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# HIGH-FREQUENCY MAGAMP POWER INVERTER

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**Abstract:** Design of a high-frequency inverter with high quality of output parameters along with reduction of its circuit complexity and cost is a topical task. In the paper, the main methods of the design of high-frequency inverters are analyzed. The principle of a magnetic switch operation based on high-frequency magnetic amplifiers, whose magnetic core is made of amorphous alloy with rectangular hysteresis loop, is described.

The paper suggests a new method of the design of the power inverter based on high-frequency magnetic amplifiers. The proposed circuitry allows obtaining the higher quality of output ac voltage, higher level of dynamic characteristics, reliability and efficiency of the inverter. It also provides low level of both radiative and conductive electromagnetic interferences. Besides, it allows the regulation of output ac voltage within a wide frequency range.

The use of the cores of different sizes for high-frequency magnetic amplifiers allows the realization of the inverters in a wide range of output powers (hundreds watts to 10 kilowatts).

Such power inverters can be used for uninterruptable power supplies, renewable power supplies and frequency regulation of electric drives.

**Key words:** controllable power supply, power inverter, high-frequency magnetic amplifier, amorphous alloy, rectangular hysteresis loop.

## 1. Introduction

Nowadays the significant part of electrical energy is consumed by electronic devices, automation and telecommunication systems, lighting systems, electric drives, etc. The requirements for the design of power supplies for such devices often include not only providing the certain levels of dc voltages and voltage stabilization, but also forming ac voltages, voltage control, the possibility of changing power supply output characteristics.

AC controllable power supplies are the most often needed units when designing regulated electric drives and uninterruptable power supply systems. The improvement of efficiency, reliability, specific power, output voltage quality at low costs is always a topical task.

In the current paper, the authors propose a new method of the design of the ac power supply based on high frequency magnetic amplifiers (MagAmps).

The purpose of this work is the development of new design methods for controllable high-frequency power supplies with:

- high quality of output ac voltage
- wide range of output ac voltage regulation
- low level of electromagnetic interferences (EMI)
- high level dynamic characteristics
- high efficiency and reliability
- high level of specific power
- meeting a wide range of exploitation requirements
- low costs.

## 2. State of the Problem

There are numerous inverter topologies with ac voltage output [1, 2]. The modern ways of forming the output ac voltage are based on two main methods. They are:

- additive commutation of the different levels of input dc voltage [3, 4]. The waveforms illustrating this method are shown in the Fig. 1;
- pulse-width modulation (PWM) with high-frequency semiconductor devices (see Fig. 2) [5].

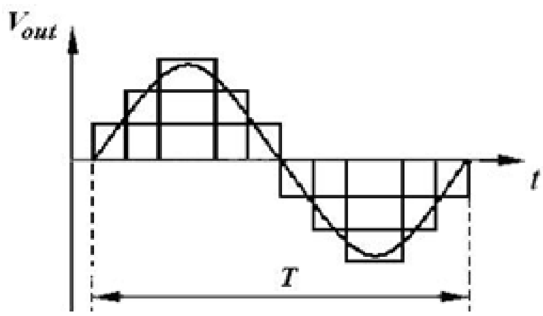


*Fig. 1. Forming the output ac voltage at multilevel dc voltage commutation.*

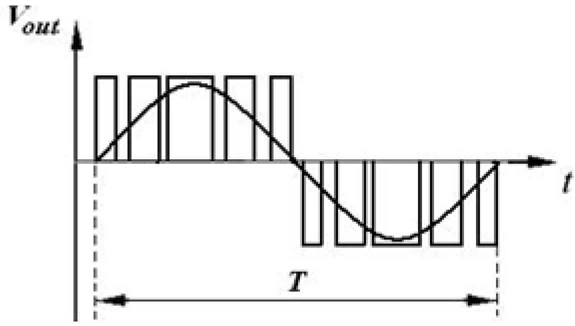


*Fig. 2. Forming the output ac voltage by pulse-width modulation of high-frequency power switches.*

