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Single-phase frequency converter

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Abstract. The paper presents a continuous voltage inverter - AC (12V / 230V) made with IGBT and two-stage voltage transformer. The sequence control transistors is achieved using a ring counter whose clock signal is obtained with a monostable circuit LM 555. The frequency of the clock signal can be adjustment with a potentiometer that modifies the charging current of the capacitor which causes constant monostable circuit time. Command sequence consists of 8 intervals of which 6 are assigned to command four transistors and two for the period break at the beginning and end of the sequence control. To obtain an alternation consisting of two different voltage level, two transistors will be comanded, connected to different windings of the transformer and the one connected to the winding providing lower voltage must be comanded twice. The output of the numerator goes through an inverter type MOS and a current amplifier with bipolar transistor.To achieve galvanic separation, an optocoupler will be used for each IGBT transistor, while protection is achieved with resistance and diode circuit. At the end there is connected an LC filter for smoothing voltage variations.

1. Introduction

The static power converters, designation used to define the power electronic devices, constitute a complex technique that includes the power switching, control, regulation and conversion by using power semiconductors, diodes, thyristors, transistors, etc., as well as auxiliary circuits for voltage measurement and protection.

Most of the current technological processes, applied in various industries, require increasingly electrical drives as cheap and robust as possible.

The frequency converters transform the alternating current of a certain frequency into alternating current of another frequency.

They have a wide range of technical applicability, since there are many receivers requiring a power source with a different frequency from the network frequency (fluorescent lamps, induction furnaces, etc.) or with variable frequency (AC electric motor drive systems).

Depending on the power circuit structure, the frequency converters can be indirect frequency converters or direct frequency converters [1].

The indirect frequency converters change the frequency in two steps, through the process of recovery and inversion. These converters can be found in the literature with the alternative designation of frequency converters with DC voltage intermediate circuit.

In contrast, the direct frequency converters enable changing the frequency in a single step, without the prior conversion of AC into DC. Both types of converters can be designed as converters driven from the supply network (autonomous) or independent (autonomous).

Based on the switching mode, the direct frequency converters can be classified in direct frequency converters with natural switching and direct frequency converters with forced switching.

The power part of the converter is realised with controlled semiconductive power devices (thyristors, transistors) or, uncontrolled (diode). This devices working in comutation conditions, having the role of a swich so, resulting in a steady state formed by a peryodic succesion of transistor conditions. Successive opening and closing of these switches is done by logic imposed by the principle of operation of the converter. This logic is insured by the electronic comand circuit. So, all the converters contain a part of power (strenght) and a commanding part [2].

The converters provide the conversion of large quantities of energy.

This requires the main sizing criteria to be the yield, which leads to differences between the power electronics and the signal electronics, where the main aim is to obtain an accurate output signal.

2. Problem formulation

2.1. Interface circuits and galvanic isolation circuits

The electronics power converters or, in general, the power electronics systems, include a part of force and a part of command and control.

The force part that ensures the circulation of the energy mainstream operates at high voltages and electric potentials, being subjected to intense electromagnetic disturbances. The command and control part operates with logic or analogue low amplitude signals. The drivers of the power semiconductor devices are placed on the border between the two parts. The communication is done in both directions by means of logic signals. Thus, a control circuit will contain, in its turn, a logical block capable to handle and process these logic signals, and an interface block, which can perform one or more of the following functions [3]:

- Reception of the logic control signals from the hierarchically superior control block, their reformation where they are affected by disturbances, and adaptation of the logic level to the one required by the control circuit of the power semiconductor;
- Sending logic signals of appropriate level, used for the reverse communication in various situations or states seized by the control circuit;
- Galvanic isolation between the control circuit and the numerical control system.

The galvanic isolation elements, optocouplers or signal transformers, can be placed either at the entry of the control circuit of the power devices or before the final stage of the transistor control circuit. Figure 1 shows an alternative embodiment, in which the galvanic isolation elements (optocouplers) are arranged at the driver entrance, the point where the driver interfaces with the numerical control system (microprocessor - μP).

