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Controlling of ZETA Full Bridge Inverter Buck – Boost Output Voltage

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ABSTRACT

The development of science and electronics is increasing rapidly, marked by the development and use of renewable energy, such as electric vehicles and solar panels. A good power converter is needed to maintain its practical service life. Renewable energy systems with DC output voltage generally require a DC-DC converter to increase or decrease the voltage level and an inverter to convert the DC voltage to AC. A ZETA Inverter, which combines a ZETA Converter with a Full Bridge Inverter, is proposed in this research. ZETA Converter can increase and decrease the output voltage as needed. The output voltage setting is also applied to the ZETA Inverter topology, using the Voltage Transducer LV25-P as the output voltage detector. The sensor reading results are then compared with the desired reference and then controlled using Proportional Integral (PI) Control, producing a pulse width modulated signal as a switching control on the power switch. Thus, the output voltage can be regulated according to needs. Simulation testing using Power Simulator (PSIM) software is carried out first and then validated by hardware testing in the laboratory. The final result was that the ZETA Inverter output voltage could adjust the reference voltage to increase and decrease voltage conditions. Under changing load conditions, the output voltage remains at the reference value. The defect (THD) level at the output voltage was 1.2%, which meets the IEEE 519 standard, below 5%. Thus, the ZETA Inverter can be a good power converter in renewable energy systems.

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1. INTRODUCTION

Solar energy is a renewable energy source with good potential to replace conventional power plants, using solar panels that we usually know as photovoltaics [1]. In some countries, using solar panels has very high potential because of the supportive climate. Indonesia has good potential to develop solar power plants because of the tropical climate, which makes sunlight available all year round [2]. With sunlight all year round and the temperature in Indonesia, which is not very hot, solar panels can work optimally, and because of that, many people want to build their own Solar Power Plants on the roofs of their houses [3]. Because of the effectiveness of solar panels, they are a renewable energy source that can replace non-renewable energy [4], [5]. Power electronics technology plays a vital role in distributed solar power plants with networks or those used by individuals. In addition to Solar Power Plants, which require high-quality power electronics, power electronics also contribute to the development of electric vehicles or what we know as Electric vehicles. The electric vehicle automotive industry is increasing in Indonesia, as seen from the many types of electric vehicles in Indonesia [6]. Electric vehicles are vehicles that are being developed because they can help reduce air pollution from the use of vehicles that use combustion [7], [8]. The rapid progress in power electronics used in electric vehicles aims for competitive performance. It can use efficient energy to reach a greater distance with the same amount of energy [9]. Therefore, the power electronics system owned by electric vehicles is an essential and quite tricky task. It must efficiently use energy for long distances and consume economical fuel. Electrical engineers are competing to create the best because the demand for power electronics is expected to have efficient performance and a compact design [10].

One of the types of power electronics is the Full Bridge inverter, which is widely used in power plants and electric vehicles. The entire bridge inverter is a power electronics that operates with a DC power source and is then converted into AC voltage or current that we usually know as alternating current [11]. In the Solar Power plant system, photovoltaics uses the Full Bridge inverter as a voltage amplifier to balance the voltage with the high-level network. It also converts direct voltage to alternating voltage [12]. At this time, the development of the electric power system is on the verge of a paradigm shift due to the increasing penetration of power electronics-based resources, namely full bridge inverters [13]. The entire bridge inverter has advantages in the fundamental components used, which can be vital for frequency and amplitude with variable values [14]. So, it can be concluded that the entire bridge inverter usually increases voltage and converts direct voltage to alternating voltage [15]. The purpose of creating a full bridge inverter is to convert the source voltage from the battery source, a place to store DC voltage that the Full Bridge inverter will convert into alternating voltage or AC [16]. Buck-boost is a condition where the converter can work on a buck or boost condition depending on the duty cycle. In buck condition, the output voltage will be lower than the input. Otherwise, the output voltage will be more significant in the boost condition than the input. This buck-boost functions as a balancer for the voltage requirements needed for the load, so it can be explained that when the load is enormous, the device will perform boost mode, which will meet the voltage shortage when the load is too much. When the large load is suddenly reduced immediately, the device will perform buck mode so that the voltage is not wasted. The user wants to create a Full Bridge inverter with a Full Bridge inverter voltage amplifier system using the zeta converter methodology in this journal. The zeta converter has advantages that can be applied at high frequencies with relatively low switching voltages [17]. This zeta converter has advantages: high voltage amplification, low diode, metal oxide semiconductor field effect or switch voltages, low ripple, and high efficiency [18]. The zeta converter can improve power quality, as seen from the small, high total harmonic distortion value and high power factor [19], [20].

