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DEPENDENCE OF THE ACTIVE POWER OF THE SERIAL RESONANT BRIDGE CONVERTER FROM THE PHASE DIFFERENCE AND THE DUTY CYCLE

Assist. prof. Dr. Eng. Stefanov G.[1], Prof. Dr. Eng. Karadzinov Lj.[2], Assos. prof. Dr. Eng. Sarac V.[3], Prof. Dr. Atanasova-Pacemska T.[4], Assist. M.Sc. Kukuseva Paneva M.[5], Prof. Dr. Eng. Dambov R.[6]
Faculty of Electrical Engineering-Radovis, University ‘Goce Delcev’-Stip, Macedonia[1,3,4,5,6]
FEIT, University Sv. Kiril and Methodius -Skopje, Macedonia[2]

1. Introduction

In power converters of interest is the power transferred from the converter on the load to be maximal. Often due to the change in the parameters of the output circuit of the converter, this power is not always maximal. In this paper with mathematical analysis are determines the quantities from which depends the active power of the resonant converter.

Derived is an equation which gives the dependence of the active power from the phase angle between the voltage and current the converter as and from the duty cycle.

2. Impact on Phase Difference and Duty Cycle at Serial Resonant Bridge Converter

Serial the resonant converter is normally used in the devices for induction heating [1], [2]. In Fig. 1 is shown the electrical scheme of this converter with output load: R = 0.24 Ω, C = 26,6 μF and L = 26,5 μH [8].

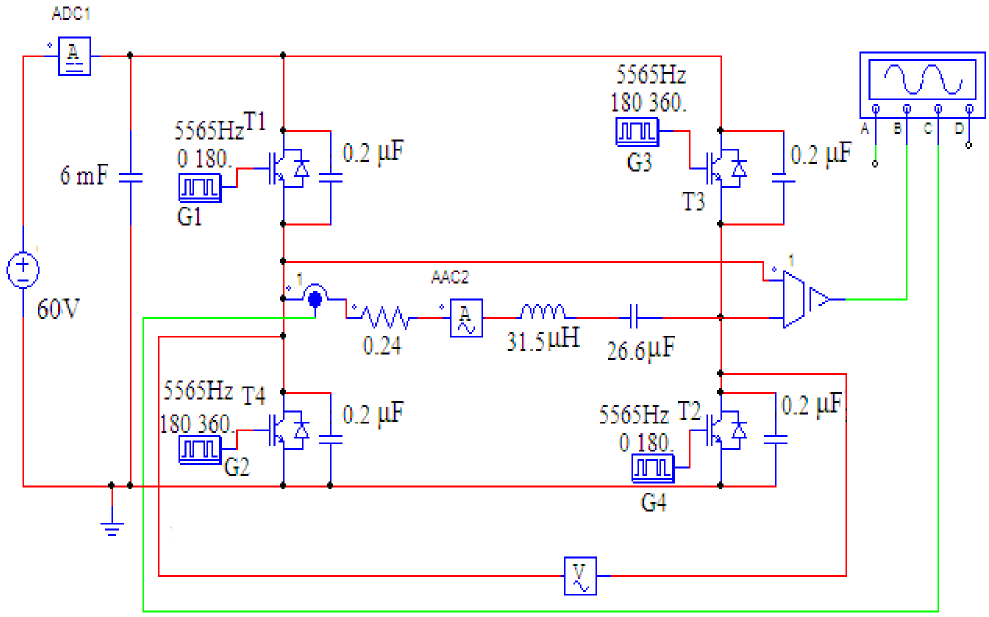


Fig. 1. Serial resonant bridge converter topology in mode of induction device.

In Fig. 2 are shown the output voltage and current waveforms in the more usual above-resonance mode of operation.

