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Design of a Single Phase HERIC-SPWM

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Abstract- **Development in the field of technology has experienced rapid development in recent years, especially in inverter. Almost every time the development of inverters is increase starting from full bridge inverters to an High Efficient and reliable Inverter Concept (HERIC). Inverters are used to convert DC voltage to AC, HERIC inverters are modifications of full bridge inverters with 2 additional IGBTs on the output side. This paper will discuss about the inverter design called single phase HERIC SPWM (sinusoidal pulse width modulation). The HERIC inverter will be compared with full bridge inverters to find out the advantages of these modifications. The modulation technique here uses SPWM modulation technique as the switching process. IGBT switching on the HERIC inverter is employed to produce the desired output waveform. The methodology for making a 1-phase HERIC SPWM inverter is by using a source from the grid road network which will then be rectified by a rectifier. The rectifier output of 311 Vdc will then be converted into AC voltage with output ± 10% of 220 V by the HERIC inverter. Therefore, by making this single-phase HERIC SPWM inverter it is possible to be more efficient and produce the desired required power supply.**

Keywords— HERIC Inverter; SPWM; Rectifier; full bridge Inverter

I. Introduction

Inverter is an interface device to transfer the electrical energy into the electrical system [1]. However, conventional inverters still have many shortcomings, especially reliability and high cost. Therefore, the author uses the HERIC topology to get an inverter with high efficiency and low production costs [2]. HERIC inverter (Highly Efficient and Reliable Inverter Concept) has produced a new innovative topological inverter with the main method used to increase efficiency. HERIC inverters are suitable for producing a constant voltage. However, if the voltage varies, it will produce a leakage current. To minimize leakage current, we can use a HERIC inverter [3]. Inverter (HERIC) concept is designed by adding AC by pass foot. This tool can be used by the public to find out which type of inverter is reliable so that later the HERIC inverter can be recognized by the public because of its advantages compared to using conventional inverters.

II. Research Method

A. Method

System design will be design as shown in diagram at Figure 1 and then modeling will be explained in the next point

B. System Design

System design of an HERIC (highly efficient and reliable inverter concept) single phase SPWM inverter system is shown in Figure 1.

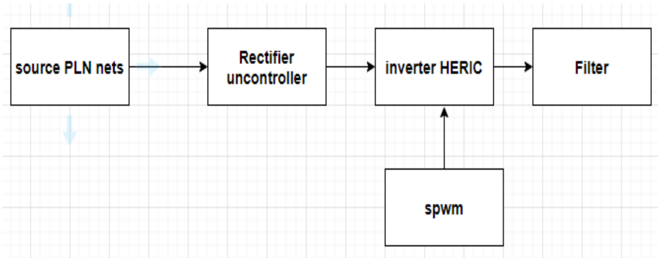

Figure 1. Overall System

the source uses a source of 220V PLN nets then rectified to a DC voltage using an uncontrolled full-bridge rectifier before being channeled to the current inverter and the voltage will be read by the sensor. A single phase HERIC inverter to AC voltage uses SPWM modulation. In order to be used for switching on the inverter, a driver circuit is needed that functions to separate the high and low periods of the SPWM signal. With SPWM modulation, the

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inverter output wave will have harmonics and not be sinusoidal (pure sine) so that a filter is needed so that the output wave from the inverter becomes sine then later it will be used to supply to the load.

1) Uncontrolled rectifier circuit

The full-wave bridge rectifier circuit functions to convert AC voltage into DC voltage with a fixed output voltage value. The full-wave bridge rectifier circuit is often used in the rectifier circuit as a DC voltage source and is widely found in the market. The working principle of the full-wave bridge rectifier circuit can be explained as follows: In the positive half period, from 0 to 180 degrees the direction of the current to diode 1 is forward biased (conduction diode) and diode 4 is forward biased (conducting diode) while diode 3 is reverse biased (diode off) and diode 2 is reverse biased (diode off) so that the current passes through diode 1 to the load from the load to the diode to the negative of the transformer. In the positive half period, which is from 180 to 360 degrees, the current direction towards diode 3 is forward biased (conduction diode) and diode 2 is forward biased (conducting diode) while diode 1 is reverse biased (diode off) and diode 4 in the reverse bias condition (diode off) so that the current passes through diode 3 to the load from the load towards diode 2 to the negative of the transformer The uncontrolled rectifier circuit can be seen in Figure 2.

