A METHOD TO CALCULATE POWER TRANSFER IN DIRECT AC-AC CONVERTER WITH SCR AND RESISTIVE-INDUCTIVE LOAD

Ecaterina-Liliana MIRON, C.G. Constantinescu, Marian PEARSICA, Constantin STRIMBU, Mihai MIRON

"Henri Coanda" Air Force Academy, Romania, liliana.miron@afahc.ro, ccg_cristi@yahoo.com, strimbu_c@yahoo.com, marianpearsica@yahoo.com, mihaimiron@hotmail.com

Abstract **– This paper is focused on predicting the power transfer in direct AC-AC converter with SCR and resistive-inductive load. The circuit simulation and results prediction were carried out using specific computational tools such MathCAD. The ac switching mode process is studied and the article presents a method to establish the mathematically model of the power transfer. Comparative evaluations with experimentally determinations are presented. For this must be study power flow on resistive-inductive load from AC-AC converter for different firing and phase shifting angles of SCR from converter structure.**

Keywords: *firing angles, phase shifting angles, SCR's turn off angles*

1. INTRODUCTION

The AC-AC converters are circuits from electronic circuits family, which allow the power control in AC circuits.
The AC-AC converters have the control function of transfer power in different application: control of illumination, heat control, in electrochemistry and electric drive. The power control is made with control of firing angle of SCRs, triacs or power transistors.
The general schematic diagram of AC-AC converters is showed in Fig.1. The waveforms of load voltage to an AC-AC converter with SCRs are presented in Fig.2.

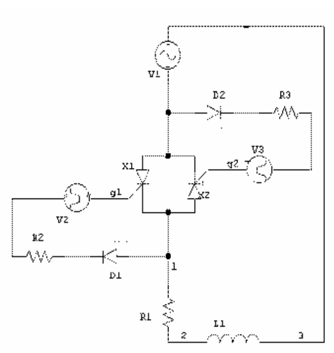

Figure 1: Schematic of ac-ac converter with resistive-inductive load

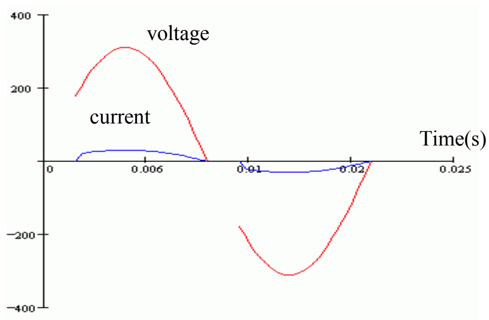

Figure 2: Waveform of voltage and current load for ac-ac converter

2. THE MATHCAD MODEL OF POWER TRANSFER

In this paper it is followed to determine the apparent power (volt amps) as a function of firing angles α and phase shifting angles φ (the values of resistance, R and inductance, L). The study is based on the following algorithm:
1.The calculus of the turn off angles for SCR and its approximations with a mathematical expression.
2.Because the waveforms are not sinusoidal, is necessary the calculus of Fourier coefficients of the voltage and current.
3.The schematic diagrams of the load voltage and current.
4.The calculus of the volt amps, active and reactive powers.
5.The determination of an approximation for all types of power.
6.The errors calculus between theoretical and experimental results.
The schematic diagram is presented in the Fig. 3.
In the phase angle control, the load voltage and current are not sinusoidal, they are followed by a number of harmonics, and so the mathematical determination of load power will be made with MathCAD functions [1] for an imposed number of harmonics.

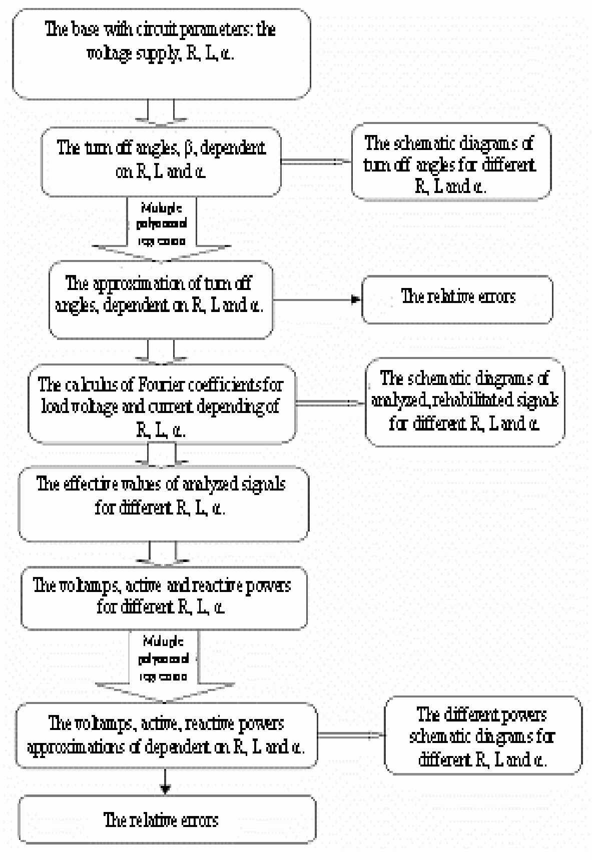

Figure 3 : The algorithm of the power transfer calculus.

