Characterizations and Performance of a Solid-State Inverter and its Applications in Photovoltaics

B.A. Ezekoye, Ph.D.* and V.N. Ugha, M.Sc.

*Department of Physics and Astronomy, University of Nigeria, Nsukka.
E-mail: bezekoye@yahoo.com

ABSTRACT

We designed, constructed, and characterized a solid-state inverter, one of the most expensive devices in a standard PV system, using locally made materials in Nigeria. The device is used to convert the DC generated by solar cells to AC for optimum utilization, and was designed with following specifications: waveform- square wave: rated output power- 50W, maximum power intake- 55W, frequency- 50Hz, input voltage- 18 – 22V, output voltage- 220 – 240V, maximum current intake- 4A. The characterization of the locally made inverter was carried out and the results show that the efficiency of this inverter varied with the solar intensity, which is in agreement with theory. The output square wave of the inverter has low power consumption, maximum utilization of available power, is economical, and is free from high frequency oscillations that may come from a nearby wave-generating- source.

(Keywords: photovoltaic, solar, direct current, alternating current, electronics)

INTRODUCTION

A photovoltaic (PV) array, regardless of its size and sophistication, can generate only direct current (DC) electricity. Fortunately, there are many applications for which DC is perfectly suitable. More fortunately, DC electricity can be converted to alternating current (AC) with relative ease and efficiency through the use of a device called an inverter. It is the inverter that makes the PV technology compatible with the type of equipment and appliances encountered in the average homes.

There are two possible input sources of PV electricity in a house: the array itself and in a stand-alone system (the battery bank). If the load demand is for AC, an inverter must occupy a position in the system between the batteries and the load.

Inverters are nothing new; they have been around as long as there has been need for converting DC electricity to AC. The early rotary type of inverter had internal moving parts. The DC electrical source powered a DC motor connected to an AC alternator, which produced AC electricity for the load. Rotary inverters are still manufactured, largely for use in marine aircraft electrical systems, where a clean AC signal is desired and efficiency is not critical.

Virtually all the inverters used with alternative power systems are transistorized, solid state devices. Solid-state inverters are preferred for their higher efficiency, ease of maintenance, and infrequency of repair. Important output specifications to consider when searching for DC to AC inverters include maximum voltage, maximum steady state current, maximum power, and frequency range. Output waveform choices include pure sine wave, square wave, stepped wave, and triangular wave. Pure sine wave is the best waveform, as it is the shape of an ideal AC electrical signal from a wall outlet. The highest quality inverters produce a true sine wave output, which requires fairly expensive components in the inverter. True sine wave outputs are normally found only in higher-end models.

A square wave is a ‘flattened-out’ version of a sine wave. Instead of the voltage smoothly increasing from the negative maximum to the positive maximum and back again, it shifts suddenly from negative to positive, stays there for a half cycle, and then jumps to full negative and stays there for half a cycle, then repeats.

A stepped wave is a quasi-square wave or sine wave. They are typically inexpensive power inverters that mimic a sine wave using a stepped waveform. The output waveform signal changes abruptly from zero volts to a maximum value, then abruptly again to a zero value. After a short off time, the signal then switches abruptly back to zero. A triangular waveform is sometimes referred to as a saw-tooth waveform for its' approximation to a saw blade.

The overall efficiency of the inverter depends on the efficiency of the sunlight into DC and the DC into AC conversion efficiencies. The efficiency of an inverter varies with load level. Although this relation is different for each inverter, a conventional model has a load/efficiency curve similar to the figures below. Therefore, a key consideration in the design and operation of inverters is how to achieve high efficiency with varying power output.

It is necessary to maintain the inverter at or near full load in order to operate in the high efficiency region. However, this is not possible. Some installations would never reach their rated power due to deficient tilt, orientation or irradiation in the region.

