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Voltage inverter with push-pull topology to inject energy into electrical systems with modulation spwm

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Abstract.

This paper presents a proposal for a voltage inverter topology based on the push-pull converters, high-frequency switching to inject energy into the grid from a source of DC power. A system using two reverse voltage static converter provides the power grid, energy in the form of alternating current that can work in conjunction with the utility supply of energy with a view to possible use of renewable energy sources that can be stored in the form of voltage continuous, such as wind, solar, hydroelectric and others. It is shown the operation of the topology, power and control circuits, as well as design of components, theoretical and practical results achieved by mounting a prototype of 100W of power and switching in 40Khz, which after filtering provides the frequency of 60Hz is compatible with the Brazilian electrical system.

Keywords: Inverter voltage, push-pull, SPWM, injection of energy.

1. Introduction

The voltage inverter developed uses SPWM modulation [6] and the technique of switching technique known as class D [1] and is presented here for the use of an injection system in the form of electricity current in the grid. The rationale power converters was based on inverter PUSH_PULL [2] where, with the use of two converters, one working on the positive half-cycle and one in the negative half-cycle current in continuous mode [11]. You can raise the tension and get the inversion of a voltage to a 12V dc voltage 127Vrms, that the technique presented can be embedded within its power to the utility grid. For the generation of pulses of the keys of the converters is used a sample of the sinusoidal network signal itself in comparison with a triangular wave, ie, the system should inject power in the network, synchronized with the signal of the same, and only when there is the utility voltage.

An integral action [12] is made between the signal line voltage electrical signal and load current (transformer primary insulator), and the result is compared with a triangular wave to generate *PWM* signal, which allows an action control in the inverter output. The block diagram of the inverter is shown in Figure 1 emphasizes that the output signal being sampled at the entrance to the formation of signal activation keys, which is broken down in the control circuit separating the pulses act in the positive half-cycle, and negative half-cycle. The secondary circuit is controlled by two bidirectional switches, developed with transistors and diodes, which control the direction of the load current according to the sequence of operation of the converters, so you can inject the power converters on the network to obtain power in both directions, providing the network, the alternating current.

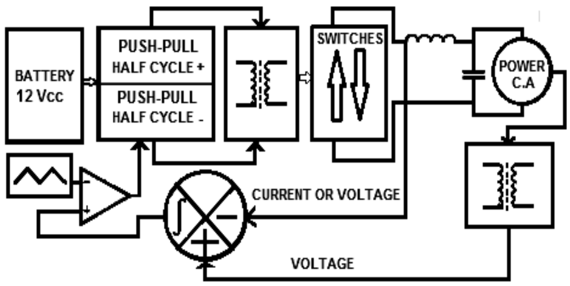

Figure 1 - Block diagram.

2. Power circuit and the switching sequence.

The waveform at the output of the converter due to the switching transistor is square and pulse width modulated in accordance with the utility voltage, thus presenting all the high frequency components. Because the purpose of the inverter is a sinusoidal waveform at the load, we developed a low-pass LC filter at the inverter output to filter out high frequency components [7], so the output waveform has a sinusoidal behavior. To the correct sequence of trigger switches to the power circuit, the converters must follow a hierarchy in which each converter is fired in a half-cycle, with a sequence of switching time determined by the letter, shown in Figure 2. The sequence of operation for the power circuit is described below, with the eight steps of the switches to trigger the formation of the alternating signal at the output of the inverter

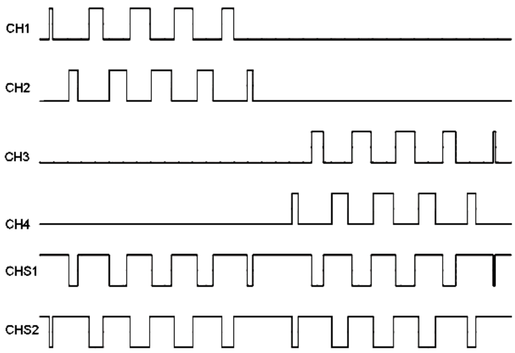

Figure 2 - Letter from the time of activation keys.

The trigger of the switches is divided into two parts with four steps each. The first four steps are related to the positive half-cycle, and the four subsequent steps, the negative half-cycle. Due to the secondary switches are electrically isolated from the primary switches, it was necessary to introduce an adjustable time delay in activation of the primary switches for the trigging conditions of the switches are simultaneously adjusted for better timing and reduced losses by Joule effect, this circuit that can be viewed in Annex A. The eight steps are described below, and the power circuit is shown in Annex B.

Step 1: The Key CH1 leads magnetizing winding LP2 and inducing voltage in the secondary windings to ensure the direction of the load current CHS1 the switch must also conduct and direction of current is shown in figure 3, taking into account the lines bold and direction of current in the diode is conducting at this time that the other switches are open.