To calculate the power transfer in direct AC-AC converters with SCRs it's need a database with SCRs firing angle, α and phase shifting angle values, φ. To obtain a good control of power transfer, the SCRs operate in interrupting mode. This means the angles of AC-AC converters perform the condition: α ≥ φ. The phase shifting angles are in matrix Φ and the firing angles in A0.

For the MathCAD calculus, it are utilized the next values:

$$U:=220\sqrt{2}\ ,\quad R:=10\ ,$$

$$A0 := \begin{pmatrix} 0 \\ 15 \\ 20 \\ 25 \\ 30 \\ 35 \\ 45 \\ 65 \\ 75 \\ 80 \\ 90 \\ 95 \end{pmatrix} \cdot deg \qquad L := \begin{pmatrix} 0.0005 \\ 0.0010 \\ 0.0025 \\ 0.0035 \\ 0.0045 \\ 0.0060 \\ 0.0065 \\ 0.007 \\ 0.01 \\ 0.020 \\ 0.3 \end{pmatrix}$$

For phase shifting angles:

$$\Phi = a\tan\frac{\omega L}{R} \qquad (1)$$

For the power calculus is necessary to know the time period when the power transfer to the load is realized. This means the determination of the turn off moment, β, of the SCRs on each pulse.

With the database the turn off angle approximation is:

$$B(A0,\Phi) = \left[\sum_{i=0}^{n}\left[A0^{i}\sum_{j=0}^{m}(A^{\langle j\rangle})_{i}\,\Phi^{j}\right]\right] \qquad (2)$$

where A is coefficients matrix and n=3, m=7.

$$A = \begin{bmatrix} 3.146 & 0.758 & 2.716 & -9.905 & 17.533 & -15.313 & 6.014 & -0.722 \\ -0.012 & 0.643 & -7.266 & 25.164 & -43.351 & 38.781 & -16.604 & 2.581 \\ 9.366\cdot10^{-3} & -0.525 & 5.881 & -18.874 & 30.433 & -26.416 & 11.357 & -1.857 \\ -2.266\cdot10^{-3} & 0.127 & -1.388 & 4.002 & -6.002 & 4.997 & -2.112 & 0.347 \end{bmatrix}$$

The expression (2) allows to determine the turn off angle without classically approach. To verify the exactitude of the calculus, it presents the waveforms for the load voltage and current in two cases: calculus and experimentally waveforms.

The examples of schematic diagrams is shown in the next figures.

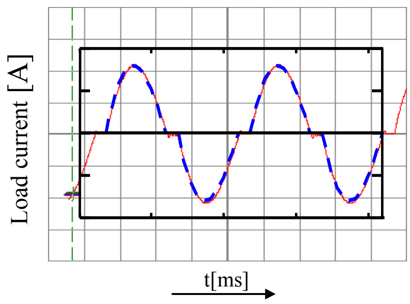

Figure 4: The load current waveform α = 65°.
The calculus waveform
The experimentally waveform

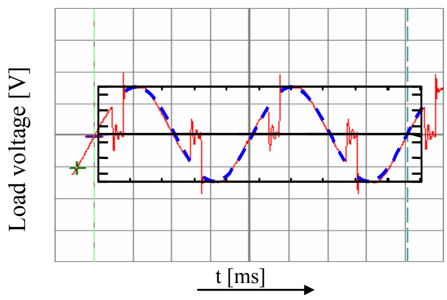

Figure 5: The load voltage waveform α = 65°.
The calculus waveform
The experimentally waveform

In Fig. 6 is presented the errors of turn off angle approximation with MathCAD functions.

