responsible for operating the switches according to specific algorithms monitoring physical quantities (usually voltages and currents) measured at the system input or output [6,7].

The modern PE era began in 1957. It was during that year the first commercial thyristor, or Silicon Controlled Rectifier (SCR), was introduced by General Electric Company. The SCR, started replacing the mercury arc rectifiers, invented in 1902, and later developed thyratron (invented in 1923) and ignitron (invented in 1931), allowed the commercialization of several industrial circuits conceived during the 1920s and 1940s (like the cycloconverter, the chopper, and the parallel inverter) as well as the Graetz bridge conceived in 1897 [8].

The SCR was the only available power device for more than 25 years after its invention (and still is very useful for extremely high power applications). Since it is very difficult to impose turn-off conditions for SCR's, faster devices, with higher voltage and current capabilities, with better controllability were developed, including the bipolar junction transistor (BJT) invented in 1970. [9]

Fig 1: A General Power Electronic System (Source: Lorenz 2009)
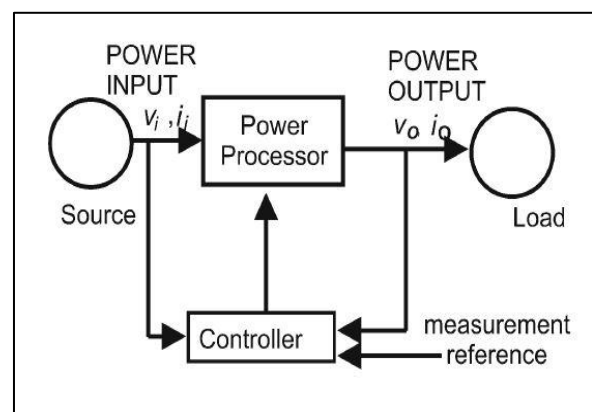
3.0 Design Methodology

This section is going to dwell on construction details, putting us through how to go about putting the circuit and every other accessory to get a 1KVA solar powered inverter together.

3.1 MOSFET driver Stage

The third generation power MOSFET from Vishay which provide the designer with the best combination of fast switching, ruggedize design, low on resistance and cost effectiveness is IRFP150.

This power MOSFET can be used in a modified sine wave power inverter to oscillate(switch) with 50Hz frequency, the 50Hz alternating signal from pin 11 and 14 of the IC operate each MOSFET channel separately.

This results in the MOSFET channel being alternatively on and off, switching process is repeated 50 times per second (according to the definition of frequency) the drain (middle pin) of all the MOSFET of one channel are connected together but insulated from the heat sink which absorbs the heat dissipates in the circuit.

The gate of each MOSFET are connected via resistor (1KΩ) to the oscillator output signal, the resistors limit the pulses going into the gates, another resistor of 10KΩ is connected between the gates and the source in order to prevent the MOSFET from false triggering.

The source terminal of the MOSFET of both channels connected together to the ground. Because the polarity of the 50Hz MOSFET drives signals are different, only one channel from the output remain on at a time, the other channel stays off.

MOSFET used for the stage is IRFP150 whose specification is in the table 1.

Table 1: IRFP150 Specification

Parameter	Symbol	Limit
Maximum voltage	V_{max}	100V
Current	$T_C = 25°C$	$I = 40A$
	$T_C = 100°C$	$I_D = 29A$
Maximum power	$T_C = 25°C$	$P_{max} = 230W$

Total power of each channel

$$P_T = P_1 + P_2 + P_3 = 230 + 230 + 230 = 690W$$

MOSFET are connected in parallel to increase the power within the circuit, 690W is an advantage to an inverter which ought to produce 500W because the remaining 190W serves as tolerance and when current is divided equally on the MOSFET of each channel, the temperature of the continuous drain current (at which the inverter will be operating both at minimum and maximum continuous drain current) reduces.

