Scientific Assessment of Locally and Factory Built 2 KVA Modified Sine Wave Solar Powered Inverters

Adeoye O. S, Yusuf, B. M, Ogunsakin, O

Abstract:** This paper presents scientific assessment of locally and factory built 2 kvA modified sine wave inverters. A data logger known as DENT ELITE PRO SP which was connected across the two solar inverters to collect relevant data. The captured data were harmonic distortion, voltage and current variation in the outputs of the solar inverters. An integrated circuit (IC) SG3524 was used to generate the necessary pulse needed to drive the MOSFET (3205IRF) to alternate the direct current (DC) supply. The output from the oscillator stage was amplified using power transistor MOSFET. The frequency at which circuit operate is determined with the oscillator stage. There were different points of interception for both current and voltage for both types of inverters over a stipulated period. The assessment summarily showed that the measurements for the factory made inverter range from 226.044V to 230.811V and these values were within the nominal voltage. However, for locally made inverter, the voltage measurements for the period under consideration were within 215.189V and 221.599V and this depicts a slight deviation from the nominal voltage values. The result showed that the factory built inverter is superior to the locally fabricated type and this implies that there should be improvement in the design of oscillating stage and the determination of the drain current of the MOSFET should be accurate.

***Keywords:** Harmonic, Voltage, Current, Inverter, Waveform*

I. INTRODUCTION

There is need for power to be constantly available in Nigeria and the present power supply is grossly inadequate due increased population, ageing of power equipment, poor planning, insufficient electricity education and energy management [1], [2]. The power generation and power demand cannot meet at point of equilibrium and hence, power balance cannot be achieved [3]. It is obvious that most of the citizens are living in the rural areas and power is yet to be supplied to them [4], [5]. Others have migrated to the urban areas and the supply of power to the group of people is grossly inadequate [6].

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It is noteworthy that most of the urban centers do not have regular power supply due to population, facilities inadequacy and load shedding which adversely affect the standard of living of the people. There is no doubt that commercial, domestic and industrial activities will be negatively affected with this menace [1]. This gap requires an urgent attention and the use of solar power inverters is the way out of domestic consumers. However, Nigeria cannot continue to import these solar inverters in order to reduce economic waste, hence, the need for locally fabricated solar inverters cannot be overemphasized [7], [8]. This makes it so important to carry out scientific assessment of locally and factory built 2kVA inverters. Inverters are circuits that convert direct current (DC) to alternating current (AC). The main objective of the inverter is to use a DC voltage source to supply a load requiring AC. The input of the inverter is taking from various DC source like a battery, photovoltaic cell [9], [10]. There are two types of circuit used in single-phase inverter circuit, which are half-bridge and full bridge configurations. Inverters have been widely used for applications, from small switched power supplies for a computer to large electric utility applications to transport bulk power [7]. A semiconductor has electrical conductivity due to electron flow (as opposed to ionic conductivity) intermediate in magnitude between that of a conductor and an insulator. Semiconducting materials are the foundation of modern electronics, and are used in transistors, solar cells, many kinds of diodes including the light-emitting diode, digital and analog integrated circuits [10]. Semiconductor photovoltaic (PV) cells directly convert light energy into electrical energy. In metals, current moves through the flow of electrons; in semiconductors, current is often schematized as being carried either by the flow of electrons or by the flow of positively charged "holes" in the electron structure of the material (in both cases only electron movements are actually involve [12], [13].

II. BLOCK DIAGRAM OF THE SYSTEM

The inverter is an electronic device, which converts DC voltage form a low dc source to ac voltage of a high output voltage. The method used for this paper comprises the design and implementation of its input subsystem, control unit and output subsystem. The design started with the overall system and then partitioned it into systems. The sections of the system are electricity supply/mains, solar panel, charge controller, battery, utility and DC/AC inverter/charger [14]–[16].

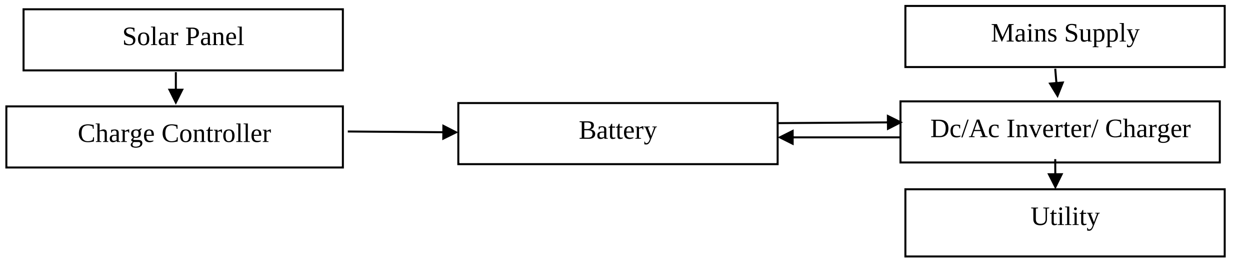

Fig.1: The Connection Arrangement of Solar Panel Inverter

The connection arrangement of the system as represented in Fig. 1. The solar panel comprises two outputs DC Voltage (i.e positive and negative). These two output voltages were connected to the battery for charging through charge controller, which regulate charging. The battery is therefore connected to the input section of the inverter. The energy produced by the battery which is DC was transferred to the inverter and was converted into AC. The alternating current produced by the inverter is transferred to the output socket where the system is subjected to load or utility to verify its performance [9], [13], [15].

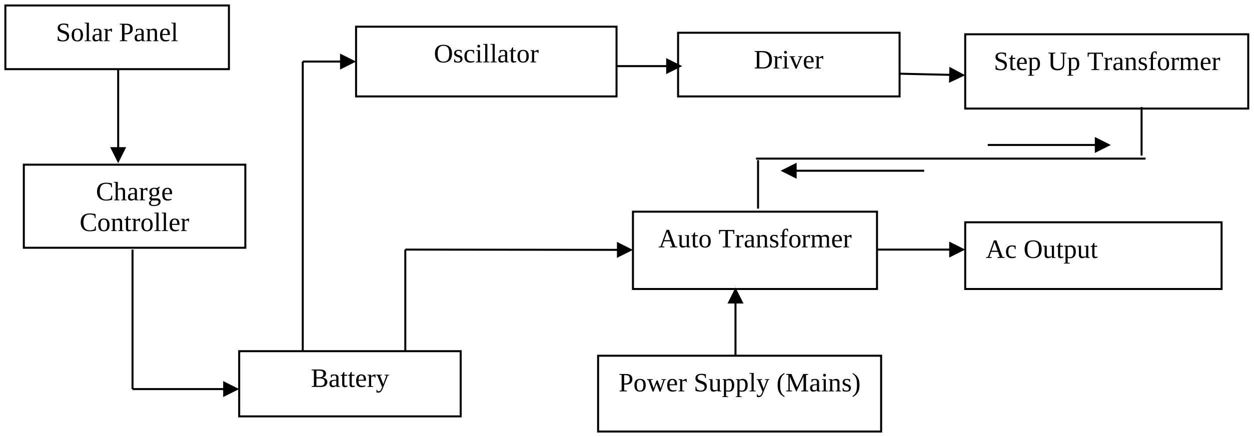

Fig.2: Block Diagram of a 2 kvA Solar Power Inverter Modified Sine Wave

III. SYSTEM OPERATION WITH BLOCK DIAGRAM

The solar panel absorbs energy produced by the sun and converts it into electrical energy. It does this by absorbing the sunrays into the modules of the solar panel, thereby producing free electrical charge carriers in the conduction and valence bands. The electricity produced by the solar panel was transferred to the charge controller as shown in Fig. 2. The charge controller regulates the rate at which electric current were drawn in and out of the battery. It turns off charge when the battery reaches the optimum charging point and turns it on when it goes below a certain level. It fully charges the battery without permitting overcharge. The regulated voltage from the charge controller was transferred to the solar battery. The batteries were the key component in this solar power system. It provided energy storage for the system. The energy stored in the batteries was used to power the load but it was converted to AC voltage by the use of an inverter because they were AC loads. The photovoltaic solar panel produced direct current was commuted periodically by controlled oscillatory system and feed to power electronic semiconductor switches such as transistors, which were connected to the power transformer. The voltage was stepped up to the desired AC voltage output. The inverter could also charge the battery when there is public power supply. The current -voltage curve of a solar cell is the superposition of the IV curve in the dark with the light generated current [15], [17].