In this study, the user wants to combine the zeta converter topology system with a full bridge inverter that can perform controlled voltage buck-boost. The load does not get excess voltage. The zeta converter is one of the various converters used to run the buck-boost system [21]. Buck-boost is very much needed to increase the voltage when overloaded and will be able to reduce the output voltage if it is not excessive [22], [23]. Controlled voltage is an essential system because if it is not controlled correctly, it will affect the output in the long or short term [24]. Controlled voltage is very beneficial in minimizing power loss so that no power is wasted, and it can also add reactive power reserves [25]. So, this study aims to create a full bridge inverter that can perform buck-boost with the help of zeta converter methodology to reduce the Total Harmonic Distortion (THD) value produced and control the voltage so that it can become a full bridge inverter with high efficiency and no power is wasted. Most traditional full bridge inverter topologies produce high total harmonic distortion values , which is not good [26]. One cause of high total harmonic distortion values in power electronics is the use of semiconductor components such as MOSFETs (Metal Oxide Semiconductor Field Effect); because the metal oxide semiconductor field effect has a high total harmonic distortion value, the user-designed this study using a small amount of metal oxide semiconductor field effect so that the total harmonic distortion value produced is not high.

The second part of the methodology will explain the system's operating mode and circuit. The third part will discuss the simulation analysis, the implementation of the entire full-bridge inverter on hardware, and the results. Finally, the conclusion will be made.

2. METHODOLOGY

As illustrated in Figure 1, it is a power circuit divided into two main components: a full-bridge inverter and a buck-boost proposed in this paper. The proposed topology is more effective because it has a more comprehensive operating range caused by the output of the entire bridge inverter directly connected to The buck-boost topology zeta converter increases or decreases the voltage.

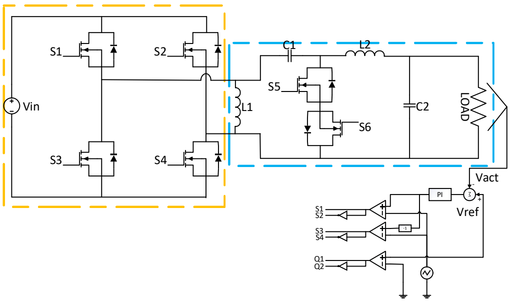


Figure 1. Voltage-controlled buck-boost full-bridge inverter zeta scheme.

In addition to being a more effective topology, the user chose this topology because it can reduce the number of existing semiconductor components. The more semiconductor components there are, the higher the total harmonic distortion value can be produced. This can create excessive heat when running at high frequencies, making the system more complex. Therefore, the user conducted this study to prove that creating a full bridge inverter buck-boost is possible using a few semiconductor components.

2.1 Operation Mode

Generally, a full-bridge inverter has two cycles: a positive cycle and a negative cycle. Like the general full-bridge inverter topology, S1 and S4 are used as positive cycles, and S2 and S3 are used as negative cycles. The following section is buck-boost using a zeta converter topology system. There will be three conditions in the buck and boost sections: the input voltage (Vin) is greater than the output (Vo), called a buck, Vin will be equal to Vo, and Vin is smaller than Vo, called boost. In addition, the following in Table I explains the logic signals in the three conditions that have been described.

