Harmonic Reduction in Two-level Power Inverter using Enhanced-Direct Current (DC) Based-Modulation Technique

CANDIDUS U. EYA[1,2,3], UGWUIJEM CHIKADIBIA DANIEL[3],
UZOMA STEPHEN EGESIMBA[4], EZIKE MORRIS OBIORA[5], LUKUMBA PHIRI[6]

[1]Africa Centre of Excellence for Sustainable Power and Energy Development,
University of Nigeria,
NIGERIA

[2]Laboratory of Industrial Electronics, Power Devices, and New Energy Systems,
University of Nigeria,
Nsukka,
NIGERIA

[3]Department of Electrical Engineering,
University of Nigeria,
Nsukka,
NIGERIA

[4]Department of Electrical/Electronic Education School of Secondary Education (Tech.)
Federal College of Education (Tech.), P.M.B 11, Omoku, Rivers State,
NIGERIA

[5]Electrical/Electronic Engineering, Federal Polytechnic,
Ohodo, Enugu, State,
NIGERIA

[6]Information and Communications University,
P.O. Box 30226, Lusaka,
ZAMBIA

Abstract: - Harmonic reduction in a two-level power inverter using an enhanced-direct current (dc) based modulation technique is presented in this paper. A buck-boost power inverter is the test system used in this study with an enhanced-DC-based based-modulation technique. In this research, an enhanced-based modulation technique is made up of negative bias-rectified sinewave signals and triangular wave signals. The negative rectified-bias sinewave and carrier wave modulation techniques are compared to produce firing signals for triggering the DC-DC buck-boost power switch. The anticipated system is exceptional because the triggering signals for switching the DC-DC power section generated positive trains of signals with two exclusive sections that handle both the higher and lower harmonics distortions concurrently unlike conventional techniques. The overall AC voltage output of the system produces 323.5V 50Hz pure sine wave with THD of 0.1072% and AC of 5.97A with THD of 0.0521% as well as efficiency of 96.68%. The proposed system experimental work was carried out.

Key-Words: - Enhanced, Harmonics, Modulation, Inverter, Two-level, Triangular.

Received: April 23, 2024. Revised: August 26, 2024. Accepted: September 19, 2024. Published: November 22, 2024.

1 Introduction

Power electronics as a discipline, has revolutionized the power sector since its inception. This is obvious in the power DC-AC converters. Power DC-AC converters invert DC power to AC power for energizing AC loads, [1]. Uninterruptible power supply (UPS), Adjustable speed drives (ASDs), static var compensators, active filters,), flexible AC transmission systems (FACTSs), and voltage compensators, to name a few applications, are driven as the result of power electronics, [2], [3]. There are numerous power inverters such as single-phase two-level inverters, single-stage-multilevel inverters, three-phase two-level inverters, three-phase multilevel inverters, current source inverters, voltage source inverters, hybrid, bidirectional power inverters, multiphase inverter etc., [4], [5]. However, the target of this research is the two-level waveform of a DC-AC power converter.

The key benefit of this research system is tailored towards mitigating the high percentage of harmonic contents prevalent in conventional two-level DC-AC power converters. Once the harmonics are lessened, other harmonics' reduced-link merits like a decrease in system heating effects, pure sine voltage output waveforms, reduced power losses, increase in efficiency, high voltage ratio and cost effectiveness of the product cannot be isolated from the operating system.

2 Problem Formulation

One of the key problems of two-level power inverters is the presence of excessive harmonic distortion (THD) rates. The existence of high harmonics distortions defaces and reduces the quality and efficiency of output voltage and current waveforms. Apart from disfiguring the shape of the waveforms, the market value of the system is not left out. Additionally, the high presence of harmonic distortions results in greater thermal effects. This paves the way for the malfunctioning of the system. Filters and different modulation techniques have been proposed by many researchers with both merits and demerits.

3 Problem Solution

The author in [5] used a sinewave modulation technique and single-pulse generated by a DC-based modulation scheme. They equally used adaptive techniques to tackle the low-order harmonics. However, they obtained a THD of 11.15% at AC voltage and frequency of 44.93V and 50Hz which is higher than the IEEE standard. The sinusoidal pulse width modulation, SPWM, and large LC filter were used by authors in [5] and [6]. Two demerits of this technique are, that the system becomes large and expensive as a result of the utilization of a large size of filter and there would be losses of triggering action of the power switches of both the DC-DC power converter and DC-AC converter. The DC and harmonics elimination techniques were utilized in reducing the total harmonics distortion, [7]. They realized a THD of 3.87% at an AC voltage of 43V and the fundamental frequency of 50Hz of their research system. This implies that by the moment there is every chance of an increase in system output voltage attaining 311V(220Vrms). Two staged conversion buck-boost multilevel DC-AC power converters for solar power generation method were presented in [8] utilizing high triggering frequency based on SPWM. A THD of 64.62% was accomplished at 50V by the authors. This led to the system having low power factor operation and high losses.

A traditional staircase modulation technique utilized in [9] was applied in regulating a hybrid multilevel DC-AC power converter configuration with a lower number of switching components. In [10], a zero-crossing digital modulator was used to exploit the basic component and reduce certain low ripples in the power inverter. Apart from this modulating scheme acting on low harmonics, it has difficult computational analysis.

The efficiency improvement of DC-DC power converters by parallel switch arrangement was studied by the authors in [11]. The solitary switch utilized in their work was switched by uniform triggering pulses at 25 kHz. The 25 kHz triggering pulses were realized with the help of an Arduino UNO microcontroller that accomplished a conversion efficiency of 70%. However, the uniform pulses produced mitigated low harmonics. A lot of DC-DC converter configurations were reviewed by authors in [12] based on their various degrees of efficiency performances. However, only circuit configuration modulation techniques that also contribute significantly to the efficiency of DC-DC converters were not taken into consideration by the authors in their work.