IV. CAUSES OF CURRENT VARIATION

The variations are caused by both linear and non-linear loads, most especially non-linear loads. When a sinusoidal voltage is applied to a certain type of load, the current drawn by the load is proportional to the voltage and impedance and follows the envelope of the voltage waveform. These loads are referred to as linear loads (loads where the voltage and current follow one another without any distortion to their pure sine waves). In contrast, some loads cause the current to vary disproportionately with the voltage during each half cycle. These loads are classified as non-linear loads, and the current and voltage have waveforms that are non-sinusoidal [18].

V. EFFECT OF CURRENT VARIATION

Since non-linear loads are part of the testing loads they draw currents abruptly with short pulses therefore containing distortions, whereby the 50-Hz waveform has numerous additional waveforms superimposed upon it, creating multiple frequencies within the normal 50-Hz sine wave. The multiple frequencies are harmonics of the fundamental frequency. It is very obvious that the locally made inverter handles current load better than the factory-built inverter, thereby making the loads connected to the locally made inverter to perform better than when connected to the factory-built inverters [19], [20].

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VI. EFFECTS OF WAVEFORM ON EQUIPMENT

Most equipment can operate properly with little voltage waveform distortion and still maintain a regulated DC output. However, with greater distortion, efficiency of the loads decreases [21].

A. Causes of Waveform Distortion

1. Improper soldering or loose connections in the making of the inverter or connections of cables
2. Overloaded conductors usually caused by the individual phase conductor currents exceed 20% of the average phase current.
3. Neutral conductor current equal to or greater than the average phase current. In an ideal situation the neutral conductor current is at least 15% less than the average phase current.
4. Low efficiency of transformer.

B. Harmonics

The presence of harmonics in electrical systems means that current and voltage are distorted and deviate from sinusoidal waveforms. Harmonic currents are caused by non-linear loads connected to the distribution system. A load is said to be non-linear when the current it draws does not have the same waveform as the supply voltage. The flow of harmonic currents through system impedances in turn creates voltage harmonics, which distort the supply voltage. The Total Harmonic Distortion (THD) is an indicator of the distortion of a signal. First harmonics or fundamental harmonics is when P =IV. We have even and odd harmonic which represents the multiples of even numbers and odd numbers. Odd harmonics are dangerous to equipment than the even harmonics. There is very high distortion (Harmonics) in the foreign made inverter when compared to the locally made. The locally made tends to have higher distortion handling than the foreign made when on load condition. They are prevalent in power electronics and they are evident in Switch Mode Power Supply (SMPS) equipment [22]–[25].

C. Materials And Methods

The method used is made up of different segments made up of determination of the oscillating frequency; drain current of the Mos fet and instrument used for testing with definite specification. The determination of oscillating frequency was defined by equations (1) and (2) and the drain current of the MOSFET was shown in equation (3) and (4). The DENT Elite Pro SP data logger was connected independently to both factory built and locally built 2 kVA solar powered inverters to capture voltages, currents and harmonic contents over a period of time.

D. Determination of the Oscillating Frequency

By supplying a constant 24Volt DC through a voltage regulator to the IC SG 3524 PWM, the frequency of the oscillating signal was determined using a 500KΩ variable resistor connected in series with another 120KΩ resistor serving as the holding resistor from pin 6 and holding capacitor of 0.104μF from pin 7 to form the RC time constant network.

$$\text{Frequency, } f = \frac{1.30}{C_T R_T} \quad (1)$$

Time Capacitor (CT) = 0.104μF

Fixed resistor = 120kΩ

Variable resistor = 130kΩ

Total resistance = 250kΩ since both are in series

$$F = \frac{1.30}{0.104 \times 10^{-6} \times 250 \times 10^{3}} \quad (2)$$

= 52Hz

f = 52Hz It should be noted that the variable resistor was varied until the frequency of the signal was 50Hz.

E. The Drain Current of The Mosfet

From the Inverter, total power is 2000Watts,

The battery Voltage is = 24V

Therefore, the drain current ID = P/V (3)

I = 2000/24

ID = 83.33A

Where the voltage output of the inverter,

V output = 220V

Full load output current, I output = P/V (4)

Therefore current I = 2000/220

= 9.09A

F. Instrument Used for Testing

The **DENT ELITE** *pro* ***SP*** is a powerful and versatile tool for pinpointing electric usage and quantifying energy usage. It is capable of measuring, storing, and analyzing consumption data including Volts, Amps, Watts, Volt-Amps (VA), Volt-Amps reactive (VAR), Kilowatts (kW), Kilowatt Hours (kWh), KVAh, kVARh, and Power Factor of an electrical load or an entire building. The **DENT ELITE** *pro* ***SP*** also offers some power quality features such as the ability to view in real-time voltage, current, and power waveforms and calculate harmonics to the 63rd order.

The **DENT ELITE** *pro* ***SP*** is line-powered from the service being measured, eliminating the need for external power or space-consuming batteries at the job site. The measurements are stored in on-board, non-volatile memory in a time series format at an interval selected by the user. The **DENT ELITE** *pro* ***SP*** can be mounted anywhere with its magnetic back and is small enough to be secured inside the electrical panel. The Windows-based **ELOG** software package is used to setup the meter, display metered values, and retrieve and analyze the collected data.

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Table 1: Specification of Dent Elite *pro* SP

Specification	Description
Service Types	Single Phase-Two Wire, Single Phase-Three Wire, Three Phase-Four Wire (WYE), Three Phase-Three Wire (DELTA)
Voltage Channels	80-600VAC (80-800VDC), Line-to-Line : 1-600 (1-800 VDC) with External Power
Current Channels	Uses voltage output CTs (0-333 mVAC) for maximum safety
Maximum Current Channel Input Voltage	0-666 mVAC or 0-1.0VDC
Measurement Type	True RMS using high-speed digital signal processing (DSP)
Line Frequency	DC/50/60/400Hz
Waveform Sampling	12 kHz
Channel Sampling Rate (internal sampling)	200 samples/cycle at 60Hz 240 samples/cycle at 50Hz 30 samples/cycle at 400Hz
Data Interval	The default integration period is fifteen minutes. The choices are 1, 3, 15, 30 seconds; 1, 2, 5, 10, 15, 20 and 30 minutes; 1 and 12 hours; 1 day.
Measurements	Volts, Amps, Amp-Hrs (Ah), kW, kWh, kVAR, kVARh, kVA, kVAh, Displacement Power Factor (dPF). All parameters for each phase and for system total.

