РЕГУЛИРАНЕ НА ИЗХОДНАТА МОЩНОСТ НА АВТОНОМНИ РЕЗОНАНСНИ ИНВЕРТОРИ

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Абстракт: *Статията представя концепция и анализ на схематично реализирано автономно инверторно захранване за различни приложения. При източниците на индукционно нагряване на течности най-популярният е сериен пълен мостов резонансен инвертор. За регулиране на температурата на инвертора използваме метода за честотно регулиране на изходната мощност. При този метод елементите, съставляващи резонансната верига, имат постоянни параметри. Работната честота се променя, за да позволи плавно регулиране на изходната мощност на индукционния нагревател.*
Ключови думи: - *сериен резонансен инвертор; вода за отопление; регулиращ*

ADJUSTMENT OF THE OUTPUT POWER OF AUTONOMOUS RESONANCE INVERTERS

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Abstract: *The paper presents the conception and analysis of schematic realize autonomous inverter supply for different applications. At sources of induction heating of fluids is the most popular serial full bridge resonant inverter. To regulate the temperature of the inverter use the method of frequency control of the output power. In this method, the elements composing the resonance circuit having constant parameters. Operating frequency is changed, to afford a smooth adjustment of the output power of the induction heater.*
Keywords – *serial resonant inverter; heating water; regulating*

Autonomous resonant inverters are widely used in a number of technological devices for converting electricity in:

- melting and hardening of metals;
- welding and cutting of metals;
- power supply of gas discharge and diode lamps;
- heating of fluids
- heating of household appliances (induction hobs), etc.

In most of the described cases, it is necessary to adjust the output voltage, output power in order to change the temperature, brightness and other indicators of the object powered by the inverter. This effect is generally obtained by adjusting the mode of operation of the resonant inverter. The resonant inverters used in the cited applications are:

- depending on the type of power supply - with open or closed input (voltage or current);
- depending on the type of circuit - bridge, half-bridge or with a midpoint of the transformer.

The article discusses in detail a resonant bridge voltage inverter, and the results obtained with a certain coefficient of equalization are valid for all circuits of resonant inverters with open input. A series resonant inverter for induction heating of water was chosen as the object of the study (Fig. 1).

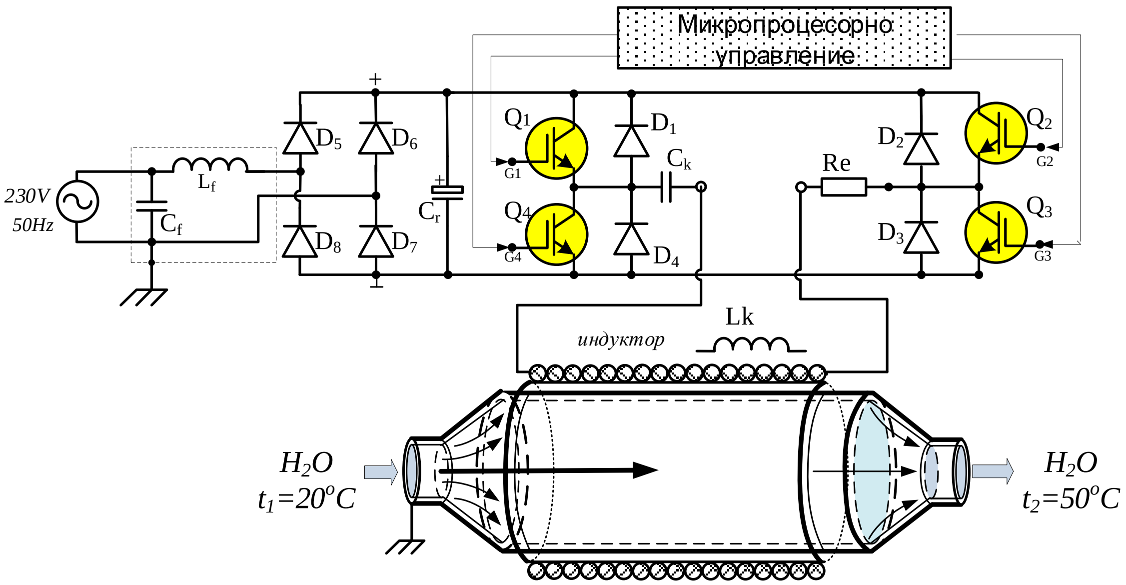

fig.1. Schematic diagram of a bridge resonant inverter for water heating

In the scheme, L_k and C_k are reactive elements of the resonant circuit. Structurally, the coil L_k is realized as an inductor. The resistor R_e is equivalent to the active resistance and reflects the power loss from the Foucault currents that heat the secondary winding of the inductor.

Resistor R_e includes all active losses in the closed circuits of the inverter (wires, transistors, diodes) and which are an order of magnitude smaller than the losses from Eddy currents.