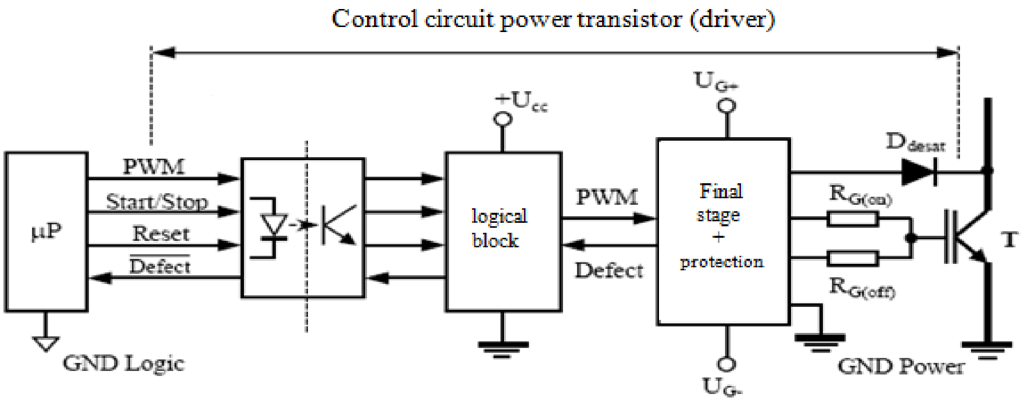

Figure 1. Implementation of the galvanic isolation function at the entrance of the power transistor control circuit

2.2. The power supply structures of the control circuits

Another important issue to be taken into account when the control circuits are designed is the selection of power supply options and sources.

In the example shown in Figure 2, the driver can operate if it is supplied with four different voltages: U_{cc1}, U_{cc2}, U_{G+} and U_{G-}.[4] A solution to simplify the power supply problem is the use of the same positive voltages, either in the logic part or in the final stage of signal processing ($U_{cc1} = U_{G+}$). For this, we must abandon the galvanic isolation and optimise the voltage amplitudes for a proper operation of both parts. Not always we can find solutions in this regard, because a complex control scheme requires certain standard voltage values for the circuits used in the logic part, and other values for the grid voltages.

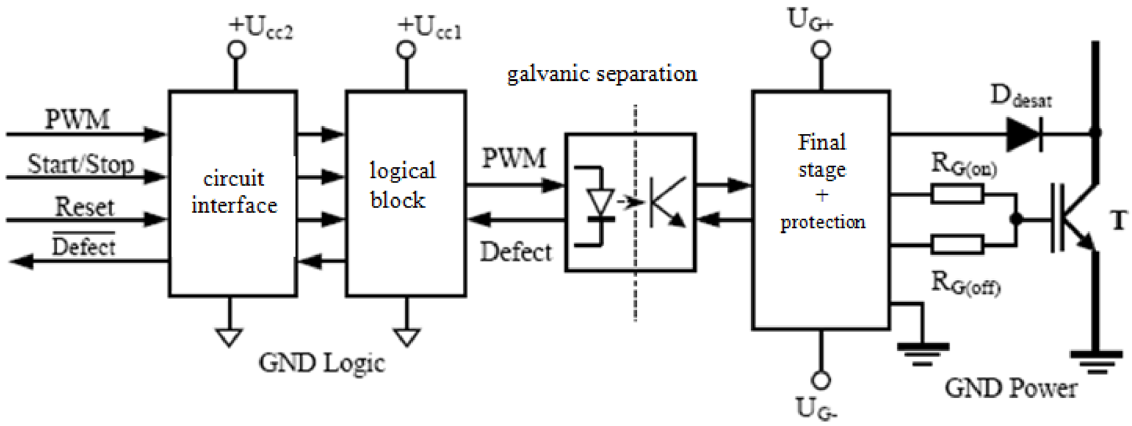

Figure 2. Power supply option for the complex control circuit blocks

For example, to obtain an effective amplitude of + 15V on the MOS grid of the power device, the voltage U_{G+} should be slightly higher to compensate the voltage on the T_{on} transistor, when this transistor is under conduction.

If the galvanic isolation is made before the final stage, the grid voltages (U_{G+}, U_{G-}) must come from a source isolated from the source that supplies the voltages to the other blocks of the control circuit.

Similarly, in the logic part of the control circuit, it might be necessary multiple power supply voltages. It is possible that some blocks, which include the specialised IC, to require a voltage U_{cc1} = +15V, and the interface circuit with the external control system to work with TTL - level logic signals, U_{cc2} = +5V.

From the foregoing, it can be said that, to solve the power supply problem faced by a control circuit, there are necessary two galvanic isolated sources, of which at least one must be able to provide multiple voltages. The problem is further complicated if the force structure contains several power transistors. At some of these transistors, the control terminal relates to a floating ground. For solving the problem of the power supply sources required by the control circuits which are part of a complex electronic power system, the designer has two choices [5]:

- Using a stabilised multi-source with a sufficient number of galvanically isolated outputs. The source may be linear, with network transformer having several isolated secondary windings. This is a classic solution that is poor in terms of gauge, mass and energy efficiency. The modern option is to use stabilised switching sources with multiple isolated outputs, such sources eliminating the disadvantages of the linear ones;
- Using certain integrated circuits or specialised control modules, specifically designed to reduce the number of sources and supply voltages.