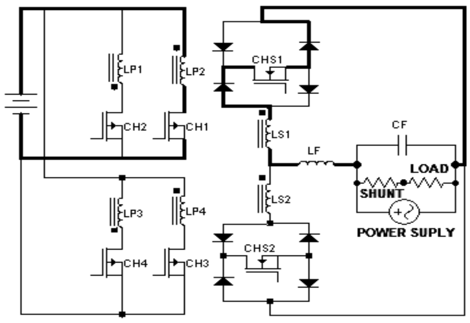

Figure 3 - Direction of current in one step

Step 2: The Key to CH1 opens and CHS2 closes. This is equivalent to the dead time between the CH1 and CH2 switches, causing the current flow between freewheel and the voltage in the windings is zero, as shown in figure 4 .

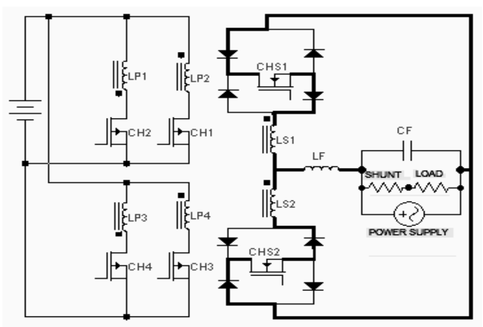

Figure 4 - Direction of current in step 2

Step 3: CH2 closes, inducing voltage with polarity opposite to the first step, just to keep the direction of current in the load, CHS1 opens and CHS2 remains conducting as shown in Figure 5.

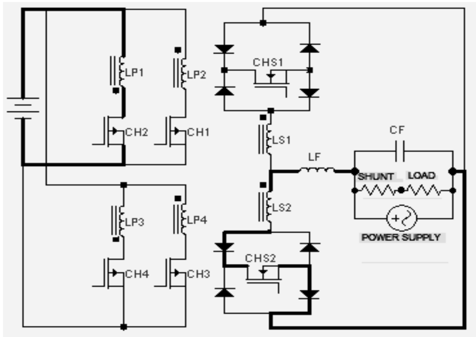

Figure 5 - Direction of current in step 3

Step 4: is the dead time between CH1 and CH2, where only CHS1 and CHS2 lead, causing the current flow between freewheel and voltage in the windings is zero, as shown in Figure 6.

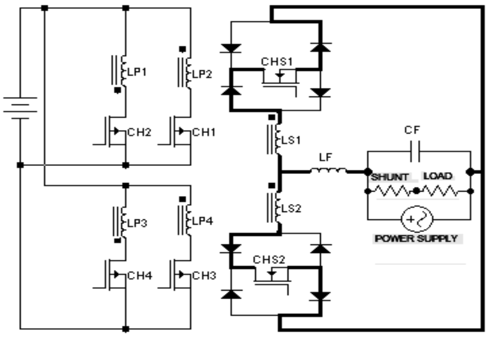

Figure 6 - Direction of current in step 4

Step 5: The Key CH3 leads LP4 magnetizing winding and inducing voltage in the secondary windings to ensure the direction of the load current CHS2 the switch must also lead, as shown in Figure 7.

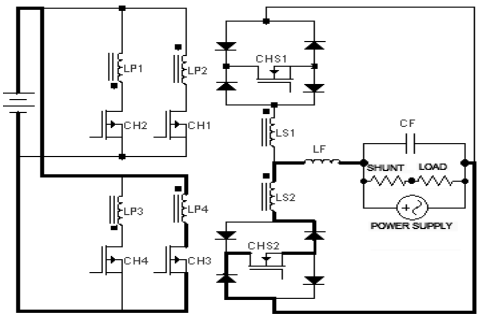

Figure 7 - Direction of current in step 5

Step 6: The switch CH3 opens and CHS1 closes, causing the current flow between freewheel, as shown in Figure 8.

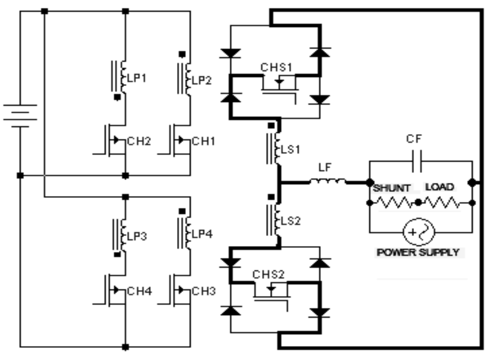

Figure 8 - Direction of current in step 6

Step 7: The switch CH4 leads induces a voltage in the secondary windings of opposite polarity to the previous step to keep the direction of the current; CHS2 opens and CHS1 begins to conduct, as shown in Figure 9.