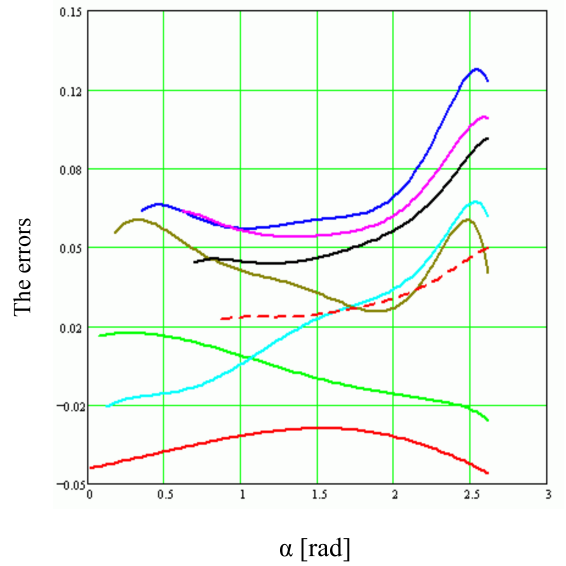

Figure 6: The errors of turn off angle approximation with MathCAD functions

Because the errors are under ±0.15%, in the next calculus, for Fourier coefficients is utilized the expression (2).
The current and voltage Fourier coefficients are calculated for 45 harmonics, which rehabilitate the initial signals. Part of the determined load power transferred matrix is shown in Table 1.

P =

	0	1	2	3	4	5
0	0.017453293	0.26179939	274.2031	274.13553	4.9333588	3.5655426
1	0.017453293	0.43633231	270.41837	270.3071	5.1726248	5.7797956
2	0.017453293	0.61086524	262.53226	262.36313	5.4774269	7.6661245
3	0.017453293	0.78539816	249.65195	249.41775	5.7761895	9.1388195
4	0.017453293	1.0471976	220.50748	220.17906	6.0557763	10.395173
5	0.017453293	1.134464	208.38347	208.02899	6.0719853	10.523417
6	0.017453293	1.4835299	151.60682	151.19382	5.6316711	9.6612506
7	0.017453293	1.6493361	122.6091	122.20027	5.1297753	8.5889762
8	0.017453293	2.0315632	61.315533	60.991685	3.443133	5.2681791
9	0.017453293	2.1642083	44.117625	43.841701	2.7764868	4.0695429
10	0.017453293	2.6179939	7.6081643	7.5094123	0.79107378	0.93117793
11	0.06981317	0.26179939	274.08869	273.26283	19.400591	8.697883

Table 1: The determined load power values

In the table 1 the columns represent:
column 0: the values of the phase shifting angles (in radians);
column 1: the values of the firing angle (in radians);
column 2: the values of the load volt amps;
column 3: the values of the load active power;
column 4: the values of the load reactive power;
column 5: the values of the load deformed power.
In Fig.7 and Fig.8 are presented the waveforms of the calculus and rehabilitated signal with Fourier coefficients for load current or rehabilitated signal with Fourier coefficients and experimentally signal for load voltage.

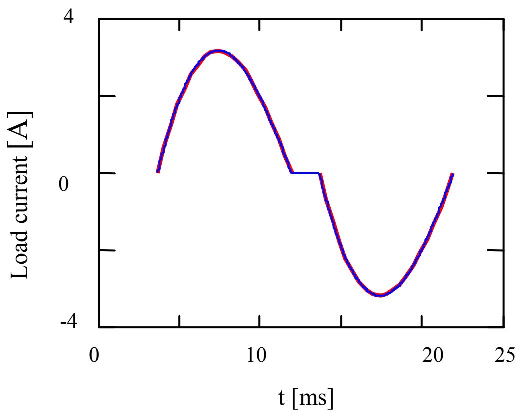

Figure 7: The load current waveform α = 65°.
The rehabilitated current waveform
The calculus waveform

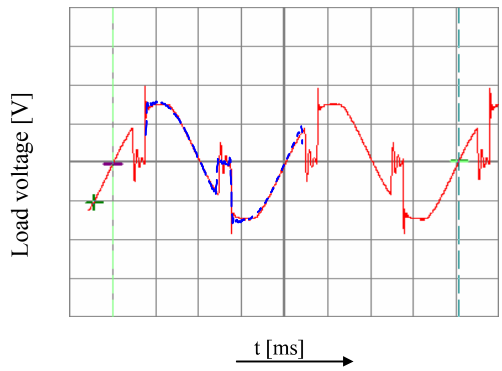

Figure 8: The load voltage waveform α = 65°.
The rehabilitated current waveform
The experimentally waveform

The waveforms are quite identical. So, for the calculus of power transfer will be used the rehabilitated signals with Fourier coefficients.
In the same way like turn off angle polynomial regression we obtain the polynomial regression for all types of load power. The expression of polynomial regression of load volt amps is (n- number of rows, m-number of column):

$$S(A0,\Phi)=\left[\sum_{i=0}^{n}\left[A0^{i}\sum_{j=0}^{m}\left(CoefS^{\langle j\rangle}\right)_{i}\Phi^{j}\right]\right] \quad (3)$$

"CoefS" is coefficients matrix with n =5 and m =10.