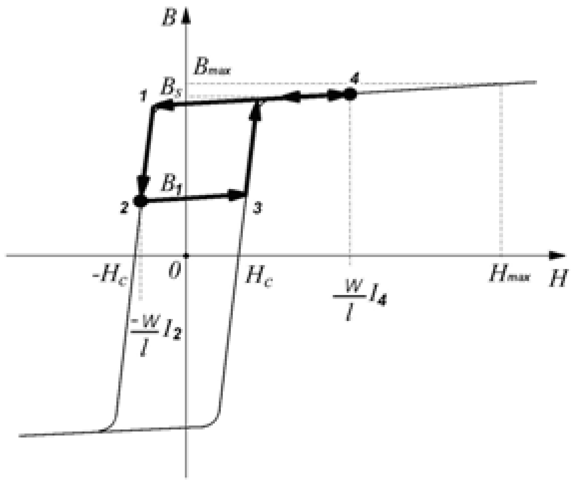


*Fig. 3. B-H characteristic (hysteresis loop) of MagAmp core material.*

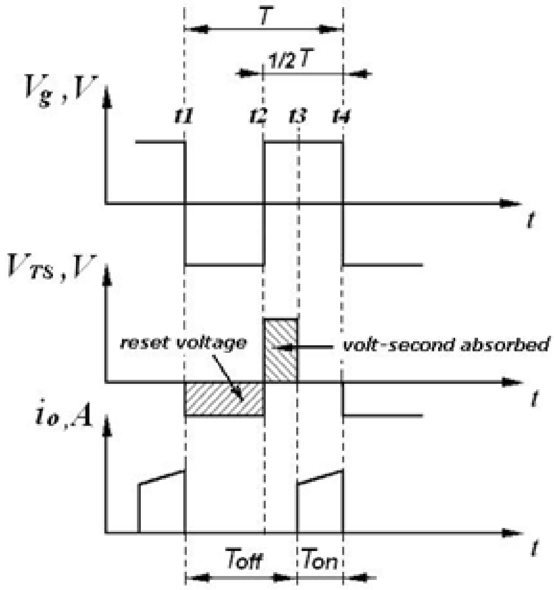


*Fig. 4. Ideal MagAmp waveforms: $V_g$ is secondary winding transformer voltage, $V_{MS}$ is MagAmp switch voltage; $i_o$ is MagAmp switch output current.*

**3. Principles of MagAmp operation**

It is suggested to use high-frequency magnetic amplifiers (MagAmps) as switching elements in controllable power supply sources.

A MagAmp switch is just a coil wound on a core of an amorphous alloy with a relatively rectangular B-H characteristic as shown in Fig. 3) [6–10]. When the voltage of negative polarity is applied to the MagAmp, its core becomes demagnetized (corresponds to 1–2 slope in Fig. 3; $t_1 \ldots t_2$ in Fig. 4). The MagAmp core stays unsaturated and, due to high impedance, no current flows through its winding. When the input voltage changes its polarity to positive, the MagAmp requires a certain volt-sec value, which is the integral of voltage over time, to be applied to its terminals for exciting the magnetic flux in the core and reaching the saturation level (interval 2–3 in Fig. 3; $t_2 \ldots t_3$ in Fig. 4). The stronger the applied field is, the more volt-secs the MagAmp needs until its saturation:

$$V = \frac{df}{dt}, \qquad (1)$$

where $V$ is the applied voltage, $f$ is the magnetic flux in the MagAmp core.

When the magnetic inductance reaches the saturation level (slope 3–4 in Fig. 3), the MagAmp impedance approaches zero, which allows the current to flow through MagAmp winding (interval 4–1 in Fig. 3; $t_3 \ldots t_4$ in Fig. 4).

The MagAmp, used as a semi-controlled switch, can block and delay the applied voltage. However, the MagAmp cannot restrain the current once it started flowing. Hence, the MagAmps are used in pulse circuits together with diode rectifiers, which cut off the current when the applied voltage changes polarity.