3.2 MOSFET current design calculation

$$Current\ rating = \frac{1000}{12} = 83.33A$$

Therefore, the current rating per channel calculated as

$$current\ per\ side = \frac{83.33}{2} = 41.67A$$

Having three identical MOSFET, the required current rating for each of the MOSFET will be

$$\frac{41.67}{3} = 13.89A$$

To prevent the MOSFET from burning out due to excessive current it is advisable to use a MOSFET of at least two times the required MOSFET current rating at the minimum temperature $T_c = 25°C$ therefore:

$$13.89 \times 2 = 27.78A$$

Hence 6 MOSFET of 41A was used with 3 on each side of the channel
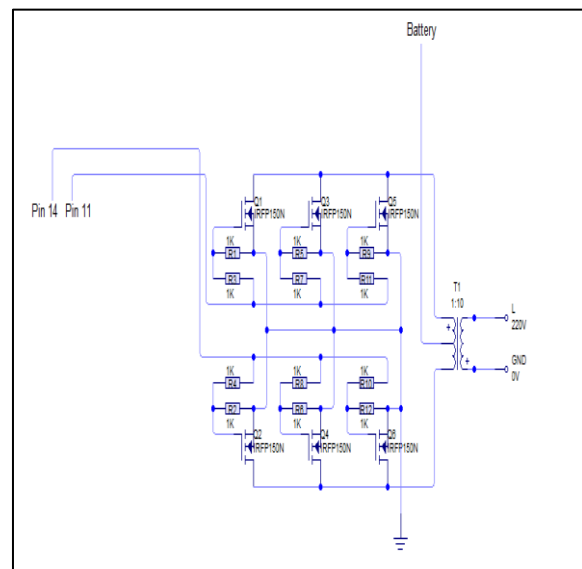
Fig 2: Showing Circuit Diagram of the Driver Stage

Table 2: Showing Component Values in Driver Stage

Component	Value
R16, R17, R18, R19, R20, R21	1KΩ
R22, R23, R24, R25, R26, R27	10KΩ
Q1, Q2, Q3, Q4, Q5, Q6	IRFP150

3.3 Oscillator stage

Sg3524 is a monolithic Integrated Circuit containing all control circuitry for a regulating power supply, inverter or switching regulator. It includes voltage reference, error amplifier oscillator pulse steering flip flop, two transistors, high gain comparator, current limiting and short down circuitry. Its features are: complete pulse width modulation, power control circuitry, single ended or push pull outputs and can operate even beyond 100KHz, other features about this IC are found in the table 3.

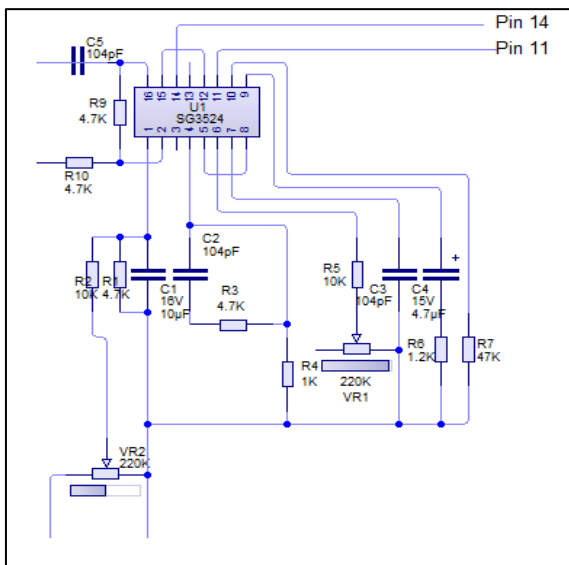**Fig 3: Showing the Circuit Diagram of an Oscillator**

Table 3: Showing Component Values of an Oscillator

Component	Value
R3, R4,R9, R4.R11	4.7KΩ - from datasheet
R5	47KΩ – from datasheet
R6	1.2KΩ - from datasheet
R7,R12	10KΩ – from datasheet
R10	1KΩ - from datasheet

R8 ($\mathbf{R_T}$)	220KΩ (VARIABLE RESISTOR) – calculated value
C3, C5($\mathbf{C_T}$), C6	104J(0.1uf) – calculated value
C4	4.7$\mathbf{\mu F}$ – from datasheet
C7	10$\mathbf{\mu F}$