The aim of the article is to analyze in sufficient depth the frequency method for regulating the power generated in the inductor of the resonant inverter to obtain the ability to regulate the heating temperature within certain limits.

Usually when heating fluids, regulation of the outlet water temperature is required. According to the formula, the required output power of the inverter is obtained at a certain water flow [1].

$$(1) \qquad Po = \Delta m.Cp.(To - Ti)[kW]$$

Where: Δm – water flow l/s;

C_p – atmospheric pressure along the saturation line kJ/kg.K;

T_o – output temperature °C;

T_i – inlet temperature °C;

Dependences are obtained from formula (1) for different water flow in the heating device (boiler) (Fig. 2).

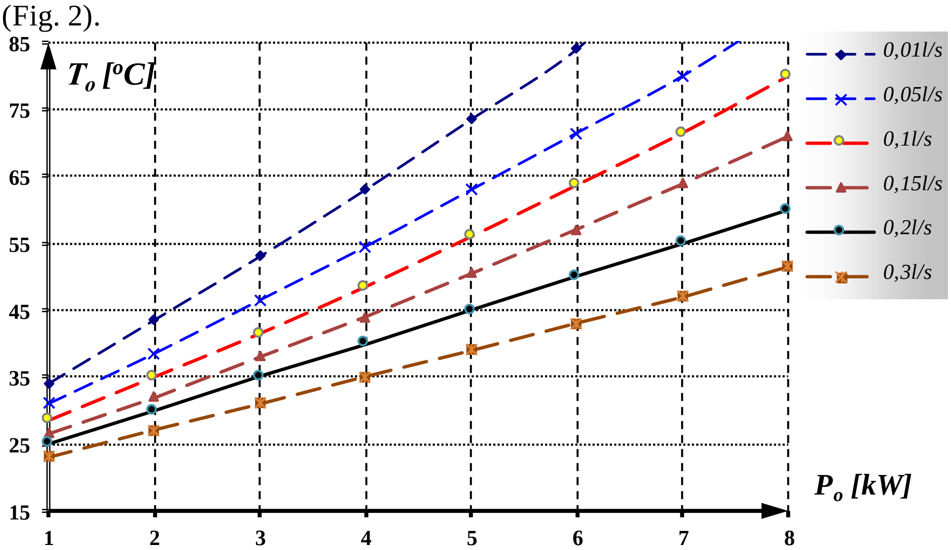

fig.2. Diagram of the output temperature T_o when changing the output power for different flow rates

In this case the inlet temperature of the water at the entrance to the boiler T_i = 20°C is accepted. From Fig. 2 it can be seen that by providing regulation of the output power of the inverter in the range from 2 to 6kW, the temperature will be regulated in a wide range from 20°C to 70°C, sufficient when using the device for domestic water heater.

The research was realized with Pspice simulation with real models of IGBT transistors type IXGH40N60A

The Pspice model of the schematic diagram of Fig. 1 is shown in Fig. 3.

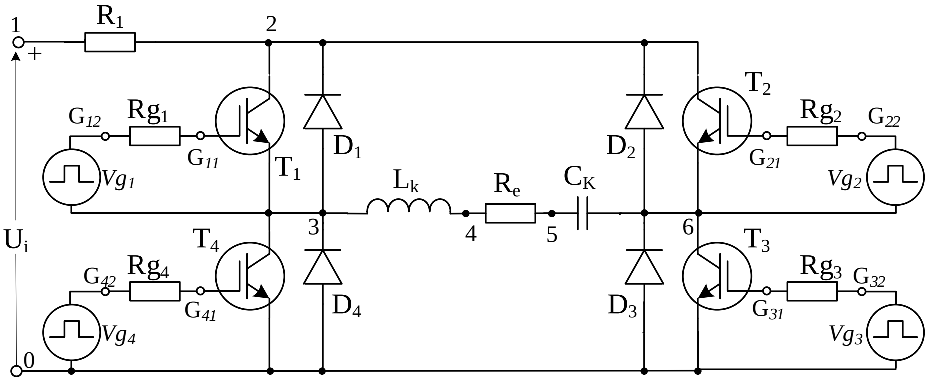

fig. 3. Pspice model of research LC inverter

The base values of the inverter are assumed P_o=6kW and U_i=315V.

The values of the inverter elements are obtained from the dependences:

$$U_m = \frac{4.U_i}{\pi} = 401\text{V}$$

- equivalent active resistance:

$$R_e = \frac{{U_i}^2}{P_o} = \frac{8.E^2}{\pi^2 P_o} = \frac{8.315^2}{\pi^2 6.10^3} = 13{,}4\Omega$$

- equivalent impedance of the oscillating circuit:

$$Z_e = \frac{R_e}{Q} = \frac{9{,}8}{1{,}5} = 9\Omega$$

where: Q - qualitative factor of the oscillating circuit and is taken in the range of 1.5 to 3. For high supply, voltages choose a low value of Q.