Table 1 Logic Signal of Power Switch

Condition	Mode	S1	S2	S3	S4	S5	S6	M	Output
1	1	ON	OFF	OFF	ON	OFF	ON	< 0.5	VL1 = Vin
	2	OFF	OFF	OFF	OFF	OFF	ON	< 0.5	Vo < Vin
	3	OFF	ON	ON	OFF	ON	OFF	< 0.5	VL1 = -Vin
	4	OFF	OFF	OFF	OFF	ON	OFF	< 0.5	Vo < -Vs
2	1	ON	OFF	OFF	ON	OFF	ON	0.5	VL1 = Vin
	2	OFF	OFF	OFF	OFF	OFF	ON	0.5	Vo = Vin
	3	OFF	ON	ON	OFF	ON	OFF	0.5	VL1 = -Vin
	4	OFF	OFF	OFF	OFF	ON	OFF	0.5	Vo = -Vs
3	1	ON	OFF	OFF	ON	OFF	ON	> 0.5	VL1 = Vin
	2	OFF	OFF	OFF	OFF	OFF	ON	> 0.5	Vo > Vin
	3	OFF	ON	ON	OFF	ON	OFF	> 0.5	VL1 = -Vin
	4	OFF	OFF	OFF	OFF	ON	OFF	> 0.5	Vo > -Vs

According to Condition 1 above, the inverter's power switch runs alternately on the positive and negative cycles, symbolized by S1, S2, S3, and S4. This also happens in the buck-boost switch section on switches S5 and S6. This condition is where the hardware works in buck mode. Buck mode is because the input voltage will be greater than the output due to the duty cycle (M), which is less than 0.5, as explained in the equation section.

Condition 2 explains that this hardware can be used as a system that produces an output voltage equal to the input voltage. This condition can occur because the duty cycle value (M) equals 0.5. A regular full bridge inverter helps convert DC to AC voltage in this mode.

Condition 3 shows that this boost mode uses the same switch as the other two modes. However, there is a difference in the duty cycle (M) value, which can cause the output to be greater than the input. The value of M shows a value of more than 0.5, so the output value can be greater than the input, which is a boost. The three logic signal conditions in Table I can be expressed by proven equations. The first is when the current Vin flows to L1 through S1 and S4, and then the equation is (1).

$$V_{L1} = V_{IN} = L_1 \frac{dil_1}{mt} \tag{1}$$

The above equation can be simplified into.

$$\frac{dil}{mt} = \frac{V_S}{L_1} \tag{2}$$

So the value of Inductor 1 (VL1) when S1 and S4 are active.

$$\Delta I_{L1\_on} = \int_0^{DT} dIL_1 = \frac{V_S MT}{L} \tag{3}$$

After arriving at L1, it will continue on the buck-boost switch, and then the equation will become.

$$\Delta I_{L1\_off} = \int_0^{(1-M)T} dIL_1 = \frac{V_O(1-M)T}{L} \tag{4}$$

The amount of energy stored in inductor one during conductive and non-conductive conditions in one cycle equals zero (0).

$$\Delta_{L1\_off} + \Delta_{L1\_on} = 0 \tag{5}$$

Next, we will substitute it into the equation above (6). This produces the M value, the duty cycle value, which is the setting in the buck-boost condition (7).

$$\Delta_{L1\_off} + \Delta_{L1\_on} = \frac{V_O(1-M)T}{L} + \frac{V_S MT}{L} = 0 \tag{6}$$

$$\frac{V_O}{V_S} = \frac{M}{1-M} \tag{7}$$

2.2 Control System

Figure 1 above is a picture of the proposed scheme, which the user has thoroughly studied. It can be seen that the control on the Full Bridge inverter is controlled by running the switch from S1 - S4, and then the buck-boost section is controlled by running S5 and S6. This control system will carry out the initial process with the output on the load or out, which will be read by the voltage sensor (read as Vact). Then, the reference voltage is the voltage we want; it will be compared with Vact to get the error value. After finding the error value, the modulator will modulate the PI control input, which will be used to activate the switch based on the error value. The following is the PI Control Equation (8):

$$\text{U(s)} = Kp\,(1 + \frac{1}{Kp/Ki}) \tag{8}$$

The user uses PI control, which is a combination of proportional (P) and integral (I) because it has a high speed of eliminating tuna conditions (offset). Proportional control is relatively easy but has a disadvantage that is difficult to accept because it has an offset value that is too long and will make a tool unable to follow when it is needed to read quickly.