VII. RESULTS AND DISCUSSION

It is obvious that in order to supply constant 24V D.C through voltage regulator, the integrated circuit SG 3524 PMW, the frequency of oscillating signal was estimated as 52Hz for the locally fabricated solar inverter. However, the variable resistor varied until frequency of the signal was 50Hz. The drain current of the MOSFET with total power of 2 kW was calculated to be 83.33A and load current was 9.09A. Table 1 shows the specification of DENT ELITE PRO SP with service types, voltage channels, current channels, maximum current channel input voltage, measurement type, line frequency, waveform sampling, channel sampling rate, data interval and measurements. Table 2 shows the result of voltage measurements for factory built and locally made inverters with two minutes intervals from 12:24 p.m to 13.28p.m on 31st March, 2021 and these measurements were taken with the aid of DENT ELITE PRO SP data logger. The measurements for the factory made inverter range from 226.044V to 230.811V and these values were within the nominal voltage. However, for locally made inverter, the voltage measurements for the period under consideration were within 215.189V and 221.599V. Fig. 3 shows the plot of superposition of voltage data collection for factory built and locally made inverters. The points of interception were at different periods such as 13:50p.m; 13:54 p.m; 13:58p.m; 14;02p.m; 14;18p.m; 14:22p.m; 14:30 p.m and 14:38p.m. Table 3 shows the result of current variation of locally made and factory made inverters for the period under consideration. The factory made has current range from 1.03 A and 2.7 A while that of locally made is from 0.8 A to 1.25 A. Fig. 4 shows the plot of superposition of current variation of locally made and factory made inverters. The current flow in the factory made the standard while there was a sharp deviation from that of locally made inverter. However, there were points of interception at different time with specifics at 13:46 p.m, 13:50 p.m, 13:55p.m, 14:06p.m, 14:30 p.m and 14:36 p.m. Fig.5 shows the waveforms of voltage, current and power of factory made being captured by DENT ELITE PRO SP. The measured voltage was sinusoidal in nature and this range from -300 V to 0 V. The voltage increased gradually from 0 V to 300 V and later reduced to 0 V and further reduction to -300 V. In the same vein, the current waveform was sinusoidal from -2 A to zero. It further reduced to -2 A and later increased 1 A which was maintained for certain period and later increased to 2 A. The current reduced further to zero and later increased to 2 A and decreased uniformly to -3 A. The power measured was also sinusoidal in nature starting from 0.5kW which reduced to zero and later to -0.2 kW. This increased uniformly at 0.4 kW until it reached 0.8 kW. Fig. 6 shows the waveform captured from data logger for voltage range from -300 V to 300 V and later reduction to -300 V. The current waveform range from -1.5 A to 1.5 A and later reduction to -1.5A. For power waveform, the range was from 0.5 kW to 0 to later reduction of 0.5 kW. Fig.7 shows the harmonic analysis of factory made inverter with r.m.s voltage of 225.5V, total harmonic distortion of voltage of 25.8%, peak voltage of 289.8V, crest factor of 1.285, line frequency of 50.1 Hz. Root mean square current of 1.22 A, total harmonic distortion (THD) of current was 63.5%, peak current was 2.78 A, crest factor was 2.281, k-factor was 28.02. The values of voltage and current on the first order were 100 V and 100 A respectively. For the third order, the values of voltage and current were 5V and 17.5 A respectively while on the fifth order, the values of voltage and current were 10 V and 18 A respectively. Fig.8 shows the harmonic analysis on locally made inverter. The R.M.S voltage was 215.2 V, THD of voltage was 23 %, peak voltage was 298 V, the crest factor was 1.385, line frequency was 50 Hz. R.M.S current was 0.93A, THD current was 31.1 %, peak current was 1.78 A, crest factor was 1.905 and k-factor was 3.82. For the first order, the values of voltage and current were 100 %; for the third order, the voltage and current were 0 % and 27 % respectively. For the fifth order, voltage and current were 0 % and 12.5 % respectively. Fig.9 shows the chart of minimum voltage of factory built and locally made inverters. The samples were carried out on twenty occasions. The factory built from samples 1 to 20 showed minimum voltage range from 218 V to 227 V while that of locally made range was from 212 V to 214 V. Fig. 10 shows the average voltage of factory built and locally made inverters. The factory built has voltage range of 226 V to 228 V while that of locally made range was from 214 V to 215 V. Fig. 11 shows the maximum voltage of factory built and locally made was inverters. The range of voltage for twenty samplings was between 226 V and 231 V while that of locally made was from 215 V to 222 V. Fig. 12 shows the minimum current of both factory made and locally made inverters over twenty samplings. For factory built , the current range was from 1 A to 1.1 A while that of the locally made inverters over twenty samplings range from 0.7 A to 0.9 A. Fig.13 shows the average current for both factory built and locally made inverters.

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The average current for twenty samplings in respect to factory built and locally made inverters, the current range from 1A to 1.2 A while for the locally made inverter, current range from 0.8 A to 1.0 A. Fig. 14 shows the chart of maximum current for both factory made and locally built inverters for samplings of twenty. The maximum current for factory built range from 1.1 A to 2.7 A while for locally built inverter, the range was from 0.7 A to 1.3 A.

Table 2: Results of Voltage Measurements for Factory Made and Locally Made Solar Inverters

Time	Factory Volt	Locally Volt
12:24:00	230.811	221.599
12:26:00	227.655	216.446
12:28:00	227.268	216.124
12:30:00	225.593	215.995
12:32:00	225.529	215.931
12:34:00	228.557	215.737
12:36:00	228.363	215.544
12:38:00	228.299	215.609
12:40:00	227.977	215.415
12:42:00	227.913	215.351
12:44:00	227.977	215.48
12:46:00	227.913	215.286
12:48:00	227.59	215.802
12:50:00	227.655	215.415
12:52:00	226.366	215.737
12:54:00	227.784	215.48
12:56:00	227.655	215.286
12:58:00	227.526	215.544
13:00:00	228.041	215.351
13:02:00	228.106	215.931
13:04:00	227.784	215.415
13:06:00	227.204	215.286
13:08:00	226.882	215.286
13:10:00	226.56	215.351
13:12:00	226.238	215.609
13:14:00	228.814	215.609
13:16:00	228.814	215.737
13:18:00	228.879	215.48
13:20:00	228.17	215.415
13:22:00	228.75	215.222
13:24:00	226.044	215.206
13:26:00	228.879	215.200
13:28:00	228.686	215.189

The Result of the Voltage test Carried out on the Superposition on the Factory and Locally Made of the Solar Inverter.

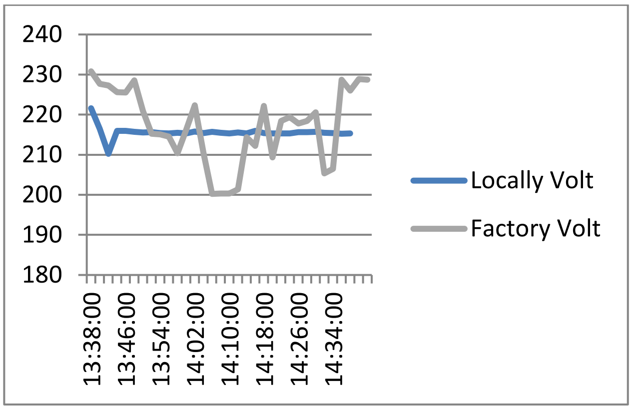

Fig. 3: Plot of Superposition of Voltage Measurement of Factory and Locally Made Inverters

Output Voltage Variation of both locally and factory made Wave Forms Output on Foreign Built and Locally Made Inverters

