Comparative Analysis of LCC Resonant DC-DC Converters

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Abstracts: **Comparative analysis of LCC resonant DC-DC converters with inductive output filter has been carried out. The operation of the converters below and above their resonant frequency has been investigated. As a result from the analysis equations of the converters' output and regulating characteristics have been obtained.**

Keywords: **LCC resonant DC-DC converter**

I. Introduction

The resonant converters have found wide application in building powerful supply equipment. The converters with resonant tanks of third row [1] are most often preferred because they can work in the whole range of idle running voltage to short-circuit while maintaining the conditions for soft commutation of the steering keys. In [2] is discussed LCC resonant converter used for the construction of medical x-ray machines.

Harmonic analysis is often used for their theoretical investigation. In order to obtain results with acceptable accuracy during this process, the influence of only the first harmonics of the currents and voltages are taken into account [3], i. e. the "method of the first harmonic" is used.

The aim of the present work is to carry out an analysis of LCC resonant DC-DC converters with inductive output filters by the method of the first harmonic, to compare the resultant output and regulating characteristics of the LCC converters under consideration, thus defining their advantages and their drawbacks.

II. Analysis of the Converters

The diagram of the converter under consideration is shown in fig. 1. It consists of an inverter (controllable switches $S_1 \div S_4$ with reverse diodes $D_1 \div D_4$), a resonant tank, a matching transformer (T_r), an inductive filter (L_F), and a load resistor (R_0).

Different configurations composed of LCC resonant tanks, each of which has been studied for the converter under consideration, are shown in fig. 2 [4].

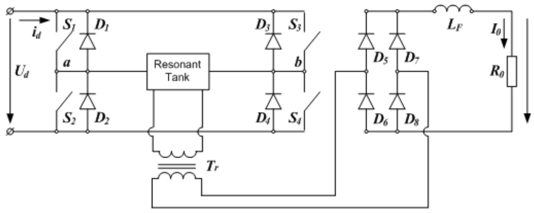

Fig.1. A resonant DC-DC converter with an inductive output filter

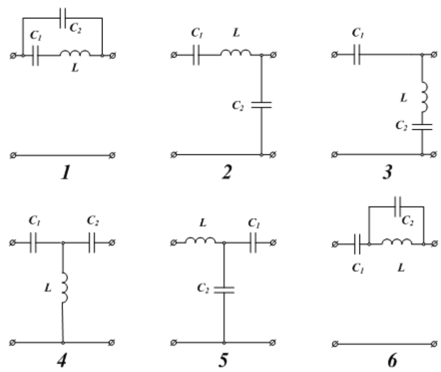

Fig.2. Configuration of LCC resonant tanks

For the purposes of the analysis it is assumed that all the elements in the diagram are ideal (no losses in them), the power devices switch from one state into another instantly, the matching transformer has a coefficient of transformation equal to unity, and the pulsations of the supplying U_d and the output voltages U_0 are negligibly small.

The following notations are accepted:

$U_0^{'} = U_0 / U_d$ - normalized output voltage;

$I_0^{'} = I_0 / (U_d / \rho_0)$ - normalized output current;

$R_0^{'} = R_0 / \rho_0 = U_0^{'} / I_0^{'}$ - normalized load parameter;

$\rho_0 = \sqrt{L / C_1}$ - wave resistance of the oscillating circuit;

$\nu = \omega_s / \omega_0$ - frequency distortion of the oscillating circuit;

ω_s - operational frequency of the converter;

$\omega_0 = 1 / \sqrt{LC_1}$ - resonant frequency of the oscillating circuit

$a = C_2 / C_1$ - capacitance's ratio between the two capacitors in the oscillating circuit.

Families of similar output and regulating characteristics shown in fig.2 are obtained for the configurations of LCC resonant circuits at *a=1,0* and at different values of the frequency distortion ν and the normalized load parameter $R_0^{'}$. The latter are shown in fig. 3÷14. The equations of the output and regulating characteristics are given as well.