- value of the switched inductance:

$$L_k = \frac{Z_e}{2.\pi.f_o} = \frac{9}{2.\pi.50.10^3} = 29\mu H$$

- value of the switching capacitor:

$$C_k = \frac{1}{(2.\pi.f_o)^2.L_k} = \frac{1}{(2.\pi.50.10^3)^2.29.10^{-6}} = 0{,}35\mu F$$

The type of time diagrams judges the operability of the studied inverter. Figure 4 shows the timing diagrams of the inverter for the nominal operating mode at which the maximum water temperature is obtained. In this mode the operating frequency is f_{sw}=50kHz. Shown are: the voltage across the transistors - (V(3)), the current through the transistors (Ic(z4)), the current through the inductor (I_{Lk}), the active power converted into Eddy currents (AVG (I(Re)*V(4,5))) and the power loss on the transistors (AVG(IC(Z4)*V(3))).

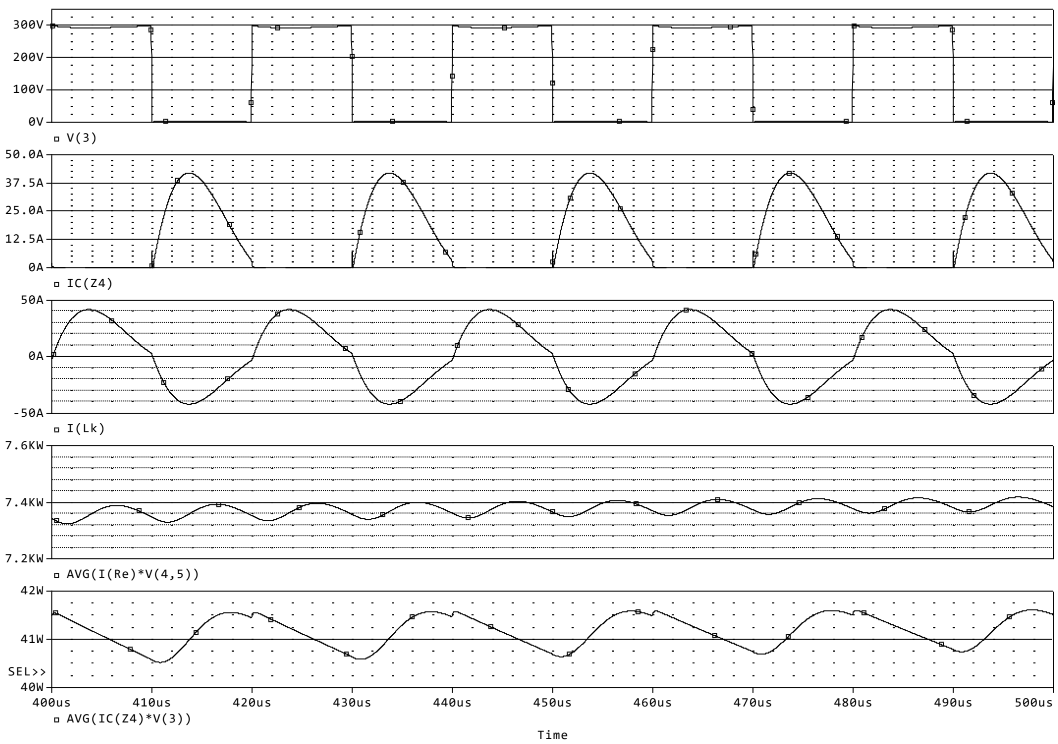

fig. 4. Time diagrams of the voltage drop across the transistor, the currents through the transistor I_C and through the inductor I_L, the power given in the load Po and the power output P_z in nominal operating mode

Figure 5 shows the same timing diagrams of the inverter for deeper control mode, which corresponds to the minimum water heating temperature.

In this mode the operating frequency is f_{sw} = 25kHz.

