UNREGULATED TRANSISTOR INVERTER
FOR HIGH-FREQUENCY MAGAMP POWER CONVERTERS

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Abstract: This article sets basic requirements for an unregulated high-frequency transistor inverter designed to work with regulators on magnetic amplifiers. The process of the development of such an inverter is described and the main results of its experimental research are given.

Key words: high-frequency magnetic amplifier, unregulated transistor inverter, push-pull converter, rectangular hysteresis loop.

1. Introduction

Modern power converters adjust power parameters between primary sources and consumers. They are realized according to the principle of high-frequency conversion and regulation. At medium power, push-pull power converters are often used. The main advantages of push-pull power converters compared to one-stroke are the following:

– higher utilization of the magnetic material of a high-frequency power transformer core improves its mass-dimensional parameters;

– push-pull rectification of the high-frequency inverter output voltage provides better operation modes for the output filter which decreases its dimensions.

However, push-pull power converters have the following disadvantages:

– more complex control circuit due to the growing complexity of the power part of the converter;

– increase in cost due to the growing complexity of both the power part and the control circuit;

– the possibility of occurrence of an asymmetric magnetization mode in the magnetic material of the high-frequency transformer which would lead to its unilateral magnetization.

The last disadvantage is the most significant. One-way magnetization of high-frequency transformer core causes its saturation and the appearance of current peaks in the power circuit which can be several times larger than average current value. At the same time, the conditions of operation modes of power switches (transistors) which are forced to close at the peak current

value significantly deteriorate. In the end, such an abnormal converter operation mode leads to the decrease in its reliability and efficiency, and the deterioration of electromagnetic compatibility. To eliminate this mode, special symmetry circuits are used for push-pull power converters [1, 2].

Considering the existing symmetry methods, it can be concluded that only converters which do not require the symmetry mentioned above, or in which this process is ensured automatically without the introduction of any additional elements or feedback in circuitry will be highly efficient with excellent specific and performance characteristics.

2. Methods of Design of MagAmp Power Converters

This problem can be solved designing power converters based on high-frequency magnetic amplifiers [2–8]. In high-frequency MagAmps the cores based on amorphous alloy with rectangular hysteresis loop are used. The functional scheme of such a power converter is shown in Fig. 1. It consists of an unregulated high-frequency transistor voltage inverter 1, power transformer TV, push-pull output rectifier VD3, VD4, saturation cores TS1, TS2, output filter 2, load, control circuit 3, demagnetizing diodes VD1, VD2 [8].
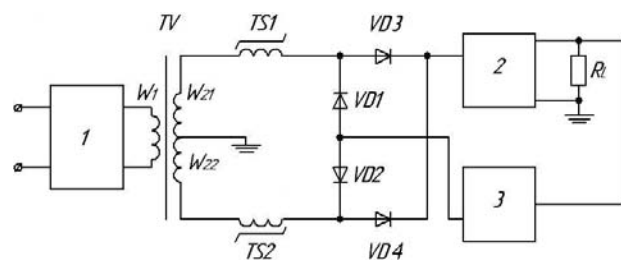

Fig. 1. Functional scheme
of MagAmp power converter [6]

The operation principle of magnetic amplifiers is described in the literature sources [3–8]. High efficiency and reliable operation of such a converter depends largely on the implementation of a high-frequency unregulated transistor inverter.

3. Methods of Design of High-Frequency Unregulated Transistor Invereter

The ways to control power transistor switch are the following:

– forcing the opening and closing modes of the transistor;

– limiting the saturation level of the transistor;

– permanent opening delay;

– automatic natural delay of transistor opening, determined by the closing time of the opened transistor.