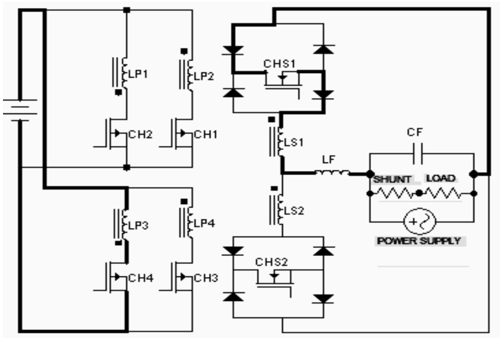

Figure 9 - Direction of current in step 7

Step 8: The switch CH3 opens and there is a dead time of CH3 CH4 as CHS1 and CHS2 lead while providing current flow in the impeller as shown in Figure 10.

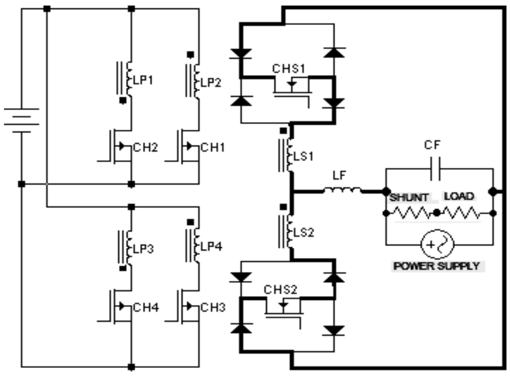

Figure 10 - Direction of current in Step 8

For the switches to the power circuit snubbers circuits were inserted to reduce the voltage spikes on them, caused by switching, due to the optical coupling between the trigger circuit and the secondary switches, it was necessary to insert a constant time delay and variable to thus synchronizing signals from the primary keys in relation to the secondary key to decrease the heat conduction due to unsynchronized, which can be viewed in Annex B.

3. Circuit Trigger

The trigger circuit receives the switches of the variation of the signal coming from the PWM control circuit to perform then the logical trigger and separation of signals to the respective switches, the logical trigger is shown in the diagram in Figure 11 and is then broken into.

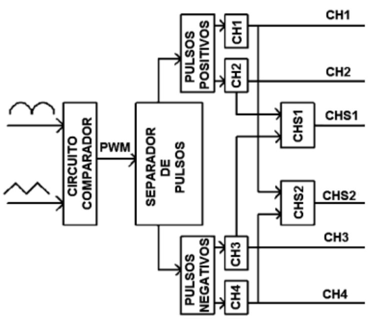

Figure 11 - Circuit Trigger

After comparison of the rectified signal with triangular wave, the signal goes to the PWM pulse separator circuit, this circuit makes the separation of the pulses of the two converters, where, when the network signal is in the positive half-cycle triggers switches first converter, and when the negative half-cycle triggers the switches of the second converter, according to Figure 12.

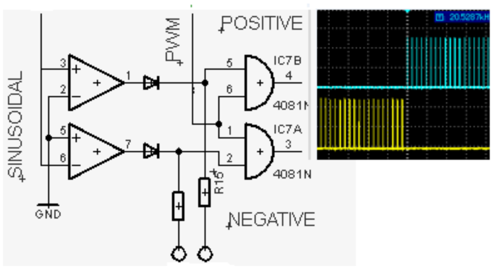

Figure 12 - Circuit breaker positive and negative pulses.

The positive pulses are then separated into two new pulses for the converter positive half-cycle, that will trigger the switches CH1 and CH2, the pulses for the negative half-cycle are separated into two to trigger the second converter that will trigger the switches CH3 and CH4, Figure 13 shows the circuit and waveforms.

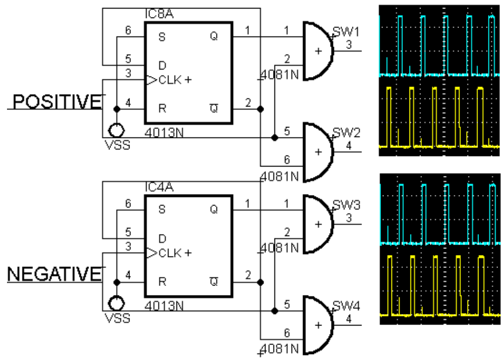

Figure 13 - Circuit breaker pulses of primary switches.

The pulses of the secondary windings of the switches that activate the switches CHS1 and CHS2 are formed by the logic XNOR between pulses of the primary switches, secondary switches (bidirectional) are powered by an auxiliary power supply that is switched and triggered by the signal from the wave generator circuit designed with the NE566 integrated circuit that also provides an output square wave. To ensure the opening of bi-directional switches, a high level of tension has been developed in the switches to the gate of the same work with less reference to ensure the opening, the information cited in the preceding lines can found in Appendix B that brings the power circuit complete, the waveform in the secondary switches are shown in Figure 14.