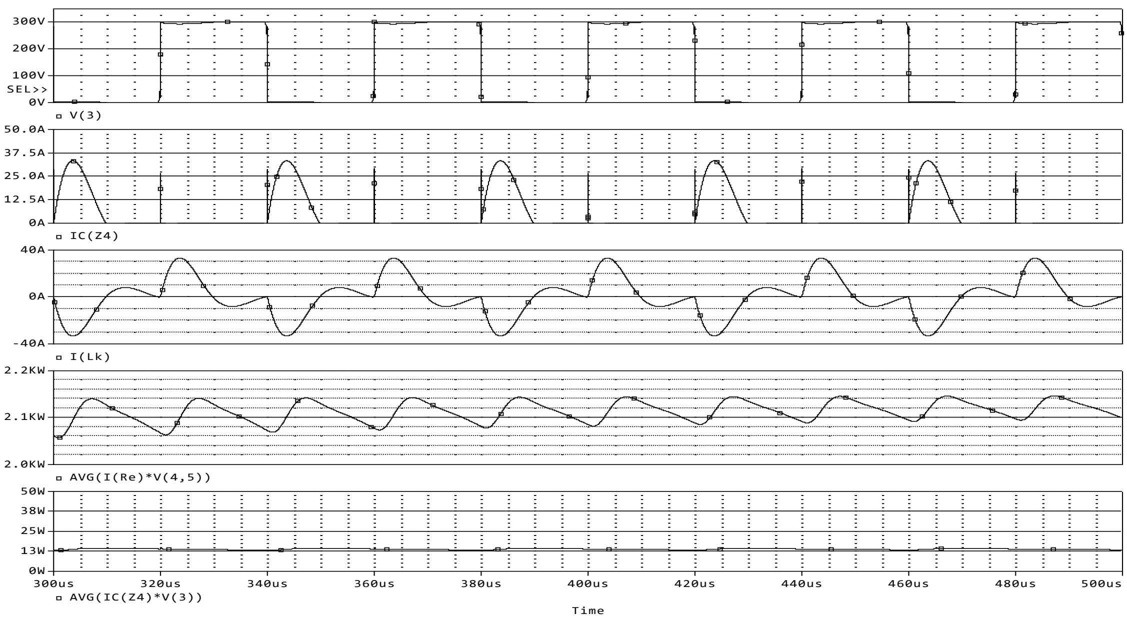

fig. 5. Time diagrams of the voltage drop across the transistor, the currents through the transistor I_c and through the inductor I_L, the power given in the load P_o and the power loss P_z in deep regulation mode

The obtained time diagrams show the preservation of a good shape of the voltage and current through the transistors, close to the sinusoidal shape of the current in the inductor, sufficient output power and minimal losses in the transistors (fig.4 T = 20us). These indicators are preserved with deep regulation of the output power (fig.5 T = 40us).

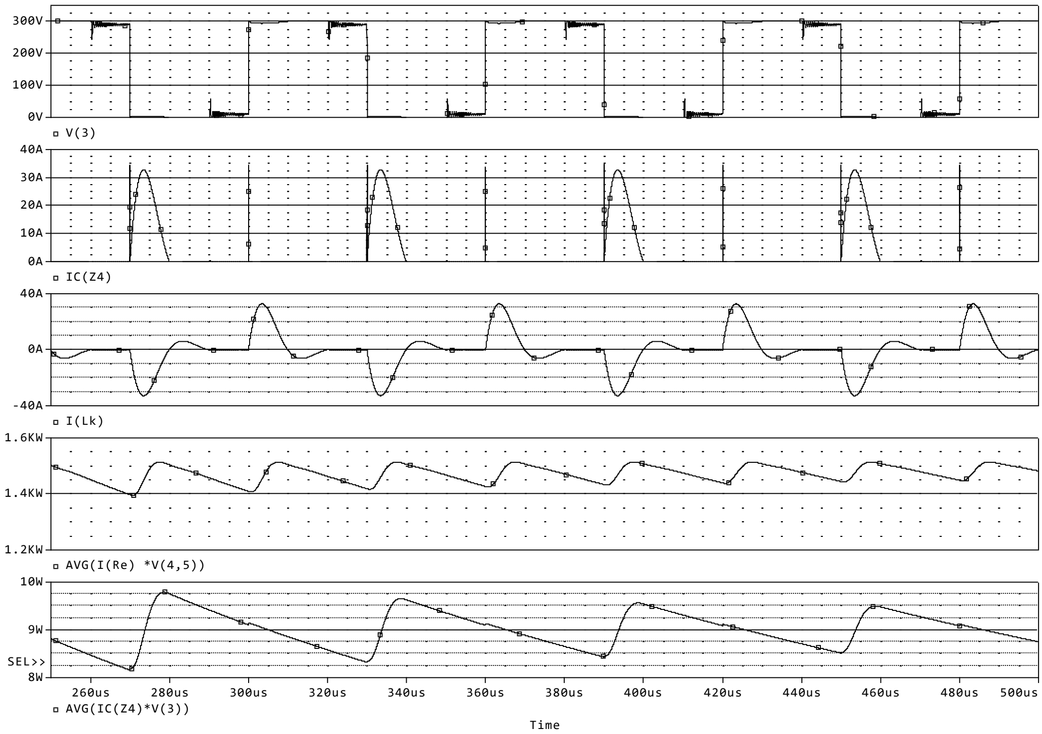

FIG. 6. Time diagrams of the voltage drop across the transistor, the currents through the transistor I_c and through the inductor I_L, the power given in the load P_o and the power loss P_z in the mode of deeper regulation

With even deeper regulation of the output power (fig.6 T = 60us), the parameters remain good, noticing transients in U_{ce} when switching the transistors on and off.