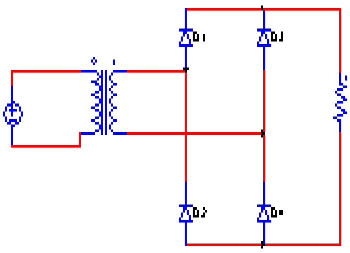

Figure 2. Uncontrolled Rectifier Circuit

2) Inverter

Inverter is a circuit which is used to converts a fixed DC voltage source voltage into a voltage source AC with a certain frequency Semiconductor components. The power used for the inverter can be IGBT and MOSFET that operate as switches and modifiers [4]. Inverter can be classified into two types: single- phase inverter and three-phase inverter. The inverters are categorized into four categories in terms of the type of commutation circuit on the SCR, namely: Pulse Width Modulation (PWM), resonant inverter, auxiliary commutation inverter and commutation inverter complement [5]-[7]. The inverter is referred to as a voltage supply inverter (Voltage-Fed Inverter-VFI) when the input voltage is always kept constant, it is called current supply inverter (Current-Fed Inverter) and if the inverter is variable (Variable Dc Linked Inverter) when the input voltage is set. Furthermore, when viewed from the conversion process, inverters are distinguished in There are three types: series, parallel and bridge [8]. Own bridge inverter consists of half bridge and full bridge inverter (Full Bridge) In a full bridge circuit (Full Bridge), in this circuit contains four for the Mosfet and 4 diodes are installed in parallel on the each Mosfet. If transistors Q1 and Q2 are turned ON automatically together, so that the input voltage Vs will appear on the load. If transistors Q3 and Q4 are turned ON at the same time then the voltage that appears on the load is the opposite of the first namely – Vs, Figure 3 shows the typical of a full-bridge inverter.

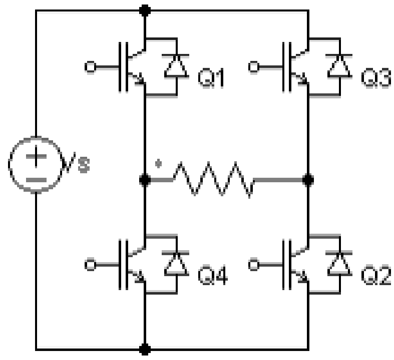

Figure 3. Full-bridge Inverter

The operation method of the simulation full bridge inverter is shown in Table 1.

Table 1. Switching Conditions on A Full Bridge Inverter

Switch				VOUT
Q1	Q2	Q3	Q4	
ON	OFF	OFF	ON	Vin
OFF	ON	ON	OFF	-Vin

3) HERIC Topology

The HERIC Topology that is commercialized by Sunways is the topology which is modified from a full bridge inverter with the addition of two back-to-back IGBTs on the output [9] side as shown in Figure 4.

This additional modification of two back-to-back switches (S5- S6) (each including a diode inside) on the AC side which operates at grid frequency. The solution used in this topology is to disconnect the PV array from the grid when zero vector connected to the load (grid). This disconnect done on the ac side by the addition of switches S5 and S6 which called the AC decoupling block. Several conditions of switches for generating

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Switches conduct mode on the HERIC inverter depicted [10]. The complete switching technique on the HERIC inverter can be seen in Table 2.

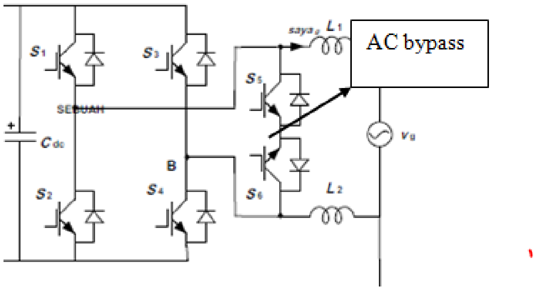

Figure 4. HERIC Inverter Topology

Table 2. Switching Conditions on HERIC Inverter

Switch						Diode		Vout
S1	S2	S3	S4	S+	S-	D+	D-	
on	Off	off	on	on	Off	off	off	Vin
off	Off	off	off	on	Off	off	on	0
off	On	on	off	off	On	off	off	-Vin
off	Off	off	off	on	On	on	off	0

AC bypass on this HERIC inverter has two vital functions:
1. Prevents reactive power exchange between filter inductor and capacitor during zero voltage state.
2. Isolate the PV module from the grid during zero voltage conditions, this is to eliminate high frequencies [11].