The circuit of a high-frequency unregulated transistor inverter is shown in Fig. 2. It operates as a power generator with collector current feedback and the inverter output voltage feedback. The use of bipolar transistors in it is conditioned by the ability to control their switching processes. The saturation core TS is made of a high-frequency amorphous alloy with a rectangular hysteresis loop. The time of full re-magnetization of the saturation core TS in the current source mode with the speed limitation of its magnetization determines the time of half-period of the inverter operating frequency. The current source is formed by the voltage of the feedback winding W_u of high-frequency power transformer TV1 and resistor R5. The restriction of the magnetization speed is achieved by the voltage drop on diodes VD1… VD4 and VD5… VD8 in the base circuits of the power transistors. Fig. 3 shows the control circuit of power switches in the high-frequency unregulated transistor inverter. The equivalent circuit for this magnetization mode is shown in Figure 4, where the voltage on Zener diodes VD1 and VD2 corresponds to the voltage drop on the diodes in the base circuits.
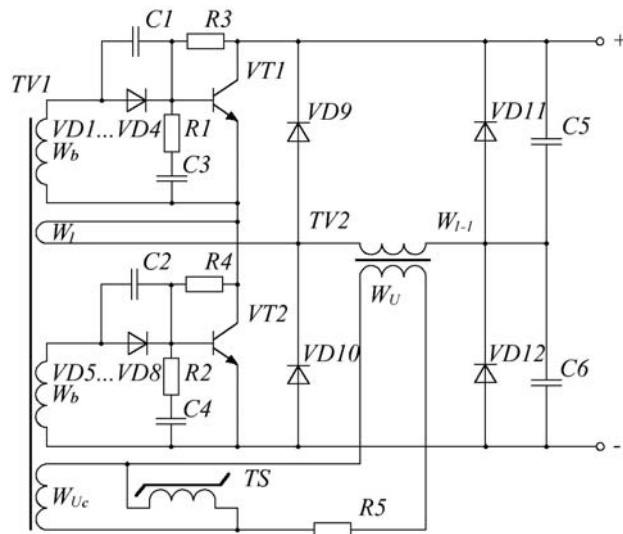
versa) under the action of the effective external field He = Hm-Hc, where Hm is the external field strength, Hc is the coercive force of the saturable core TS. If an external field significantly exceeds the coercive force of the magnetic core TS, the change in the induction of the material having a rectangular hysteresis loop occurs by the law shown in Figure 5 [9].
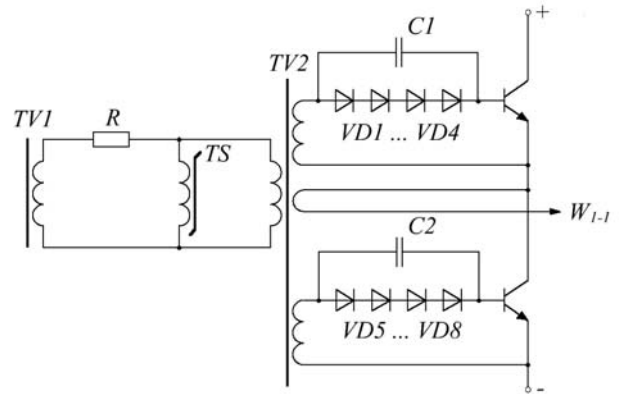

Fig. 3. Control circuit of power switches in the high-frequency unregulated transistor inverter.
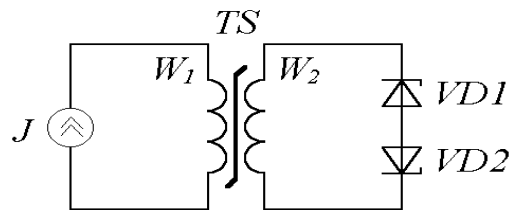

Fig. 4. Equivalent circuit of the TS magnetization mode in the positive feedback circuit of the inverter output voltage.

Fig. 2. High-frequency unregulated transistor inverter.

The magnetization of the saturable core TS occurs along the full hysteresis loop from - Bs to + Bs (and vice
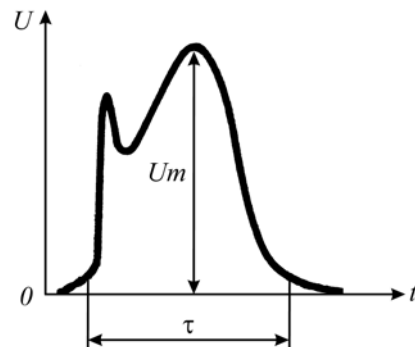

Fig. 5. Change of the induction in the material with a rectangular hysteresis loop.