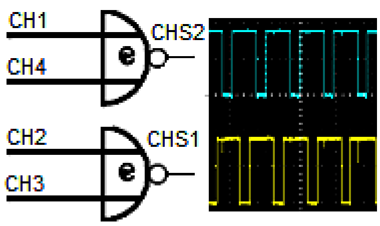

Figure 14 - Circuit of pulses of the secondary switches.

4. Control Circuit

To control the voltage and current at the inverter output was implemented a control circuit which makes use of an integral action, so you can work with varying loads and can even compensate for unstable loads such behavior[9]. The control circuit is implemented can work in two different ways. The first is a voltage feedback control using sample of the output voltage of the inverter for the correction, in this way it can be fed loads not connected on the network such as electrical appliances, lamps, among others, but that can be turned on or off at any time, just need to make the inverter output voltage offset so as not to provide variations of tension loads. The second form of control relates exactly to the power injection in conjunction with the grid, this way of working, the inverter output will be connected directly to mains, so the output voltage of the inverter will not change in case of change of load due to the power grid to compensate, but for the inverter to inject more or less power in the network due to load variation, was inserted into a feedback control of current, so when the load varies, the current will follow the same behavior, control will sense this change and will compensate by injecting more or less power in the form of current. Figure 15 shows the control circuit, which can work both ways cited according to the choice of key S.

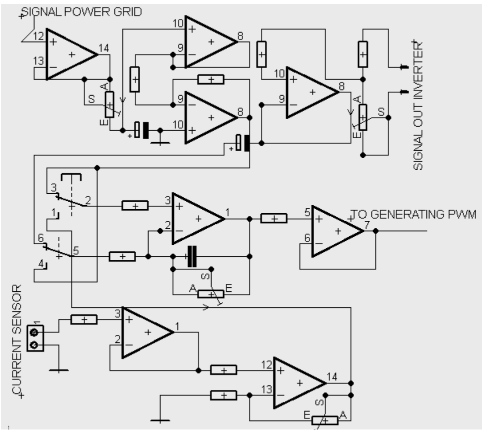

Figure 15 - Control Circuit

5. Sizing of the inverter.

Here is aborted the design of the main components of the inverter to the following characteristics [2]:

$$\begin{cases} \text{Out Power}: 100\text{ W}. \\ \text{Output Voltage}: 127\text{ V}_{RMS}. \\ \text{Input Voltage}: 12\text{V}_{CC}. \end{cases}$$

5.1 Rms current in the output:

$$I_{RMS} = \frac{P_{OUT}}{V_{RMS}} = \left(\frac{100}{127}\right)/2 = 0,394A \qquad (1)$$

5.2 Rms current in the primary of each trigger:

$$I_P = (I_S.D).N = 0,394x0,45x25 = 4,432A \qquad (2)$$

Where: $\begin{cases} D = \text{duty cycle} \\ \text{N} = \text{transformation ratio} \\ \text{Ip} = \text{current in the primary} \\ \text{Is} = \text{secondary current} \end{cases}$

5.3 Calculation of primary keys:

Primary switches must support twice the voltage *Vi*, ie:

$$\text{VDS} \geq 24\text{V}$$

The RMS current in the primary is 4.432A, previously calculated for these values were chosen for the keys to the primary windings IRFZ48N transistors that have the electrical characteristics shown in table 1.

Table 1

V_{DS}	55V
I_D	64A
Ptot	140W
$R_{DS(on)}$	16mΩ

5.4 Calculation of the secondary keys.

The bidirectional switches (CHS1 and CHS2) must support twice the output voltage, was chosen as the ratio of 25 has a voltage peak value of 2 × 12 × 25 = 600Vcc, which the bank in relation to the modulation, and must also support the maximum output current calculated above, was chosen so that the transistors FQB5N80 has the following characteristics shown in table 2.

Table 2

V_{DS}	800V
I_D	4,8A
P_{tot}	140W
$R_{DS(on)}$	2,6Ω

5.5 Calculation of transformer push-pull converter.

5.5.1 Product areas (PA).

adopting B=0.3, Ku=0.1, Pout= 100VA, z=1.136, f=20KHz e Kj=397 we [2]:

$$A_P = \left[\frac{7,96.P_S.10^4}{Kj.0,3x20.10^3}\right]^z = 3,937cm^4 \qquad (3)$$

Using a toroidal core can reduce the volume until 50% of the not toroidal core. The core design was used in the model NT 53/32/20 due to the availability in the laboratory, the calculation was performed with a frequency of 20KHz, because it works a converter at a time, so the PWM generator will work to 40KHz.