Test On Foreign Made

Voltage, Current and Power Waveforms of Factory Made Inverter

Table 3: Result of Current Variation of Locally and Factory-Made Solar Inverter

Time	Max. Amp	Max. Amp
13:38:00	2.7	1.17
13:40:00	1.28	1.25
13:42:00	1.26	1.07
13:44:00	1.29	1.07
13:46:00	1.24	1.12
13:48:00	1.25	1.05
13:50:00	1.3	1.07
13:52:00	1.29	1.03
13:54:00	1.24	1.02
13:56:00	1.23	1.08
13:58:00	1.24	1.06
14:00:00	1.23	1.01
14:02:00	1.24	1.00
14:04:00	1.22	0.86
14:06:00	1.24	0.88
14:08:00	1.24	1.06
14:10:00	1.12	1.05
14:12:00	1.13	1.02
14:14:00	1.11	1
14:16:00	1.07	1.03
14:18:00	1.06	0.85
14:20:00	1.1	0.81
14:22:00	1.09	0.8
14:24:00	1.1	0.81
14:26:00	1.11	0.94
14:28:00	1.12	1.12
14:30:00	1.11	1.06
14:32:00	1.05	1.03
14:34:00	1.06	1.01
14:36:00	1.03	0.99
14:38:00	1.03	1.03

The Result of the Current Test Carried out on the Superposition on the Factory and Locally Made of the Solar Inverter.

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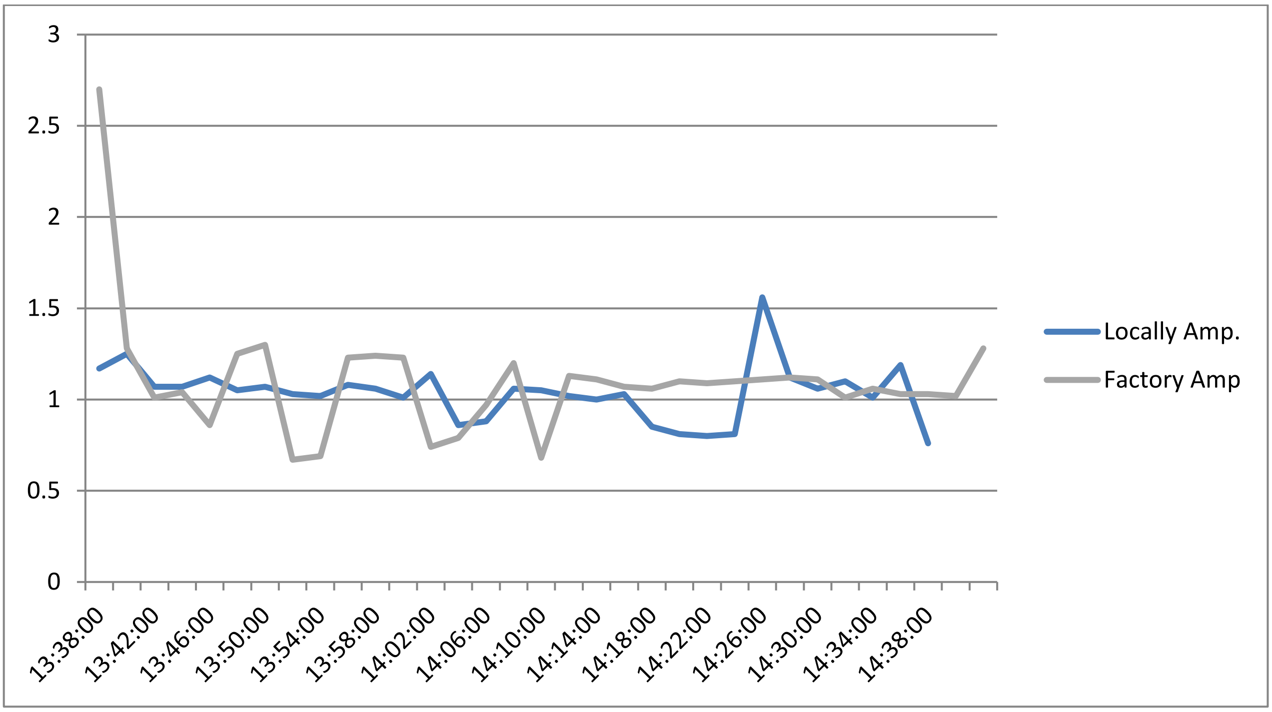

Fig. 4: Plot of Superposition of the Current Variation of Locally and Factory-Made Inverter