3.4 Calculation of frequency

$$F = \frac{1.3}{R_T \times C_T} \quad \text{Where: } C_T = 0.1uf, \quad F = 50Hz,$$
$$R_T = ?, \quad 50 = \frac{1.3}{0.1 \times 10^{-6} \times R_T}$$
$$1.3 = 50 \times 0.1 \times 10^{-6} \times R_T, \quad 1.3$$
$$= 5 \times 10^{-6} \times R_T$$
$$R_T = \frac{1.3}{5 \times 10^{-6}} = 260000, R_T = 260K\Omega, C_T$$
Has a tolerance of 5%
$$\frac{5}{100} \times 0.1 \times 10^{-6} = 5 \times 10^{-9}$$
To obtain the tolerance
$$C_{TMAX} = 0.1 \times 10^{-6} + 5 \times 10^{-9}$$
$$C_{TMAX} = 1.05 \times 10^{-7}$$
$$C_{TMIN} = 0.1 \times 10^{-6} - 5 \times 10^{-9}$$
$$C_{TMIN} = 9.5 \times 10^{-8}$$
$$R_T = \frac{1.3}{1.05 \times 10^{-7} \times 50} = 247619.04 = 250K\Omega$$
$$R_T = \frac{1.3}{9.5 \times 10^{-8} \times 50} = 273684.212 = 300K\Omega$$

Therefore for selecting R_T, variable resistor between the ranges of 250k to 300k can be selected and varied during operation to obtain 50Hz or 60Hz. But it is important to understand the fact that all 1watt variable resistor has plus or minus 30% tolerance as their specification and by selecting 220k variable resistor the oscillator will work within the range.

To calculate R$_T$ range for 220k
$$\frac{30}{100} \times \frac{220000}{1} = 66000$$
$$R_{TMAX} = 220000 + 66000 = 286000$$
$$R_{TMIN} = 220000 - 66000 = 154000$$

Therefore, it is best to use 230k (since it covers capacitor tolerance range of 247619.04 and 273684.21) and adjusted to obtain 50-60Hz frequency.

3.5 Circuit construction

In constructing the circuit, the following components were made available as shown above – resistors, capacitors, MOSFET, wires, transformer, variable resistor, IC regulator (LM7809), IC SG3524

all according to the design specification. A vero board is needed as this is what will hold the circuit in which I refer to as the "motherboard" as in this case it holds the IC SG3524 which every other component is built around.

Fig 4: Showing Oscillator Component Mounted on Vero Board
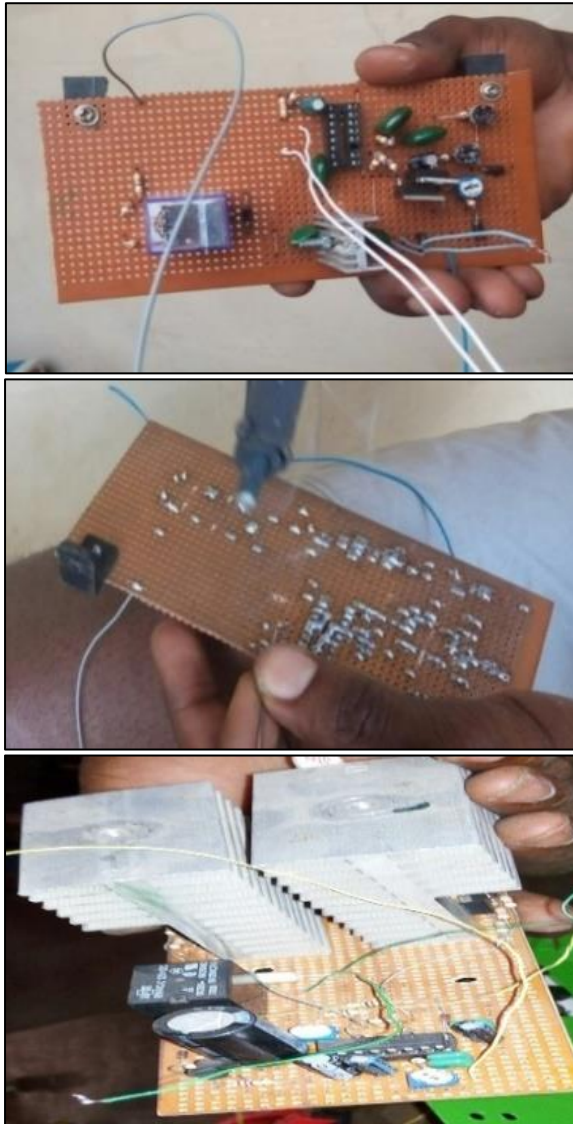
To begin with, the vero board is cleaned, the metallic part is cleaned to remove dirt to allow for the solder to hold when soldering. The next thing was to start placing each component on the vero board beginning with the IC socket for the IC SG3524, following the circuit configuration in figure (4) and solder accordingly. In soldering one should be careful to avoid short circuiting due to spikes from the solder.

