LOAD CHARACTERISTICS AND OPERATIONAL REGIMENS AT PHASE-SHIFT METHOD OF POWER CONTROL OF RESONANT DC/DC CONVERTER

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Analysis of the load characteristics of DC/DC converter, using phase-shift method of power control and operating at frequencies higher than resonant frequency are made. The converter consists of two half-bridge inverters, connected and a parallel bridge rectifier.

The load characteristics of a converter are based on the method of the first harmonic. Various operating regimens are studied. Evaluations of the range of work of the converter are made.

Keywords: resonant DC/DC converters, control methods, phase-shift control

1. INTRODUCTION

Large number of changes in the DC/DC converters output power could be made by phase-shift control method. This would require the use of two or more resonant inverters, transferring energy into a common load at one and same time. The current in the load circuit can be changed lightly by diphase change between the inverters output currents.

Analysis on the method of a resonant DC/DC converter first harmonic at phase-shift method of control is conducted in [1]. Dependencies between the basic quantities in relative units are obtained.

Purpose of this research is to feature load characteristics of the converter based on the analysis conducted in [1], whereupon to discuss possible operating regimens for the device.

2. ANALYSIS

The functional scheme of this converter is shown in fig.1. It contains three main components – two identical half-bridge resonant inverters (I and II), connected in parallel and a bridge rectifier (III) with load resistor into its output. The potential at point between the capacitors C_f is assumed to be zero. The inverters operate at constant frequency, higher than the resonant frequency, however the voltage u_b lags behind at angle α of u_a.

The analysis on the method of first harmonic allows representing different quantities through their vectors.

A simple vector diagram of the first harmonics of the voltages and falls on the relevant parts of the converter scheme is shown in fig.2. Whereas $U_{a(1)}$, $U_{b(1)}$, $U_{c(1)}$, $I_{1(1)}$, $I_{2(1)}$, $I_{(1)}$ represent the effective values of the first harmonics of u_a, u_b, u_c, i_1, i_2, i.