More in-depth conclusions about the operation of the circuit with smooth regulation of the outlet temperature are obtained in the following studies:

Fig. 7 shows the dependences of the average output power of the investigated resonant inverter with a series oscillating load circuit when changing the parameter f_{sw}, for three values of the supply voltage - corresponding to ± 15% tolerance of the supply network.

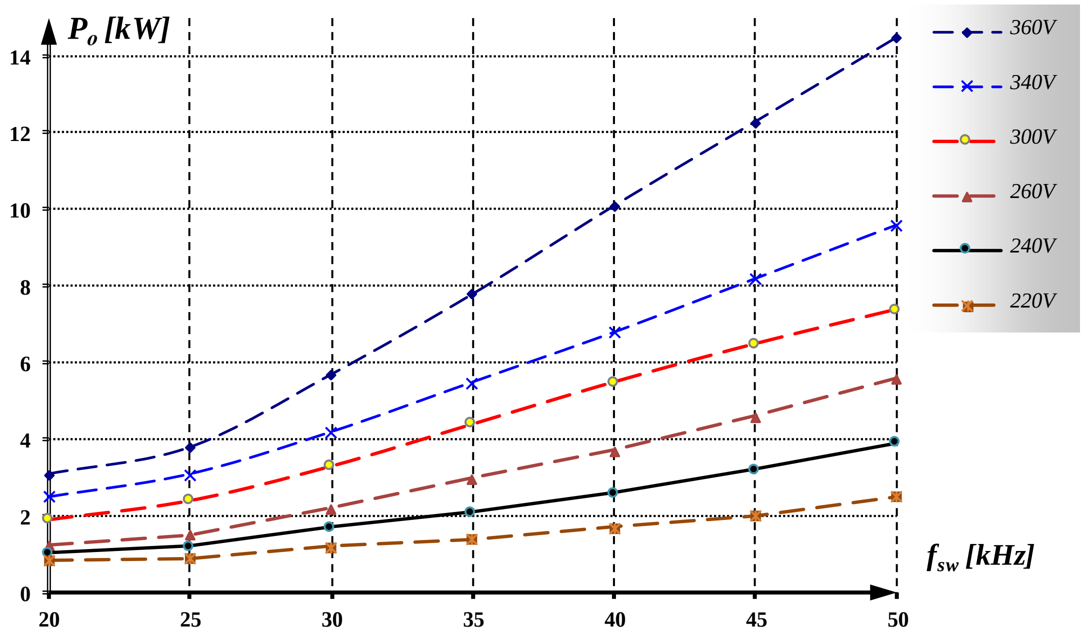

Fig.7. Diagram of the average value of the output power Po in the inductor

The power released in the load has a smoothly changing character when changing the operating frequency f_{sw}. When the supply voltage changes within ± 15%, the graphs are parallel, increasing at higher frequencies. This allows for smooth regulation when changing the operating frequency f_{sw} and covers the tolerance of the supply voltage to achieve the desired power. Figure 8 shows the dependences of the average loss P_{Zevr} power of the investigated resonant inverter with a series oscillating load circuit when changing the parameter f_{sw}, for three values of the supply voltage - corresponding to ± 15% tolerance of the supply network.