Reference [13] worked on the Harmonic reduction method for a single-phase DC-AC converter without an output filter using half-wave rectified AC signals compared with DC voltage for producing switching pulses for triggering the DC power switch. The percentage THD of the output voltage of 227V of the inverter realized was 4.97% within the IEEE standard. However, the half-wave rectified AC signals used were operating in a discontinuous current mode which would lead to a decrease in the system efficiency.

The common things on the already work reviewed are handling the harmonics generated by the DC-DC input converters with uniform switching pulses. This shows that they either take care of the high-order harmonics or low-order harmonics differently. So, this paper aimed to close the gap between handling low-order harmonics and high-order harmonics by comparing the negative DC bias-rectified sinewave with negative carrier wave signals in every cycle. The DC bias-rectified sinewave with negative carrier wave signals operates in continuous current mode. The outcome of the comparison will produce two distinctive regions in a cycle. One region with large space takes care of mitigating low-order harmonics while the compressed region reduces the high-order harmonics and this is a unique feature other ones do not possess. This implies that for every cycle, both low-order harmonics are minimized at the same time, unlike the conventional schemes that handle either differently. So as soon as both high and low order are reduced simultaneously per cycle, the power losses will be minimized, low output filter or negligible filter will be utilized, improved output waveforms will be obtained, negligible heating effects and good efficiency.

3.1 Materials and Methodology

The materials used in this work are active switches (IGBTs) and passive elements (inductor, La, diode, Dm, filters, Ca, La, C_b) This paper adopts analytical, simulation and implementation methods. The functional circuit for the proposed system is shown in Figure 1. The first stage used a conventional boost DC-DC power converter and operation duty cycle above 50% to produce the boosted voltage as shown in the input supply of Figure 1. The second stage utilizes the boosted voltage to generate AC power by sequential switching actions of Power switches SQ1-SQ4.

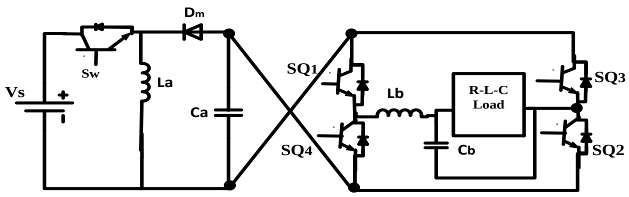

Fig. 1: Two level Buck-boost DC-AC power converter, [14], [15]

Equations for the duty cycle, inductance, and capacitance of the system of the DC-DC buck-boost converter are given in (1), (2), and (3), [1]. These are used for the design of the boost converter as referred to in [1].

$$D = \frac{|Vo|}{Vs+|Vo|} \quad (1)$$

$$L_a = \frac{V_S DT}{\Delta i_L} + 25.5\% \frac{V_S DT}{\Delta i_L} \quad (2)$$

$$C_a = \frac{D}{R_L\left({}^{\Delta V_0}/_{V_0}\right) f_{sw}} + 25.5\% \frac{D}{R_L\left({}^{\Delta V_0}/_{V_0}\right) f_{sw}} \quad (3)$$

3.2 Enhanced-Direct Current (DC) Based-Modulation Technique

Enhanced-direct current (DC) based-modulation technique (EDBMT) is accomplished by comparing the triangular wave with negative rectified AC biased-voltage signals. The negative rectified AC biased-voltage signals are operating in continuous current mode. The negative voltage of the triangular waveform is expressed as in equation 4. The (4) is an expression model for representing triangular waveforms of repeating sequence blocks in MATLAB/Simulink environment. It is deduced from Figure 2. The EDBMT in (6) is realized by comparing (4) and (5f)

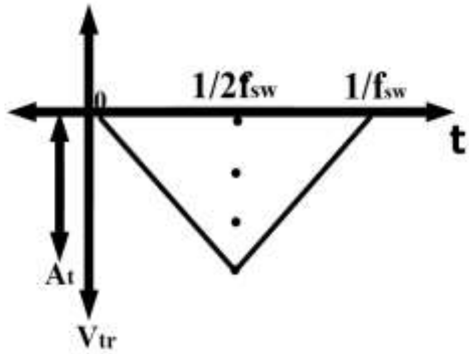

Fig. 2: Graphical representation of one cycle of negative carrier wave

$$V_t = \begin{bmatrix} 0 & {}^{1}/_{2f_{sw}} & {}^{1}/_{f_{sw}} \\ 0 & -A_t & 0 \end{bmatrix} \quad (4)$$

The voltage waveform of the negative rectified AC biased-voltage signal is deduced in equation 5(a-e) using the Figure 3.

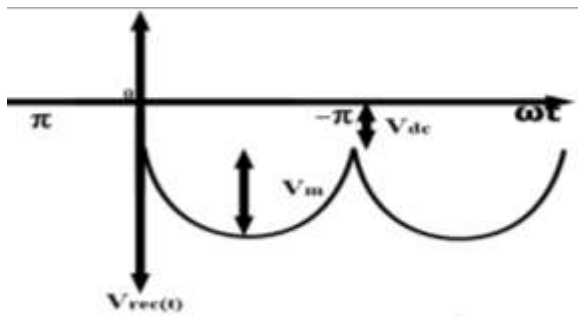

Fig 3: Graphical representation of one cycle of negative rectified AC voltage

$$V_{rec(t)} = -\left[V_{dc} + \left[\frac{2V_m}{\pi}\int_0^{\pi/2} cosdt + \frac{2}{\pi}\int_0^{\pi/2} cos\frac{t}{2}.cosntdt\right]\right] \quad (5a)$$

$$= -\left[\mathrm{V}_{dc} + \left[\frac{2V_m}{\pi}\int_0^{\pi/2} cost dt + \frac{1}{\pi}\int_0^{\pi/2}\left\{\cos\left(n-\frac{1}{2}\right)t + \cos\left(n+\frac{1}{2}\right)t\right\}dt\right]\right] \quad (5b)$$

$$= -\left[\mathrm{V}_{dc} + \frac{2V_m}{\pi} + \frac{V_m}{\pi}\left[\frac{sin\left(1-\frac{1}{2}\right)t}{n-\frac{1}{2}} + \frac{sin\left(1+\frac{1}{2}\right)t}{n+\frac{1}{2}}\right]_0^{\pi}\right] \quad (5c)$$

$$= -\left[\mathrm{V}_{dc} + \frac{2V_m}{\pi} + \frac{4V_m}{\pi}\left(\frac{1}{4n^2-1}\right)(1)^{n+1}\right] \quad (5d)$$

$$\mathrm{V}_{rec(t)} = -\left[\mathrm{V}_{dc} + \frac{2V_m}{\pi}\left[1 + 2\sum_{n=1}^{\infty}\left[(-1)^{n+1}.\frac{cosn\omega t}{4n^2-1}\right]\right]\right] \quad (5e)$$