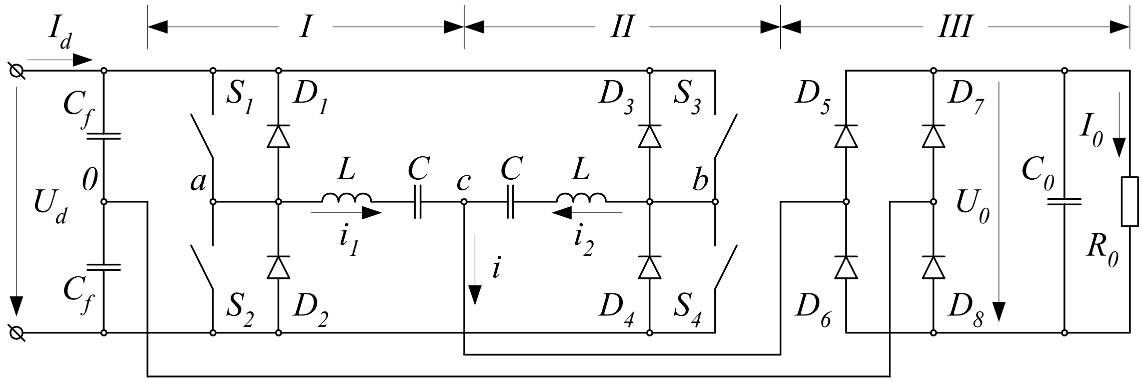


Fig. 1. Functional scheme of the converter

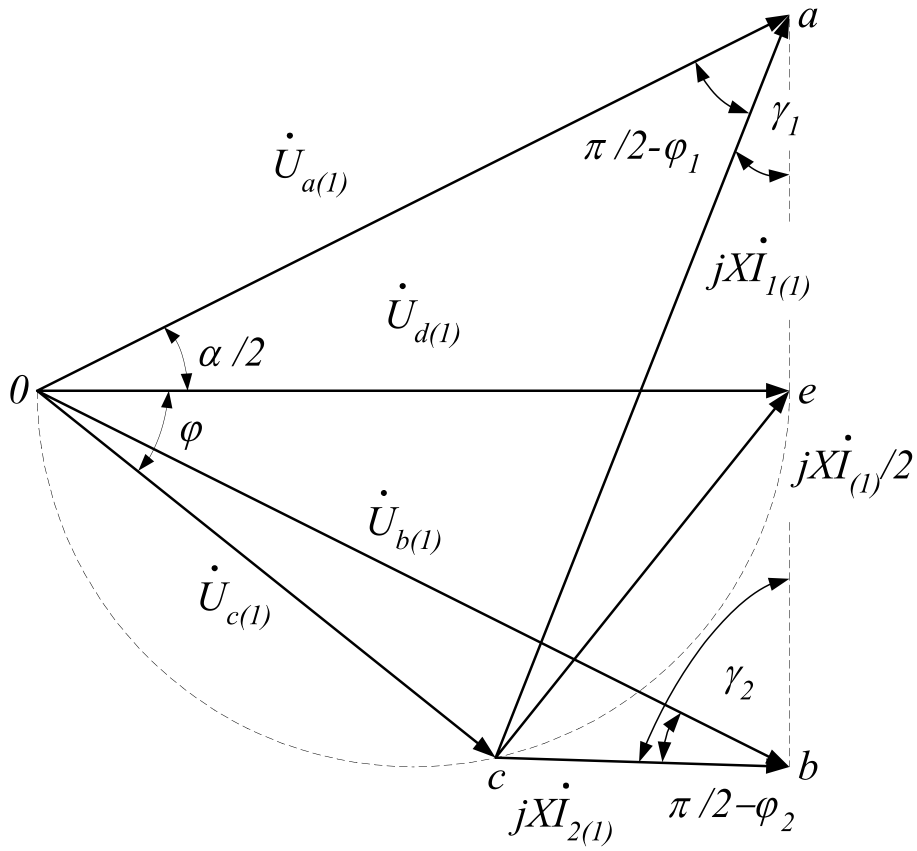
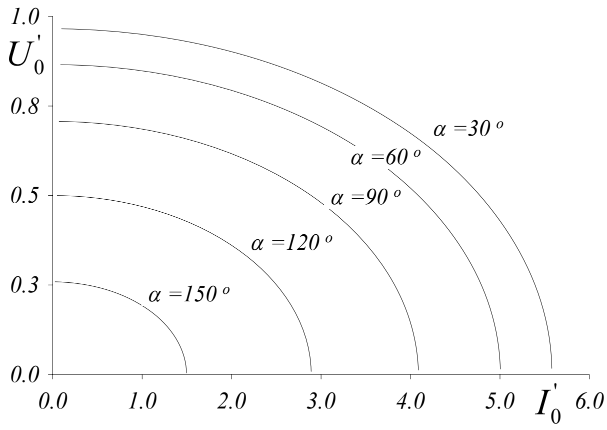


Fig. 2. Vector diagram of the converter voltages and falls

In this case $U_{e(1)}$ is an equivalent voltage, which substitutes the simultaneous applying of $U_{a(1)}$, $U_{b(1)}$ [1]. Respectively φ, φ_1 and φ_2 are the diphase angles between $U_{e(1)}$, $I_{(1)}$; $U_{a(1)}$, $I_{1(1)}$ and $U_{b(1)}$, $I_{2(1)}$. The reactance in the resonant circuits of the inverters is marked with X.

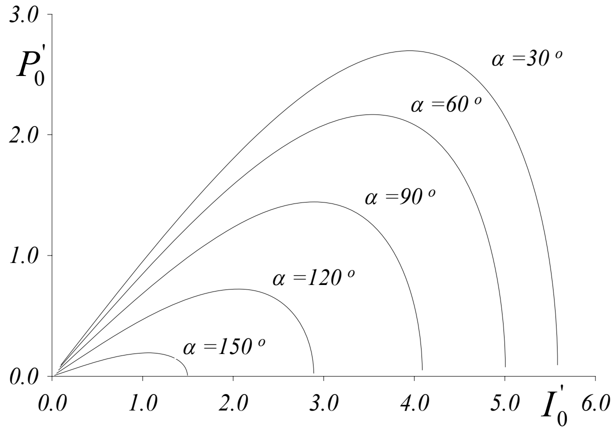
It may be noted that the current of the two inverters $I_{1(1)}$ and $I_{2(1)}$ have different values. This is due to the fact that as in the value of the load R_0 changes, the vector vertex ***c*** of the voltage $U_{c(1)}$ describes an arc of a circumference between ***0*** and ***e***. Both currents have equal values only at the end points ***0*** (short circuit) and ***e*** (no-load).