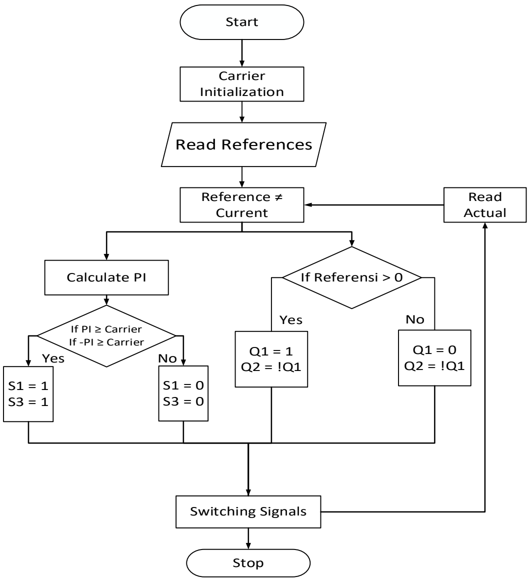


Figure 2 Working system algorithm.

The tool cannot work correctly. Integral has the advantage of eliminating offset values rapidly. Still, it has the disadvantage of causing a high transient response, making it difficult for the system to achieve a response with steady-state conditions. In contrast, proportional control can achieve steady-state conditions well but with low transient response. So, the user chose to use a combination of the two controls so that the PI control was selected, which can complement the shortcomings of each control.

The modulation work system compares the PI control output with the carrier signal, which will produce pulse width modulation (PWM) as the modulation output. The signal that has become PWM will be used to run the power switch on the full bridge inverter circuit, namely switches S1, S2, S3, and S4 work at high frequencies to form a sinusoidal signal. While the buck-boost switch compares the Vref value with zero, the resulting signal will rotate switches S5 and S6. Therefore, this concept is used by users because the output voltage of the full bridge buck-boost inverter can always be maintained adequately as desired, even though there is a change in the load value on the output side. This can be seen by comparing the reference voltage with the output voltage of the circuit, which can ensure that the output voltage will always follow the given reference. Figure 2 explains the working system algorithm of the control used.

2.3 Components and Parameters

This work is re-validated using parameters and components that have the same value and quantity, which is done in two events: first, an experiment is carried out using a simulation on a computer, and after the simulation is carried out successfully, it is made as hardware in the laboratory where the application is submitted. Why start with simulation? The components used will be adjusted to those simulated when making the hardware. Then, the simulation results will be compared with components generally available in stores that will be easier to implement. One of the values that must be considered is the load value, and the power value must also be considered to maintain the load or resistance properly. Therefore, Table II explains the names of the components used in the hardware and those used for the component values in the simulation.

Table 2 Components

Components	Type
Power Switch	MOSFET IRFP250
Voltage Sensor	LV25-P
Optocoupler	IR2111 and TLP250
Microcontroller	STM32F407
Load	50 - 100Ω
DC Supply	12V
Capacitor 1	100uF
Capacitor 2	10uF
Inductor 1	1.5m
Inductor 2	0.3m
Switching Frequency	10KHz
Gain Integral	2
Gain Proportional	0.05

The components displayed in Table II are all the components used. Still, the voltage sensor (LV25-P) is necessary for this study. Why is this component also listed as an essential component? Without this sensor, the microcontroller cannot read the AC voltage value on the output, which causes the control not to run. This LV25-P reads the AC voltage value issued on the output; after the sensor captures the AC voltage data, the data will be sent to the microcontroller to be compared with the reference signal and produce an error value. This value will be processed so that the output results can match the reference value; the better the output results are, the smaller the error value will be.