Where $V_t, f_{sw}, A_t, V_{rec(t)}, \mathrm{V}_{dc}, \mathrm{V}_m$ and n represent the negative carrier wave, carrier wave switching frequency, the amplitude of the triangular wave, negative reference signal voltage, negative silent DC-biased voltage, the amplitude of reference rectified voltage and integer respectively. The dc-biased reference signal has the range of $0 \geq -\mathrm{V}_{dc} \geq -V_m$ in a positive direction. This implies that $\mathrm{V}_{\Delta_{bias}}$ is less than zero but greater than $-A_{\Delta 1}$.

This generates the following pulsating voltage expression, V_a.

$$V_a = \begin{cases} 1, & for\ \mathrm{V}_{rect} > V_t \\ 0, & for\ V_t \geq \mathrm{V}_{rect} \end{cases} \quad (6)$$

The (6) produces two distinct regions for reducing both low and high-order harmonics simultaneously unlike the conventional methods.

3.3 Modulation Technique for single-phase Inverter

The single-phase power switches' firing pulses are realized by comparing (7) and (8) to generate (10) as well as comparing (7) and (9) to produce (12). The (11) and (13) are the complementary signals of (10) and (12) respectively.

The expression of carrier wave is written in (7), [16] while the modulating signal and its 180º phase-shifted are represented in (7) and (8), [17], [18].

$$k_1 = \begin{bmatrix} 0 & {}^{1}/_{2f_{sw}} & {}^{3}/_{4f_{sw}} & {}^{1}/_{f_{sw}} \\ 0 & A_{\Delta 2} & 0 & -A_{\Delta 2} \end{bmatrix} \quad (7)$$

$$V_{Q1} = A_{S_Q}\cos\theta \quad (8)$$

$$V_{Q2} = -A_{S_Q}\cos\theta \quad (9)$$

$$S_{Q1} = \begin{cases} 1, & for\ V_{Q1} > k_1 \\ 0, & for\ V_{Q1} < k_1 \end{cases} \quad (10)$$

$$S_{Q4} = \overline{S_{Q1}} \quad (11)$$

$$S_{Q3} = \begin{cases} 1, & for\ V_{Q2} > k_1 \\ 0, & for\ V_{Q2} < k_1 \end{cases} \quad (12)$$

$$S_{Q2} = \overline{S_{Q3}} \quad (13)$$

Where $k_1, A_{\Delta 2}, V_{Q1}, V_{Q2}$, $A_{S_Q} S_{Q1}$, S_{Q2}, S_{Q3} and $S_{Q4}$are the triangular wave for H-bridge, the amplitude of the triangular wave, the voltage of modulating sine wave, the voltage of phase-shifted sine wave and its amplitude and power switches of the H-bridge respectively.

4 Simulated Results' Discussion

MATLAB/ Simulink model of the proposed system of Figure 1 is presented in Figure 4. It is observed that the modelled system has total harmonic distortions voltage and current of 0.1072% and 0.0521%. Figure 4 also presented Simulink built-up blocks of the negative DC-bias rectified sine waveform in comparison with the negative carrier wave.

The results obtained during the simulation of the system in MATLAB/Simulink environment are discussed as follows. Figure 5a graphically illustrates where the voltages of the proposed modulation scheme are plotted again time. It is noticed that the negative DC-biased rectified sinewave has a peak voltage of -0.96V and a frequency of 100Hz. The carrier wave signal has -1.1V and a switching frequency of 7.8 kHz. Figure 5b presented the improved switching signals. It is observed that the switching pulses have two unique regions for every cycle. One region with compressed pulses and the second region with spaced pulses. It also showed that for every cycle, the compressed region has 40 small pulses while the spaced region has two pulses.

The 40 small pulses tackled the high-order harmonics while the two pulses handled the low-order harmonics simultaneously unlike the conventional PWM. And by so doing the total harmonics distortion is highly mitigated.

Figure 6(a) shows the power output of the test system at a steady state after undergoing a transient time response of 0.015 seconds. Figure 6(b) represents the output voltage and current waveforms of the inverter. It can be observed that the voltage and current waveforms have 323.5 V and 5.5A at steady state.

Figure 7 displayed a plot of voltage and current versus normalized frequency. The plot shows the presence of appearances of ripples on both output voltage and current against normalized frequency. It indicated that the ripples in the voltage output waveform spread from 0.01 to 0.42 rads and disappeared while the ripples in the voltage output waveform spread from 0.01 to 0.2 rads.

Harmonics voltage output against frequency is plotted in Figure 8. It is noticed that at an output voltage of 323.5V and operating frequency of 50Hz, the system has a THD of 0.1072%. And it corresponded with the value shown in Figure 4.