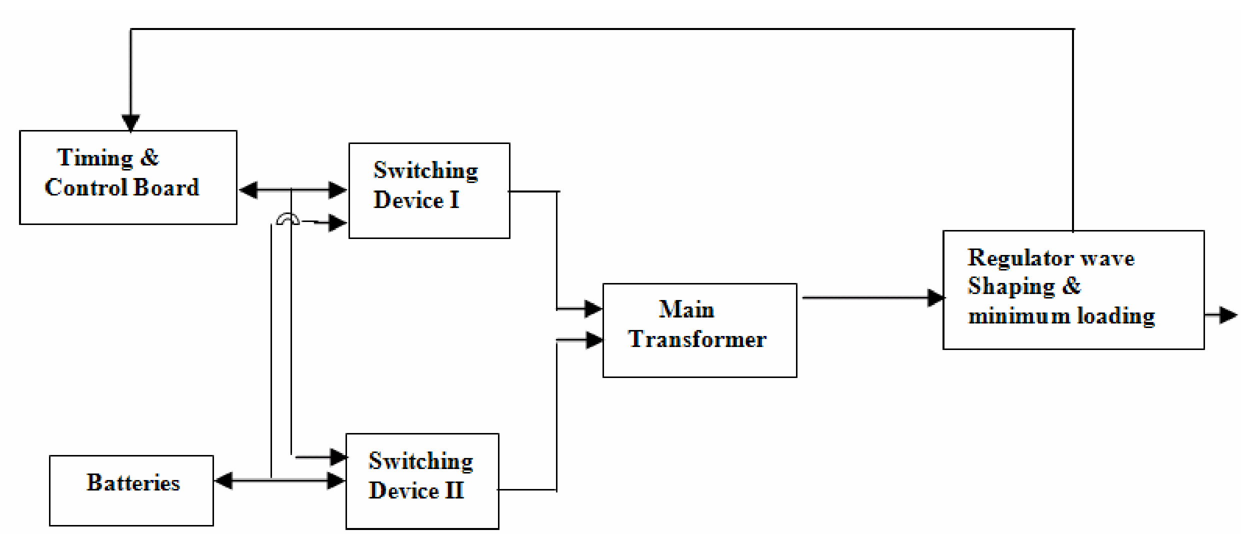

Figure 1: SA Inverter [3, 5].

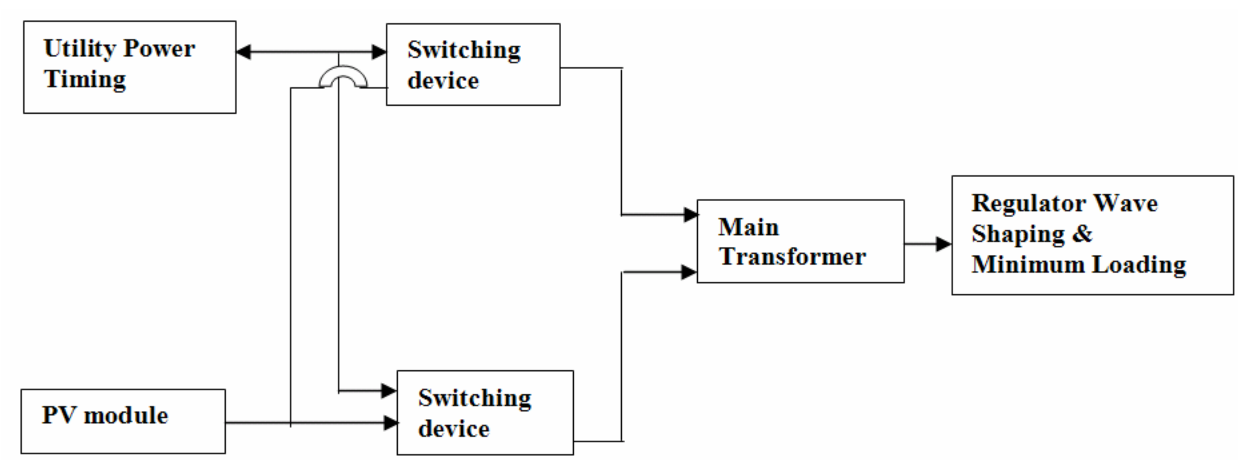

Figure 2: UI System [3, 5].

DESIGN AND CONSTRUCTION

The inverter was designed to meet the specifications on the PV module in Centre for Energy Research and Development, which reads.

Power – 55W
Open circuit voltage – 21.7V
Rated voltage - 17.4 V
Short circuit current – 3.45W
Rated current – 3.15W

These were considered before the square wave inverter was designed. A square wave inverter was chosen, though it has high distortion, it also has some advantages over since wave inverters, which are:

- Low power consumption
- Maximum utilization of available power
- Easier and cheaper to design.

The inverter was designed to be free from high frequency oscillations that may come from nearby wave generating sources. It was designed to the national frequency, which is 50Hz and a Root mean Square voltage of 220V.