At the analysis, presented in [1], expressions for the basic quantities in relative units are obtained, as functions of the load current I_0, the control angle α and the dephase angle φ. Based on these expressions, the most important dependencies graphic images are shown below to illustrate how the studied device operates.



$$\cos^2\frac{\alpha}{2} = U_0'^2 + X_0'^2 I_0'^2$$

Fig.3 Output characteristics of converter



$$P_0' = I_0'\sqrt{\cos^2\frac{\alpha}{2} - X_0'^2 I_0'^2}$$

Fig.4 Dependence of the output power on the output current

Fig.3 presents the output characteristics of the converter for different controlling angles α. They form ellipses, the radii of which decrease as α increases.

Fig.4 shows output power P_0 dependencies in relative units as a function of the load current I_0 at different controlling angle α values. It is evident that the characteristics have marked maximum, obtained at certain load resistance value [1]. Moreover, the output power decreases as the α increases.

The above characteristics (fig.3 and fig.4) are similar to the relevant characteristics of a resonant converter, operating over its resonant frequency [2]. In this sense, the device herein reacts to the load circuit in a similar way as the above mentioned devices.

3. OPERATIONAL REGIMENS

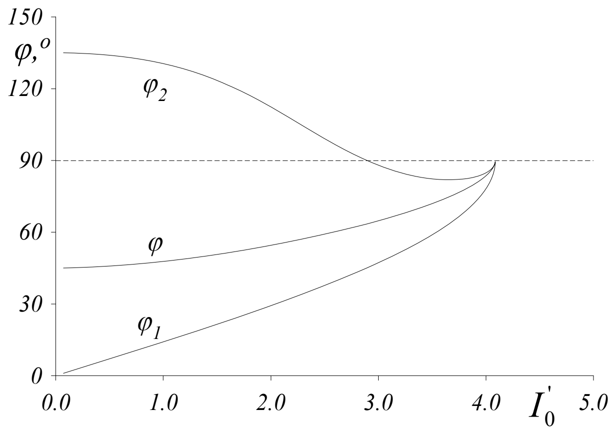
With purpose to explain the specific operational features of the converter, basic dependencies in relative units, obtained for the sample model at controlling angle α=90° are presented below.

Fig.5 shows the dependencies of the dephase angles φ, φ_1 and φ_2 between $U_{e(1)}$, $I_{(1)}$; $U_{a(1)}$, $I_{1(1)}$ and $U_{b(1)}$, $I_{2(1)}$ on the output current I_0. Angle φ changes from 0° to 90°.

This corresponds to the change in operational regimen from no-load to short circuit. Energy is being transferred from the inverters to the load.

Angle φ_1 changes from 45° to 90° without over exceeding them. This means, that the first inverter (I) merely consumes energy from the power source.

Angle φ_2 changes from 135° to 90° as the output current increases. In this case, at low output current values, the second inverter (II) turns energy back to the power source, i.e. operates in a rectification regimen.

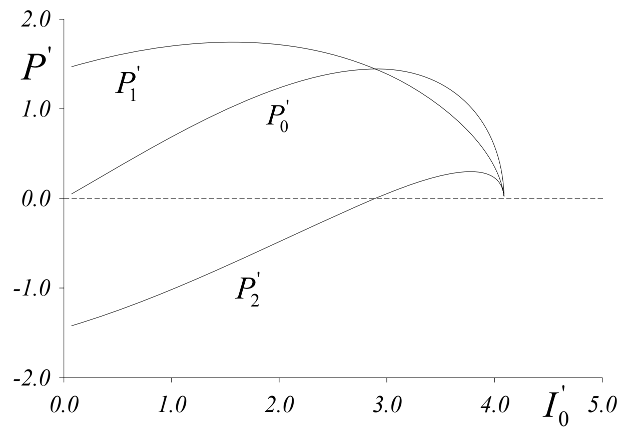


$$\varphi = arctg\frac{X_0' I_0'}{\sqrt{\cos^2\frac{\alpha}{2} - X_0'^2 I_0'^2}}$$