The HERIC inverter topology has the following advantages: 1) Unipolar voltage across the filter side $(0,+VPV,0,-VPV,0)$, resulting in lower core losses. 2) High efficiency as long as there is no reactive energy exchange between L and CPV at zero voltage and lower switching frequency on one leg. Weakness: Required two extra switches [11].

The mathematical equation from switching operating at high frequency only the first half period where:

$$I_{rms} = \sqrt{\frac{1}{T}\int_0^T \text{Iout }(t)^2(t)d(t)} \quad (1)$$

in the freewheeling diode state thus blocking the input voltage and having an average current given by

$$I_{avg} = \frac{1}{T}\int_0^T \text{Iout }(t)(1-D(t)) \quad (2)$$

Where: Iout(t): the output current,
D(t): the duty cycle ranges from zero to one

The output voltage Vo as

$$vo = \sum_{n=1,3,5,..}^{\infty} \frac{2V}{n\pi}\sin n\omega t \quad (3)$$

Where 2π is the frequency of the output voltage in rad/s [12]. Due to the symmetrical quaternary waveform of the output voltage along the x-axis, even harmonic voltages are absent [13]. For n = 1, Eq. (4) gives the rms value of the fundamental component as:

$$v_{01} = \frac{2v_s}{\sqrt{2}\pi} = 0{,}45\ V_S \quad (4)$$

4) Inverter Switching

In many uses, an inverter is needed to control the output voltage which functions to:
a. To overcome the variation of the DC input voltage.
b. For voltage regulation of the inverter.
c. For fixed voltage or frequency control requests

One of the switching techniques used, namely Sinusoidal Pulse Width Modulation (SPWM) is a switching technique obtained by comparing a sine signal with a modulated triangular wave [14] as shown in Figure 5. The working principle of single-phase [15] SPWM signal generation is to adjust the pulse width following a sinusoidal wave pattern. The frequency of the reference signal determines the output frequency of the inverter can be seen in Figure 6.

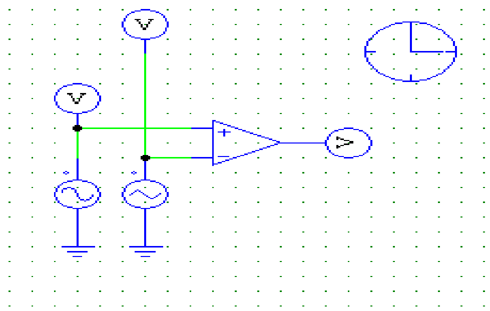

Figure 5. SPWM Circuit

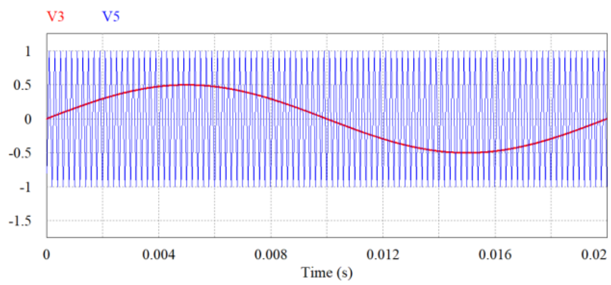

Figure 6. Comparison of Sine Wave and Saw

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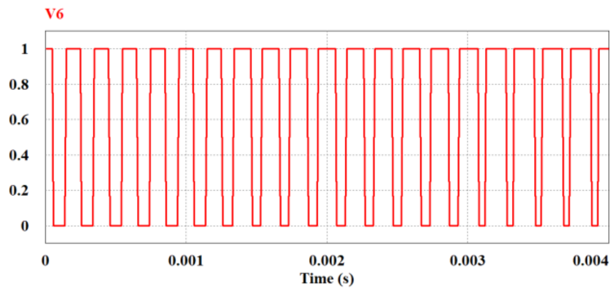

Figure 7. Output SPWM

The working principle of single-phase SPWM signal generation is to adjust the pulse width following a sinusoidal wave pattern where the output is square wave [16] is shown in Figure 7. The reference signal frequency determines the inverter output frequency to find out the frequency modulation ratio of the SPWM generation can be calculated by the equation:

$$M_f = \frac{\text{Fc}}{\text{Fm}} \tag{5}$$

Where : Mf = modulation ratio
fc = frequency of triangular wave
fm = frequency of sine wave.