2.3. Surge protection circuits for transistors

For circuit analysis blocking protection, the parasitic inductances in the converter have been neglected, so the surges generated when blocking the current flow through the transistor have been neglected as well. The surge protection can be obtained using RCD-type circuits, as the one shown in Figure 3(a), where it has been considered that the parasitic inductances can be replaced by an equivalent inductance.

At baseline, the transistor is open and the voltage VC_{0V} across the capacitor in the surge protection circuit is equal to V_i (the capacitor is precharged).

When blocking, assuming that the time interval required for cancelling the current flow through the transistor is very small, the current flowing through the inductor L_α is maintained at the value of I_0, the load current flow circuit being closed through the leakage diode D_f. For this state, the equivalent circuit is shown in Figure 3(b), where the diode D_f is shorted, and the transistor is blocked.

The energy stored in the parasitic inductances is now transferred through the diode D_{0V} into the capacitor C_{0V}, and charges it up. The capacitor voltage increases beyond the value of V_i.

In this state, the overvoltage ΔV_{Cov} occurs also across the transistor:

$$\Delta V_{Cov} = \Delta V_{CE} \tag{1}$$

and can be determined by replacing the precharged capacitor with an equivalent circuit, as shown in Figure 3(c).

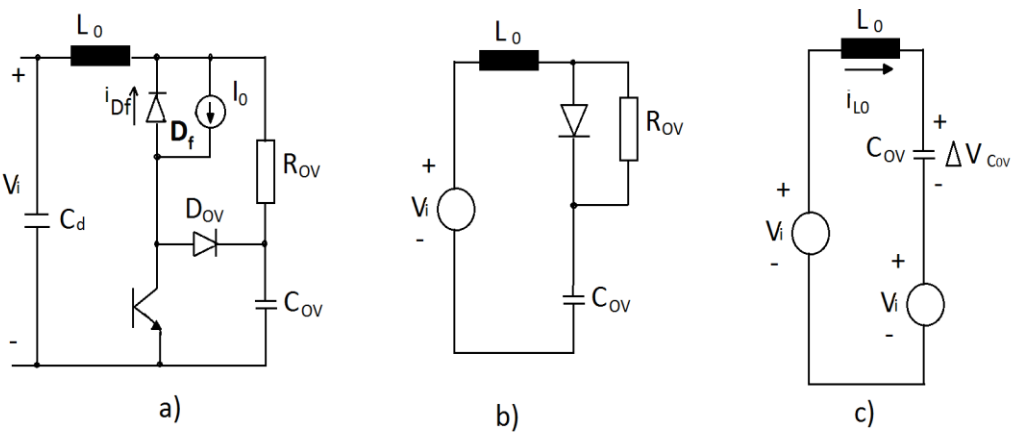

Figure 3. (a). Surge protection circuit; (b), (c). Equivalent circuits when blocking the transistor

The equation (1) shows that a high value of the capacitor C_{0v} would minimise the overvoltage ΔV_{CEmax}. Once the inductor current reached zero, the capacitor is discharged through the resistor R_{0v}, with the time constant $R_{0v}C_{0v}$, which must be small enough to enable the voltage on C_{0v} to fall to about V_i, thus making the protection circuit operational before the transistor is blocked again [6].

2.4. The control circuit

The commanding part is realised with a monostable circuit as a tact signal for a ring counter that generates the commanding sequence for the commutation elements from the invertors scheme.

The monostable circuit is realised with a LM555 circuit which provides the adjustable frequency command pulse. The frequency can be modified from a potentiometer. The output pulses are tact signals for a counter, realised with a CD4017 which provides sequences of 8 intervals necessary for commanding the invertors transistors.