Such a MagAmp switch combined with a rectifying diode and demagnetizing circuit forms a synchronous rectifier, whose control circuit contains just 1 or 2 active components. Power-width modulation in such a switch is achieved through the regulation of the ratio of the time during which the core is in saturated state to the time when the core is unsaturated. This regulation is achieved due to the change of the core demagnetization depth being a function of the controlled parameters of the regulation algorithm. MagAmp operation principles, the analysis of the processes in a regulator based on the MagAmp, comparative analysis of MagAmps and transistor switches are described in detail in multiple literature sources [6, 7, 9].

The basic functional diagram of the voltage regulator based on the MagAmp switch is shown in Fig. 5.

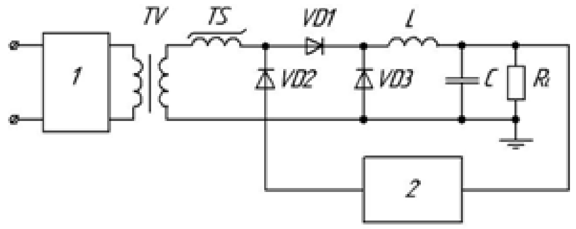


*Fig. 5. Functional diagram of the voltage regulator based on the MagAmp switch (1 is an unregulated high-frequency transistor inverter; 2 is a control circuit).*

For instance, the pulse power inverter designed by the authors [11] as a self-oscillator, can be used as a high-frequency unregulated transistor inverter. Its peculiarity is a saturable choke with a rectangular hysteresis characteristic in its positive feedback loop to the output voltage of the inverter. The moment of the choke saturation defines the change of the commutation state of power switches. Besides, the choke is a time-setting component, as the time of its complete re-magnetization defines the half-period of the inverter working frequency. Moreover, the symmetry of the hysteresis loop of the choke eliminates the magnetic bias of a high-frequency power transformer of the inverter [12, 13]. The use of the common saturable choke for several power self-oscillators provides their parallel operation with synchronous and cophased commutation within the whole range of the change of the load current [14]. Such topology is used for power converters with high load current.

**4. Proposed circuit design of MagAmp power inverter**

The circuit diagram of the controllable power supply circuit based on the MagAmps is shown in Fig. 6 [15].

The unregulated converter 1 supplies high frequency ac voltage to the transformer TV. MagAmp switches TS1 and TS2 (TS3, TS4) ensure the stabilization of dc positive (negative) voltage through pulse-width modulation in accordance with the control signal. Switches VT1 and VT2 commute the voltages of opposite polarities. Thus, we get the ac output voltage, whose frequency is determined by the frequency of control signals V1 and V2.

The AC controllable power supply operates in the following way: when the voltage applied to TS1 (TS4) is negative, a so-called control half-period takes place. During this time, a subinterval diode VD1 (VD8) is in non-conducting state, diode VD2 (VD7) is in conducting state, so the current flows through the control circuit 2, demagnetizing diode VD2 (VD7) and MagAmp switch TS1 (TS4). This current causes demagnetization of TS1 (TS4) core material from the saturation induction $B_s$ to some induction $B_1$. The demagnetization depth is regulated with the control circuit 2 as a function of the output voltage. When the polarity of the input voltage changes, the remagnetization begins from the memorized inductance $B_1$. When it is a control half-period for MagAmp switch TS2 (TS3), it is a so-called operating half-period for MagAmp switch TS1 (TS4). In this case, the demagnetizing diode (VD7) is in non-conducting state, diode VD1 (VD8) is in conducting state, and the high frequency ac input voltage source is connected to the load through MagAmp switch TS1 (TS4) and diode VD1 (VD8). The operating half-period consists of two subintervals. During the first subinterval, MagAmp switch TS1 (TS4) is getting remagnetized from some previous induction $B_1$ to the saturation induction $B_s$. The time needed for this remagnetization is significantly shorter compared to the time of demagnetization during the control half-period, since the speed of remagnetization is not limited (the load impedance is much smaller than the equivalent impedance of the control circuit). Therefore, the MagAmp core becomes saturated within one half-period of the frequency of input ac voltage. When saturated, MagAmp impedance is close to zero (it equals the resistance of the winding), and the current is limited only by the load impedance (the second subinterval). As a result, ac output voltage is formed. The voltage commutation at the load is performed with the switches VT1, VT2, which determine the necessary frequency of output ac voltage.