Why is controlled voltage needed in a system being studied by the user? The user considers that power quality problems often result in the load received by the power electronics being unstable, known as an unbalanced load. An unbalanced load is a condition where there is an excessive load on a system, which results in the voltage received by some loads being lacking, which sometimes results in some devices being unable to work optimally and can even cause damage to the device if it is continuously forced. Therefore, a voltage sensor (LV25-P) is used, which reads the output voltage so that.

It can read the voltage section. If there is a shortage or excess, the data can be sent to the microcontroller, which will compare it with the desired reference value so that buck or boost will be carried out according to the load given. Then, the entire load will get the voltage supply according to what is needed, resulting in the device working optimally and having a longer service life.

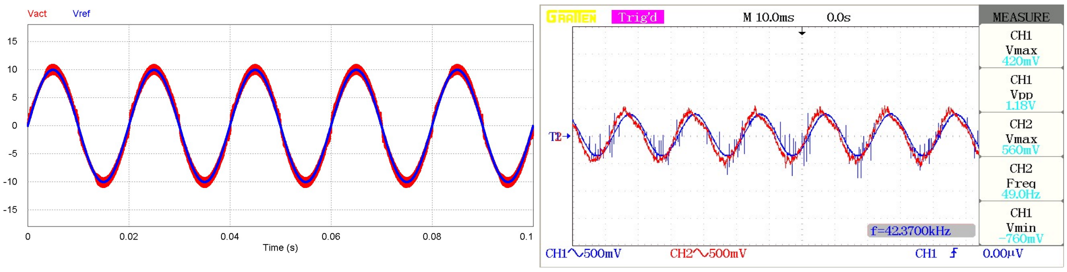
3. RESULTS

Figure 3 shows the results of the hardware implemented in the laboratory, and all existing parameters have been adjusted to Table II.

Figure 3 Hardware Implementation.

The test results in the simulation here are used as a comparison produced by the hardware. The results from the hardware in buck mode with the oscilloscope propeller set to 1x gain only will be displayed in the implementation image.

In the simulation conducted by the user, it is seen that the actual voltage (Vact) will always be the same as the existing reference voltage (Vref). Therefore, the control method (PI) can be used appropriately as a predetermined parameter in this study. As seen in Figure 4 (a), which displays the simulation results, the actual voltage (Vact) is always the same as the reference voltage (Vref). Then, Figure 4 (b), which displays hardware data, shows that the actual voltage is the same as the reference voltage. So, it can be concluded that there is a similarity or match in the simulation and hardware implementation, so it is considered to have run as desired.



(a) (b)

Figure 4 Vact and Vref of buck mode (a) simulation and (b)hardware.

Then after the actual voltage and reference voltage look the same, the Load Change test is carried out to ensure that the output voltage remains the same on the full bridge inverter in buck mode even though there is a load change, proving that the voltage sensor can work. So, in this study, a load change test was carried out to see whether the voltage sensor used could work properly. The results of the load change experiment are shown in Figure 5, which shows the voltage and output current waves that occur when there is a change in load on the hardware. So, it can be said that the hardware in this study has succeeded in dealing with load changes, with a constant voltage at the beginning, but the current will change so that the power needed by the load can be met.

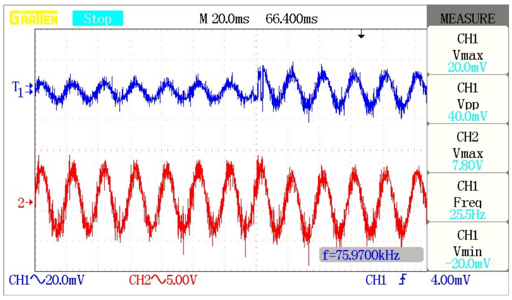


Figure 5 Load changes concerning current and stress result from the hardware.