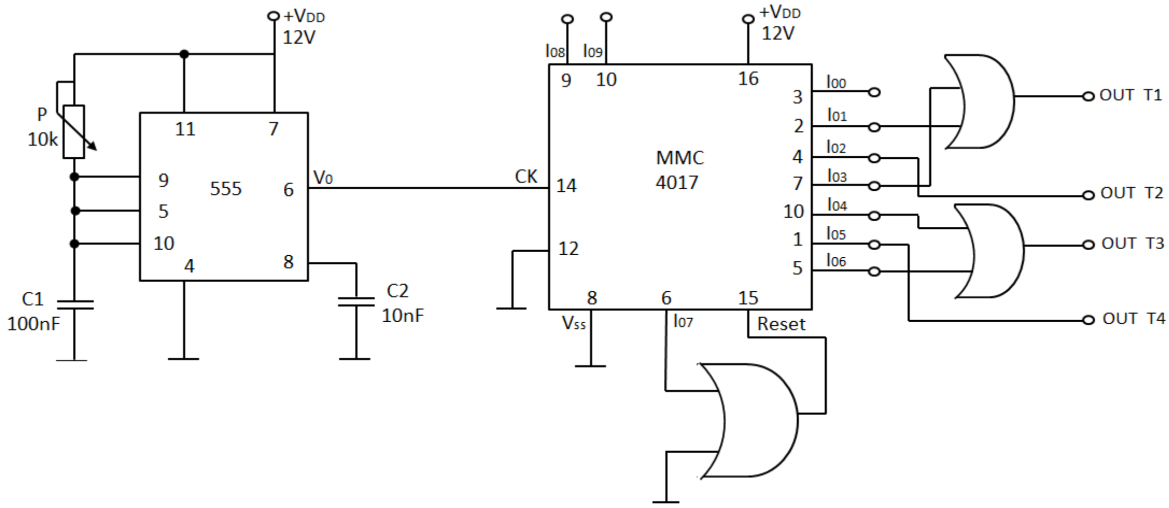

Figure 4. The control circuit of the voltage inverter

Four IGBT transistors are used, which command a four primary winding transformer which provide two steps of voltage at the output [7].

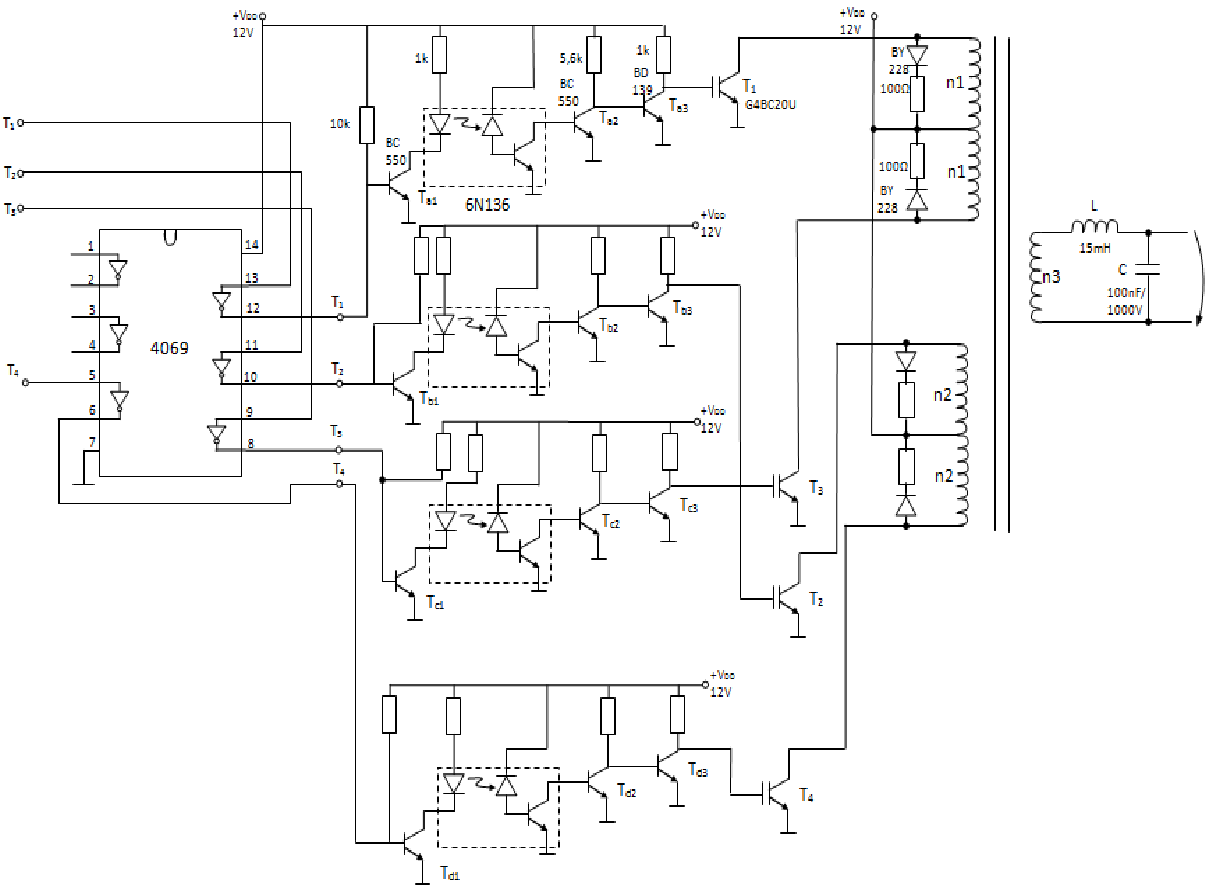

Figure 5. Single-phase inverter wiring diagram

The commanding sequence from the counter is brought to the IGBT grid through a MOS(4069) inversor. Each output is connected to a current amplifier with a bipolar transistor(BC550) to provide enough current for the optocupler used for the galvanic separation of the comand circuit on the power circuit. The signal obtained from the optocuplers output is amplified into curent with same bipolar transistor (BC 550) following to be inversed again with a BD 139 stage transistor. This second reversal is necessary to amplify both current command and therefore a faster switching transistors and IGBT for controlling the phase of the output sequence from numbers that will produce output voltage of the synthetic form. For a form as close to one using sinusoidal output filter LC [8].