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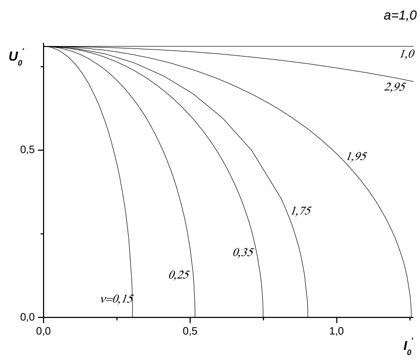
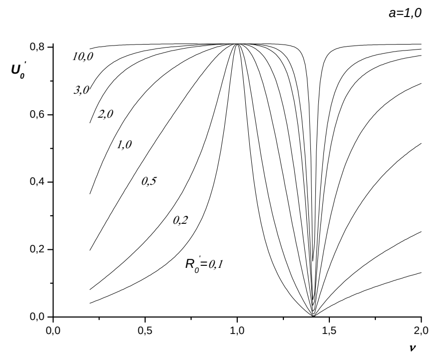


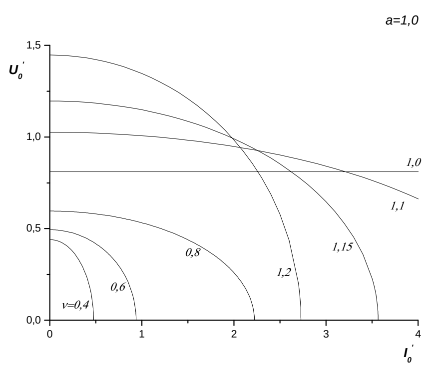
$$U_0^{'} = \frac{8}{\pi^2}.\sqrt{\frac{(\nu+\nu.a-\nu^3.a)^2-(\nu^2-1)^2.I_0^{'2}}{(\nu+\nu.a-\nu^3.a)^2}} \qquad (1)$$

Fig.3. Output characteristics for configuration №1 from Fig.2



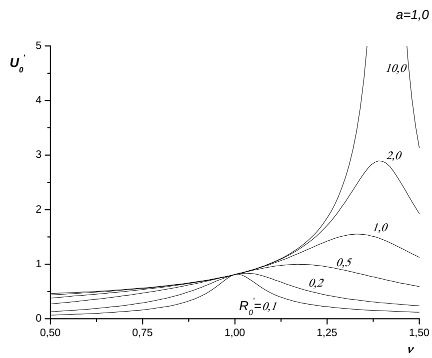
$$U_0^{'} = \sqrt{\frac{64.R_0^{'2}.(\nu+\nu.a-\nu^3.a)^2}{\pi^4.R_0^{'2}.(\nu+\nu.a-\nu^3.a)^2+64.(\nu^2-1)^2}} \qquad (2)$$

Fig.4. Regulating characteristics for configuration №1 from Fig.2



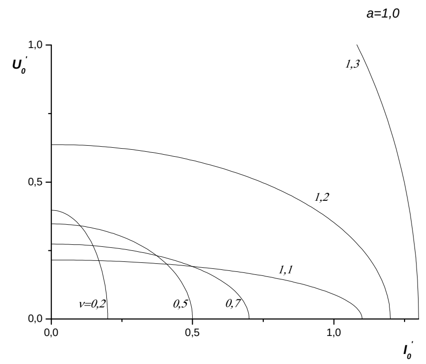
$$U_0^{'} = \frac{8}{\pi^2}.\sqrt{\frac{\nu^2-(\nu^2-1)^2.I_0^{'2}}{(-a.\nu^3+a.\nu+\nu)^2}} \qquad (3)$$

Fig.5. Output characteristics for configuration №2 from Fig.2



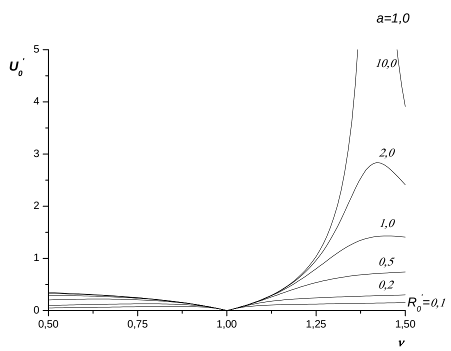
$$U_0^{'} = \frac{8.\nu.R_0^{'}}{\sqrt{64.(\nu^2-1)^2+\pi^4.(-a.\nu^3+a.\nu+\nu)^2.R_0^{'2}}} \qquad (4)$$

Fig.6. Regulating characteristics for configuration №2 from Fig.2



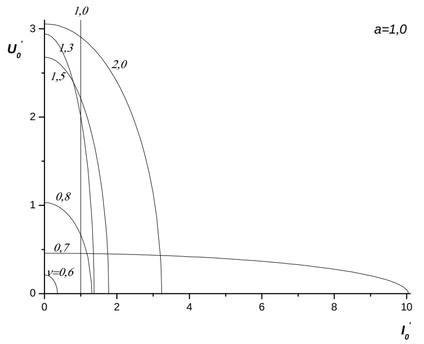
$$U_0^{'} = \frac{8}{\pi^2}.\sqrt{\frac{(\nu^2.a^2-I_0^{'2}).(\nu^2-1)^2}{(\nu^3.a-\nu.a-\nu)^2}} \qquad (5)$$