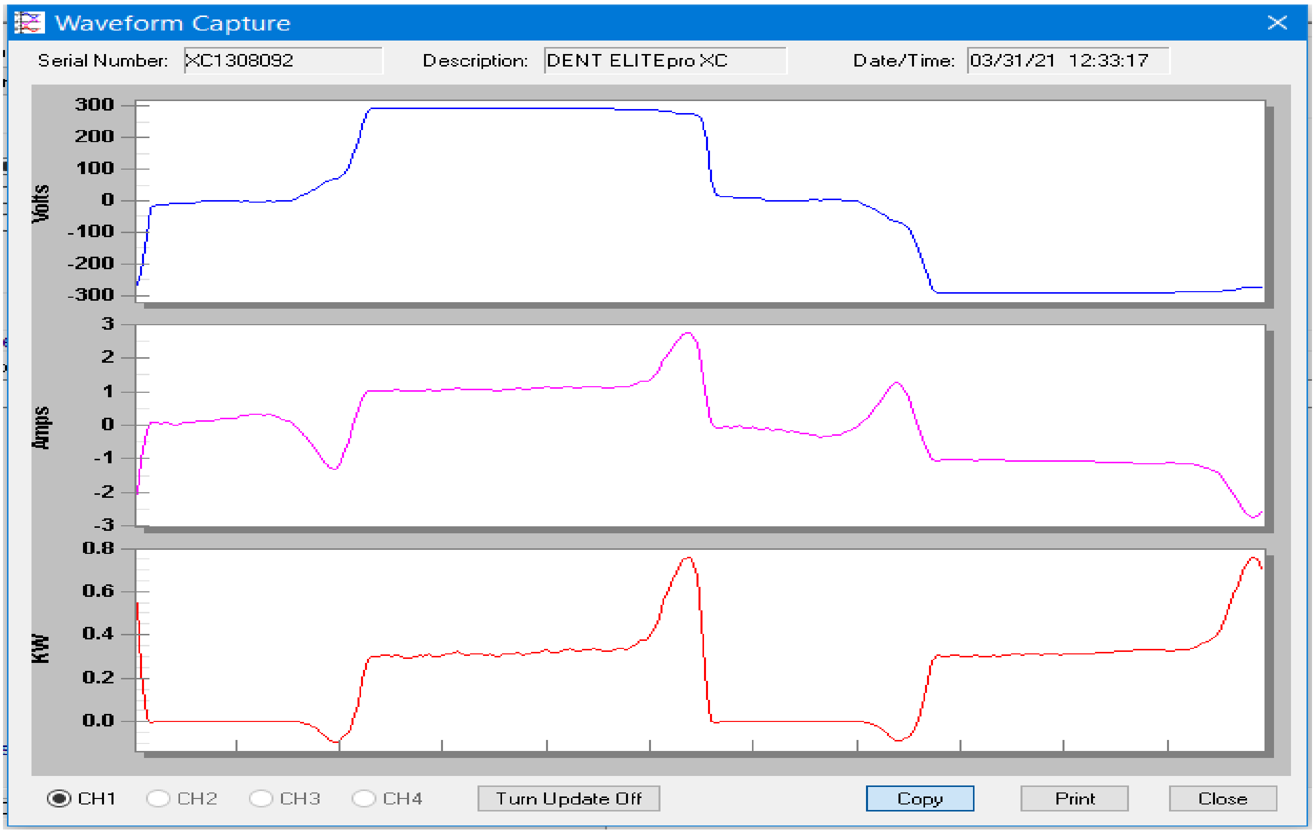

Fig.5: Waveforms of Voltage, Current and Power of Factory-Made Inverter

Harmonics Measurements on Factory Made and Locally Made Solar Inverters

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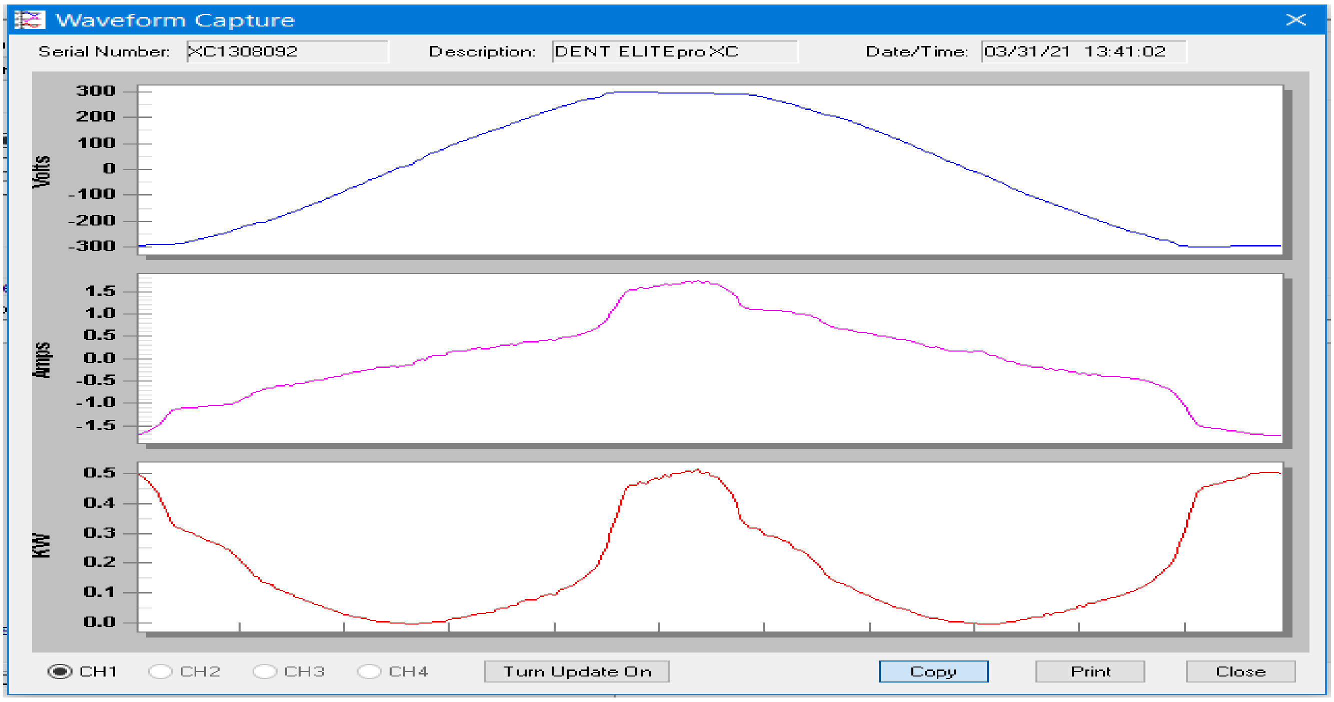

Fig. 6 Waveforms of Voltage, Current and Power of Locally Made Inverter

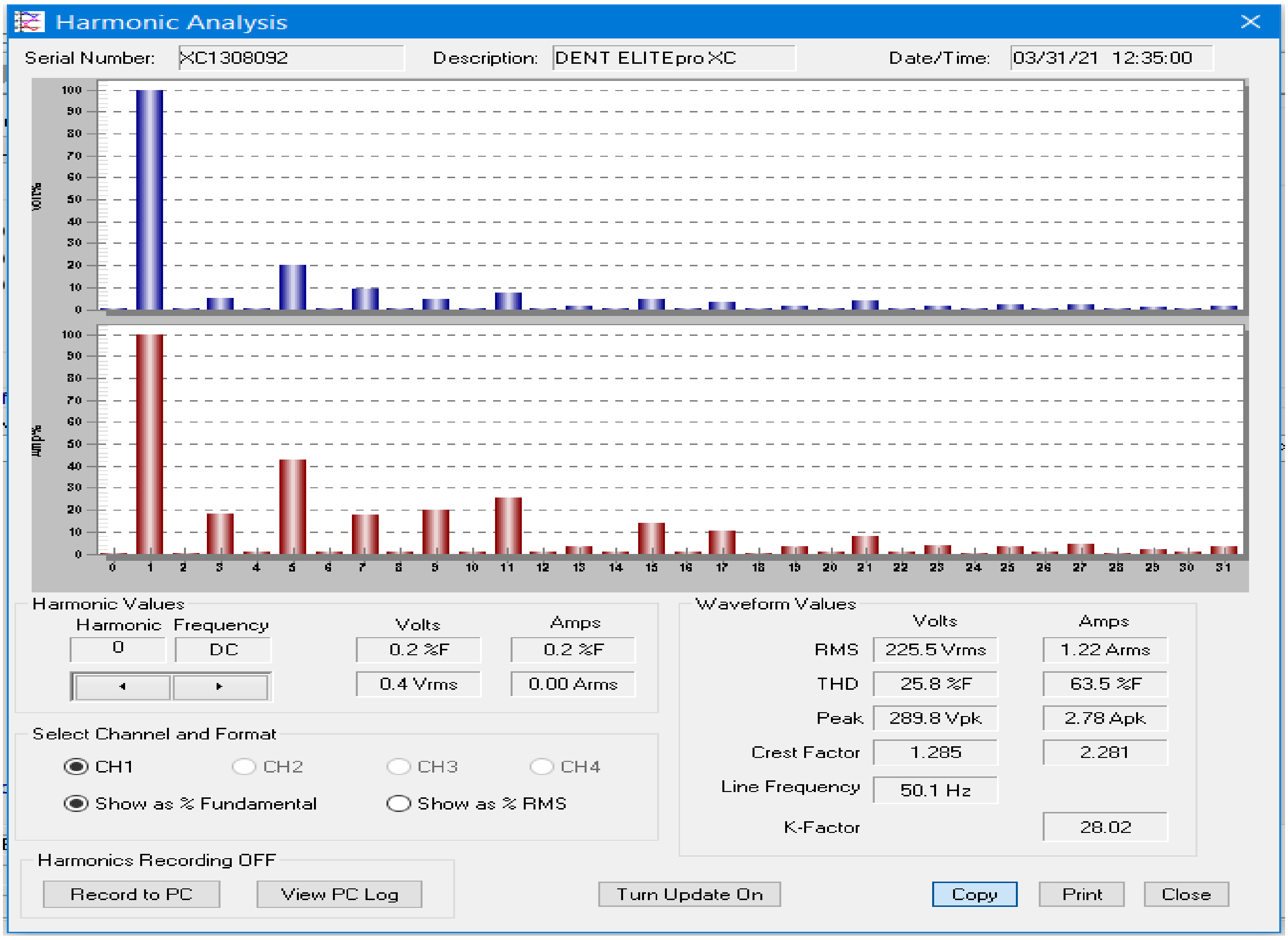

Fig 7: Harmonic Analysis of factory-made solar inverter

Voltage And Current Assessment Charts

The following chart shows the voltage and current output of both factory and locally made inverter at minimum, average and maximum level when the inverters are placed on load during testing.