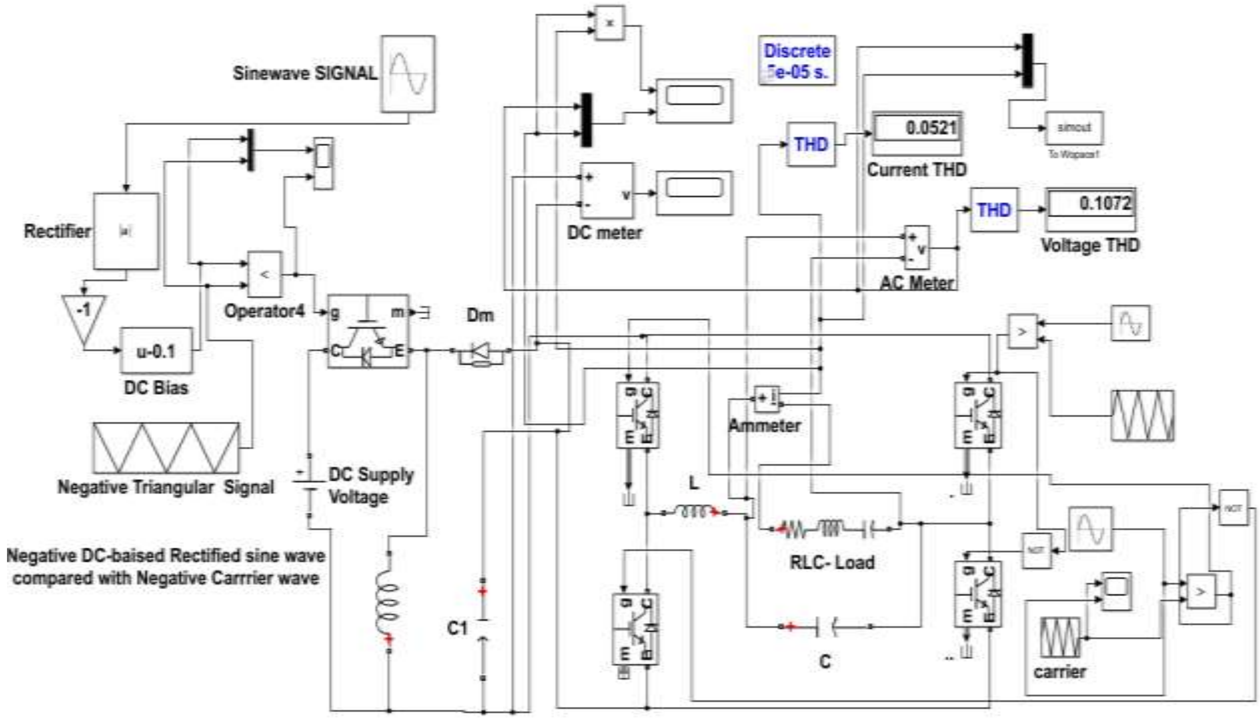

Fig. 4: The MATLAB/Simulink model for the proposed system

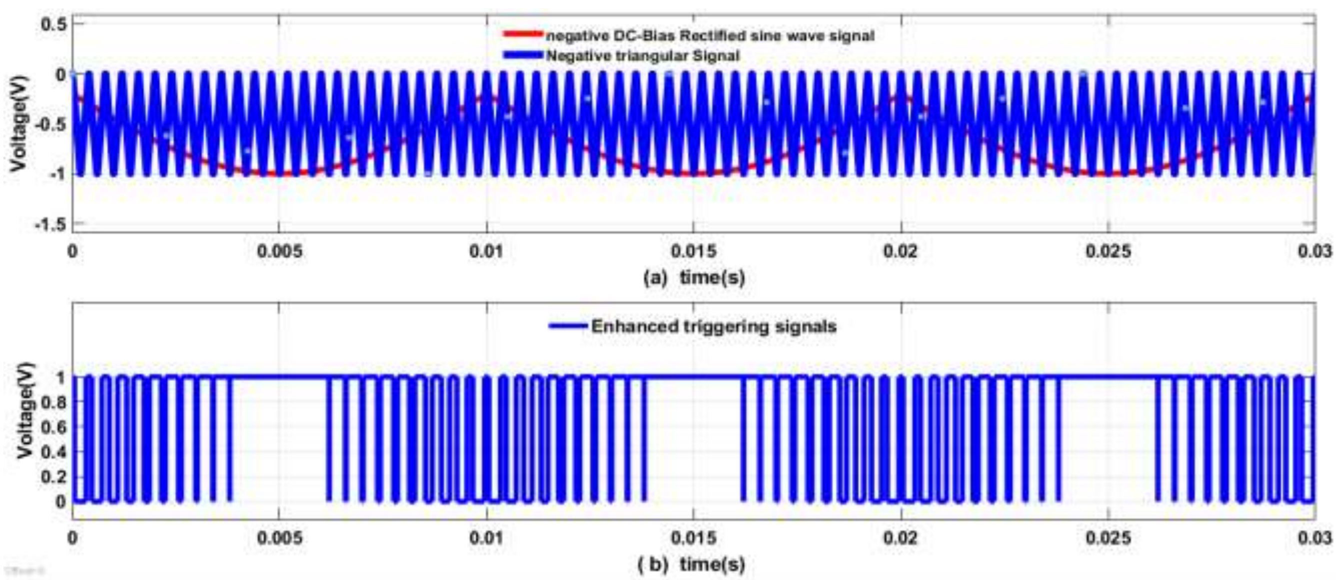

Fig. 5: (a) Comparison of negative triangular wave and DC-biased rectified sine wave. (b)Enhanced switching pulses