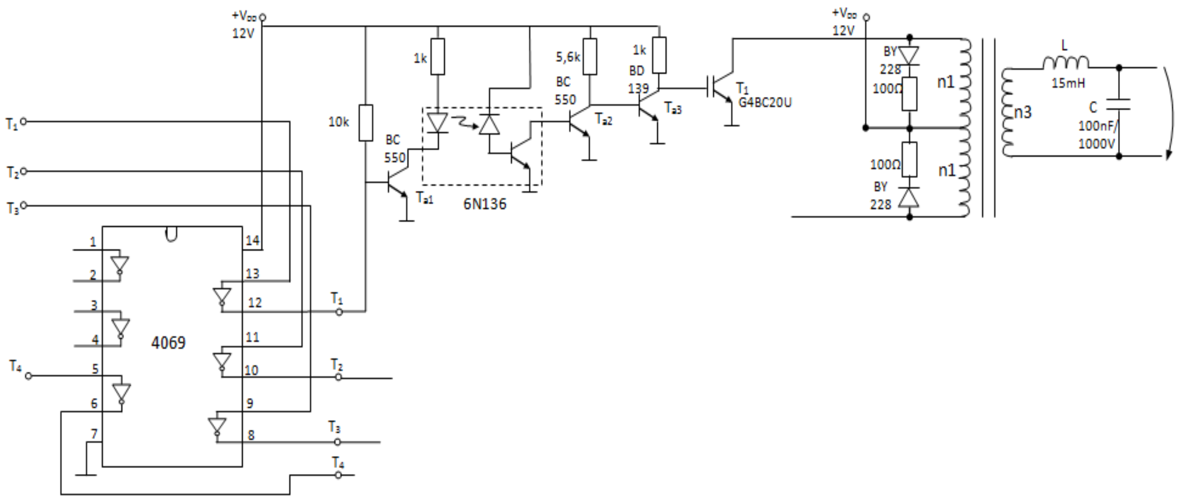

Figure 6. Wiring diagram for control of a IGBT transistor

3. Problem solutions

The proper functioning of the circuit is highlighted by presenting the wave forms, in different points of the scheme, as it follows.