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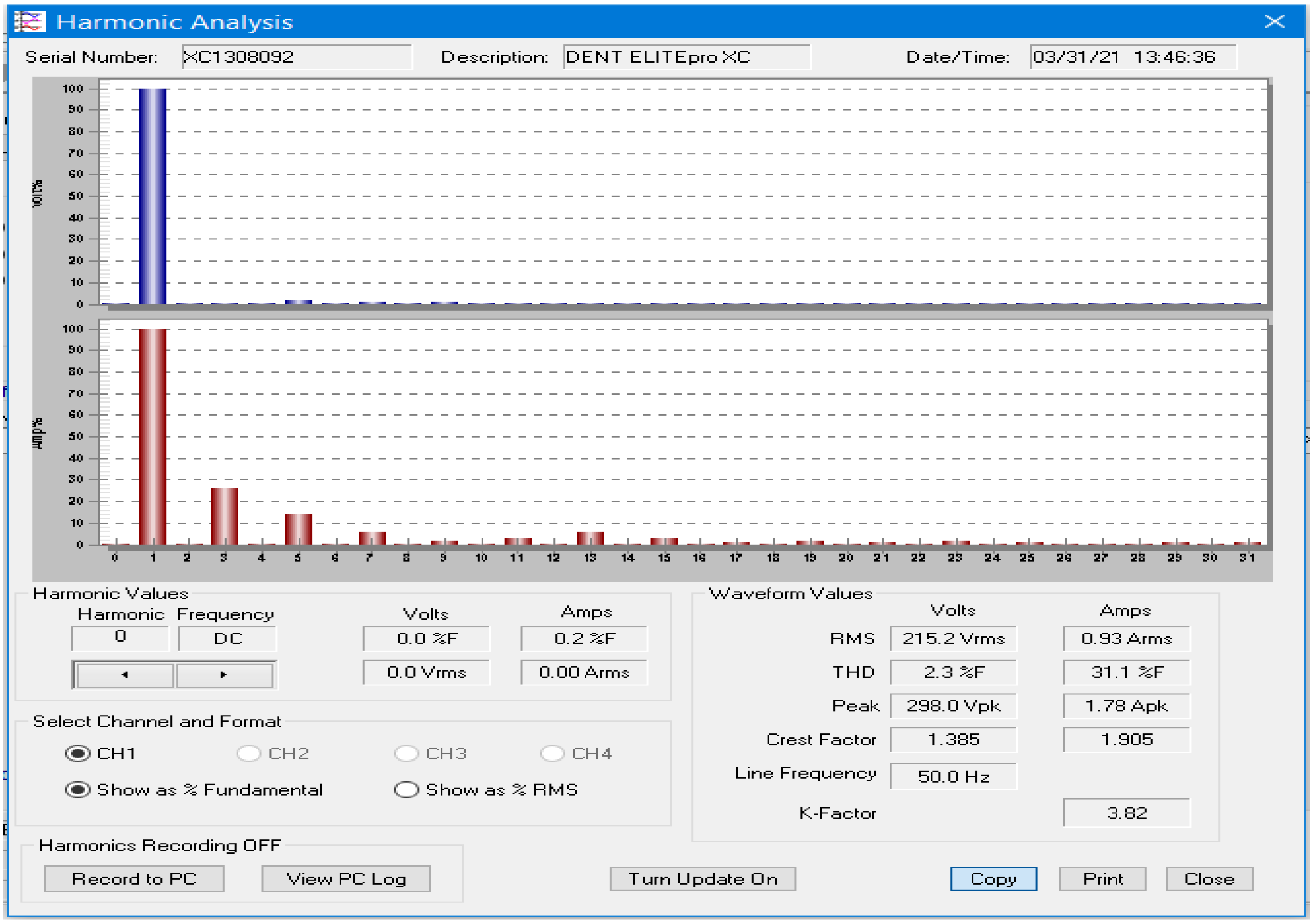

Fig. 8: Harmonic Analysis on Locally Made Solar Inverter

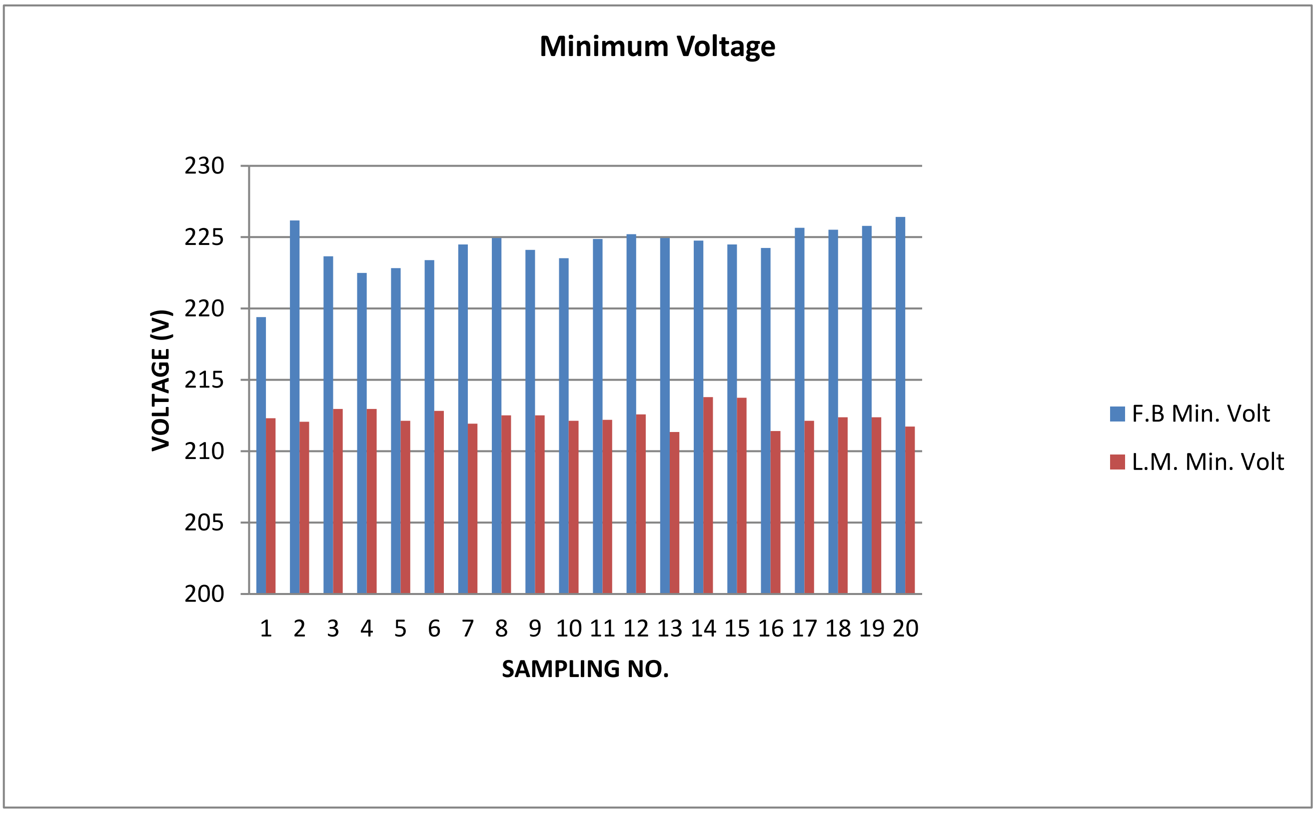

Fig.9: Chart of Minimum Voltage of Factory Built and Locally Made Solar Powered Inverter