After conducting the load change test, it is necessary to prove that what happens to the device is a buck condition, which means that the input voltage will be greater than the output voltage. Figure 6 shows the results of comparing the input and output voltages, which are the results of hardware data taken by the user using a digital oscilloscope. Figure 6 shows that the input voltage is a DC voltage that is converted into an AC voltage, and it can also be seen that the DC voltage is far above the AC voltage, which can be said that this buck mode has been successful.

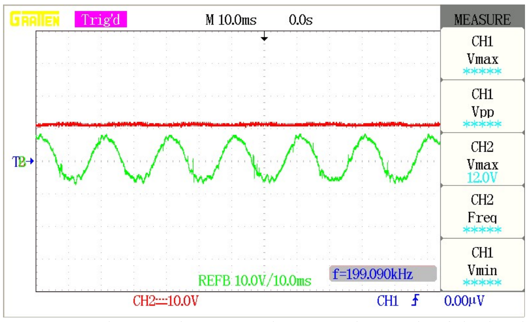


Figure 6 Input voltage and output voltage are the result of the hardware.

The final proof for buck mode will display the comparison results between the output voltage and output current taken from the hardware. This section proves that the device produces output power with Alternating Current (AC) type current and voltage. The device works because if loaded, the voltage and current will appear in the same shape, with only the size changing. This can be seen in Figure 7, which displays the voltage and current at the output, which are the results of hardware data taken from the oscilloscope.

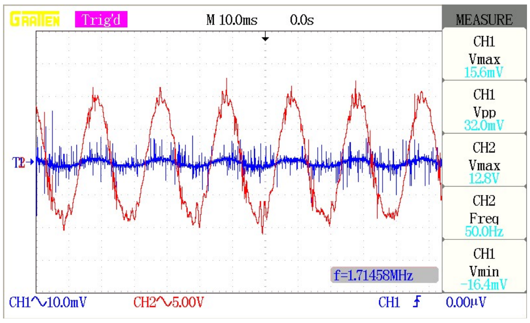
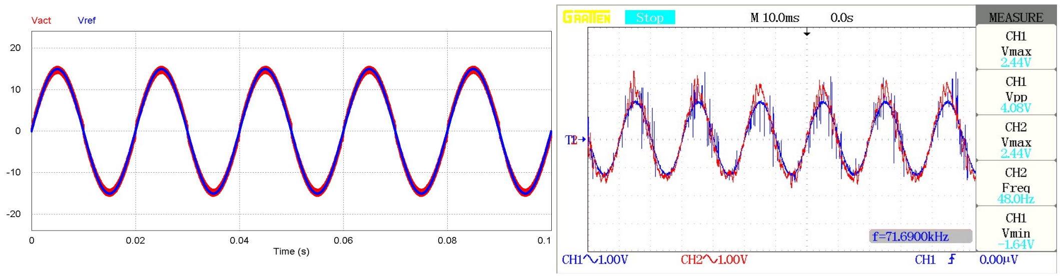


Figure 7 Output voltage and current are the hardware's results.

Full bridge inverter testing in boost mode is done after buck mode testing because it will be more accessible when a buck has been done first, which has been successful. What distinguishes buck and boost is that the reference voltage will be increased during boost mode testing, as seen in Figure 8. Figure 8 is the result of the comparison between the actual voltage and the reference voltage in part (a), which is the simulation result, and (b), which is the hardware result using the same components and reference values as the simulation.



(a) (b)

Figure 8 Vact and Vref: (a) simulation and (b) hardware

After it is known that Vact and Vref have succeeded, the next step, as in buck mode, is to test the load change to find out whether the full bridge inverter on the mobe boost voltage controller continues to work and to find out whether this inverter can adjust to the power change when implemented in hardware. Figure 9 shows the hardware results using a digital oscilloscope used on the hardware output when a load change occurs. It can be seen in Figure 9 that when a load change occurs, there will be an increase in current and voltage at the same value.