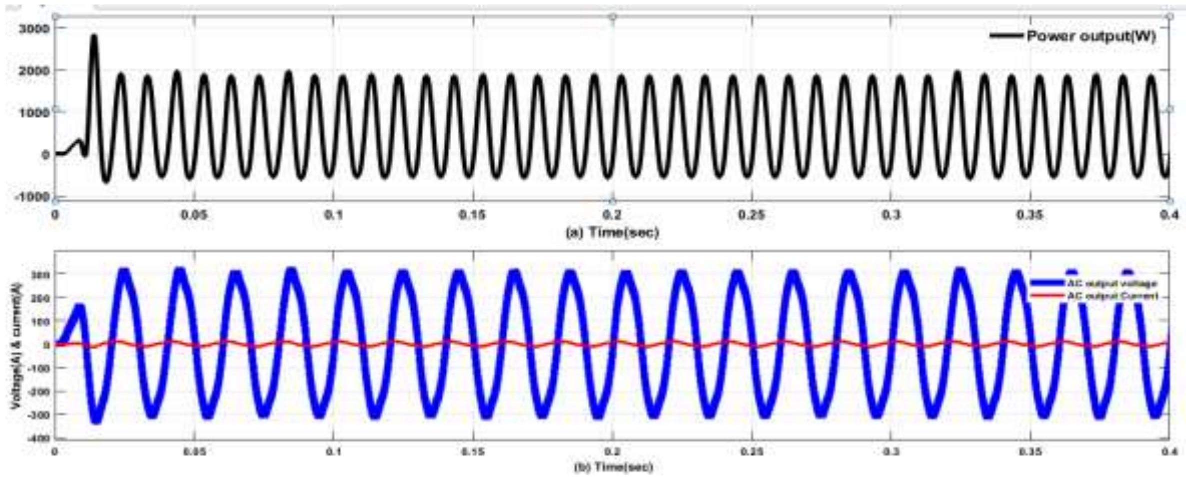

Fig. 6: (a) power output (b) Output Voltage and Voltage

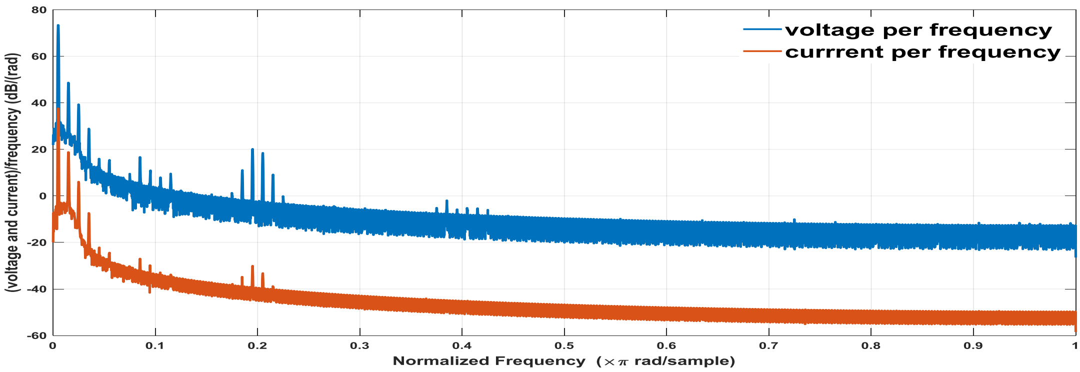

Fig. 7: Output voltage and current versus frequency

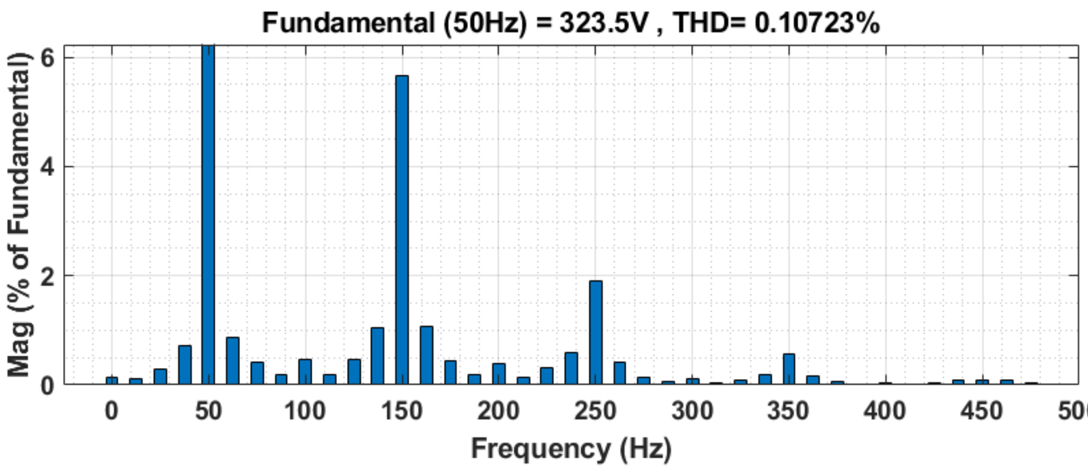

Fig. 8: Harmonics display of Output Filtered Voltage of the Proposed System under RLC Loads

Table 1. Comparison analysis of the proposed system with other already published two-level inverters

Modulation techniques	Harmonic Mitigation Method for the DC-AC Converter in a Single Phase System[5]	Modeling of the single-phase inverter in isolated photovoltaic systems to investigate the effect of low-frequency ripple on the capacitive input filter with a uniform modulation scheme[7]	Two-Stage Buck-Boost Multilevel Inverter for PV Power Generation. Faculty of Energy Eng, PWM[8]	Saw-tooth based-unipolar modulation with DC-compared with a triangular wave.[10]	Triangular wave-based bipolar modulation DC-compared with triangular wave.[10]	Harmonic reduction method for a single-phase DC-AC converter without output filter.[13]	Proposed system
DC-AC Power converter Output voltage	44.930V	43.00V	50.00V	294.10V	297.40V	227V	*323.5V*
Percentage level of THD of voltage output	11.150%	3.87%	64.62%	0.2865%	0.1471%	4.97%	0.1072%

Table 1 compares the proposed system with other already published work on two-level power inverters. According to the authors in [5] the AC output voltage of their inverter and its percentage total harmonic distortions are 44.930V and 11.150%. [7] has 43V and 3.87% as its inverter and percentage total harmonic distortions respectively. The inverter output voltage and percentage total distortion of [8] is 50V and 64.62%. Moreover, 297.40V and 0.1471% are the output voltage of the DC-AC converter and THD [10]. [13], also presented 227V and THD of 4.97%. However, in the proposed system, the output voltage and THD are 323.5V and 0.1072% So, it is observed that the proposed modulation scheme used in the DC-DC power switch in switching and delivering power to the test system shows that the inverter output voltage has the lowest percentage harmonics distortions and highest voltage output value among the other ones in the Table 1 for comparison analysis.