5.5.2 Number of turns of the primary:

$$N_P = \frac{V_i.D_{\max}}{A_e.B.f} \cong 5\,esp \qquad (4)$$

5.5.3 Area covers the primary winding:

$$A_{cu} = \frac{I_{ef}}{J} = \frac{4.432}{258.18} = 0.0102cm^2 \qquad (5)$$

To reduce the skin effect [2], was used 13 to 28 AWG conductors in parallel resulting in a copper area equal to the calculated (5).

5.5.4 Number of turns of the secondary: Choosing a transformation ratio of 25 are:

$$N_s = N_p x25 = 125\,esp \qquad (6)$$

5.5.5 Area covers the secondary winding:

$$A_{cu} = \frac{I_{ef}}{J} = \frac{0.394}{258.18} = 0.00153cm^2 \qquad (7)$$

Conductor 25 AWG.

5.5.6 Calculation of the output LC filter [6]: Adopting a cutoff frequency of 1 kHz.

$$C_f = \frac{1}{4\pi.\xi.f_c.R_0} = 0.552nF \qquad (8)$$

Where ζ =0,9 the damping factor is chosen according to [6]. Adopting commercial value of 1μF capacitor to have:

$$L_f = 4.R_0^{\,2}.\xi^2.C_f = 82.94mF \qquad (10)$$

6. Experimental Results.

The experimental results presented below were divided into five stages, the first, the data were extracted from the inverter in open loop [9], ie, with only a resistive load, without closing the loop and no connection to the grid. Figure 16 shows the waveform at the output without the LC filter and a resistive load of 160Ω and using the PWM signal to compose only a sample of the signal from the utility. It appears that the signal components at high frequency, due to the actuation of switches.

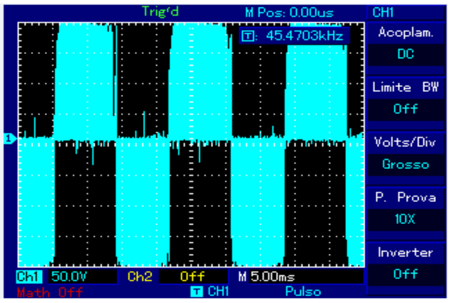

Figure 16 - Voltage output without the LC filter (open loop)

In the second part of the tests, the LC filter was added at the inverter output, so they were eliminated frequencies above the filter cutoff frequency (1kHz), resulting in a sinusoidal waveform shown in Figure 17.

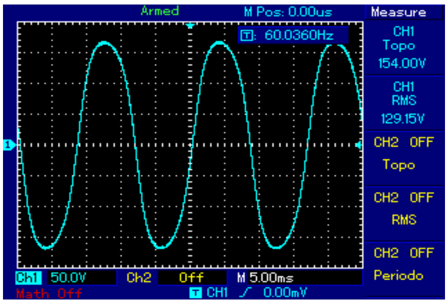

Figure 17 - Waveform of the output LC filter (open loop)

After testing in open lo , the third part of the experiment began ,where the function was inserted between the sample of the full supply voltage and a sample of the output voltage of the inverter, even without turning on the inverter output to the network, in this way there can be used to feed the inverter loads disconnected from the grid, and the use of control action, the charges may vary within the specification of power inverter that tends to keep the output around 127Vca. Figure 18 shows the sample signal from the power supply (1 channel - blue), and the sample voltage at the inverter output (channel 2 - yellow), so that way of work, the resulting signal is a sine integral action and follows the main voltage.

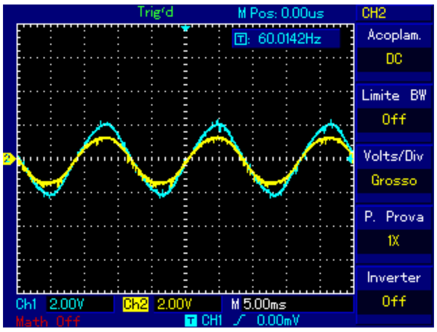

Figure 18 - Channel 1 sample of the mains voltage
Channel 2 sample output voltage of the inverter.

In the fourth part of the tests was included the form of a feedback current to make the sign of comparison for PWM generation, a sample of the load current sensor removal of a shunt in series with the load was compared with the sample signal from the power grid but as the behavior of the load current is the reverse of the behavior of the load voltage, the logic of integral action had to be reversed, because when the load increases (decreased impedance) the current in the shunt will increase, thereby offsetting the PWM signal should be done in reverse, so the control circuit has a switch that makes the inversion of the signals for comparing the input voltage and current of the action integral. The waveforms of line voltage (channel 2 - yellow) and load current (channel 1 - blue) are shown in Figure 19, and the tension resulting from the integral action will also be a sinusoid, but now follows the load current.