After soldering we traced all the lines to ensure that there was no bridge at any point and where there was, we made sure to correct the abnormality. The completed circuit on the vero board is shown in the figure 4.

3.6 Transformer Design
Transformer specification

Table 4: Showing Transformer Specification

output voltage	220V
input voltage	12V
Power rating	1KVA
Frequency	50Hz
Phase	Single

3.6.1 Core size

In determining the size, the dimensions of the laminated core were measured and from the measurement taken, the core size was calculated as shown below

Core cross-sectional area (cm^2)

$$A = L \times B = 5.1 \times 6.2 = 31.62 cm^2$$

Let B (flux density) = 0.72T

$\phi_m = BA$ Where A is the cross-sectional area of the core

$$\phi_m = 0.72 \times 31.62 \times 10^{-4} = 22.7 mWb$$

Volt per turn

$$E = 4.44 f \phi_m N \ (N = 1)$$

$$E = 4.44 \times 50 \times 22.7 \times 10^{-3} \times 1 = 0.505 \ V/Turn$$

$$N_1 = \frac{V_1}{E} = \frac{12}{0.505} = 24 \ turns$$

$$\frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{230}{12} = \frac{N_2}{24}$$

$$N_2 = \frac{230 \times 24}{12} = \frac{5520}{12} = 460 \ turns$$

3.6.2 Wire size selection for transformer construction

$$P = IV \qquad I_1 = \frac{P}{V_1} = \frac{1000}{230} = 4.35A \qquad I_2 = \frac{P}{V_2}$$

$$= \frac{1000}{12} = 83.33 = 83A$$

Assume 75% of I_2 will be used (for modified sine wave system)

$$0.75 \times 83 = 62.25 = 62A$$

Current density J will be in ampere per circular mils

Take J = $200A/cmils$

$A_1 = I_1J = 4.35 \times 200 = 870cmils$

$A_2 = I_2J = 62 \times 200 = 12400cmils$

Circular mil next to 870cmils = 1024.9cmils, this corresponds to 21AWG. Circular mil next to 12400cmils = 13086cmils, this corresponds to 14AWG.

3.7 Efficiency of the transformer

In determining the efficiency of the transformer an open circuit test was done to know the losses of the transformer, the result of the test is shown below:

V_p	V_s	W	I_o	R_p
200	10V	20W	0.5A	1.8Ω

$$os\phi = \frac{W}{V_P I_O} = \frac{20}{200 \times 0.5} = \frac{20}{100} = 0.2 \qquad \phi$$
$$= COS^{-1}0.2 = 78.46$$
$$sin\phi = 0.98 \qquad I_u = I_O sin\phi = 0.5 \times 0.98 = 0.49A$$
$$I_w = I_O cos\phi = 0.5 \times 0.2 = 0.10A$$

$$primary \; C_u \; loss = I_O^2 R_P = 0.5^2 \times 1.8 = 0.25 \times 1.8$$
$$= 0.45W$$
$$iron \; loss = 20 - 0.45 = 19.55W$$
$$\therefore Efficiency = \left(1 - \frac{losses}{input}\right) \times 100$$
$$= \left(1 - \frac{20}{1000}\right) \times 100$$
$$Efficiency = (1 - 0.02) \times 100 = 0.98 \times 100$$
$$= 98\%$$

It is proven theoretically that 1KVA is equivalent to 800watt for a pure sine wave system, and all modified sine wave is expected to have 25 percent distortion, which leads to humming as a result of the distortion on the waveform, therefore an ideal modified sine is expected to be 75 percent efficiency.