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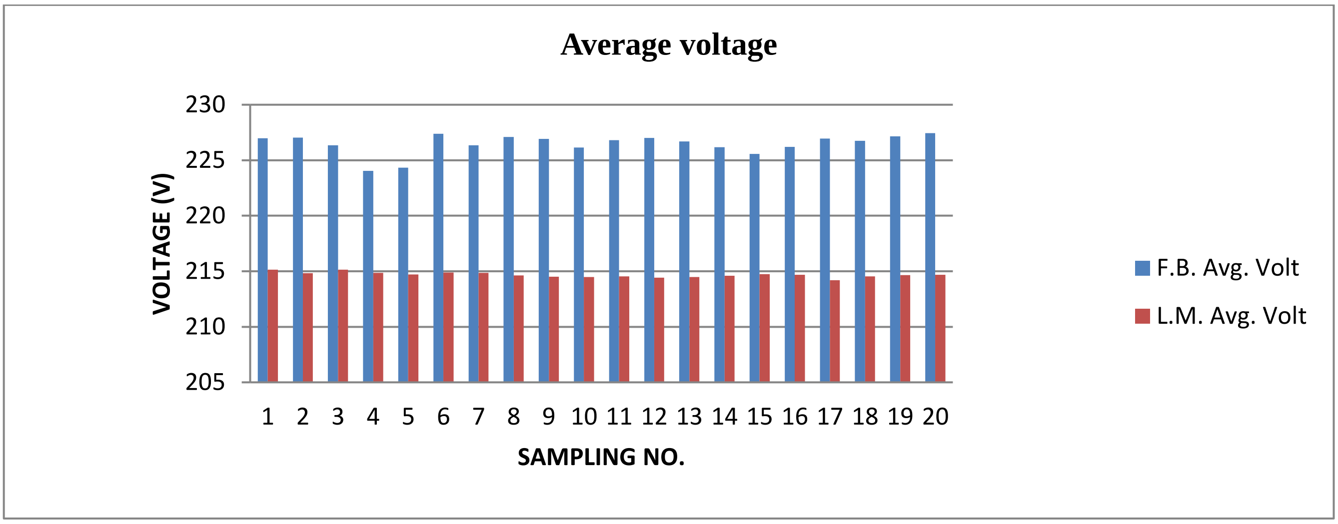

Fig.10: Chart of Average Voltage of Factory Built and Locally Made Inverter

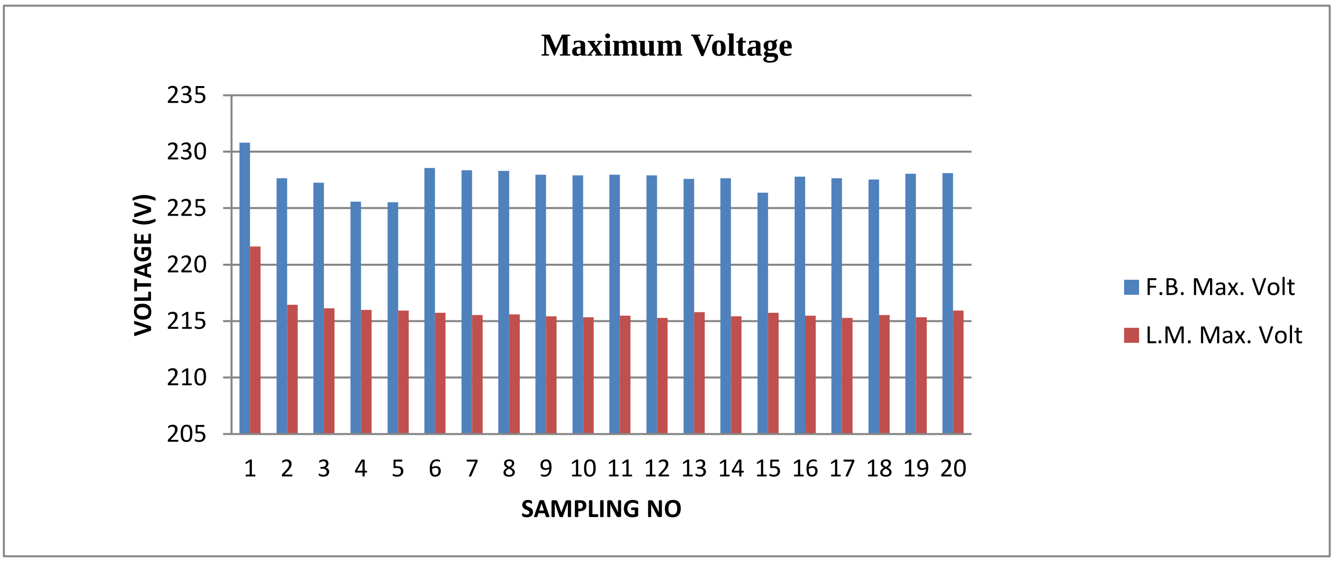

Fig.11: Chart of Maximum Voltage of Factory Built and Locally Made Inverter.

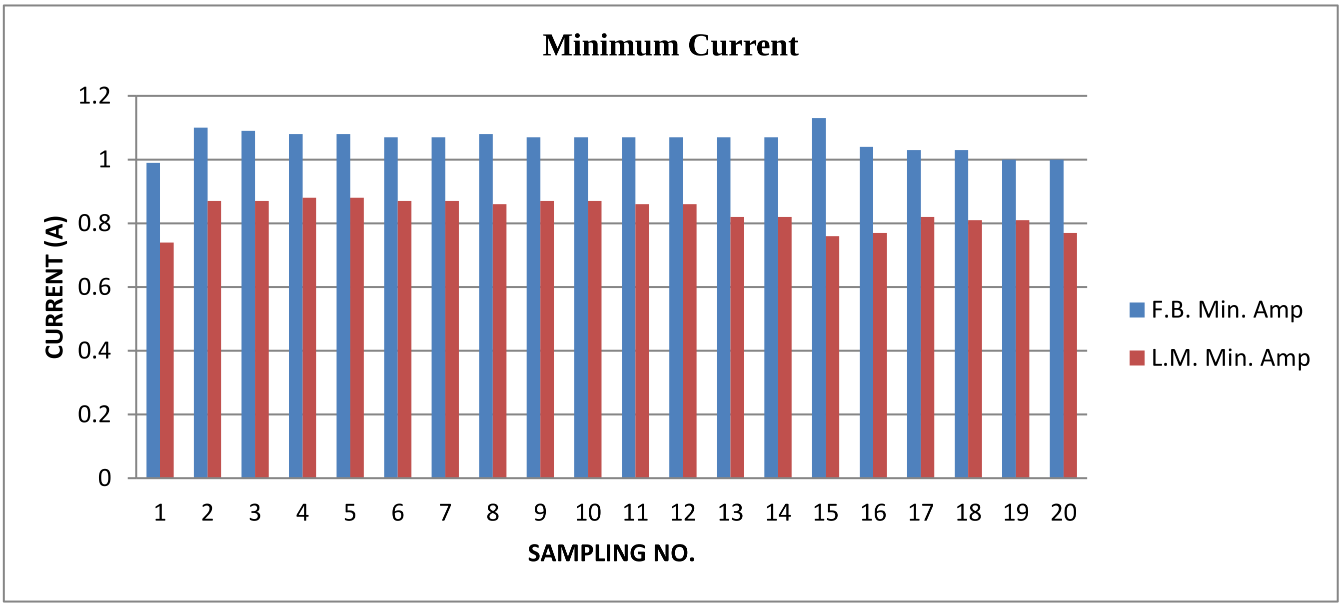

Fig.12: Chart of Min Current of Both Factory Built and Locally Made Inverter.