$$\varphi_1 = \frac{\alpha}{2} + \gamma_1$$

$$\varphi_2 = \pi - \frac{\alpha}{2} - \gamma_2$$

Fig.5 Dependencies of the dephase angles on the output current



$$P_0' = I_0' \sqrt{\cos^2\frac{\alpha}{2} - X_0'^2 I_0'^2}$$

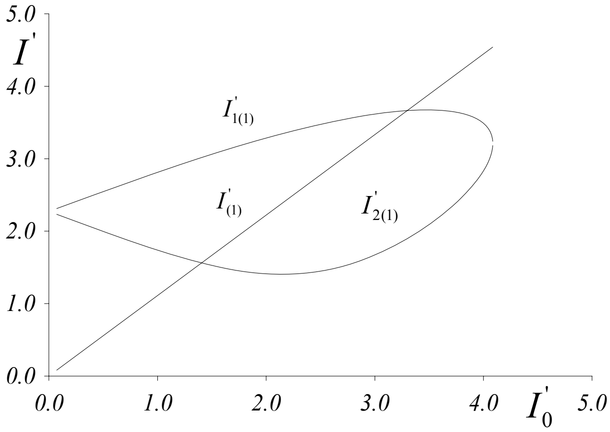
$$P_1' = U_{a(1)}' I_{1(1)}' \cos\varphi_1$$

$$P_2' = U_{b(1)}' I_{2(1)}' \cos\varphi_2$$

Fig.6 Dependencies of the powers on the output current

Fig.6 shows in relative units the dependencies of the power P_0, transferred to the load and the powers P_1 and P_2, consumed by the inverters as functions of the output current I_0. The latter ones confirm the conclusions, drawn by the previous figure. Evidently, while at no-load regimen, the same amount of power that transfers from the power source to the first inverter is being sent back from the second inverter to the power source. In other words, at this regimen there is an exchange of energy going on between the two inverters only. As the load increases, however, the consumption of energy by the first inverter increases and the energy, which is sent back by the second inverter, decreases. This way, part of the energy, consumed by the first inverter transfers to the load and other part turns back through the second inverter to the power source. Over certain load current value, both inverters consume energy and transfer it to the load.

Fig.7 shows in relative units the dependencies of the converter currents $I_{1(1)}$, $I_{2(1)}$ and $I_{(1)}$ and fig.8 shows those of the voltages U_{CImax} and U_{CIImax} of inverters capacitors, as functions of the load current I_0. These characteristics show clear correlation between the currents through the inductors and the voltages across the capacitors. They also confirm the conclusion, which has already been drawn, that as the load current increases, the first inverter gets additionally loaded, while the second inverter unloads. This on its side leads to increase in the maximum voltage of the first inverter capacitor, while with the second inverter it decreases. The non-zero values of the currents through the inverters at float run regimen are of great interest. Their range depends on the size of the controlling angle α.

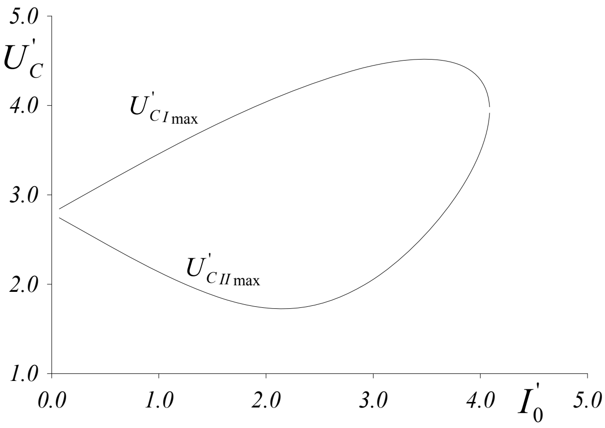


$$I'_{(1)} = \frac{\pi}{2\sqrt{2}} I'_0$$

$$I'_{1(1)} = \frac{\pi}{4\sqrt{2}} \cdot \frac{\sqrt{\sin^2\frac{\alpha}{2} + X_0'^2 I_0'^2 + 2X_0' I_0' \sin\frac{\alpha}{2}\cos\varphi}}{X_0'}$$

$$I'_{2(1)} = \frac{\pi}{4\sqrt{2}} \cdot \frac{\sqrt{\sin^2\frac{\alpha}{2} + X_0'^2 I_0^2 - 2X_0' I_0 \sin\frac{\alpha}{2}\cos\varphi}}{X_0'}$$