CoefS =

	0	1	2	3	4	5	6	7	8	9
0	252.6	850.6	$-1.9\cdot10^{4}$	$1.8\cdot10^{5}$	$-8.4\cdot10^{5}$	$2.2\cdot10^{6}$	$-3.2\cdot10^{6}$	$2.7\cdot10^{6}$	$-1.2\cdot10^{6}$	$2.1\cdot10^{5}$
1	45.9	$2.2\cdot10^{3}$	$-4.4\cdot10^{4}$	$3.7\cdot10^{5}$	$-1.5\cdot10^{6}$	$3.5\cdot10^{6}$	$-4.6\cdot10^{6}$	$3.5\cdot10^{6}$	$-1.4\cdot10^{6}$	$2.4\cdot10^{5}$
2	-75.2	$-4.3\cdot10^{3}$	$8.7\cdot10^{4}$	$-7.5\cdot10^{5}$	$3.2\cdot10^{6}$	$-7.7\cdot10^{6}$	$1.1\cdot10^{7}$	$-8.4\cdot10^{6}$	$3.5\cdot10^{6}$	$-6\cdot10^{5}$
3	-12	$2.1\cdot10^{3}$	$-4.3\cdot10^{4}$	$3.8\cdot10^{5}$	$-1.6\cdot10^{6}$	$3.9\cdot10^{6}$	$-5.4\cdot10^{6}$	$4.3\cdot10^{6}$	$-1.8\cdot10^{6}$	$3.1\cdot10^{5}$
4	7.5	-326	$6.6\cdot10^{3}$	$-5.7\cdot10^{4}$	$2.5\cdot10^{5}$	$-6\cdot10^{5}$	$8.3\cdot10^{5}$	$-6.6\cdot10^{5}$	$2.8\cdot10^{5}$	$-4.8\cdot10^{4}$

The expression (3) is valid for all types of power. In fig. 9 is presented the MathCAD modeling of volt amps.

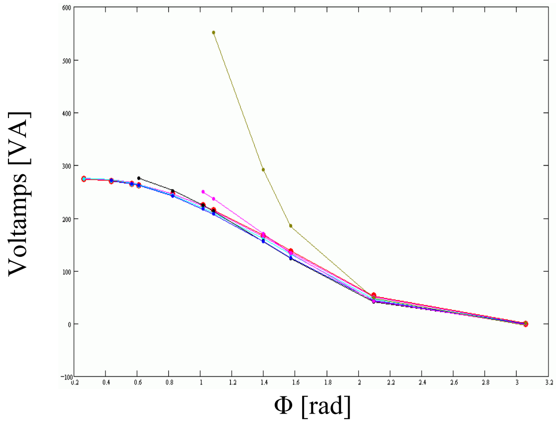

Figure 9: Voltamps for α = ct and different φ
______Power with polynomial regression approximation;
. . . . . . Direct calculus of power

In matrix "ErS" the error between effective calculated power and calculated polynomial regression power is indicated.

ErS =

	0	1	2	3	4
22	0.122	0.262	274.07	270.021	1.477
23	0.122	0.436	269.782	267.694	0.774
24	0.122	0.565	263.906	261.857	0.776
25	0.122	0.611	261.215	259.035	0.835
26	0.122	0.825	243.747	240.837	1.194
27	0.122	1.016	221.478	218.603	1.298
28	0.122	1.084	212.153	209.548	1.228
29	0.122	1.396	162.381	162.321	0.037
30	0.122	1.571	131.905	133.388	-1.124

column 0: the values of the phase shifting angles (in radians);
column 1: the values of the firing angle (in radians);
column 2: the calculated values of the load volt amps;
column 3: the values of the load volt amps with polynomial regression;
column 4: the error between column 3 and column 4.
The errors are under ±2%.
The calculus and the curves like that presented for the volt amps, it is possible to realize for all types of power, like active and reactive power, but the degrees of the polynomial regression are different.

3. CONCLUSIONS

Power transfer can be controlled with variable phase angle or phase shifting angle values. The approximation of power transfer with polynomial regression is a function of phase angle and phase shifting angle. The algorithm, which was presented, helps us to determine more easily the power in the designing of the AC converter circuit with resistive inductive load. For one asked value of load power, the firing angles and phase shifting angles (the values of resistance, R and inductance, L) of SCRs are determined with the expression (3), without retrace all steps of the algorithm from fig.3.

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