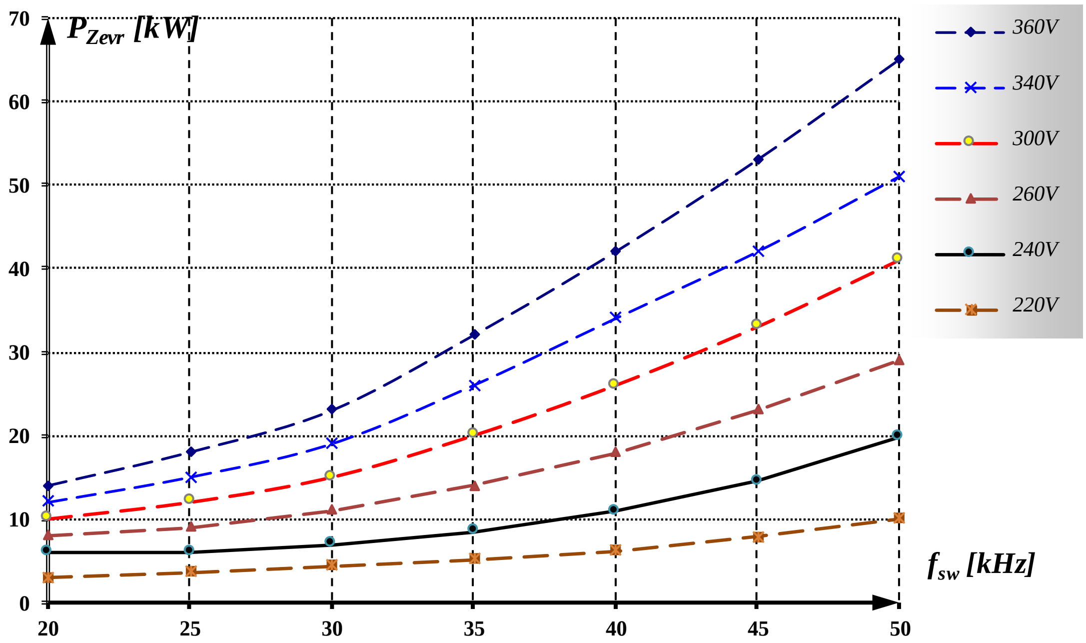

fig.8. Diagram of the average value of the power loss P_{Zevr} in the inductor

At the average power loss in the transistors there is a smooth increase with a linear change for each value of the supply voltage. This is done within small limits and is within the allowable range for efficient operation.

Figure 9 shows the dependences of the current through one of the transistors of the studied resonant inverter with a series oscillating load circuit when changing the parameter f_{sw}, for three values of the supply voltage (U_i = 220V, 240V, 260V, 300V, 340V, 360V).

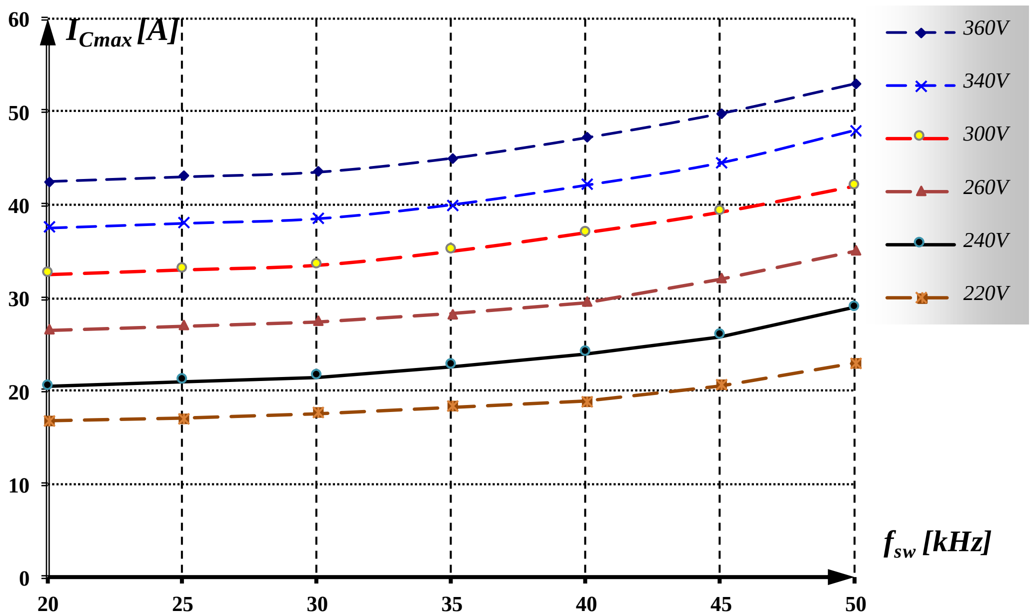

Fig.9. Diagram of the maximum current through the transistors I_{Cmax}

In the diagram of the maximum current Ice through each of the transistors $T_1 \div T_4$ is observed almost linear change for each value of the supply voltage, increasing at frequencies exceeding 35MHz due to a change in the value of the quality factor Q of the series oscillating circuit. The transistors operate at the maximum permissible current in pulse mode.

Fig. 10 shows the dependences of the efficiency η of the investigated resonant inverter with a series oscillating load circuit when changing the parameter f_{sw}, for three values of the supply voltage (Ui = 220V, 240V, 260V, 300V, 340V, 360V).