Fig. 6 shows the results of modeling of the magnetization modes of a material with a rectangular hysteresis loop without limiting the speed of its magnetization (1) and with limiting the speed of

magnetization (2) using the dynamic Preisach model for amorphous material 84CoCrSeRu [2].
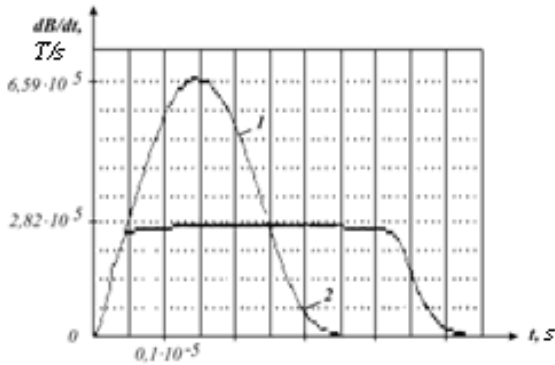

Fig. 6. Results of modeling of the modes of magnetization of a material with a rectangular hysteresis loop.

The process of magnetization of the magnetic core TS in current source mode with the limiting speed of the magnetization does not depend neither on the input voltage change nor on the change of the load current. The equality of the volt-second integrals of the magnetic core TS ensures the absence of the asymmetry in core magnetization of the power transformer TV2. This unregulated inverter is optimal for joint operation with power MagAmp regulators.

However, providing the magnetic core TS magnetization in the current source mode leads to losses on resistor R5, which are constant and independent from the load current. Their value can reach 10 watts. For the inverter with a power output of 300–500 watts, they are quite noticeable.

A high-frequency unregulated transistor inverter was proposed, in which a current generator based on semiconductor elements was used to provide TS magnetization, as shown in Fig. 7 [10].
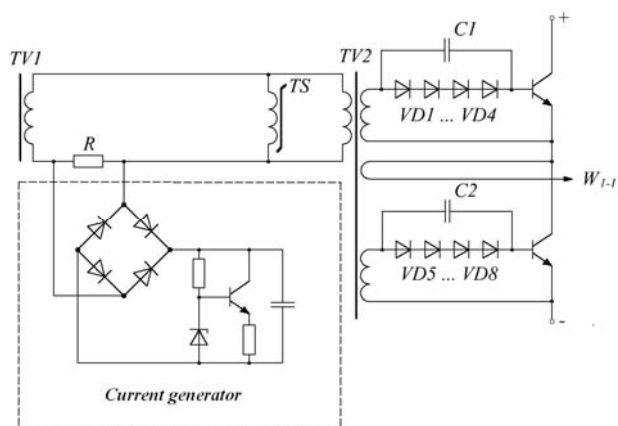

Fig. 7. Current generator on the semiconductor devices in the positive feedback circuit of the inverter output voltage of high-frequency unregulated transistor inverter.

Since it is a direct current generator, it needs high-frequency AC rectification by the bridge circuit. Its losses are several times lower. However, the additional rectification of high-frequency alternating voltage leads to electromagnetic interference. It occurs due to the non-ideal characteristics of the rectifying diodes and extends through the control circuits into the power part of the inverter.

The following solution to this problem is proposed [11]. An additional step-down transformer is introduced into the positive feedback circuit of the inverter output voltage. In this case, the resistance of a much smaller value is required to organize the current source mode. The scheme of such high-efficiency positive feedback circuit for the inverter output voltage is shown in Fig. 8.
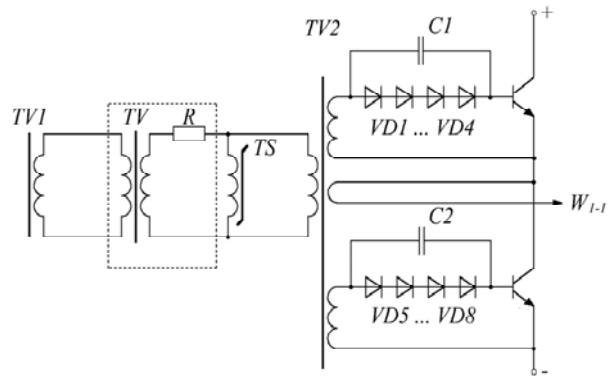

Fig. 8. Scheme of the high-efficiency positive feedback circuit for the output voltage of the inverter

