A Method for Power Control of a Transistor Resonant Inverter

Nikolay D. Bankov [1] and Vesselka A. Kostova [2]

Abstract - **A method for power control of a transistor inverter functioning with a frequency higher than resonance one, has been suggested. The control has been done by changing the transistor conduction time. A family of load characteristics of the transistor inverter has been drawn. The results of the analysis are confirmed by means of experimental study.**

Keywords – **Resonant inverter, Methods for power control**

I. Introduction

In most cases the output power of the resonant inverters changes a lot as the size and character of the load as well as the supply voltage changes. Therefore a measure should be taken for its stabilization. It is often necessary to regulate the output power according to a certain rule.

There are modern methods for deep regulation of the output power inside the resonant inverter [1], [4]÷[7]. At the same time the input direct-current source can be unregulated. A method for output power control of resonant inverters, belonging to this group of methods, which has not been thoroughly studied, is based on the change in the transistor conduction time [4], [5].

A method for power control of a transistor resonant inverter functioning at a frequency higher than resonance one, through changing the transistor conduction time, is suggested in the present work. Its load characteristics at the supply of very changeable loads are drawn. A version of an operating mode is shown.

II. Analysis and Load Characteristics of the Inverter

On Fig.1 the basic circuit diagram of the mentioned inverter is shown and on Fig.2 - the current i in the resonant circuit and voltage u_c of the resonance capacitor C. The inverter work most often at a resonant operation mode ($R < 2\sqrt{L/C}$). Then the method for analyzing the tiristor resonant inverters with free - wheeling diodes, mentioned in [2], [3], can be used with a small modification. The results from the analysis are shown in Table1.

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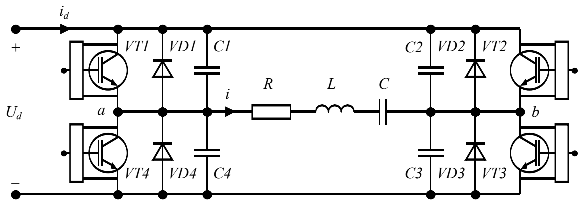

Fig. 1. Basic circuit diagram of the inverter

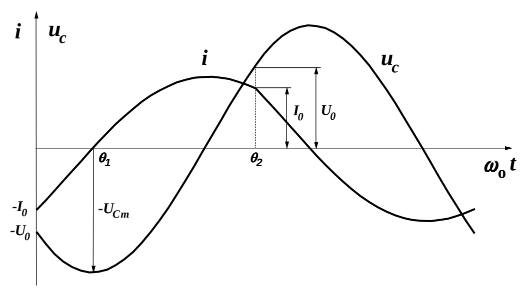

Fig. 2. Waveforms of the current in the resonant circuit and of the voltage of the resonance capacitor

TABLE I
RESULTS FROM ANALYSIS

Quantity	Expression
$i(\theta)$	$\frac{U_d+U_0}{\omega_0 L} e^{-\frac{\delta}{\omega_0}\theta}\sin\theta + I_0 e^{-\frac{\delta}{\omega_0}\theta}\left(\frac{\delta}{\omega_0}\sin\theta-\cos\theta\right)$
$u_C(\theta)$	$U_d-(U_d+U_0)e^{-\frac{\delta}{\omega_0}\theta}\left(\frac{\delta}{\omega_0}\sin\theta+\cos\theta\right)-\frac{I_0}{\omega_0 C}e^{-\frac{\delta}{\omega_0}\theta}\sin\theta$
θ_2	$\pi\,\omega_0/\omega$
θ_1	$arctg\frac{\sin\theta_2}{e^{\frac{\delta}{\omega_0}\theta_2}+\cos\theta_2}$
α	$\frac{I_0\omega_0 L}{U_d+U_0}=\frac{\sin\theta_2}{e^{\frac{\delta}{\omega_0}\theta_2}+\cos\theta_2-\frac{\delta}{\omega_0}\sin\theta_2}$
K	$\frac{1}{1+e^{-\frac{\delta}{\omega_0}\theta_2}\left[\left(\alpha+\frac{\delta}{\omega_0}+\alpha\frac{\delta^2}{\omega_0^2}\right)\sin\theta_2+\cos\theta_2\right]}$
K_1	$\frac{1}{1+e^{-\frac{\delta}{\omega_0}\theta_1}\left[\left(\alpha+\frac{\delta}{\omega_0}+\alpha\frac{\delta^2}{\omega_0^2}\right)\sin\theta_1+\cos\theta_1\right]}$