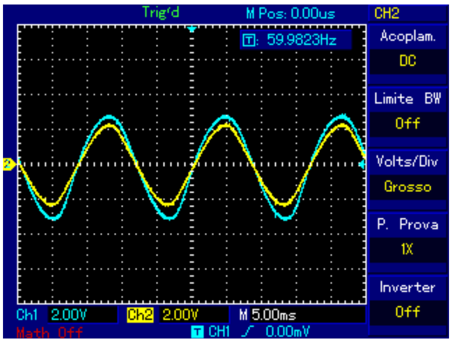

Figure 19 - Channel 1 (sample load current)
Channel 2 (sample line voltage)

The fifth test mode of operation was then connect the power grid in the output of the inverter so that it can provide power to the load synchronized with the grid, and thus, when the load requires more power (decreasing its impedance) the inverter will this compensation in the form of current, since the output voltage is set by the voltage electricity network that is connected to the output, so the inverter will inject more power in the form of current to compensate for the load requirement. When connected to power grid, the output voltage is set by supply voltage, so the output voltage, and the network will be one, shown in Figure 20 and the output voltage is already connected to grid (channel-1 blue) and load current (channel 2 - yellow), so if the current increases, it is because the load requires more power, the inverter will inject more than offset by the load current control circuit.

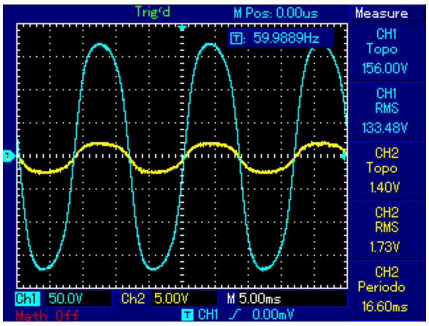

Figure 20 - Channel 1 (Voltage output connected to the mains) Channel 2 (Sample load current)

7. Conclusions.

The system developed proved to be compact due to the use of the technique of switching at high frequency could be a decrease in weight and volume of the transformer core, together with the choice of toroidal core model that has the best features of concentration lines the field. With a perfect synchronization between the primary and secondary keys obtained from the calibration circuit delay time of the shooting of the gates, you can reduce heat loss by conduction is caused by possible simultaneous. The yield obtained was approximately 75% depending on the power project to be chosen for the low (100W), because only with the power control circuits, switching and auxiliary sources is spent approximately 15W, but a project will cause more power the percentage of power used to power the circuit is lower compared to the total power of the project, providing a better final yield. The experimental results validate the proposed system of inversion that can be implemented in conjunction with any system of co-generation of energy that can supply DC voltages can be obtained from any source of renewable energy. So far this research opens the way for the continuation of the development being developed for a three-phase system and also a control circuit implemented with DSP (digital signal processor). Figure 21 shows the prototype of the inverter.