Table 2 shows simulation parameters and results. It observed that the test system has power out of 1931.295W and the efficiency of 96.68%.

5 Discussion of Laboratory Results

The results obtained from the laboratory implementation of the proposed system are displayed in Figure 9, Figure 10, Figure 11 and Figure 12. Figure 9 presented a digital oscilloscopic display -13V negative carrier wave that was compared with a -10.V DC-biased rectified modulating signal.

Table 2. Simulation parameters and results

Items	Ratings
Input Voltage V_s	48.00V
Input Inductance, La, and Capacitance C1	0.20mH and 47.5μF-98 μF
Duty Cycle, D	0.49-0.95
Input current	41.55A
Power input	1994.40W
Power output	1931.295W
Voltage Ripple	1.01%
Inverter Peak Voltage and Current	323.5V and 5.5A
Frequency of the negative rectified voltage	100Hz
Fundamental and Switching Frequencies	50Hz and 7.8kHz
Total Harmonic Distortion	0.1072%
Negative DC-biased Voltage	-0.101V
Efficiency	96.68%
Filter Capacitance C_f and Inductance L_f	50μF and 4.12mH
Amplitude of modulating Waveform and negative carrier wave	-0.96V and -1.1V

The -13V negative carrier wave shown in Figure 9 is the laboratory-implemented triangular wave. This triangular wave is operating at a frequency of 7.8kHz. On the other hand, the DC-biased rectified modulating signal operated at 100Hz. Figure 9 has already been shown in Figure 3 and Figure 4 and represented in (4) and (5e).

The improved switching pulses are displayed in Figure 10 they showed two distinctive regions as already shown in computer simulated waveform of Figure 4. Figure 10 showed that the spaced regions have two pulses while the compressed section has 32 pulses at a switching frequency of 7.160kHz. These two regions led to the mitigation of the THD in the system.

Figure 11 depicts the voltage waveform obtained across the RLC load. It is observed that it has a maximum value of 256V at the operating frequency of 50Hz. It represented the practical output voltage of the inverter.

Figure 12 shows the energized laboratory hardware prototype of the proposed system with buck-boost inverter and oscilloscopic display of voltage waveform. It consists of an implemented DC-DC power converter section, control units, a DC-AC power converter, and a digital oscilloscope. The control units are made of a DC control unit and an AC control unit. The DC control unit is responsible for producing enhanced switching pulses for triggering the DC-DC power converter's switch.

6 Conclusion

Presented in this paper is harmonic reduction in a two-level power inverter using an enhanced-direct current (DC) based- modulation technique. The simulation of the proposed system was done in MATLAB/Simulink 2018a and prototype validation was carried out in the Industrial Electronics Lab. Under the simulation part, the following results were obtained: DC-offset of rectified sinewave signal at amplitude of -0.96V and frequency of 100Hz, triangular wave of -1.1V and 7800Hz, enhanced switching pulses with two unique regions and frequency of 7.8kHz for boost switch, Sw, input power of 1994.40W, output current of 5.5A, and output voltage of 323.5V with THD of 0.1072%. 50Hz and pure sine waveform.

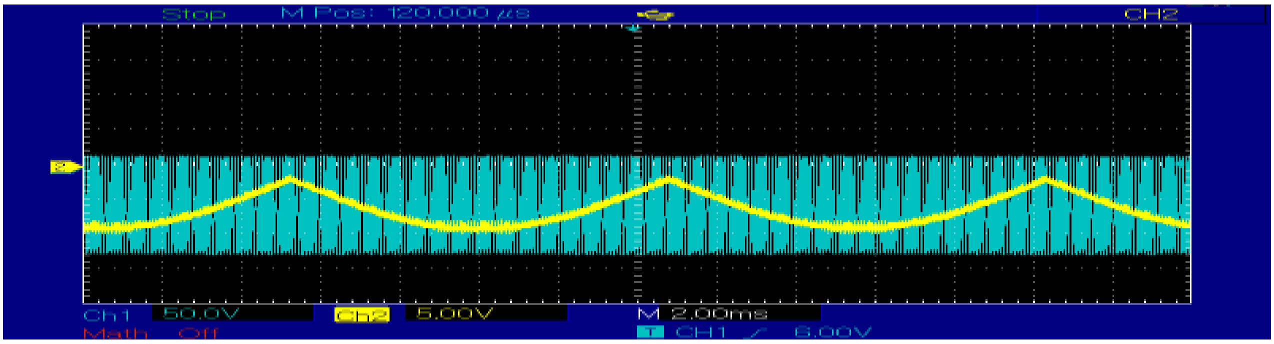

Fig. 9: Lab. Implementation of Comparison of negative triangular wave and DC-biased rectified sine wave