$i'(\theta)$	$\frac{i(\theta)}{\omega C U_d}=2K\frac{\omega_0}{\omega}\left(1+\frac{\delta^2}{\omega_0^2}\right)e^{-\frac{\delta}{\omega_0}\theta}\left[\left(1+\alpha\frac{\delta}{\omega_0}\right)\sin\theta-\alpha\cos\theta\right]$
$u'_C(\theta)$	$\frac{u_C(\theta)}{U_d}=1-2Ke^{-\frac{\delta}{\omega_0}\theta}\left[\left(\alpha+\frac{\delta}{\omega_0}+\alpha\frac{\delta^2}{\omega_0^2}\right)\sin\theta+\cos\theta\right]$
U'_0	$U_0/U_d=2K-1$
I'_0	$\frac{I_0}{\omega C U_d}=2K\alpha\frac{\omega_0}{\omega}\left(1+\frac{\delta^2}{\omega_0^2}\right)$
U'_{Cm}	$-u'_C(\theta_1)=2K(1/K_1-1)-1$
I'_d	$\frac{1}{\theta_2}\int_0^{\theta_2}i'(\theta)d\theta=\frac{2}{\pi}(2K-1)$
I'_{VTav}	$\frac{1}{2\theta_2}\int_{\theta_1}^{\theta_2}i'(\theta)d\theta=\frac{1}{\pi}\left(\frac{K}{K_1}-1\right)$
I'_{VDav}	$\frac{1}{2\theta_2}\int_{\theta_1}^{0}i'(\theta)d\theta=\frac{1}{\pi}\cdot\frac{K}{K_1}(1-2K_1)$
P'_d	$U_d I_d/\omega C U_d^2=I'_d$
I'	$I/\omega C U_d=\sqrt{I'_d\frac{\omega_0}{2\delta}\cdot\frac{\omega_0}{\omega}\left(1+\frac{\delta^2}{\omega_0^2}\right)}$
U'	$P'_d/I'=I'_d/I'$

The following common symbols are used:

$\omega_0=\sqrt{\frac{1}{LC}-\delta^2}$ - resonant frequency;

$\delta=\frac{R}{2L}$ - coefficient of calm down resonant circuit

ω - work frequency;

I_0, U_0 - current and voltage starting values of the resonance capacitor;

K - summarized vibration coefficient.

For unifying purposes all units are presented as relative ones: the voltages as a ratio to the supply voltage U_d ; the currents to the current $I_0=\omega C U_d$; the input direct current power to the power $P_0=\omega C U_d^2$.

When a parameter for regulation of the inverter output power is the transistor conduction time t_{VT}, the latter in relative units should be presented to the semi period of the non-calm-down variations of the consecutive resonant circuit $T'_0/2$ $\left(T'_0/2=\pi\sqrt{LC}=const\right)$ in the following way:

$$t'_{VT}=\frac{t_2-t_1}{\pi\sqrt{LC}}=\frac{\theta_2-\theta_1}{\pi\omega_0\sqrt{LC}}=\frac{\theta_2-\theta_1}{\pi}\sqrt{1+\frac{\delta^2}{\omega_0^2}} \tag{1}$$

The following ratio is well known [3]:

$$\frac{\delta}{\omega_0}=\frac{1}{\pi}\cdot\ln\frac{k}{k-1} \tag{2}$$

where κ is a vibration coefficient of the resonant inverters without free - wheeling diodes.

Using the expressions for θ_1 and θ_2 in Table 1 and Eq. (2), Eq. (1) acquires the following form:

$$\frac{\pi\omega_0}{\omega}-arctg\frac{\sin\frac{\pi\omega_0}{\omega}}{e^{\frac{\omega_0}{\omega}\cdot\ln\frac{k}{k-1}}+\cos\frac{\pi\omega_0}{\omega}}=\frac{\pi^2\cdot t'_{VT}}{\sqrt{\pi^2+\ln^2\frac{k}{k-1}}} \tag{3}$$

The dependencies between the basic inverter quantities and both the vibration coefficient κ and the transistor conduction time t'_{VT} in relative units are calculated, if in the expression in Table 1 we substitute the ratio δ/ω_0 with Eq. (2), as well as the ratio $\omega/\omega_0=f(k,t'_{VT})$ with Eq. (3). Solving these equations we can draw an inverter family of load characteristics. The following can be of great interest: the inverter output voltage $U'(I',t'_{VT})$; the input direct current power and the input current $P'_d=I'_d(I',t'_{VT})$; the average transistor current $I'_{VTav}(I',t'_{VT})$; the average diode current $I'_{VDav}(I',t'_{VT})$ and the peak capacitor voltage $U'_{Cm}(I',t'_{VT})$. The respective graphic diagrams are shown on Fig. 3 ÷ 7.