5) Output filter

The LC filter serves to remove the harmonic frequency from an unwanted wave [17]. The output of this filter is expected to be a pure sine wave by forgetting the fundamental frequency of 50 Hz and eliminating harmonic frequencies other than the fundamental frequency [18]. The inductor component is used to remove the current harmonics, the inductor used inductor couple inductor [19] and the capacitor component is used to remove the voltage harmonics. The output capacitor can then be calculated by determine the cut off frequency (fc) for 30 times grid frequency [20], the switching tenth filter frequency for more details please see the Table 3.

$$C_f = \frac{1}{4\pi^2 \text{F}_\text{C}^2 L_1} \tag{6}$$

Where: C_f =capasitor
fc = frequency cut off
L = inductor

III. Results and Discussion

In this simulation, we will compare the performance of the conventional inverter and the conventional inverter, but first convert the ac voltage into a dc voltage using a rectifier so that the desired dc source voltage is matched in this simulation, the desired dc voltage is 311 vdc so that the simulation is carried out as shown in the Figure 8.

Table 3. Circuit Parameters

Parameter	value
VDC	311
Capacitor	0,287mF
Inductor	8,83mH
Frequency switching	1000hz

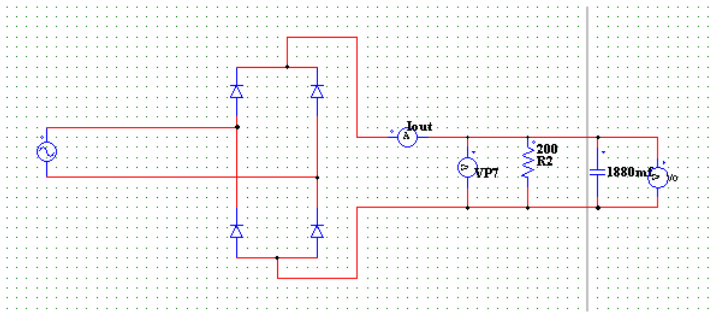

Figure 8. Rectifier Simulation Circuit

The Figure explains how to convert ac voltage to dc voltage using 4 diodes with an R value of 200 Ω then on the output side there is a capacitor of 1800 μF to eliminate voltage ripples as shown in Figure 9.

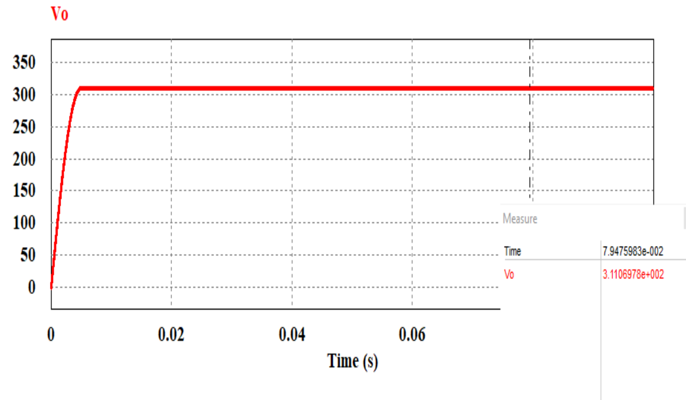

Figure 9. Rectifier Output Waveform With Filter

In Figure 10 it can be seen that after installing a capacitor of 1800 the dc waveform is no longer experiencing riplle and the output voltage is according to the design of 311 vdc.

Figure 10 describes the simulation between a full bridge inverter and a HERIC inverter in a circuit without using a filter in a full bridge circuit using only 4 IGBT

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funds on a HERIC inverter circuit using 6 IGBT so that the waveform in the following Figure 12 is generated.

Figure 11 the waveform before using the wave filter is still box-shaped but there are differences in the HERIC wave and the full bridge wave it can be seen
that the square wave on the HERIC inverter is higher, causing a higher voltage value than the conventional inverter, for more details can be seen in the Table 4.