The proposed method allows obtaining the output ac voltage frequency within the range from zero to dozens kilohertz. The regulation is performed by MagAmp switches at high frequency (50–200 kHz). The distortions are refined within one half-period of this switching frequency, as the MagAmp switch is a non-inertial element with the delay of one half-period of the switching frequency. This ensures the high level of dynamic characteristics [16].

However, to form the output ac voltage, this controllable ac power supply contains two voltage regulators of opposite polarity. Each of them includes two high-frequency MagAmps. This increases the circuit complexity and does not allow reducing costs, increasing the specific power and eliminating the influence of the spread of technological parameters of magnetic material.

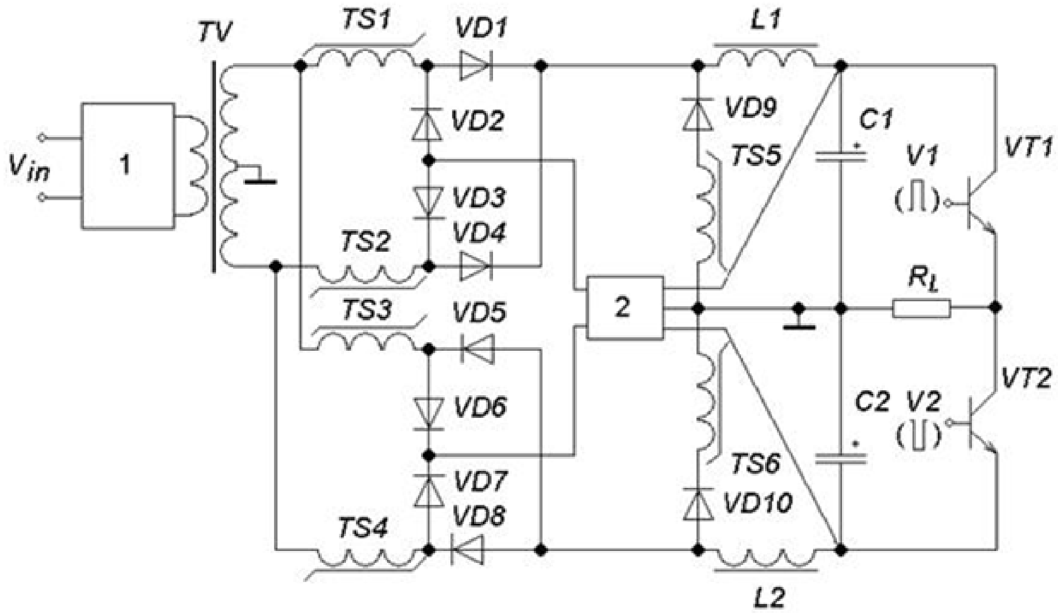


*Fig. 6. Proposed circuit diagram of MagAmp Power Inverter (1 – uncontrolled transistor inverter; 2 – control circuit).*