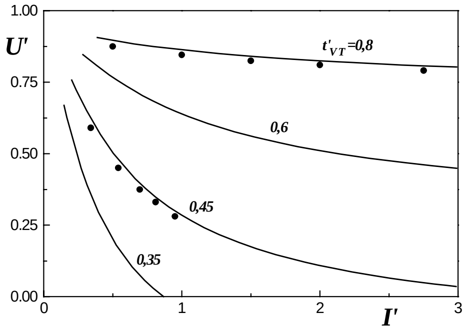

Fig. 3. Output characteristics of the inverter

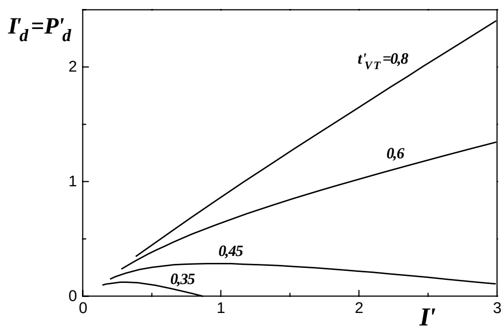

Fig. 4. Dependence of input power (input current) on output current

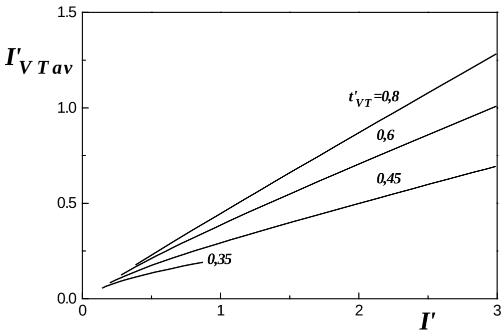

Fig. 5. Dependence of average transistor current on output current

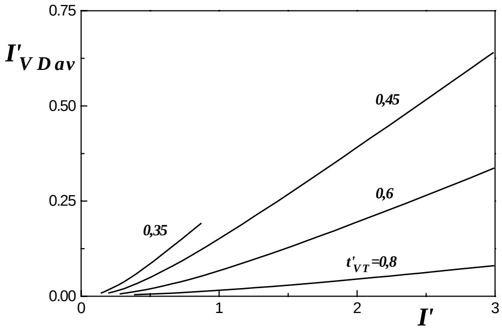

Fig. 6. Dependence of average diode current on output current

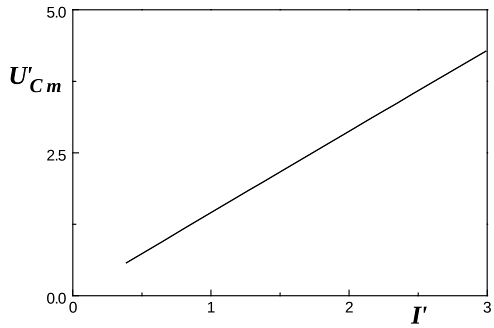

Fig. 7. Dependence of peak capacitor voltage on output current

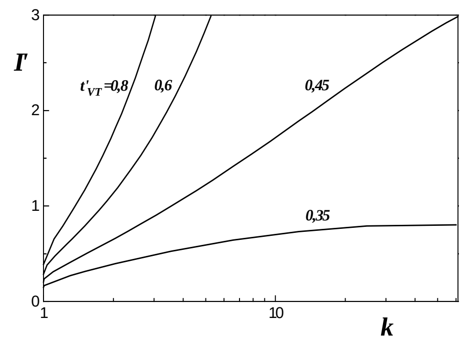

Fig. 8. Dependence of output current on vibration efficiency

What is important here is that the independent variable (argument) is the output current I', but not the vibration coefficient κ. The argument κ substituting with I' is done by using the relation $I'(k, t'_{VT})$, shown in Fig.8.

Fig.3 is shows the output characteristics of the inverters $U'(I', t'_{VT})$. When $1 > t'_{VT} > 0,45$, the inverter has fixed characteristics typical of a direct-voltage source. In this interval of parameter change t'_{VT} measures should be taken to limit the current in the resonant circuit when overloaded or short-circuit. When $t'_{VT} < 0,45$, the inverter can be considered as a current source, stable at work and short-circuit.

Fig.4 illustrates the suggested method for regulation of the inverter output power. It is evident that the inverter output power decreases ≈20 times when t'_{VT} varies from 0,8 to 0,35.

The major requirements about the inverter elements can be determined from the graphs in Fig. 5÷7. For example, the average transistors current I'_{VTav} can be set from Fig.5 for selected values of I' and t'_{VT}.

III. INVERTER OPERATING MODE

Fig.9 shows the block-diagram of the operating mode (OM). The action of OM is synchronized with current ***i*** in the consecutive oscillating circuit.

The input synchronized unit (ISU) forms impulses which give information about current going through zero in the oscillating circuit. These impulses turn the generator of linear changing voltage (GLCV) on, the increase voltage time being equal to the transistors admittance time.