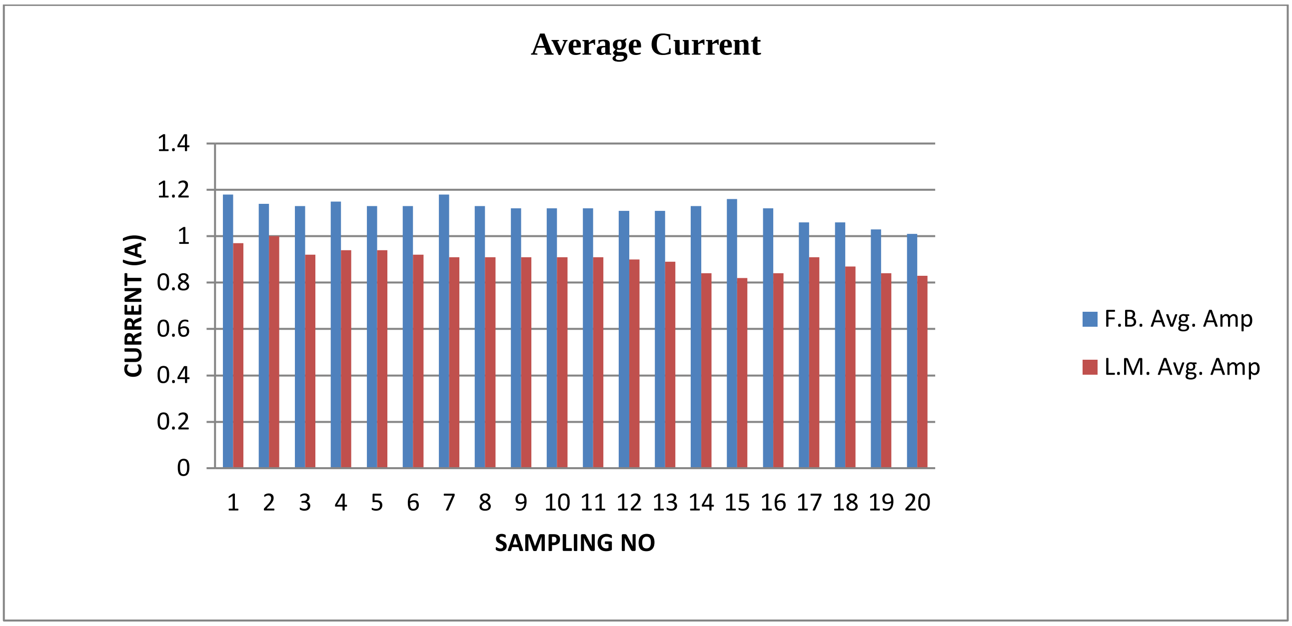

Fig.13: Chart of Average Current of both Factory Built and Locally Made Inverter.

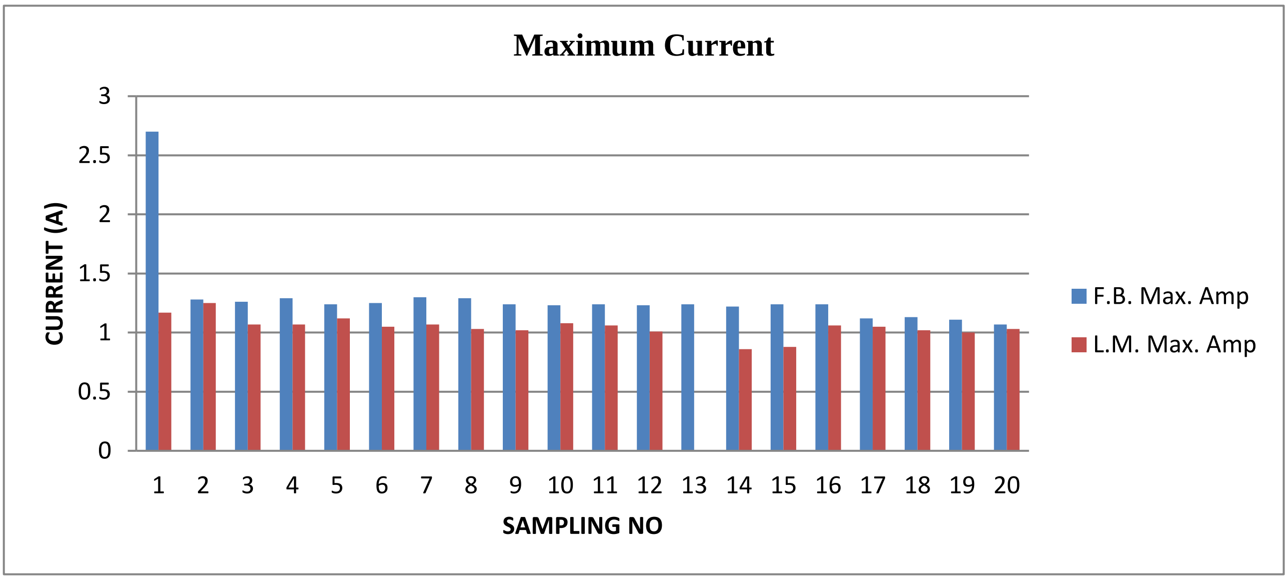

Fig. 14: Chart of Maximum Current of Both Factory Built and Locally Made Inverter.

VIII. CONCLUSION

This paper concluded that the scientific assessment of factory made and locally made modified sine wave inverter is vital to technological advancement and it provides an alternative source of power that can put an end to unclean, inadequate and incessant power supply to Nigerians in the 21st Century. The assessment truly showed that the locally fabricated inverter needs improvement and when this is achieved, mass production can be embarked upon to generate economic wealth for individuals, institutions and the country at large. The measurements for the factory-made inverter range from 226.044V to 230.811V and these values were within the nominal voltage. However, for locally made inverter, the voltage measurements for the period under consideration were within 215.189V and 221.599V and this depicts a slight deviation from the nominal voltage values. The paper showed that root mean square voltage was 215.2V, the total harmonic distortion of voltage was 23%, the peak voltage was 298V, the crest factor was 1.385, the line frequency was 50Hz, the root mean square current was 0.93A, total harmonic distortion of current was 31.1%, the peak current was 1.78A, crest factor was 1.905 and k factor was 3.82. The first, third and fifth order of harmonic for voltage were 100V, 5V and 10V respectively. The first, third and fifth order of harmonic for current were 100A, 17.5A and 18A for locally made solar powered inverter. However, the measured parameters for the factory made solar powered inverter are therefore presented with the root mean square voltage as 225.5V, total harmonic distortion of voltage was 25.8%, peak voltage was 289.8V, the crest factor was 1.285, line frequency of 50.1Hz. Root mean square current of 1.22A, total harmonic of distortion of current was 63.5Hz, peak current of 2.78A, crest factor of 2.281, k factor of 28.02. The first, third and fifth order of harmonic for voltage were 100V, 0Vand 0V respectively. The first, third and fifth order of harmonic for current were 100A, 27A and 12.5A.

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RECOMMENDATIONS

The performance indices showed that the factory-built inverter was superior to the locally made type. There is need to improve on the locally made inverter through intensive effort on the design of oscillating stage and the determination of the drain current of the MOSFET should be accurate.

DECLARATION

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Availability of Data and Material/ Data Access Statement	Data were collected from data logger called DENT ELITE PRO SP data logger.
Authors Contributions	Adeoye, O.S made 40% contribution, Yusuf, B, M made 35% contribution while Ogunsakin made 25% contribution to this research.

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