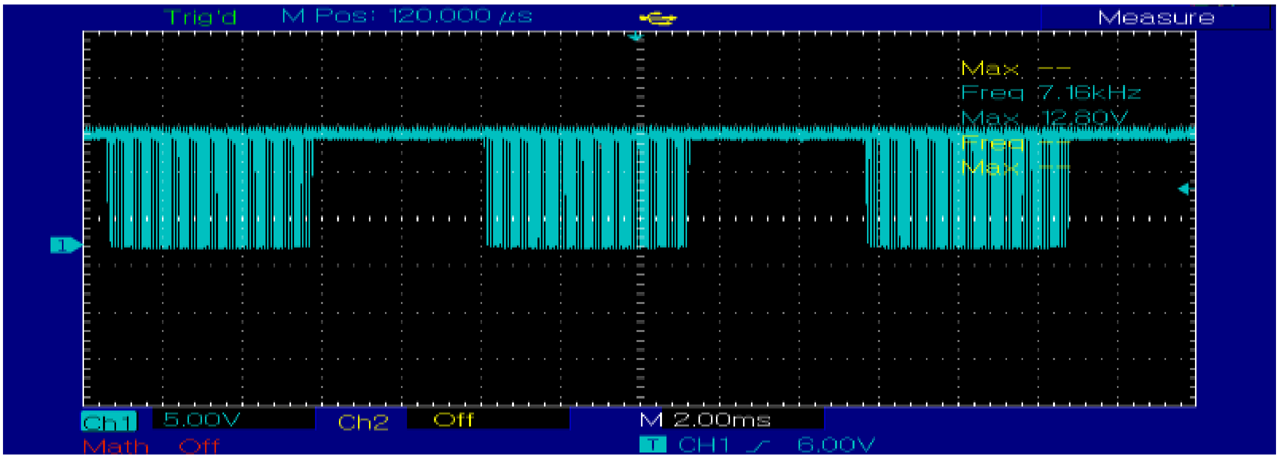

Fig. 10: An enhanced switching pulses

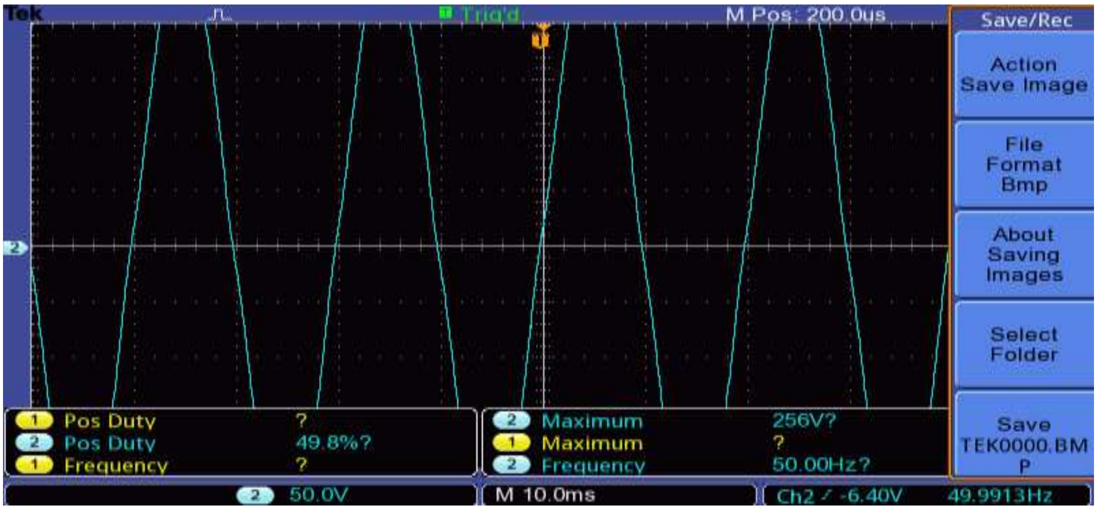

Fig. 11: Output Voltage of Two-level buck-boost DC-AC Converter

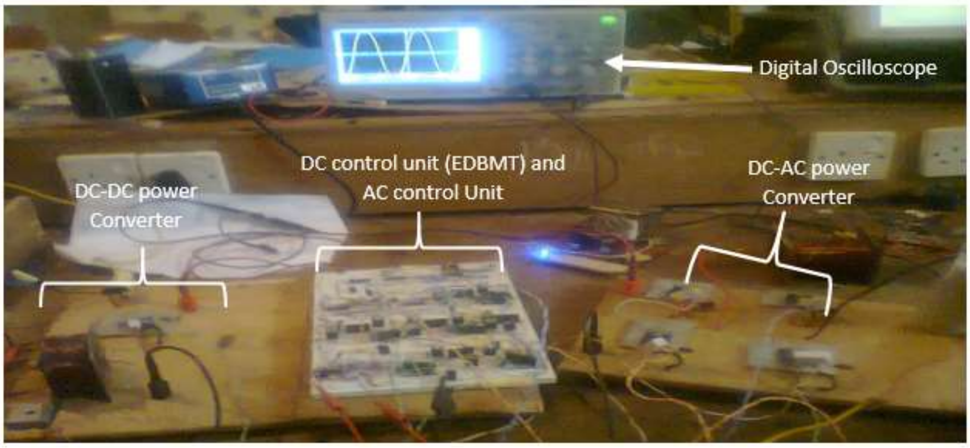

Fig. 12: Prototype of the test system with the proposed modulation scheme

Experimentally, the results realized are as follows: negative DC-biased rectified sinewave signal at an amplitude of -10V and frequency of 101.56Hz, triangular wave of -13.0V and 7.16kHz improved switching pulses with two distinct regions and frequency of 7.16kHz for buck-boost switch, Sw, output current of 4.50A, and output voltage of 256V, 50Hz and pure sine waveform.

It is observed that there are good similarities between the simulated results of the proposed system and the experimented system. This validates the research work carried out in this paper. This means that there are close relationships or similarities between the waveforms of simulated work in the MATLAB/Simulink environment and the oscilloscopic waveforms of the laboratory implementation of the same work. The enhanced modulation scheme used is desired to be extended to be applied in other stages of power conversion systems, and hybrid multilevel inverters in future research in distributed generations. For instance, complementing the switching pulses will enable producing complementary switching for switching two power switches in bidirectional DC-DC power converters.

Acknowledgment:
The authors acknowledge the support received from the Africa Centre of Excellence for Sustainable Power and Energy Development (ACE-SPED), University of Nigeria, Nsukka that enabled the timely completion of this research work. They also appreciate and acknowledge the Laboratory of Industrial Electronics, Power Devices, and New Energy Systems, University of Nigeria, Nsukka that assisted us in using their Computer systems to carry out the MatLab/Simulink simulation work

References:

[1] Daniel. W. Hart. (2011), *Power Electronics*, New York: McGraw-Hill. ISBN: 978-0073380674.

[2] M. H. Rashid. (2011), *Power Electronics Handbook Devices, Circuits, and Applications*, Burlington, USA: Elsevier Inc, [Online]. https://drive.google.com/file/d/0B0UDKg1bCXX0eXNCYmFzeVNON2c/view (Accessed Date: February 24, 2024).