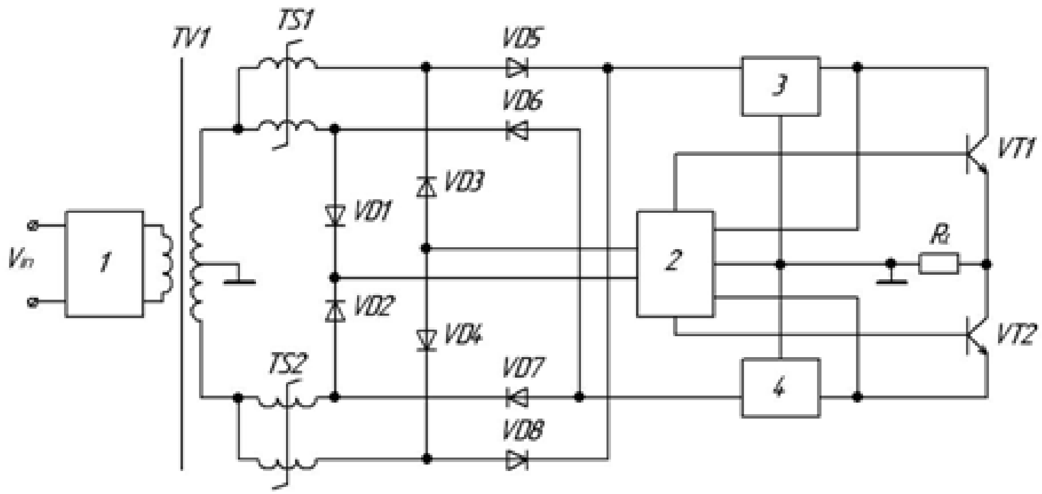


*Fig. 7. Improved functional diagram of proposed high-frequency MagAmp inverter (1 – uncontrolled transistor inverter; 2 – control circuit; 3, 4 – output filters ).*

**5. Improved MagAmp power inverter topology**

The functional diagram of a controllable power supply containing the proposed MagAmps for forming both positive and negative half-periods of the output ac voltage is shown in a Fig. 7 [17, 18].

The windings of both MagAmp voltage regulators of opposite polarity are wound on a single magnetic core.

This ensures the wide range of output frequency of ac voltage and high level of its dynamic characteristics along with:

- elimination of the influence of the spread of technological parameters of the magnetic material ($K_r$ is a coefficient of rectangularity, $B_S$ is saturation induction) on the operation of the controllable power supply;
- increase in specific power;
- cost reduction.

Fig. 8 shows the theoretical waveforms of the high-frequency MagAmp invertor.

High-frequency voltage $V_{TV}$ of the transformer is applied to the MagAmps. The MagAmp remagtetization of the switch core (voltage $V_{TS}$ ) is controlled with input voltage $V_{TV}$ and control circuit current. Output voltage $V_{out}$ is obtained as a result of the integration of output voltages of all rectifiers.

The MagAmp operation frequency is determined by the working frequency of non-regulated transistor inverter 1 (Fig. 7) and equals 50–100 kHz. Maximum remagnetization frequency of modern amorphous magnetic alloys is about 200 kHz [19]. This provides output power density up to 1kW/dm$^3$.

The proposed circuit design provides no overvoltages during high-frequency transient processes [16]. The predicted efficiency of such inverter is 90-97 %. For instance, the efficiency of 24V, 10A MagAmp power converter is 92 % [9].