It was also designed to dissipate heat at a fast rate in order to avoid heating up the system. The inverter also has good frequency stability since a resistor and a capacitor, whose resistance and capacitance depend mostly on temperature, determine the frequency. These two components were put in the part of the system where there is high temperature stability. All these factors were considered before construction commenced.

COMPONENTS SPECIFICATION

Wave shape – Square wave
Rated output power – 50W
Maximum power intake – 55W
Frequency – 50Hz
Input Voltage – 18 - 22V
Output Voltage – 220 - 240V
Maximum Current Intake – 4A

The block schematic of the inverter is shown below:

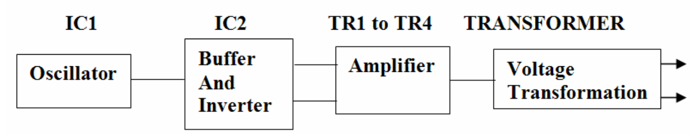

Figure 3: Block Schematics of Inverter.

The circuit is based on NE555 timer in its astable mode. It is the IC1, and also the oscillator. It generates a pulse of frequency 50Hz with the help of R1, VR1 and C1. VR1 is adjusted to give a resistance of 64.1 kΩ.

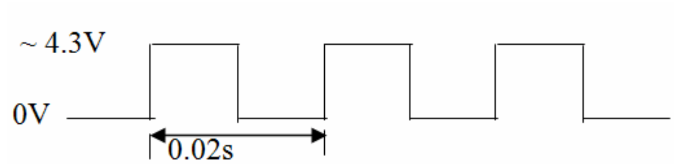

Figure 4: Pulse Waveform.

This in conjunction with C1 and R1 of values 0.22μF and 1.2 kΩ respectively set the oscillating frequency of IC1 to 50Hz as shown below [1].

$$F = 1/T$$
$$= 1.44/(R1 + 2R2)\,C$$

$$F = 1.44/(1200 + 2\times 64100) \times 0.22\times 10^{6}$$
$$\sim 50 \text{ Hz}$$

The output IC1 is fed into IC2, a hex-inverter, which has three of its six gates used. Gates 1 and 2 serve as buffers to reduce the load on the oscillator and gate 3 inverts the output of gate 2 to get a signal that is out of phase with the output of gate 2. The resultant waveform leaving the buffer and inverter section of the system are shown below

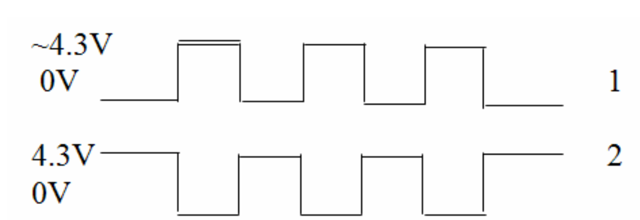

Figure 5: Resultant Waveform.

IC2's dual outputs are fed into the power amplifier section, which consists of two pairs of transistors biased in the common emitter mode. The first pair, TR1 and TR2, acts as drivers to TR3 and TR4, which are the output transistors. The waveform of each output transistor is like that drawn above only that the peak voltage is 15V and the current amplified to 4A maximum.

This dual waveform from the output transistors is fed into a 30V center tapped transformer whose center tapping is connected to a positive supply rail. This output transistor drives the transformer as shown in Figure 4. As can bee seen, when 1 is high, 2 is low (referring to dual waveform in Figure3). When 1 goes high, TR1 is saturated and therefore cuts off supply to TR3, but TR2 is cut off and allows a voltage of 15V to drop across V_{BE} through R_B which sends TR4 to conduct its maximum current of 4A through one-half of the transformer as shown below (Figure 6). This causes current to flow in the output of the transformer in the specified direction as in Figure 6.

When 2 goes high, TR2 is saturated and drops, the total voltage across it cutting off TR4, simultaneously 1 goes low cutting TR1 and causing the total voltage to drop across the V_{BE} of TR3 through R5 and the direction of the output voltage is shown below (Figure 7).