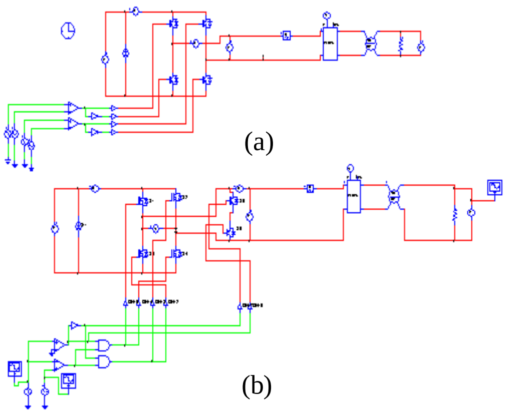
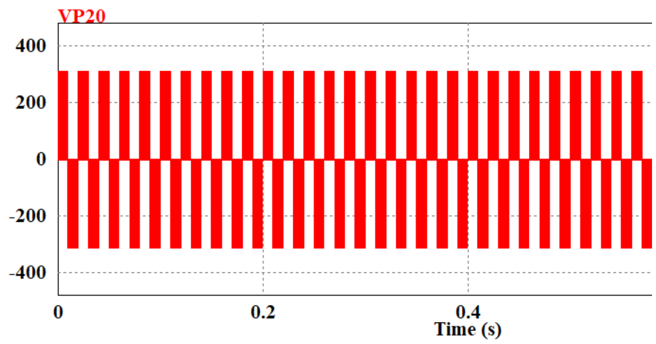
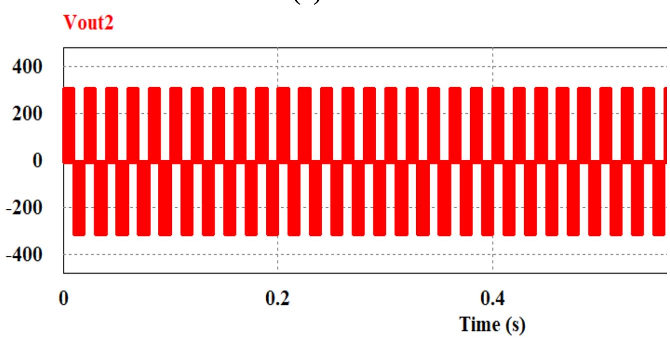


Figure 10. (a) Simulation Circuits of Unfiltered Full Bridge Inverter and (b) Unfiltered HERIC Inverter



(a)



(b)

Figure 11. (a) Wave Output of Unfiltered Full Bridge Inverter and (b) Unfiltered HERIC Inverter

The Table explains that the same input voltage value produces different input current values in the HERIC inverter, the current value is greater by 21.9 while the full bridge inverter has a current value of 17.3, causing the input power to the HERIC inverter to be greater than the input power to the full bridge inverter as well as the output power. the HERIC inverter is greater than the conventional inverter, causing the efficiency value of the HERIC inverter to be greater than the conventional inverter, while for the pf it is better for the full bridge inverter here the pf of the full bridge inverter before being given a capacitor of 9.6 and the HERIC inverter of 9.5 while the efficiency of the HERIC inverter 98.37% and inventer Full bridge around 98.28%.

Table 4. Simulation Results of Unfiltered Inverter

Parameter	Inverter Full Bridge	Inverter HERIC
Vin	311 V	311 V
Iin	17.3 A	21.9 A
Iout	17.5 A	20.2 A
Vout	173 V	219 v
Pin	3089 Watt	4833 Watt
P out	3044 Watt	4755 Watt
Pf	9.6	9.5
Var	3062	4803
Efficiency	98.28%	98.37%

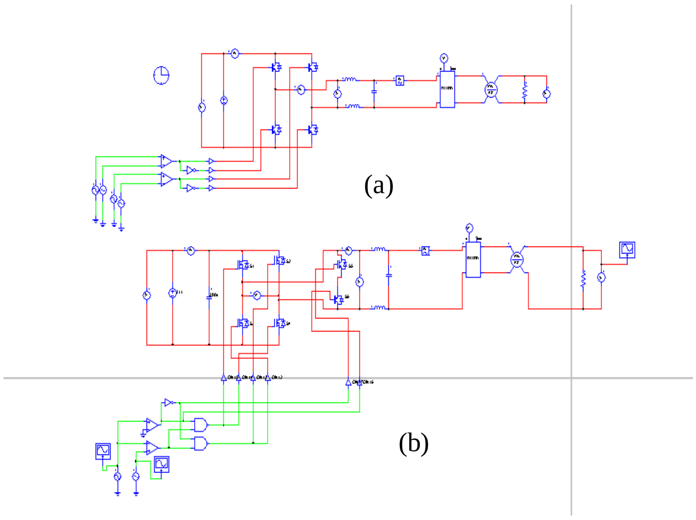


Figure 12. (a) Full Bridge Inverter Simulation Circuit and (b) HERIC Inverter With Filter