Fig.7 Dependencies of the converter currents on the output current



$$U'_{C\,I\max} = \frac{\sqrt{2} I'_{1(1)}}{\nu}$$

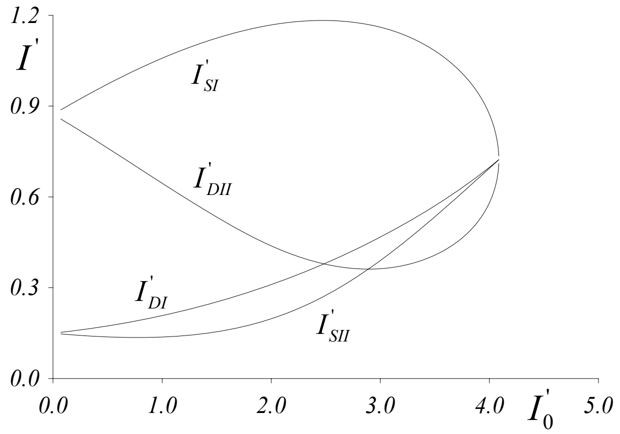
$$U'_{C\,II\max} = \frac{\sqrt{2} I'_{2(1)}}{\nu}$$

Fig.8 Dependencies of the capacitors voltages on the output current

Dependencies in relative units of the average values of the currents I_{SI} and I_{SII} through the switches and I_{DI} and I_{DII} through the reverse diodes of the two inverters on the output current I_0 are shown on fig.9. It is evident that the switches of the first inverter get loaded more than the ones of the second inverter ($I_{SI} > I_{SII}$), while with the diodes it is exactly opposite ($I_{DI} < I_{DII}$). In addition, the amount of current I_{DII} through the diodes of the second inverter, for low values of the load current I_0, is larger than the one through its switches I_{SII}. This also comes to show, that under certain conditions, second inverter operates in rectifying regimen.

4. Conclusions

Load characteristics in relative units of resonant DC/DC converter, using phase-shift method of control and operating at frequency, higher than the resonant frequency are presented.



$$I'_{S\,I_{AV}} = \frac{\sqrt{2}}{2\pi} I'_{1(1)}(1+\cos\varphi_1) \qquad I'_{D\,I_{AV}} = \frac{\sqrt{2}}{2\pi} I'_{1(1)}(1-\cos\varphi_1)$$

$$I'_{S\,II_{AV}} = \frac{\sqrt{2}}{2\pi} I'_{2(1)}(1+\cos\varphi_2) \qquad I'_{D\,II_{AV}} = \frac{\sqrt{2}}{2\pi} I'_{2(1)}(1-\cos\varphi_2)$$

Fig.9 Dependencies of the average values of currents, running through the inverters switches and diodes on the output current

The characteristics are drawn based on existing analysis of studied converter on the method of the first harmonic. A research on the operational regimens of the two inverters, forming the converter and their influence on the scheme elements is conducted.

It is established that the two inverters do not have equal loading. Even at wide range of changes, the second inverter mostly sends energy back towards the power source, i.e. it operates in rectifying regimen. Even when the converter operates at no-load, considerable amount of current power could run through its switches. This, however, gives positive effect – unlike other serial resonant inverters, the studied device can operate at no-load regimen at certain minimal controlling angle.

Another advantage of the device is the relatively simple control of the power switches in the conditions of soft comutation.

REFERENCES

[1] Bankov N., A. Vuchev, *Research of phase-shift method of resonant DC/DC converter power control,* The Fifteen International Scientific and Applied Science Conference "Electronics – ET'2006", Sozopol, Bulgaria, 2006.

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

[3] Savary, P., M. Nakaoka, T. Maruhashi, *Novel type of high-frequency link inverter for photovoltaic residental applications*, IEEE Proceedings, Vol.133, Pt.B, №4, July 1986.