Fig.7. Output characteristics for configuration №3 from fig.2



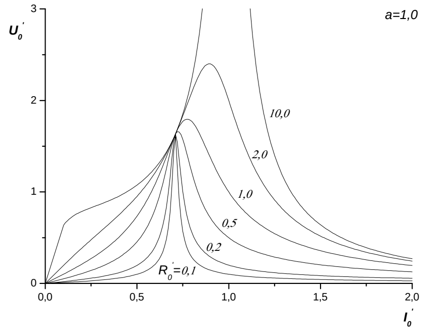
$$U_0^{'} = \frac{8.\nu.a.(\nu^2-1).R_0^{'}}{\sqrt{64.(\nu^2-1)^2+\pi^4.R_0^{'2}.(\nu^3.a-\nu.a-\nu)^2}} \qquad (6)$$

Fig.8. Regulating characteristics for configuration №3 from fig.2



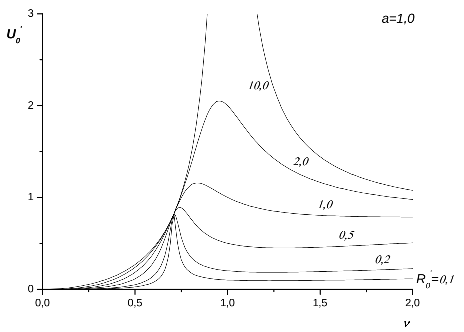
$$U_0^{'} = \sqrt{\frac{\nu^9.a^2 - (\nu^2.a + \nu^2 - 1)^2.I_0^{'2}}{(\pi^4/64).(\nu^3.a - \nu.a)^2}} \qquad (7)$$

Fig.9. Output characteristics for configuration №4 from fig.2



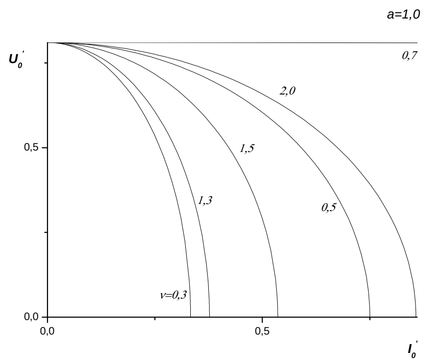
$$U_0^{'} = \frac{8.\nu.R_0^{'}}{\sqrt{\pi^4.R_0^{'2}.(\nu^3.a - \nu)^2 + 64.(\nu^2.a + \nu^2 - 1)^2}} \qquad (10)$$

Fig.12. Regulating characteristics for configuration №5 from fig.2



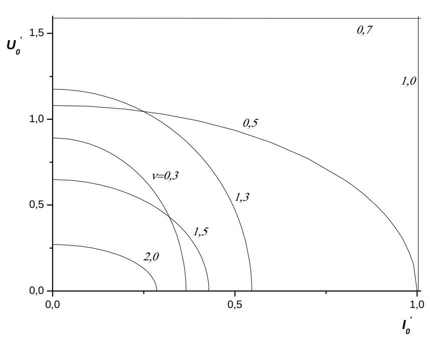
$$U_0^{'} = \frac{8.\nu^3.a.R_0^{'}}{\sqrt{64.(\nu^2.a + \nu^2 - 1)^2 + \pi^4.R_0^{'2}.(\nu^3.a - \nu.a)^2}} \qquad (8)$$

Fig.10. Regulating characteristics for configuration №4 from fig.2



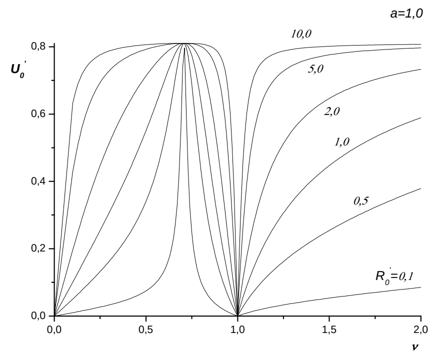
$$U_0^{'} = \frac{8}{\pi^2}.\sqrt{\frac{(\nu - \nu^3.a)^2 - (1 - \nu^2.a - \nu^2)^2.I_0^{'2}}{(\nu - \nu^3.a)^2}} \qquad (11)$$

Fig.13. Output characteristics for configuration №6 from fig.2



$$U_0^{'} = \sqrt{\frac{\nu^2 - (\nu^2.a + \nu^2 - 1)^2.I_0^{'2}}{(\pi^4/64).(\nu^3.a - \nu)^2}} \qquad (9)$$