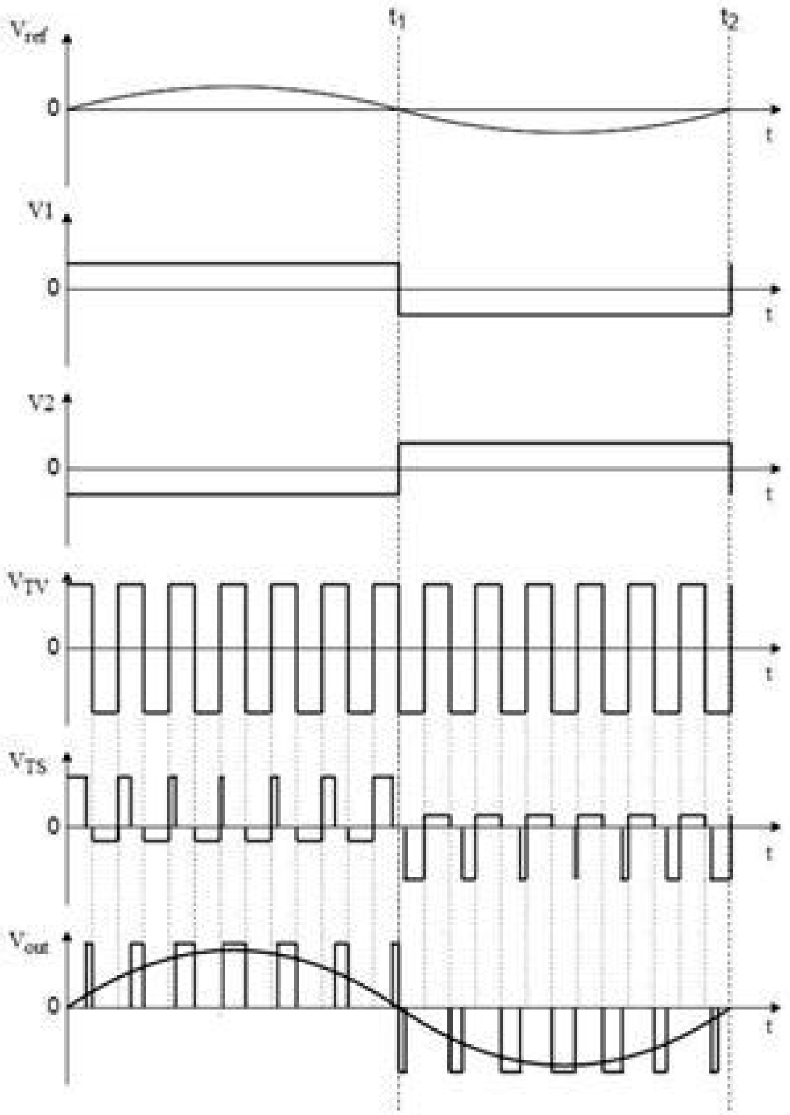


*Fig. 8. Theoretical waveforms of MagAmp inverter.*

**6. Conclusion**

A new design of a power inverter based on high-frequency MagAmps was proposed. It allows achieving the high quality of output ac voltage while the topology complexity is significantly decreased. It also provides the wide range of the regulation of output ac voltage, high level of dynamic characteristics, high efficiency and reliability, low level of electromagnetic interferences, high specific power.

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## ВИСОКОЧАСТОТНИЙ СИЛОВИЙ ІНВЕРТОР НА ОСНОВІ МАГНІТНИХ ПІДСИЛЮВАЧІВ

Володимир Яськів, Анна Яськів

Розроблено високочастотного інвертора з високою якістю вихідних параметрів зі зменшенням його схемотехнічної складності та вартості є актуальним завданням. Проаналізовано основні методи побудови високочастотних інверторів. Описано принцип роботи ключа на основі високочастотних магнітних підсилювачів, в яких як

магнітопровід використано аморфний сплав з прямокутною петлею гістерезису.

Наведено новий метод побудови силового інвертора на основі високочастотних магнітних підсилювачів. Запропоноване схемотехнічне рішення дає змогу отримати вищу якість вихідної змінної напруги, вищий рівень динамічних характеристик, надійності та коефіцієнта корисної дії інвертора. Воно також забезпечує низький рівень електромагнітних завад, як випромінювання, так і кондуктивних,. крім того, дає змогу регулювати вихідну змінну напругу в широкому частотному діапазоні. Використання осердь високочастотних магнітних підсилювачів різних типорозмірів дозволяє реалізувати інвертори в широкому діапазоні вихідних потужностей (сотні Вт – 10 кВт).

Такі силові інвертори можна використовувати для безперебійного електроживлення, відновлювальних джерел електроенергії та для частотного регулюваня електроприводів.

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**Anna Yaskiv –** BS and MS in Biotechnical and Medical Systems and Apparatus awarded by Ternopil Ivan Puliuy National Technical University in 2011 and 2012, respectfully. In February-July 2012 within a framework of the master programme she studied at University of California, Irvine, USA. Working at Power Electronics Laboratory under the supervision of Prof. Keyue Smedley, she prepared her MS thesis on “Mathematical Modeling for Design of High-Frequency Power Converters for Electromedical Apparatus”. Since October 2012 Anna Yaskiv has been carrying out her Ph. D. research at Ternopil Ivan Puliuy National Technical University, specialty – Mathematical Modeling and Numerical Methods. Her scientific interests include mathematical modeling and computer-aided design for power electronics.