4. Experimental Investigations of High-Frequency Unregulated Transistor Invereter

The high-frequency unregulated transistor inverter with output power up to 500 W has been designed and investigated. Its design allows using 2T847A type transistors and their analogs. The number of winds of the control transformer winding was selected to provide the transistor current ratio equal to 10. In Fig. 9, the waveforms of the collector-emitter voltage Uce (top waveform) and the collector current Ic (lower waveform) are shown: a) taking into account the current of the shunt diode and b) without taking it into account. For the Uce waveform, the scale is set to 100 V/div. For the Ic waveform, the scale is set to 2 A/div. The working frequency of invereter is equal to 50 kHz (2 mks/div). Waveforms of collector current Ic (top waveform) and base voltage Ube (lower waveform) are shown in Fig. 10. For the Ic waveform, the scale is set to 1 A/div. For the Ube waveform, the scale is set to 2 V/div.
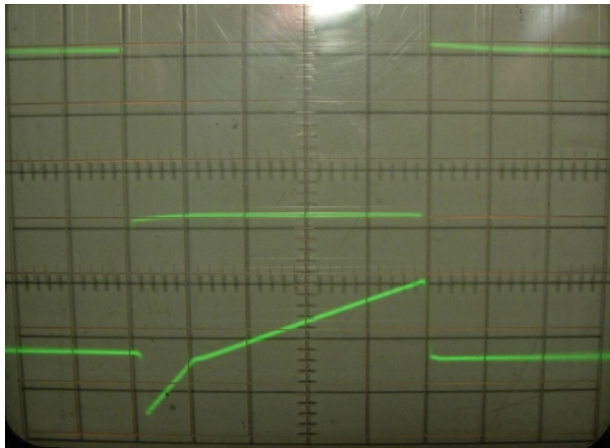
a)
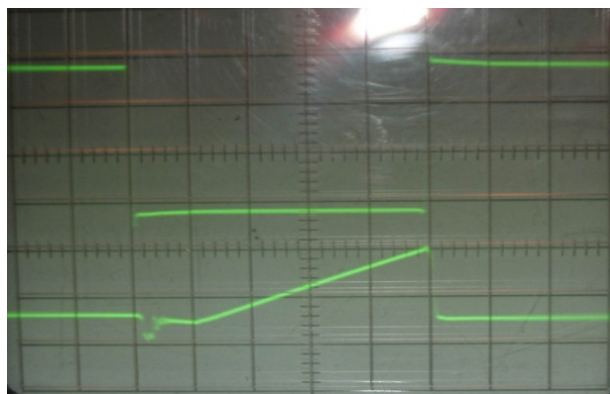
b)

Fig. 9. Waveforms of the collector-emiter voltage Uce
and the collector current Ic: a) taking into account
the current of the shunt diode; b) without taking into account
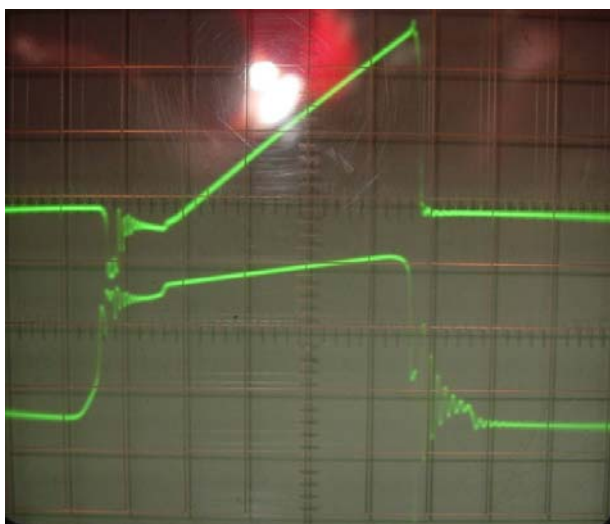the current of the shunt diode.

Fig. 10. Waveforms of collector current Ic
and base voltage Ube.