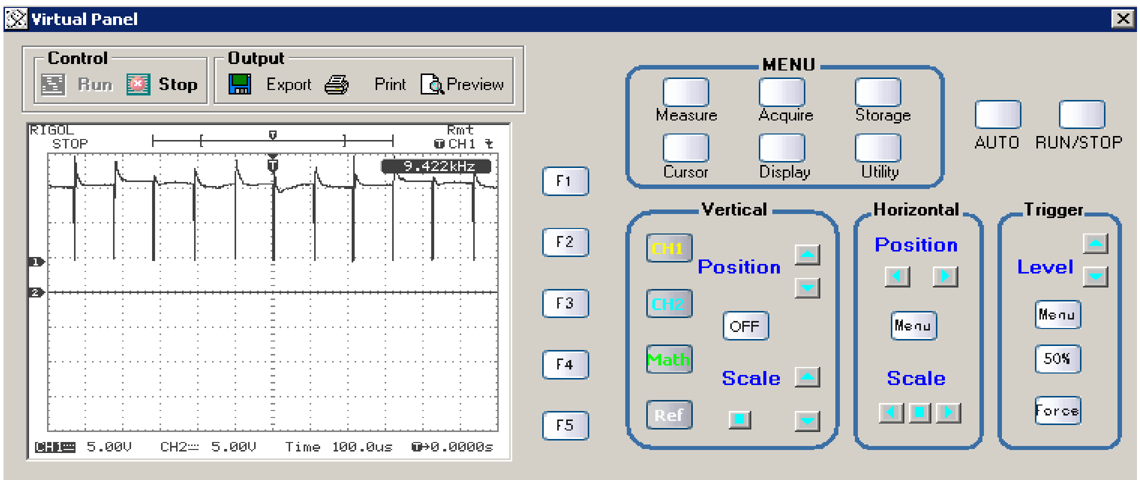

Figure 7. Tact pulses for the counter

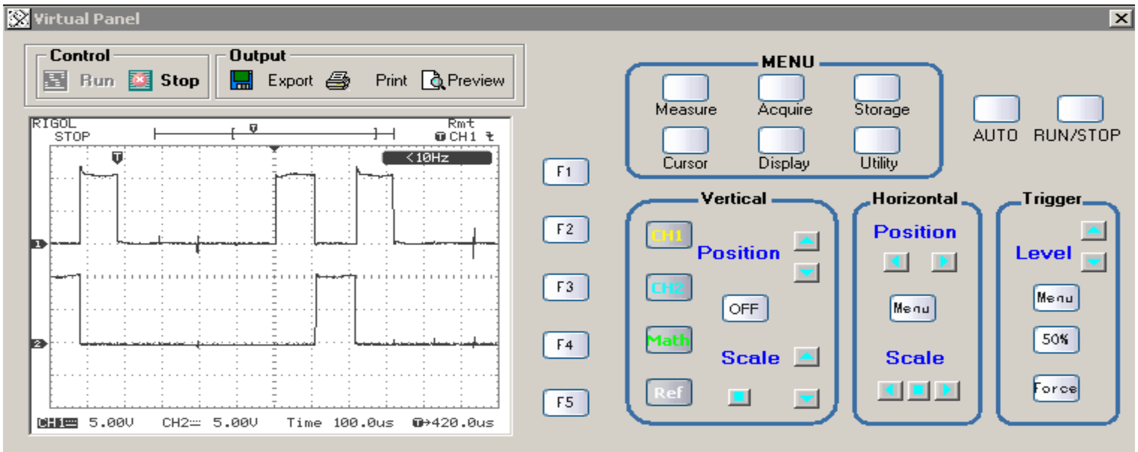

Figure 8. Comand impulses for optocupleurs one and two

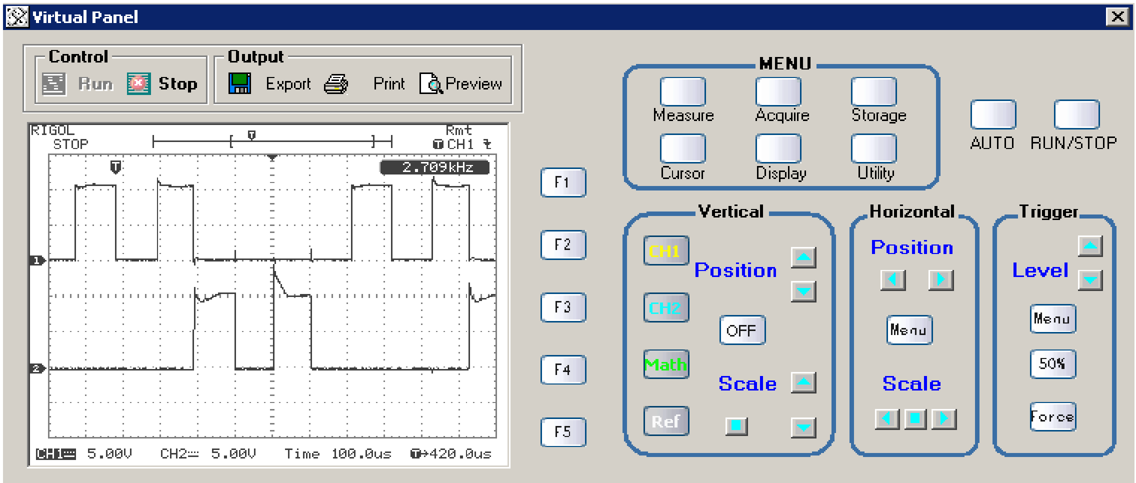

Figure 9. Comand impulses for optocupleurs one and three

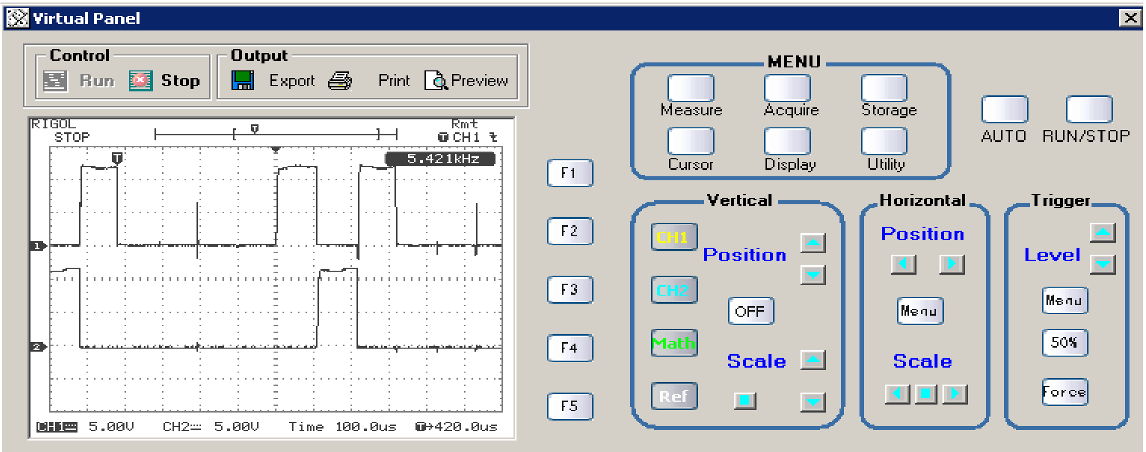

Figure 10. Command impulses for transistors T1 and T2

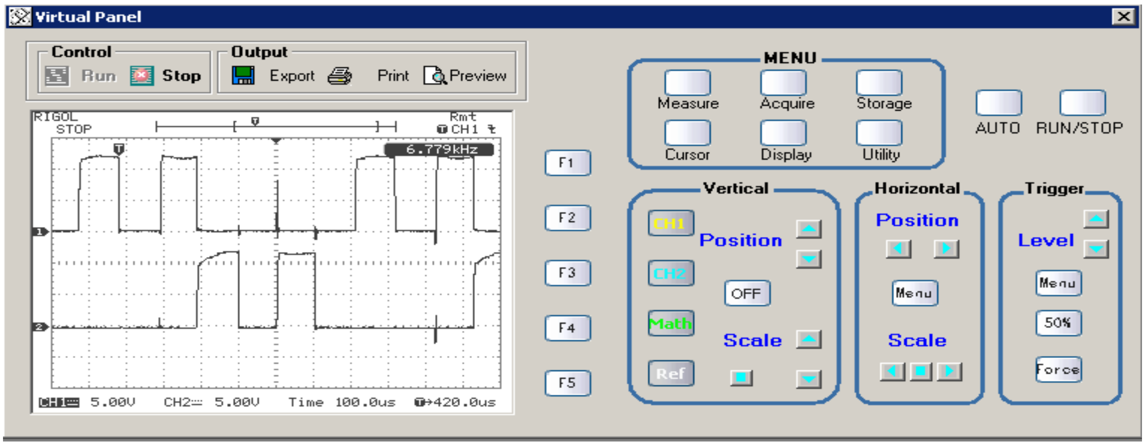

Figure 11. Command impulses for transistors T1 and T3

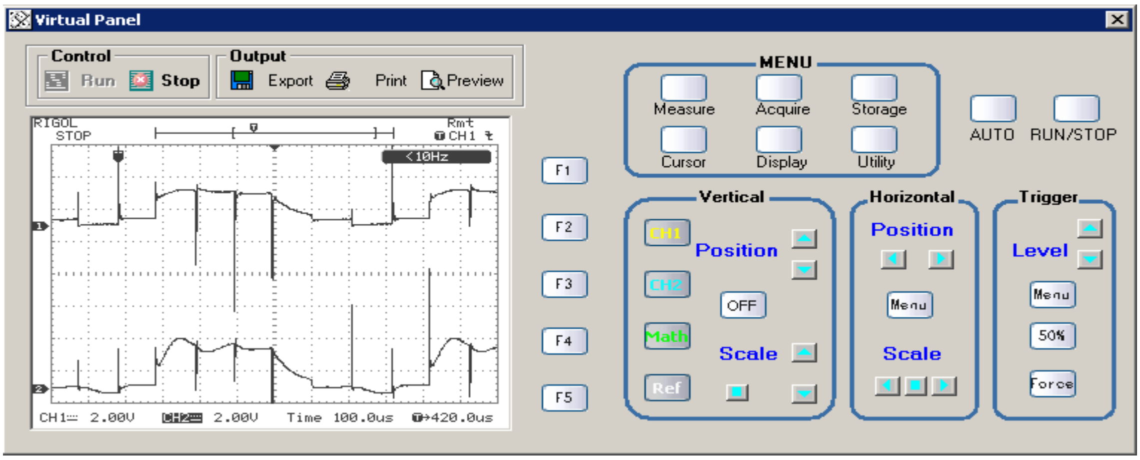

Figure 12. Collector - emitter voltage for T1 and T2

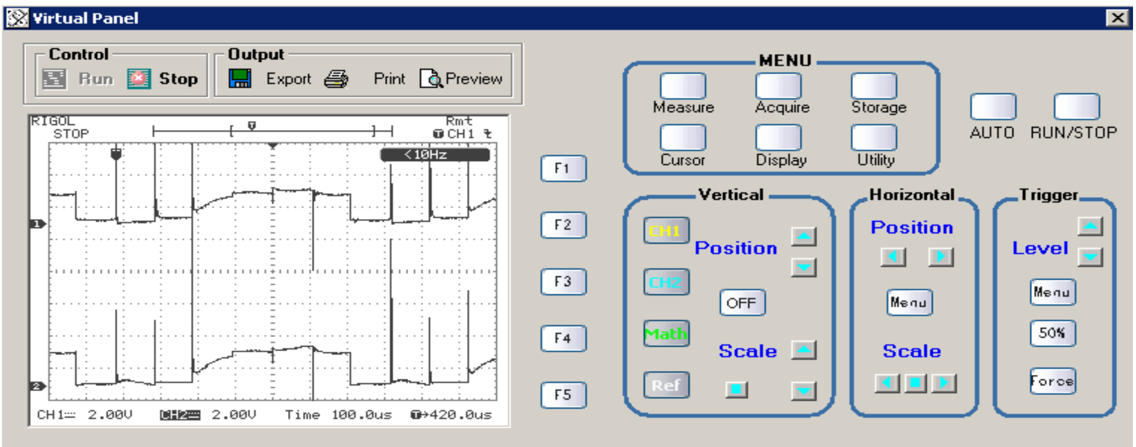

Figure 13. Collector - emitter voltage for T3 and T4

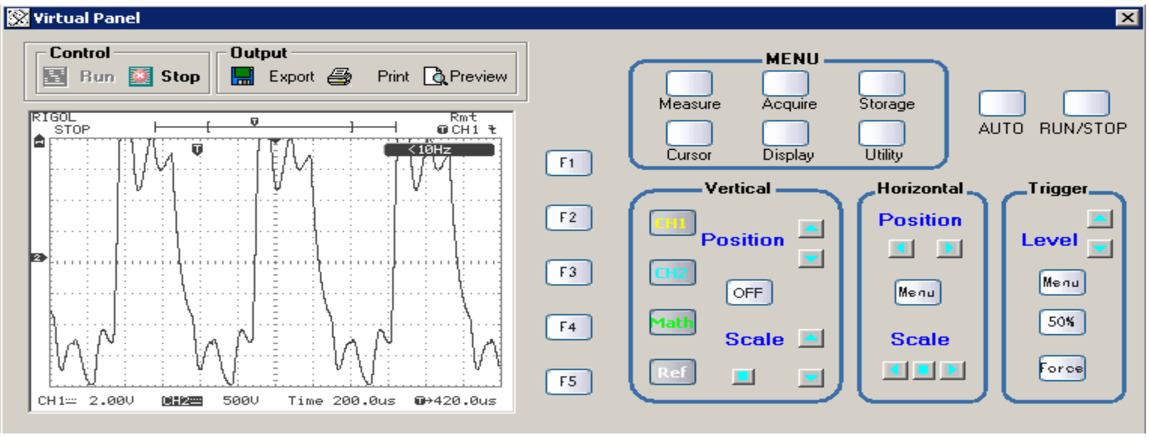

Figure 14. Output voltage

4. Conclusions

It appears an output voltage which no sudden jumps and shape is similar to sinusoid. Command sequence is under full waveform, which requires the use of large radiating surface radiators.