The output voltage of GLCV is given to the first input of the compared scheme (CS). The output voltage of an automatic regulation scheme (ARS) is given to the other input of CS.

The CS output impulses reduce to zero *i* in GLCV, in the same time giving the impulses to impulse distributor (ID). ID forms 2 channels of control pulses, dephased at 180°, and the impulse amplifiers (IA1 and IA2) provide the needed power, amplitudes and galvanic separation of the control signals.

ARS provides the needed change of the CS control function, aiming to stabilize or regulate the inverter parameters according to a certain rule under back coupling unit (BCU).

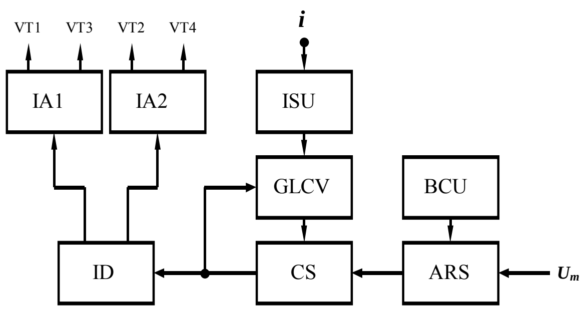

Fig.9. Block diagram of the operating mode

IV. EXPERIMENTAL RESEARCH

The experiments carried out, have led to creating and testing of a transistor inverter functioning at frequencies higher than the resonance one. The inverter loading voltage is 200 V, the output power – 2kW and the operating frequency of a nominal load –110 kHz. MOSFET transistors, type IRFP450, have been used. Protecting groups free of loss are parallel connected to the transistors. Each group consists of one capacitor only and its value is 1nF.

The inverter operating mode is realized according to the block scheme shown on Fig. 9. The values of the resonant circuit elements are C=25,48nF; L=108,65µH. The load resistor R is changed within the range 10-100Ω.

Fig.3 shows experimentally determined points from the output characteristics for $t'_{VT} = 0{,}8$ и $t'_{VT} = 0{,}45$. A good coincidence between theoretical and experimental results can be seen. The slight differences between them are due to the losses at disclosed state of the semiconductor switches.

Fig.10 shows oscillograms of the voltage over one of the transistors and the current through the resonant circuit with inverter nominal load.

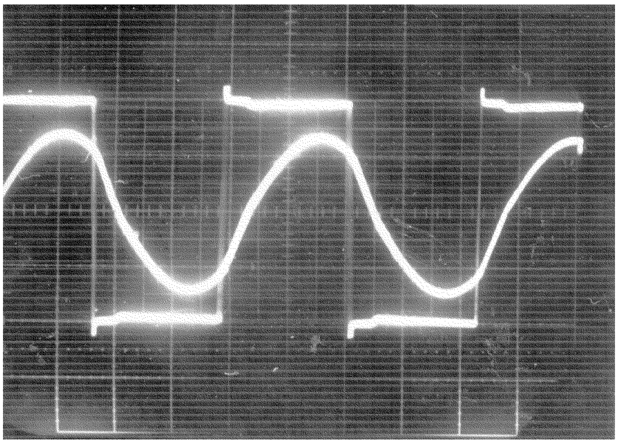

Fig. 10. Oscillograms of the voltage of the transistor-50V/div and of the current through the resonant circuit-10A/div. (x=2µs/div).

V. CONCLUSIONS

A method has been suggested for a deep regulation of transistor inverter power functioning at frequencies higher than the resonance one, through change of the transistor conduction time. A version of an operating mode is shown. Inverter analysis has been done and its load characteristics have been built. They allow to evaluate the behavior of the mentioned resonance inverter when the load is changed during the time of a real technological process. A very good coincidence has been obtained between theoretical analysis results and those from experiments.

REFERENCES

[1] M.Ch. Anchev and G.J. Maleev, "Transistor inverter analysis functioning at frequencies higher than the resonance one", E+E, 2000, 5-6, 12-17, (in Bulg.).

[2] R.D. Karov, " Translation techniques", Sofia, Technika, 1994, (in Bulg.).

[3] N.A. Nachev and G.J.Maleev, "Power electronics", Sofia, Technika, 1979, (in Bulg.).

[4] Y. Cheron, "La commutation douce dans la conversion statique de l'energie electrique", Technique et Documentation - Lavoisier, 1989.

[5] Y. Cheron, H. Foch, J. Roux, "Power transfer control methods in high frequency resonant converters", PCI Proceedings, Munich, 1986, pp.92-103.

[6] R. Oruganti, F.C. Lee, "Resonant Power Processors: Part II - Methods of Control", IAS Annual Meeting, 1984, pp.868-878.

[7] St.S. Valtchev, J.B. Klaassens, "Efficient resonant power conversion", IEEE Transactions on Industrial Electronics, vol.37, №6, December 1990, pp.490-495.