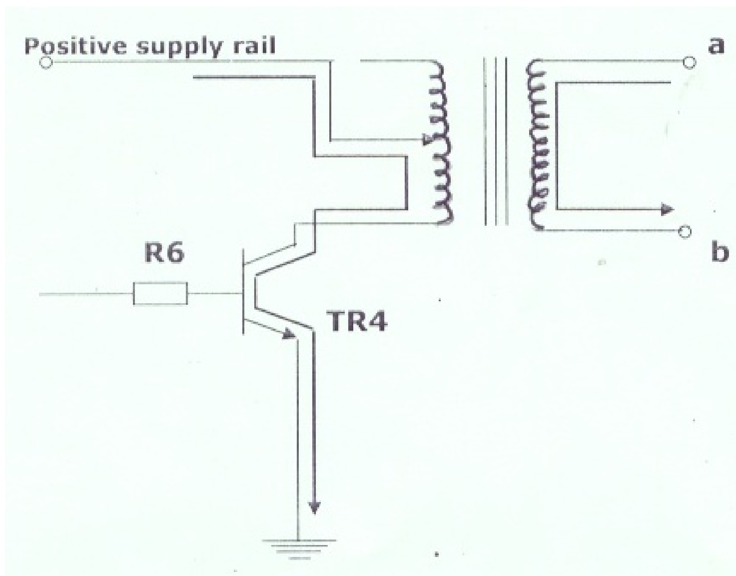

Figure 6

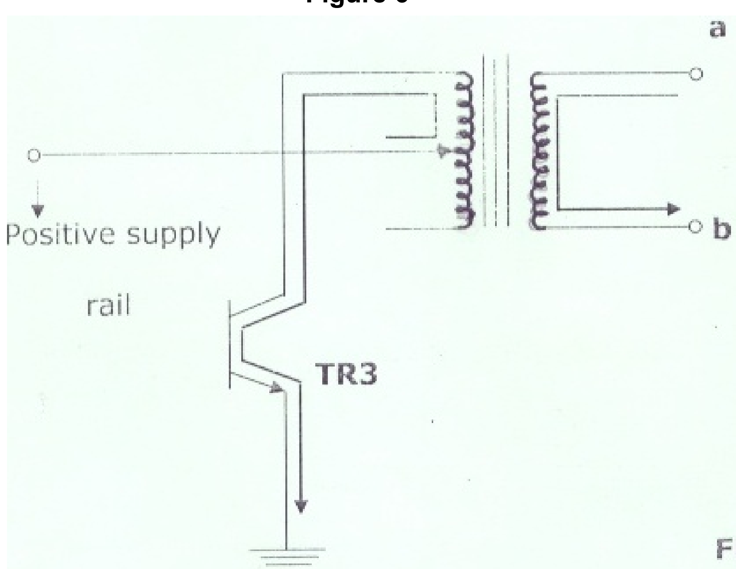

Figure 7

If terminal **a** is a positive with respect to terminal **b** in Figure 4 it becomes negative in Figure 5 with respect to **b** giving an output waveform of the shape below, with **a** going 220 –240V above and below **b** to give a square wave AC of rms voltage of 220- 240V.

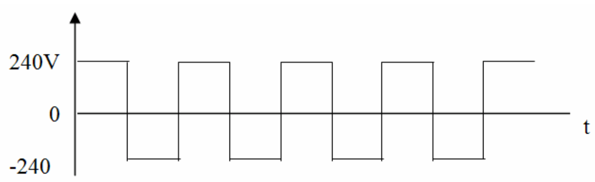

Figure 8: Output waveform of inverter ($240V_{max}$ & $240V_{min}$).