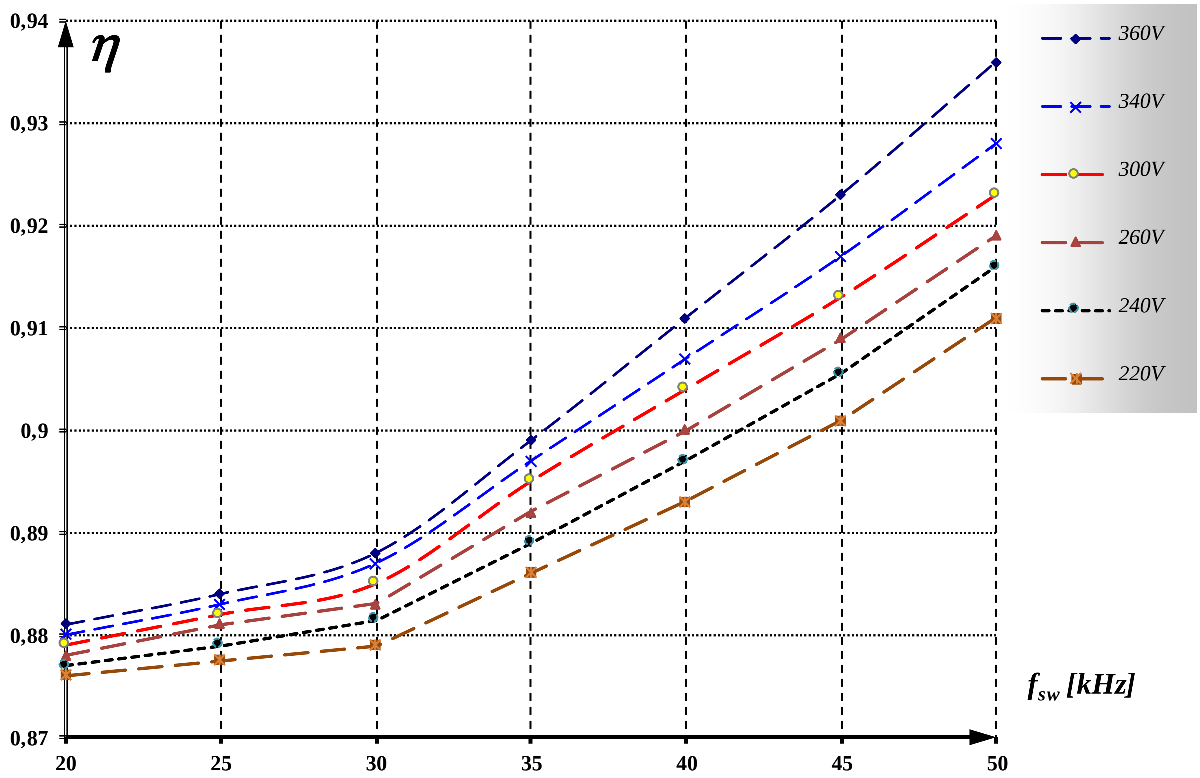

fig.10. Efficiency diagram η

The efficiency increases almost linearly, as with increasing operating frequency at all three values of the supply voltage almost does not change and is in the range of about 0,9. This testifies to the stable and good operation of the resonant inverter in the regulation process.

Since the main parameter in water heating systems is the value of the temperature to which the leaving water is heated, the operation of the inverter must be related to this indicator. Table 1 shows the correspondence of the water outlet temperature to the power of the inverter, at the inlet water temperature $T_i = 20^oC$.

Table 1

T_{oC}	°C	25	30	35	40	45	50	55	60	65	70	75	80
P_o	kW	1	2	3	4	5	6	7	8	9	10	11	12

Figure 11 shows the temperature dependences of the outlet water obtained from the investigated resonant inverter with a series oscillating load circuit when changing the parameter f_{sw}, for three values of the supply voltage (U_i = 260V, 300V, 340V).

The power released in the load has a smoothly changing nature when changing the operating frequency f_{sw}. When the supply voltage changes within ± 15%, the graphs are parallel. This allows for smooth adjustment when changing the operating frequency f_{sw} and covers the tolerance of the supply voltage to achieve the desired power.