This was necessary because it was used a transformer laminations ferro silicon.

During the conduction of a transistor output voltage is variable as shown in figure.

The solution to this problem stands in realizing an impulse commanding sequence instead the one with full wave and replacing the transformer with a ferrite core one.

References

[1] Tamer Khatib T N, Mohamed A, Amin N and Sopian K 2010 An efficient maximumpower point tracking controller for photovoltaic systems using new boost converter design and improved control algorithm, *WSEAS Transactions on Power Systems* **5**(2) 53- 63

[2] Alexa D and Hrubaru O 1989 *Applications of the static power converters*, Technical Publishing, Bucharest, Romania

[3] Măgureanu R and Micu D 1994 *Static frequency converters in drives with induction motors*, Technical Publishing, Bucharest, Romania

[4] Lascu D 2004 *Techniques and circuits for active correction of the power factor*, Western Publishing, Timişoara, Romania

[5] Ionescu F, Florincău D, Niţu S, Six J P, Delarue Ph and Boguş C 1998 *Power Electronics. Static Converters*, Technical Publishing, Bucharest, Romania

[6] Deaconu S I, Topor M, Popa G N and Bistrian D 2010 Experimental Study and Comparative Analysis of Transients of Induction Motor with Soft Starter Startup, *Advances in Electrical and Computer Engineering* **10**(3) 27-33

[7] Popa G N, Popa I, Diniş C M, Deaconu S I and Abrudean C 2016 *Control of Single-Phase Inverter with PIC Microcontroller,* The XVI National Conference "Prof. Dorin Pavel - The Founder of Romanian Hydropower", Since and Engineering, Sebes, Romania, June 10-11, pp 447-457

[8] Iagăr A, Popa G N and Diniş C M 2015 Analysis the electrical parameters of a high-frequency coreless induction furnace, *IOP Conf. Ser.: Mater. Sci. Eng.* **85** 012013