Fig.11. Output characteristics for configuration №5 from fig.2



$$U_0^{'} = \sqrt{\frac{64.(\nu - \nu^3.a)^2.R_0^{'2}}{\pi^4.R_0^{'2}.(\nu - \nu^3.a)^2 + 64.(1 - \nu^2.a - \nu^2)^2}} \qquad (12)$$

Fig.14. Regulating characteristics for configuration №6 from fig.2

The output characteristics shown in fig. 3 are arranged concentrically and represent that, when the converter operates above and below its resonant frequency, with the increase of the operating frequency with $\nu = 0{,}15 \div 0{,}35$ and $\nu = 1{,}75 \div 2{,}95$, the short circuit current increases but the idle running voltage remains at a constant value. These characteristics are inherent to the voltage source, limited in current.

The output characteristics presented in fig. 5 show that, when the converter operates below its resonant frequency, with the increase of the operating frequency with $\nu = 0{,}4 \div 0{,}8$, the short circuit current and the idle running voltage increase. These are characteristics arranged concentrically and are innate to the current source of stable operation, even with short circuit.

When the converter operates above its resonant frequency, with the increase of the operating frequency to $\nu = 1{,}1 \div 1{,}2$, the short circuit current decreases but the idle running voltage increases. These are characteristics which intersect and are inherent to the voltage source, restricted in current. The output characteristics displayed in Fig.7 represent that, when the converter operates below its resonant frequency, with the increase of the operating frequency to $\nu = 0{,}2 \div 0{,}7$ the short circuit current increases and the idle running voltage decreases. These are characteristics which intersect and are inherent to the voltage source, limited in current.

When the converter operates above its resonant frequency, with the increase of the operating frequency to $\nu = 1{,}1 \div 1{,}3$, the short circuit current and the idle running voltage increase. These are characteristics that are concentric and are inherent to the current source of stable operation, even with short circuit.

The output characteristics given in fig. 9 manifest that, when the converter operates below its resonant frequency, with the increase of the operating frequency to $\nu = 0{,}6 \div 0{,}7$, the short circuit current and the idle running voltage increase, and at $\nu = 0{,}7 \div 0{,}8$ the short circuit current decreases, but the idle running voltage increases. These are characteristics that are concentric and are inherent to the current source of stable operation, even with short circuit.

When the converter operates above its resonant frequency, with the increase of the operating frequency to $\nu = 1{,}3 \div 1{,}5$, the short circuit current increases, while the idle running voltage diminishes, at $\nu = 1{,}5 \div 2{,}0$ the short circuit current and the idle running voltage increase. These are characteristics which are innate to the voltage source, limited in current. The output characteristics fixed in fig.11 and fig.13 are peculiar to the voltage source, restricted in current. It can be noted that all output characteristics are represented graphically by arcs from ellipses, while all regulating characteristics have a clearly defined maximum, whose value increases with increasing the value of the load resistor. The location of the maximum is displaced at the same time. It can be noted as well, that some of the obtained output and regulating characteristics are similar. For example, the ones, given in fig. 3÷4 are similar with the ones in fig. 13÷14. It can be seen from the graphs of the output characteristics (fig.3 and fig.13) that together with the increase in the operating frequency, the short circuit current also increases, while the idle running voltage stays the same. From the graphs of the regulating characteristics it is obvious (fig. 4 and fig. 14) that certain change in the output voltage is achieved by relatively small change in the operating frequency. Together with the other regulating characteristics (fig. 6, 8, 10 and 12) they show that with the increase of the value of $R_0^{'}$, the idle running voltage and the operating frequency also increase.

An area of operation can be noticed in some of the output characteristics, where the output voltage becomes higher than the supplying one, i.e., $U_0^{'} > 1$. It can be seen from figures 5,7,9, and 11.

III. Conclusion

Comparative analysis of LCC resonant DC-DC converters with inductive output filter has been carried out by the method of the first harmonic. Their operation below and above the operating frequency has been investigated.

As a result of the analysis are obtained output and regulating characteristics for the configurations of LCC resonant tanks. The output characteristics represent that on definite conditions, the converter can operate as a source of voltage limited in current or current source of stable operation, even with short circuit. The regulating characteristics manifest at what degree of increase in the value of the load resistor, there is also increase of the operating frequency of the discussed converter.

It has been established that the output voltage of the converter can have a higher value than the one of the supplying voltage.

The results from this investigation could be applied to designing LCC converters used as supplying devices of electrical arc welding aggregates, luminescent lamps, lasers etc.

IV. References

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