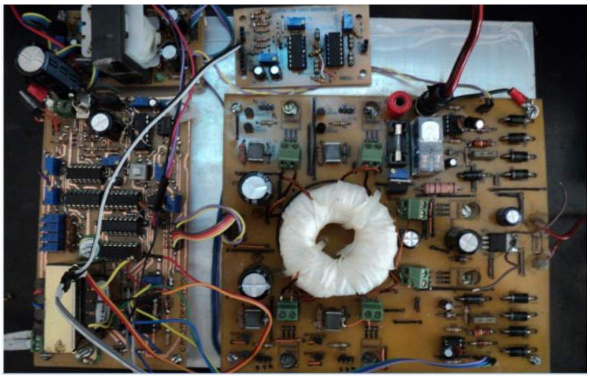

Figura 21- Protótipe do inverter

8. References:

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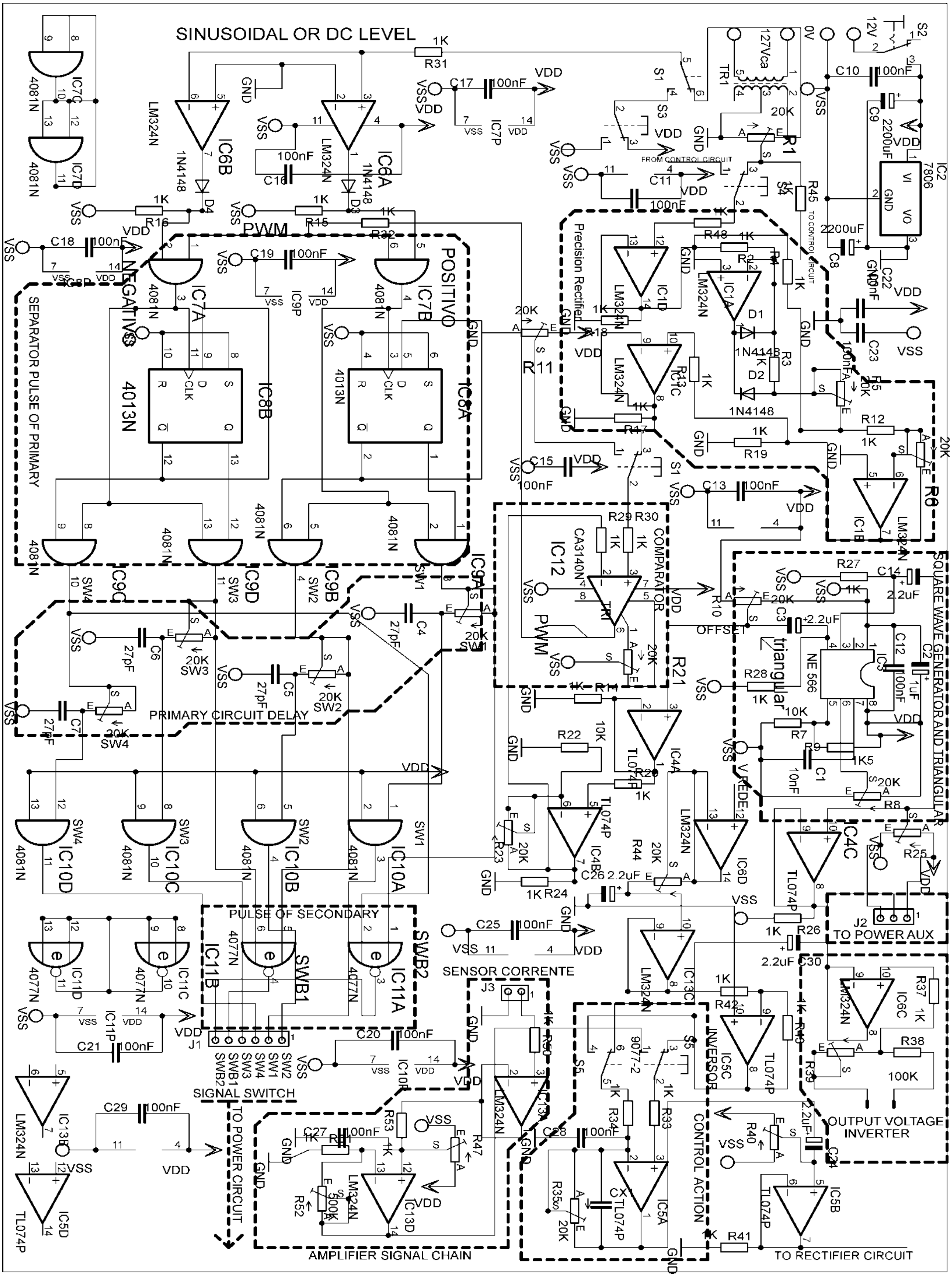
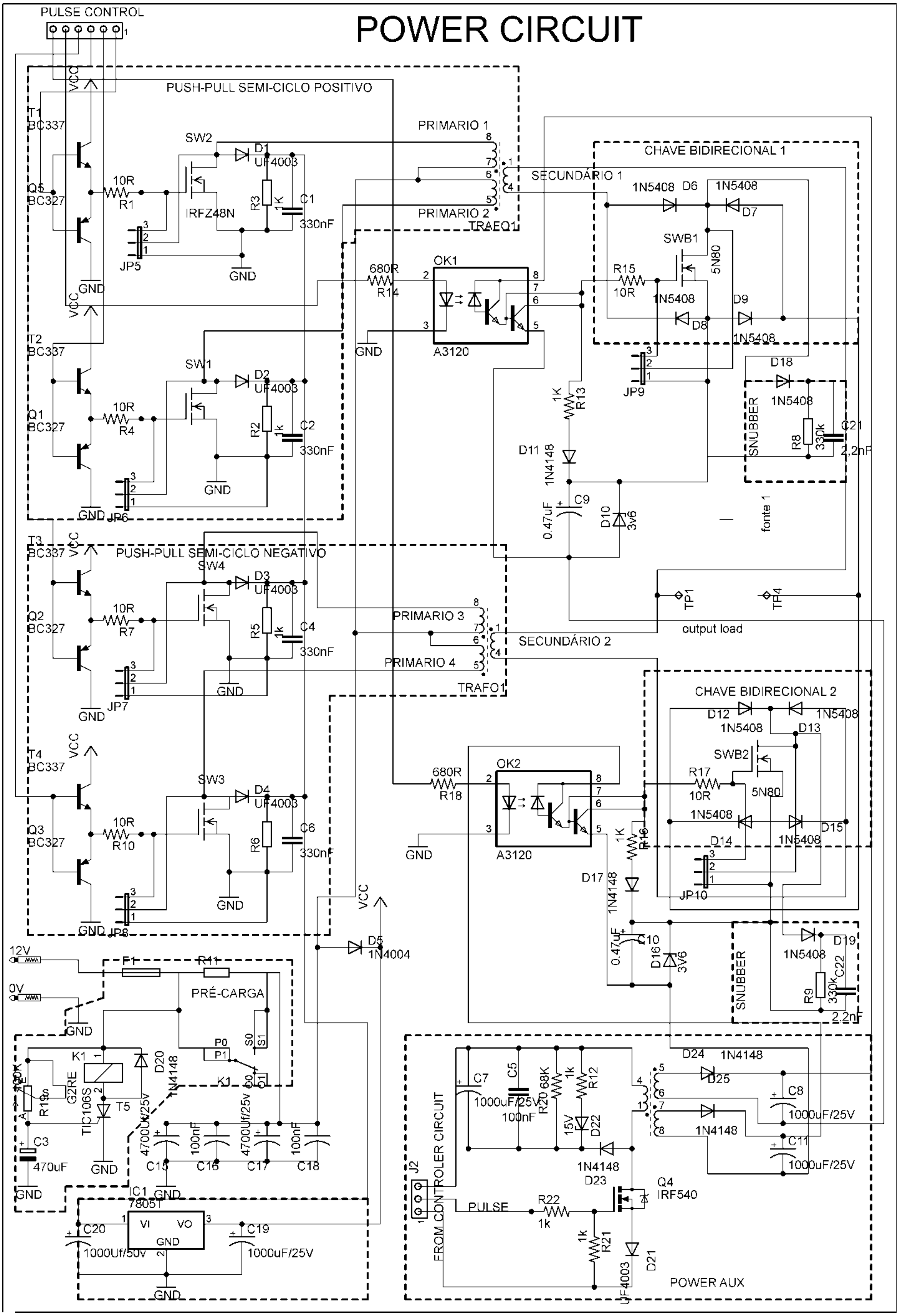
ANNEX A