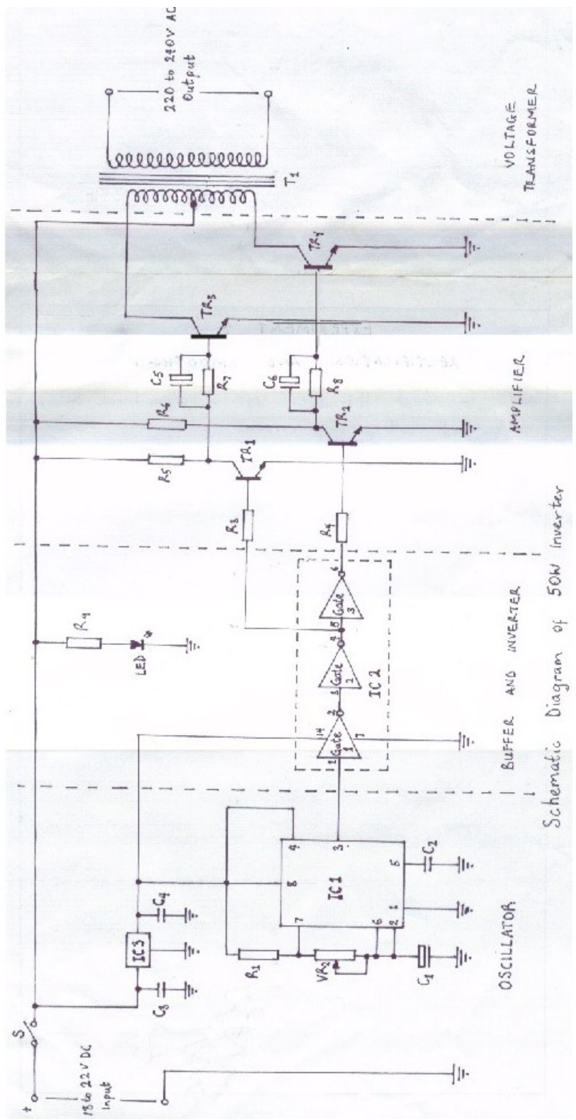

Figure 9: The Inverter [1, 5].

Table 1: Components and Their Functions.

Component	Value	Function
Semiconductor		
IC1	NE555	Oscillator.
IC2	7404	Acts as buffer and dual Out-of-phase generator.
IC3	7805	5V-regulator for voltage supply to IC1 and IC2.
TR1, TR2	PN2222A Ic = 500mA V_{CEO} = 40V h_{FE} = 100	Driver for TR3 and TR4. Generates a current of 0.08A, which they give to TR3 and TR4.
LED	---	To indicate that power has been turned on.
TR3, TR4	2N3055 Ic = 15A V_{CEO} = 60V h_{FE} = 40	Amplifies the current entering into it by a factor of it's h_{FE} (40), therefore it increases the current entering into it and delivers it to the transformer.
Capacitors		
C1	0.22µF	Determines the oscillating frequency of IC1.
C2, C3, C4	100µF	For removal of high frequency signals which may enter the system. Bypass pulsating voltage across R8 and R9 respectively.
C5, C6	1000µF	---
Resistors		
R1	1.2kΩ 1/ 2W	Determines the oscillating frequency of IC1.
R2	100kΩ 1/ 2W Variable resistor	Determines the oscillating frequency of IC1.
R3, R4	1kΩ 1/2W	Sets the base current of TR1 and TR2 to 0.0008A.
R5, R6	150Ω 5W	Sets the maximum collector frequency of TR1 and TR2 to 0.1A.
R7, R8	10Ω	Couples driver transistors to output transistors.
R9	680Ω	Used to set the LED to I_L.

CHARACTERIZATION

A test for the efficiency of the inverter was conducted at the Center for Energy Research and Development, Nsukka. At different solar intensities, the readings for input current (DC), input voltage (AC), open circuit voltage, output current (AC), output voltage (AC) were recorded and tabulated as shown in Table 2.

The solarimeter which measures intensity in millivolts was used for the test, and the conversion factor is 73mV = 1000W/m^2. The efficiency of the inverter was calculated using the formula given by:

Efficiency, η = output power/ input power

The intensity in W/m^2, the efficiency, output power and input power is illustrated in Table 3.

The graph of efficiency against power was plotted and the result is shown in Figure 10.

Table 2: Current and Voltage Readings.

Intensity (mV)	I_{in} (A)	V_{in} (V)	I_{out} (A)	V_{out} (V)	$V_{open\ circuit}$
29 40	2.40	12.98	0.16	174	16.52
32.00	2.46	14.55	0.17	195	17.14
37.70	2.64	15.90	0.19	200	17.74
40.02	2.60	16.10	0.19	210	18.77
51.10	2.71	16.80	0.18	238	18.04
68.00	2.75	17.23	0.19	239	18.52
78.30	2.78	17.55	0.20	232	19.80
79.20	2.83	17.65	0.20	240	19.48
82.30	2.82	17.81	0.20	241	19.62
88.80	2.81	17.95	0.21	238	19.13

Table 3: Efficiency and Power.