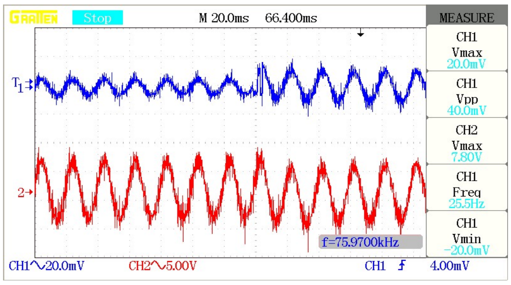


Figure 9 Load changes on boost mode current and voltage result from the hardware.

Then, after it is known that this boost mode can go through load change testing, just like in buck mode, testing will be done on the input and output voltage that will be compared. So, what should happen is that, in the opposite buck mode, the DC input voltage will be smaller than the AC output voltage because this is in boost mode. Figure 10 shows the results of data taken from hardware using a digital oscilloscope. The results can be said to be successful because the DC input voltage is smaller than the AC output voltage produced by the device.

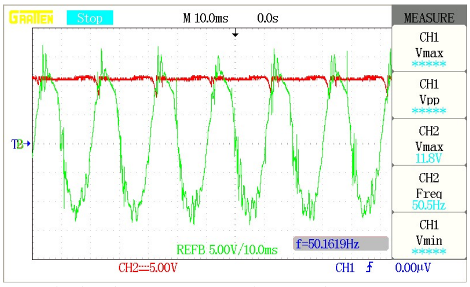


Figure 10 The hardware compares input voltage to output voltage.

The last data needed in this boost mode, as in buck mode, is the ratio of the output voltage and current, which has the same purpose as in buck mode: to see if the output of this device is an AC voltage to see if the device is flowing current to the load. This can be seen in Figure 11, which is data from the hardware viewed using a digital oscilloscope in the output section showing the current and voltage waves of the full-bridge inverter output.

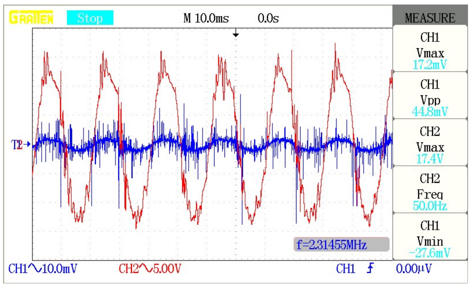
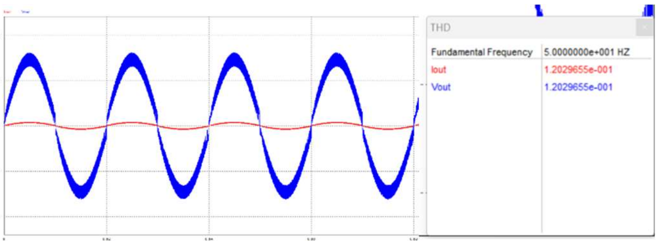


Figure 11 Comparison between output voltage and current in boost mode is the result of the hardware.

Figure 12 shows the THD value data from the tool used in this study. THD is the total harmonic voltage or current, and at the output of the Zeta full bridge inverter, there is 1.2% in the output voltage and current. In IEEE Std 519-2014, the THD value is required to be less than 5%, so this topology meets the requirements.


THD

Fundamental Frequency	5.0000000e+001 HZ
Iout	1.2029655e-001
Vout	1.2029655e-001

Figure 12 THD in output voltage and current.

4. CONCLUSION

This study is a new topology combining a full bridge inverter and a zeta converter working system. With the proof that the simulation results are the same as the hardware results and the THD value at the output of 1.2%, which is small, this topology can be used. The THD value can affect the load given. If the THD value is high, the quality of the power produced is getting worse; if the power quality is getting worse, it can damage the load. Then, there is proof that this tool can do buck-boost to meet the voltage shortage by increasing its current; this is proven from the load change test, and this tool can maintain its output. The buck and boost system is set by changing its Iref to do buck or boost.

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