SINUSOIDAL OR DC LEVEL
SEPARATOR PULSE OF PRIMARY
PWM
NEGATIVE
POSITIVO
PRIMARY CIRCUIT DELAY
PULSE OF SECONDARY
SIGNAL SWITCH
TO POWER CIRCUIT
SENSOR CORRENTE
AMPLIFIER SIGNAL CHAIN
CONTROL ACTION
INVERSOR
TO RECTIFIER CIRCUIT
OUTPUT VOLTAGE INVERTER
TO POWER AUX
SQUARE WAVE GENERATOR AND TRIANGULAR
COMPARATOR
Precision Rectified
FROM CONTROL CIRCUIT
TO CONTROL CIRCUIT
OFFSET
triangular

ANNEX B


POWER CIRCUIT
PULSE CONTROL
PUSH-PULL SEMI-CICLO POSITIVO
PUSH-PULL SEMI-CICLO NEGATIVO
PRIMARIO 1
PRIMARIO 2
PRIMARIO 3
PRIMARIO 4
SECUNDÁRIO 1
SECUNDÁRIO 2
TRAFO1
CHAVE BIDIRECIONAL 1
CHAVE BIDIRECIONAL 2
SNUBBER
fonte 1
output load
TP1
TP4
T1 BC337
Q5 BC327
T2 BC337
Q1 BC327
T3 BC337
Q2 BC327
T4 BC337
Q3 BC327
SW1
SW2
SW3
SW4
IRFZ48N
D1 UF4003
D2 UF4003
D3 UF4003
D4 UF4003
R1 10R
R4 10R
R7 10R
R10 10R
C1 330nF
C2 330nF
C4 330nF
C6 330nF
JP5
JP6
JP7
JP8
JP9
JP10
OK1 A3120
OK2 A3120
R14 680R
R18 680R
SWB1 5N80
SWB2 5N80
R15 10R
R17 10R
D6 1N5408
D7 1N5408
D8 1N5408
D9 1N5408
D12 1N5408
D13 1N5408
D14 1N5408
D15 1N5408
D18 1N5408
D19 1N5408
R8 330k
R9 330k
C21 2,2nF
C22 2.2nF
R13 1K
R16 1K
D11 1N4148
D17 1N4148
C9 0.47uF
C10 0.47uF
D10 3v6
D16 3v6
VCC
GND
12V
0V
F1
R11
PRÉ-CARGA
K1 G2RE
D20 1N4148
T5 TIC106S
R19 100K
C3 470uF
C15 4700Uf/25v
C16 100nF
C17 4700Uf/25v
C18 100nF
D5 1N4004
IC1 7805T
VI VO GND
C20 1000Uf/50v
C19 1000uF/25V
C7 1000uF/25V
C5 100nF
R20 68K
R12 1k
D22 15V
D23 1N4148
D24 1N4148
D25
C8 1000uF/25V
C11 1000uF/25V
J2 FROM CONTROLER CIRCUIT
PULSE
R22 1k
R21 1k
Q4 IRF540
D21 UF4003
POWER AUX