Intensity (W/m^2)	P_{in} (W)	P_{out} (W)	Efficiency, η.
402.74	31.15	27.84	0.89
438.36	35.79	33.15	0.93
516.44	41.98	38.00	0.95
548.22	41.86	39.90	0.95
700.00	45.53	42.84	0.94
931.50	47.38	45.41	0.96
1072.60	48.79	46.40	0.95
1084,93	49.95	48.00	0.96
1127.39	50.22	48.22	0.96
1216.44	50.44	49.98	0.99

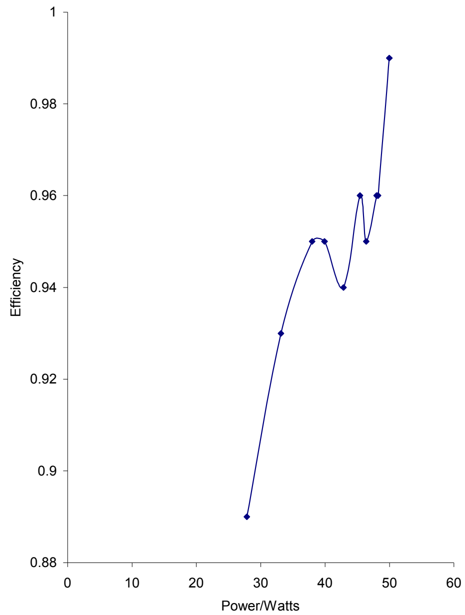

Figure 10: Efficiency vs. Power

RESULTS AND DISCUSSION

The curve above is the efficiency curve of a locally made inverter. The curve has kinks, which can be attributed to some physical discrepancies, like faulty apparatus, weather conditions, etc.

The minimum input voltage, which could power my load (40W bulb), was 12.98V, at solar intensity of 402.74W/m^2. This accounts for the graph not starting from the origin.

From the graph and table above, it can be inferred that the efficiency of an inverter gets better with an increase in the output power level, which corresponds, to a consequent increase in intensity level. The inverter performed optimally at an intensity level of about 1216.44w/m^2, power output of about 49.98W and efficiency of about 0.99, which makes the inverter a relatively efficient one despite anomalies due to physical factors.

Finally, knowing that the sun's intensity is not always constant (say 1216.44W/m^2), we found it very difficult determining the efficiency of the inverter.

CONCLUSION

We designed, constructed, and characterized a solid-state inverter, one of the most expensive components in standard PV system, using locally available materials in Nigeria. The device is used to convert the DC generated by solar cells to AC for optimum utilization and was designed with following specifications: waveform- square wave,: rated output power- 50W, maximum power intake- 55W, frequency- 50Hz, input voltage- 18 – 22V, output voltage- 220 – 240V, maximum current intake- 4A.

The characterization of the locally made inverter was carried out and the result shows that the efficiency of this inverter varied with the solar intensity which is in agreement with theory. The output square wave of the inverter has low power consumption, maximum utilization of available power, economical and free from high frequency oscillations that may come from a nearby wave-generating- source.

REFERENCES

1. Boylestad, R.L. and Nashelsky, L. 2001. *Electronic Devices and Circuit Theory*. Prentice Hall: Princeton, NJ.

2. Energy Commission of Nigeria (EGC). 2004. “Rural Renewable Energy Needs and Supply Technologies”. EGC: Lagos.

3. Haeberlin, H. 2001. “Evolution of Inverter for Grid Connected PV System”. The 17th European Photovoltaic Solar Energy Conference. Munich, Germany.

4. Okeke, P.N. and Soon, W.H.: 2000. *Introduction to Astronomy and Astrophysics*. San Press Ltd.

5. Strong, S.J. 1994. *The Solar Electric House*. Sustainability Press: Still River, MA.

6. Theraja, B.L. and Theraja, A.K. 1997. “Electrical Technology”. S. Chand and Co. Ltd.: New Delhi.

ABOUT THE AUTHORS

B.A. Ezekoye, Ph.D., MSESN, is a faculty member of the Solid State & Material Science Dividison, Department of Physics and Astronomy, University of Nigeria, Nsukka, Nigeria. He currently serves a s a lecturer in the Department and his research interests are primarily in the areas of crystal growth and characterizations. He is presently specializing in thin film growth by the solution growth method.

V.N. Ugha, M.Sc. is a researcher with interests in electronics and solar energy applications.

SUGGESTED CITATION

Ezekoye, B.A. and V.N. Ugha. 2007. "Characterizations and Performance of a Solid-State Inverter and its Applications in Photovoltaics". *Pacific Journal of Science and Technology*. 8(1):4-11.

Pacific Journal of Science and Technology