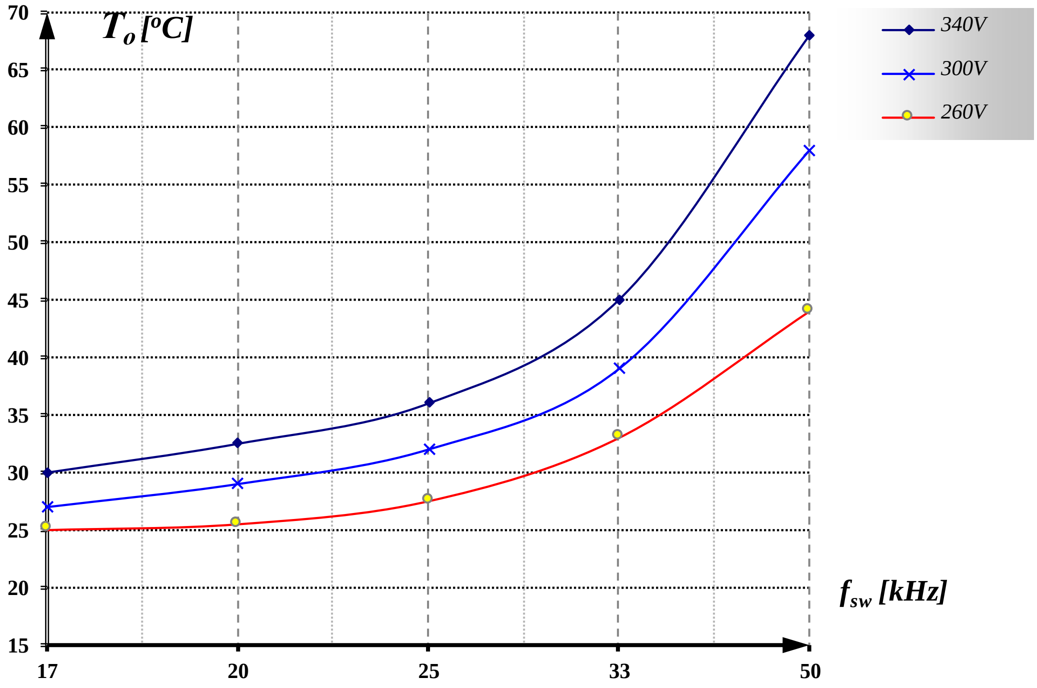

fig.11. Output temperature diagram T_O

Fig. 12 shows the dependences of the outlet water temperature obtained from the investigated resonant inverter with a series oscillating load circuit when changing the parameter f_{sw}, for three values of the flow rate of the flowing fluid (Δ_m=0,1*l*/s, 0, 2*l*/s, 0,3*l*/s.)

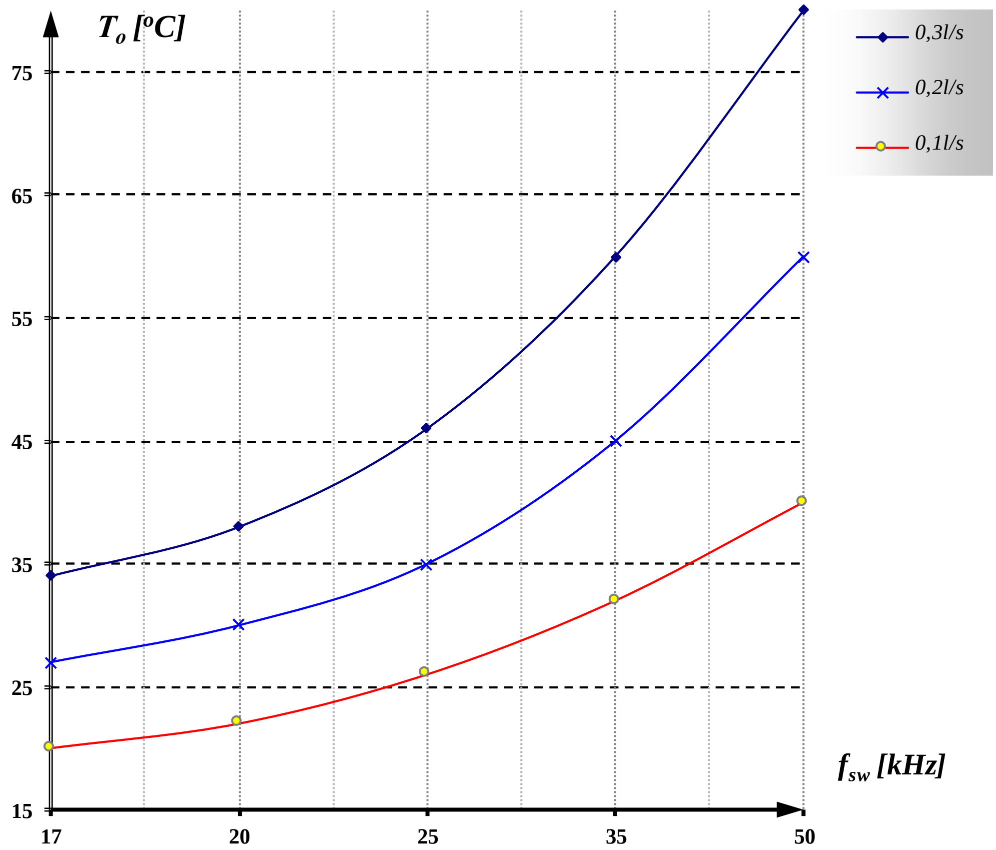

fig.12. Diagram of the outlet temperature T_O at change of the operating frequency for three values of the flow rate Δ_m

The required temperature released in the fluid has a smoothly changing character, with a change in the operating frequency f_{sw}. When the water flow, rate changes, the graphs run in parallel, increasing at higher frequencies.

Conclusions:

1. The series resonant inverter shows good control characteristics when used in fluid heating systems.
2. The current and voltage shapes of the transistors remain close to sinusoidal at wide limits of regulation.
3. The efficiency does not change in a large range (0,88 to 0,93) and satisfies the requirements for induction heating of fluids.
4. The results obtained for the resonant inverter powered by a voltage source can be successfully applied to the technological applications of the resonant inverter described above.

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