Figure12 describes the simulation between a full bridge inverter and a HERIC inverter in a circuit with using a filter LC where the parameter value L1 = L2 is 8.83 mH and the C value is 0.287 mF in the two circuits above using the same filter value in a full

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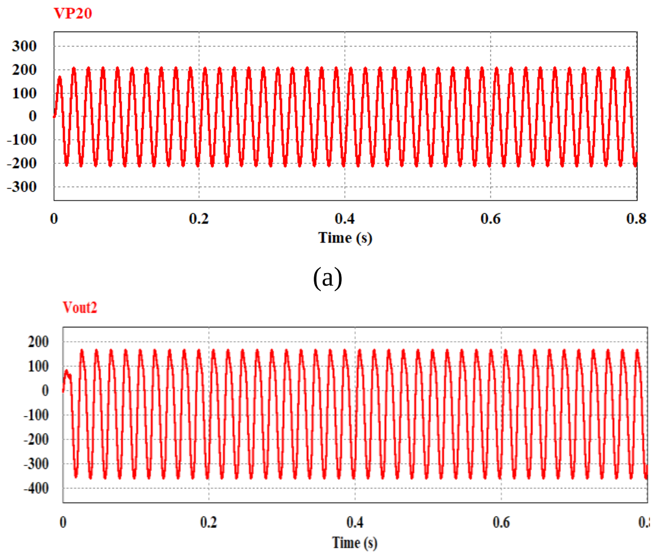
bridge circuit using only 4 IGBT funds on a HERIC inverter circuit using 6 IGBT so that the waveform in the following Figure 13 is generated.



(a)

(b)

Figure 13. (a) Wave Outputs Of Full Bridge Inverter and (b) HERIC Inverter

In Figure 13, the top waveform is the output of the full-bridge inverter waveform and the bottom is the output of the HERIC I inverter, in the full-bridge inverter waveform the waveform is sinusoidal without any ripple, while the HERIC inverter has a sinusoidal waveform but has ripple at the beginning but and after
that the wave is sinusoidal sinus formation process carried out by SPWM.SPWM (Sinusoidal Pulse Width Modulation) method by comparing a triangular wave with a sine wave which will later be inserted into the foot of the IGBT gate. The frequency of the sine wave used is 50 Hz which is the output frequency value of the inverter while the triangular frequency used is 1k Hz. SPWM simulation results, the comparison of a sine wave with a triangular wave and also the comparison of a triangular wave and a sine wave.

Table 5 explains that the same input voltage value produces different input current values in the HERIC inverter, the current value is 22.3A while the fullbridge inverter has a current value of 12.8A, causing the input power to the HERIC inverter to be greater than the inverter input power. fullbridge as well as on the output power. And the current after passing through the full-bidge inverter filter is 19.7A while the HERIC inverter is greater that is 27.38 A so that the output power generated by the HERIC inverter is 4161 watts at the fullbridge inverter power of 2126 so that the power generated is greater in the HERIC inverter and for the efficiency value of the full inverter. bridge by 98.19% and inverter HERIC by 98.22%

Table 5. Simulation Results of Inverter with Filter

Parameter	Inverter full bridge	Inverter HERIC
Vin (input voltage)	311 V	311 V
Iin (inflow)	12.8 A	22.3 A
Iout (current before passing through the filter)	19.7 A	27.38 A
Vout (voltage before passing through the filter)	175 V	224 V
Iout (current after filter)	14.4 A	18.8 A
Vout (voltage after filter)	146 V	205 V
Pin (power in)	2165 Watt	4236 Watt
P out (power after passing through the filter)	2126 Watt	4161 Watt
pf	9.5	9.3
Var	2144	4252
efficiency	98.19%	98,22 %

IV. Conclusion

Full bridge inverters are used at low power capacity and HERIC inverters are used at large enough power capacities, while for efficiency it obtained around 98.19% for full bridge inverters and 98.22% for HERIC inverters.

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