Capacitors C1 and C2 in the basic circuits are designed to actively block transistor switches. Waveform of base current Ib is shown in Fig. 11. For the Ib

waveform, the scale is set to 0.5 A/div. Such a method of power transistors control allows opening and closing them during 50 ns.
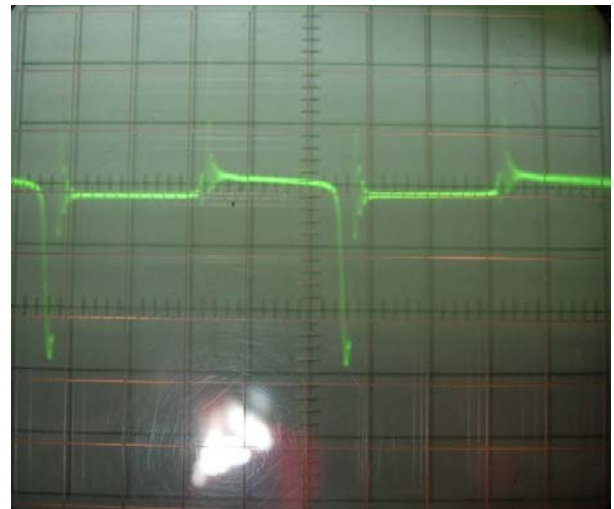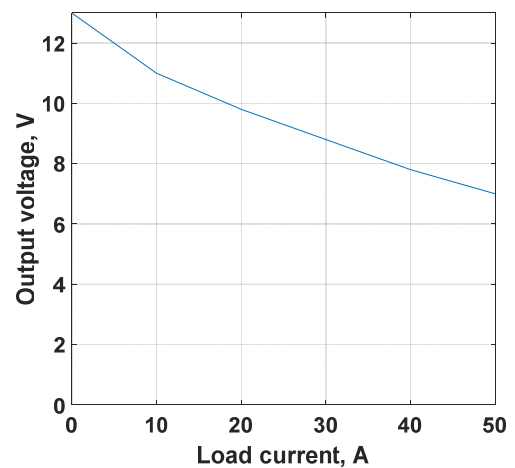

Fig. 11. Waveforms of base current Ib

Fig. 12. Load characteristic
of high-frequency unregulated transistor inverter

High efficiency of the designed inverter is confirmed by load characteristic, experimentally obtained using a mid-point diode rectifier based on MBR2080 diodes and shown in Fig. 12.

6. Conclusion

The working frequency of the inverter, as well as the switching trajectory of the power transistor, is determined by the magnetization modes of saturable core in the positive feedback on the inverter output voltage. The saturable core is made of an amorphous alloy with a rectangular hysteresis loop.

The main advantages of the inverter include:
– high efficiency;
– high reliability;

– low level of electromagnetic interference;

– high switching frequency stability over a wide range of input voltage and at 100 % load current range;

– simplicity of topology - no power transistor control circuit, no additional power supply needed for the control circuit;

– soft start with high switching frequency;

– absence of magnetization asymmetry of the power transformer;

– when overloaded, only one transistor breaks down;

– low cost.

Developed high-frequency unregulated transistor inverter together with MagAmp power regulators are implemented according to customers' requirements and work uninterruptedly in their equipment.

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НЕРЕГУЛЬОВАНИЙ ТРАНЗИСТОРНИЙ ІНВЕРТОР ДЛЯ ВИСОКОЧАСТОТНИХ ПЕРЕТВОРЮ-ВАЧІВ ЕЛЕКТРОНЕРГГЇ НА ОСНОВІ МАГНІТНИХ ПІДСИЛЮВАЧІВ

Володимир Яськів, Олег Юрченко

В статті сформульовані основні вимоги для нере-гульованого високочастотного транзисторного інвертора призначеного для сумісної роботи з регуляторами пос-тійної напруги на основі магнітних підсилювачів. Процес побудови такого інвертора описано. Основні результати його експериментальних досліджень приведено.

Volodymyr Yaskiv received his MS degree in Electrical Engineering at Lviv Politechnical Institute, Lviv, Ukraine in 1986. Specialization: Electric Drive and Automation of Industrial Installations. Since 1986 worked in Lviv Scientific Research Radiotechnical Institute as engineer-designer of power supplies. Since 1989 Post Graduate Student in Moscow Power Engineering Institute (MPEI), Moscow, Russia. Received Ph.D. degree in Electrical Engineering in MPEI in 1993. Specialization: Semiconductor electric power converters. From 1993 Associate Professor in Ternopil Ivan Puluj National Technical University (TNTU), Ternopil, Ukraine. Now he is Dean of Applied Information Technologies and Electrical Engineering Faculty, Head of the TNTU Power Electronics Laboratory.

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