Therefore, the efficiency of an ideal pure sine wave 1KVA (800watt) and modified sine wave inverter is 750KVA (600 watt)

The Maximum Start up power of any load must not exceed 750KVA (600watt)

The Maximum Operating wattage of the inverter must not exceed 640KVA (500 watt)

The Normal Operating wattage of the inverter must not be up to the maximum operating wattage (640KVA)

Putting all this into consideration, this 1KVA modified sine wave inverter has an efficiency of 70 percent.

3.8 Solar panel

A typical 12v panel of about 25inch by 54 inch = 36 cells

$$one \; cell = 0.5V \; and \; 0.5 \times 36 = 18V$$

3.8.1 Ampere rating of battery charge controller

$$P = IV, \quad I = \frac{P}{V}$$

Where: P = the power rating of the solar panel

I = charging current of the charge controller

V = the voltage of the battery

Parameters: P = 150W, V = 12Vdc, $I = \frac{150}{12} = 12.5A$

Therefore, the ampere rating of the charge controller is 12.5A. 100AH is the total capacity of the battery, if 60A is drawn from it

Therefore: $\frac{100AH}{60A} = 1.6Hr$

Note: the battery will only last 1.6Hr if 60A is drawn

3.8.2 Charging time of the battery

$$Hours \; taken \; to \; fully \; charge = \frac{energy}{solar \; panel \; power}$$

Where: $P = IV$

$$P = 100 \times 12 = 1200WH$$

Rated solar panel=150W

$$hours \; to \; be \; fully \; charged = \frac{1200WH}{150W} = 8.0Hr$$

Therefore, for a rated solar panel of 150W charging a battery of 100AH needs 8.0Hrs to be fully charged

3.8.3 Charge controller sizing

Efficiency of the charge regulator = 100%

The tolerance = 25%

Therefore, total efficiency of the charge regulator = 125

Electrical data specification of the solar panel is shown in the table 5.

Table 5: Solar Module Specification

Peak power (P_{MAX})	150W
Maximum power voltage (V_{MAX})	18V
Maximum power current	7.22A
Open circuit voltage (V_{OC})	22V
Short circuit current (I_{SC})	7.80

The regulated sunlight and specific temperature condition can increase the output current of a solar panel by 25% above its rated output current. The solar regulator must be sized to handle the increased current.

The 150W panel has a rated output current of 7.22A and a rated short circuit current of 7.80A from the solar specification

I_{SC} = 7.80A, efficiency = 100%, tolerance =25%

$$\text{total efficiency} = 125\% = \frac{125}{100}$$
$$= 1.25, \ 7.80 \times 1.25 = 9.75A$$

Therefore, if the 36 cells are connected in series, it produces 18v as its output

From the above calculation it is recommended that the regulator selected must be larger than the value 7.80A to ensure that it is not constantly operated at 100% of its rating, particularly in region with higher temperature

3.9 Solar power generated energy over a period of time

For the solar 150W panel in 5Hr of sunshine

Energy produced $= 150 \times 5 \times 0.85 = 637.5WH$

Where 0.85 is the factor which allows for natural system losses therefore 637.5WH is the amount of energy the solar panel can supply in 5Hr

3.10 Enclosure of construction

This part of the job was contracted out as it involves metal, but the design dimensions are shown by figure 5.

The vent holes and screw holes were bored by us using a hand drill. The case dimension picked considered the fact that we wanted enough space that is adequate for the components it is going to house and also we wanted enough room for air flow. We are using a suction method of cooling in that the fan sucks the air, so cool air flows in through the vents on both sides which in turn regulates the temperature within the case.