[3] Frede Bjaabjerg, Zhe Chen and Soeren Baekhoej Kjaer. (2004). *Power electronics as efficient interface in dispersed power generation systems*," IEEE Transactions on Power Electronics, vol. 19, no. 5, pp. 1184-1194, https://doi.org/10.1109/TPEL.2004.833453.

[4] D. Cherifi, Y. Miloud and M. Mostefai. Performance of Neutral Point-Clamped Five Level Inverter Using Space Vector Modulation Control Fed by DPC-VF-SVM Rectifier, *WSEAS Transaction on Power Systems,* Vol, 16. pp. 275-287. https://doi.org/10.37394/232016.2021.16.28.

[5] P. Singh. C.S and Lakhmanan.M. (2015). Harmonic Mitigation Method for the DC-AC Converter in a Single-Phase System," Harmonic Mitigation Method for the DC-AC Converter in a Single Phase System. *International Journal for Trends In Engineering & Tech.*, Vol. 5 Issue 2. pp. 2349-9303, [Online]. https://www.academia.edu/16732226/Harmonic_Mitigation_Method_for_the_DC_AC_Converter_in_a_Single_Phase_System (Accessed Date: March 9, 2024).

[6] R.O. Caceres and I. Barbi(1999) A boost DC-AC converter: analysis, design, and experimentation, *IEEE Transactions on Power Electronics* ,Vol. 14, Issue: 1,pp. 134-141. https://doi.org/10.1109/63.737601.

[7] J. José Antonio, P.RAMIREZ, Javier. G.Elizalde (2019),Modeling of the Single-Phase Inverter on Isolated Photovoltaic Systems To Investigate The Effect Of Low Frequency Ripple on The Capacitive Input Filter DYNA, *Energía y Sostenibilidad*, vol. 8, no. 1, https://doi.org/10.6036/ES9233.

[8] Asmaa EL-Hosainy, A, Azazi, H.Z., Hamed, H.A.,and El- Kholy, E. E.(2017.), *A Two-Stage Buck-Boost Multilevel Inverter for PV Power Generation.* Faculty of Energy Eng. - Aswan University, Aswan, Egypt, pp.6-28, [Online]. https://www.researchgate.net/publication/341412141 (Accessed Date: June 25, 2024).

[9] Tiago Davi C. Busarello,A. L. S. M, Adriano P and M. G. Simões (2019), Understanding the Staircase Modulation Strategy and its Application in both Isolated and Grid-Connected Asymmetric Cascaded H-Bridge Multilevel Inverters. *IEEE Transactions on Industry Applications*. Vol. 55, Issue: 5, pp. 5371-5382, https://doi.org/10.1109/TIA.2019.2927189.

[10] N. R. Klaes, C. M. Ong. (1987), Implementation and study of a digital staircase pulse width modulator, in *Proceedings of the IEEE Power Electronics Specialists Conference*, pp. 128–134, Blacksburg, VA, USA, https://doi.org/10.1109/PESC.1987.7077174.

[11] M. F. Mohammed, A. H. Ahmad, A. T. Humod. (2018). Efficiency improvement of DC-DC boost converter by parallel switches connection," *International Journal of Applied Engineering Research*, vol. 13, pp. 7033–7036, [Online]. http://www.ripublication.com (Accessed Date: January 20, 2024).

[12] A. Tomaszuk, A. Krupa. (2011). High efficiency high step-up DC/ DC converters-a review," *Bulletin of the Polish Academy of Sciences: Technical Sciences*, vol. 59, no. 4, pp. 475–483, http://dx.doi.org/10.2478/v10175-011-0059-1.

[13] Konstantinos G. Georgakas, Panagis N. Vovos (2014). Harmonic reduction method for a single-phase DC-AC converter without output filter. *IEEE Transactions on Power Electronics.* pp.1-8. DOI: 10.1109/TPEL.2013.2286918.

[14] Nimy V P and Surasmi N L,(2015), *Harmonics and DC offset elimination scheme for buck-boost converter fed-single phase inverter*, *IEEE International Conference on Control, Communication & Computing India (ICCC)*, Trivandrum, pp.254-259, https://doi.org/10.1109/iccc.2015.7432901.

[15] R.O. Caceres and I. Barbi ((2002) A buck-boost DC-AC converter: operation, analysis, and control, *6th IEEE Power Electronics Congress. Technical Proceedings. CIEP 98* (Cat. No.98TH8375), 134 – 141, Morelia, Mexico, https://doi.org/10.1109/CIEP.1998.750672.

[16] Robert W. Erickson and Dragan Maksimovic (2020), *Fundamentals of Power Electronics*, Springer Cham, Springer Nature Switzerland AG, 3rd Edition, eBook ISBN: 978-3-030-

43881-4. https://doi.org/10.1007/978-3-030-43881-4A.

[17] Musa and G. Galadanci, (2009),*5KVA Power Inverters Design and Simulation Based on Boost Converter & H-Bridge Inverter Topology*, *Bayero Journal of Pure and Applied Sciences*, vol. 2, Issue 1, pp. 6-13, https://doi.org/10.4314/BAJOPAS.V2I1.58448.

[18] A. O. S, S. E. O. C U. Eya, (2021), Constant and Wireless Controlled DC-to-AC Based Boost Diff. Converter with a Sensor-less Changeover System, *International Journal of System Ass. Eng. and Ma.*, pp.1-19. https://doi.org/10.1007/s13198-021-01451-x.

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

- Candidus .U Eya, carried out the conceptualization and laboratory experimental coupling of different sections of the work. He also typed the work.
- Ugwuijem Chikadibia Daniel worked on designing of the system parameters and simulating the system using MATLAB/Simulink software.
- Uzoma Stephen Egesimba is responsible for the statistical analysis of the research system.
- Ezike Morris Obiora participated in harmonic analysis of the system and in checking any typographical errors in the work.
- Lukumba Phiri played the role of online gathering of materials and review research of the related work and critical analysis of the implemented work.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

There is no source of funding.

Conflict of Interest

The authors have no conflicts of interest to declare.