Fig 5: Inverter Casing
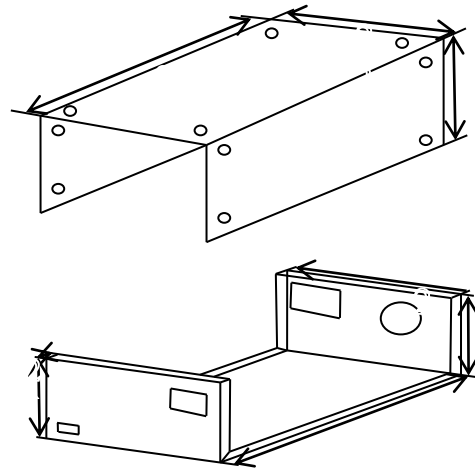

3.11 Assembling

The circuit board being ready and the casing available, this stage involves fixing in the components into the casing. First in was the transformer, holes were drilled in which it was screwed to the bottom to hold the transformer firm, then the circuit board and every other thing followed – indicators, fan, fuse, LEDs, of which after everything as in place with proper connections made and soldered, it was covered and screwed together. The finished work is shown by figure 6.

Fig 6: Showing Inverter Construction.

Other component parts of the whole system were bought i.e. the solar module (panel), deep cycle battery and the charge controller.

Fig 7: Circuit Diagram of the Inverter
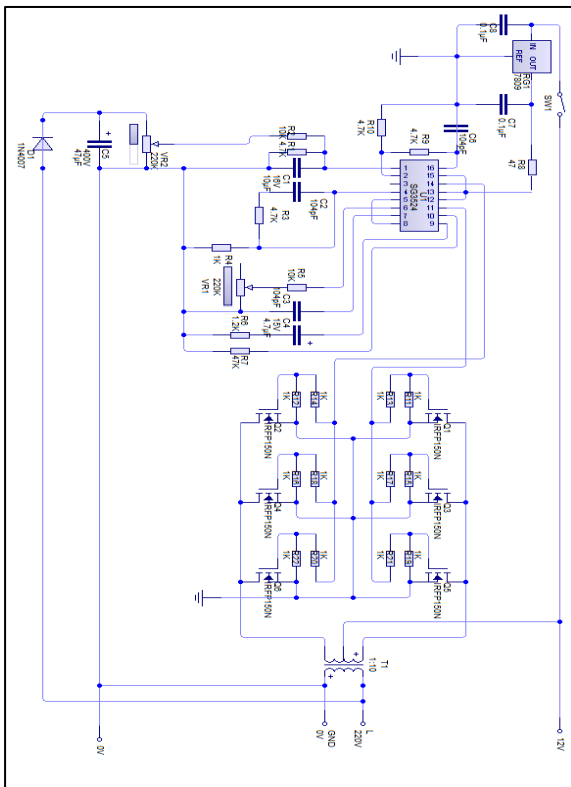
4.0 Theory of Operation

Sg3524 consist of error amplifier which share the same terminal with current limiting circuitry and short down circuitry at the comparator input, this common terminal is called the compensation pin, and this pin can be used to either control the gain of the error amplifier or to compensate the error amplifier. It can also be used to provide additional control to the regulator. The frequency of the Sg3524 is determined by the timing resistor (Rt) and the timing capacitor (Ct) and this establish a constant charging current for the timing capacitor (Ct) leading to a linear voltage ramp at (Ct) which is fed to the comparator input and a linear control of the output pulse width produced by the error amplifier. External ladder network divides the internal reference voltage to provide a reference within the common mode range of the error amp and the output error signals is amplified; this amplified error signal voltage is compared to the linear voltage ramp at the timing capacitor (Ct) by the comparator. Oscillator output pulse (also known as blank pulse) ensure that both output are never ON simultaneously during the transition time, the duration of the pulse (blank pulse) is controlled by the value of the timing

capacitor (Ct). The resulting modulated pulse from the output of the high gain comparator is steered to appropriate output pass transistor by a pulse steering flip flop which is synchronously toggled by the oscillator output. The image of the internal circuit configuration of Sg3524 is shown below.

Fig 8: Showing Internal Circuit Configuration of SG3524 Datasheet (2015)
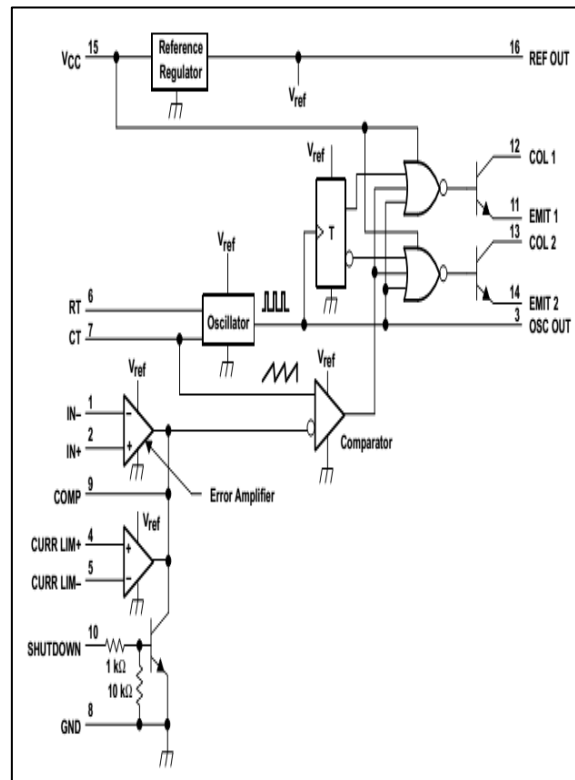
The push-pull transformer coupled circuit configuration is used in the circuit diagram given above with little modification with respect to the datasheet. Modification in pin 6 and pin 7 is done to calculate the frequency. Modification in pin 11, 12, 13 and 14 is done in order to reduce cost. Modification in pin 10 is done to compensate the push pull transformer coupled circuit diagram. Modification in pin 1 is done in order to vary the error amplifier inverting input voltage

5.0 Conclusions

The various tests carried out and the results obtained demonstrate that the inverter system achieved its design and construction aims. The system worked according to specification and quite

satisfactory. The inverter system is relatively affordable and reliable. It is easy to operate, and provides a high level of power supply when there is power outage. Finally, it reduces the danger and noise associated with a generator when using it as an alternative source of power supply.

This design of solar powered inverter can still be improved upon to get a more efficient renewable source of energy. To achieve that next level of study carry out for further workby incorporating a means where by utility supply can be combine with the system. Also using incasedcent bulb with the inverter will cause the battery to drain faster Thus, for energy saving bulb should be used so as to keep the battery for a long period of time of synchronizing alike inverter thereby generating higher capacity generating unit.

References

[1] TT Oladimeji, CO Okereke. Performance Analysis of a Branded and Locally Constructed Modified 1 KVA Sine Wave Solar Power Inverter for Domestic Electric Power Supply, Journal of Electrical & Electronic Systems (JEE), 2018, DOI: 10.4172/2332-0796.1000254

[2] OE Fashina, SO Olayiwola, MO Sadiq, AA Busari. Electrical Power Generation from Inverter for Domestic Usage in Nigeria: A Means of Youth Empowerment, Journal of Scientific and Engineering Research, 4(5), 2017, 16-24,

[3] The Authoritative Dictionary of IEEE Standards Terms. Seventh Edition, IEEE Press, ISBN 0- 7381-2601-2, 2000, 588.

[4] JO Ajala. Design and construction of 1000 Watts Inverter. Unpublished B.Tech Thesis, Department of Electronic and Electrical Engineering LadokeAkintola University of Technology Ogbomoso, 2004, 4.

[5] AK Theraja, BL Theraja. A Textbook of Electrical Technology, 22nd Edition, S Chand and Company Ltd, India, 2004.

[6] VK Mehta. Principles of Electronics, 8th Edition, S. Chand and Company Ltd, India. Mild steel laminated iron sheet, microchip technology, 2009.

[7] R Erickson, D Maksimovic. Fundamentals of power electronics. Springer, New York, 2001, 267

[8] N Mohan, TM Undeland, WP Robbins. Power electronics: Converters, applications and design. John Wiley and Sons Inc., New York, NY, USA, 1989.

[9] L Lorenz. Power semiconductor devices and smart power IC's: the enabling technology for future high efficient power conversion systems. In: Proceedings of the IPEMC, 2009, 193–201.