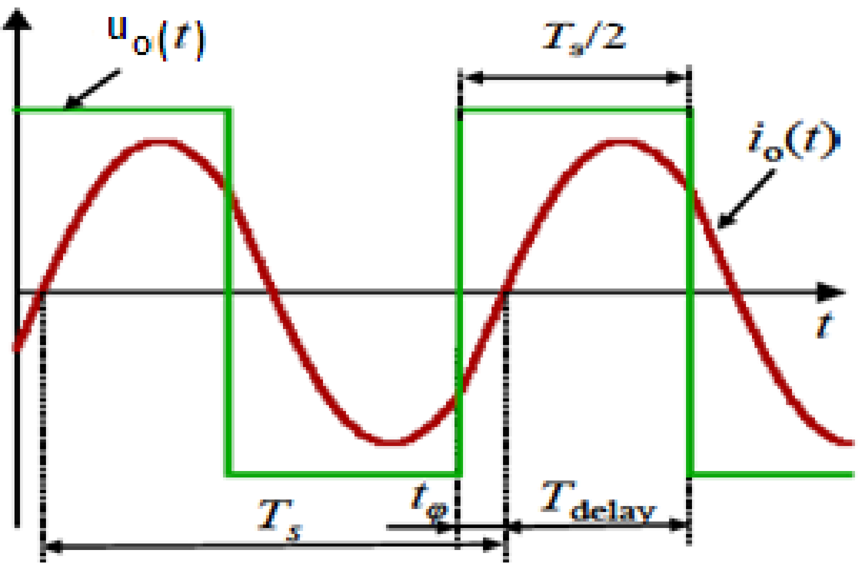


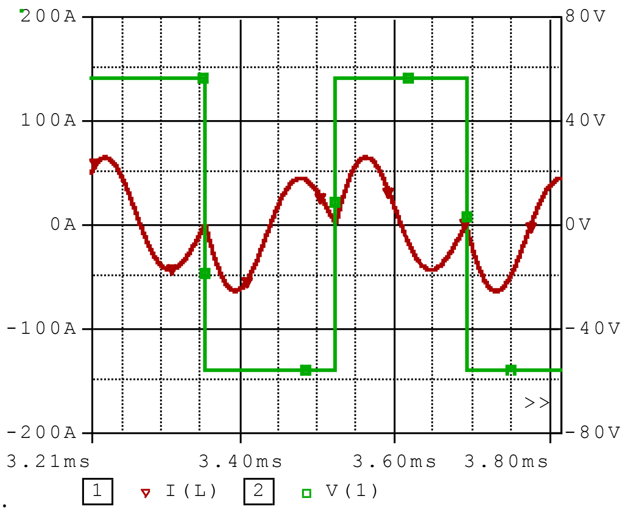
Fig. 2 Output voltage and current waveforms in above-resonance mode.

In Table I are given the values on the switching frequency fsw , output voltage *U*o, output current *I*o, output power *P*o and phase difference *φ* for chance on the resistance and the inductance for 20 %, i.e.: change on *R* from 0.24 Ω on 0.29 Ω, and change on *L* from 26.5 μH on 31.5 μH. In Fig. 3 gives PowerSim simulation results of steady state for several values of the switching frequency below and above resonance.

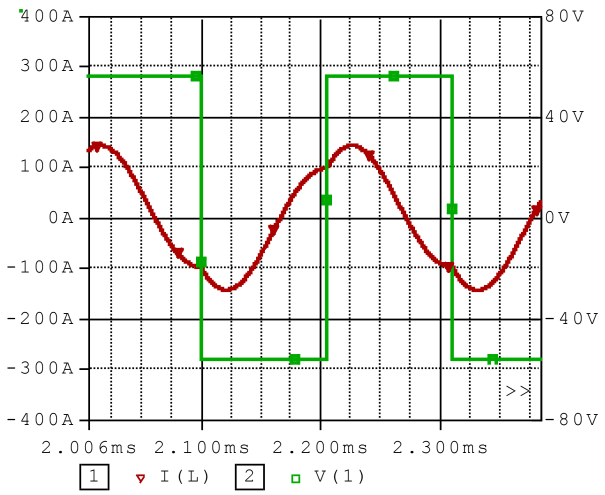
Table I: Values of the output converter parameters for changes of resistance and inductance for 20%.

L [μH]	R [Ω]	φ_i [°]	f_{sw} [kHz]	I_o [A]	U_o [V]	P_o [kVA]
26,5	0,24	5,00	6.27	208	56	10,7
31,5	0,29	31,34	6.27	145	56	6,16

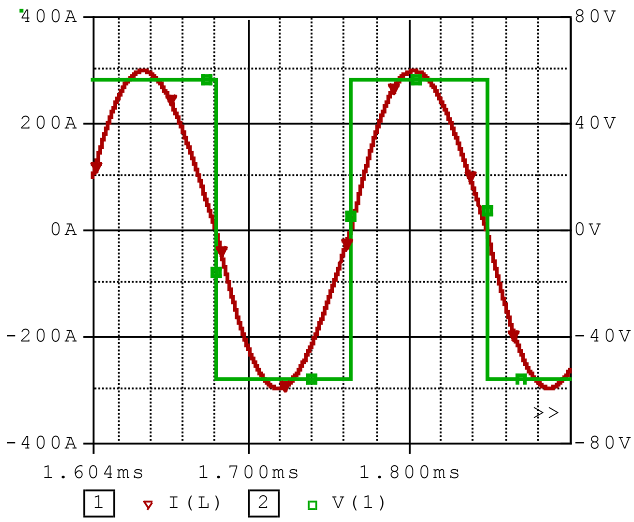
In the Fig. 4 is shown harmonic specter for the output voltage of the converter for duty cycle 0.5 and 0.2.



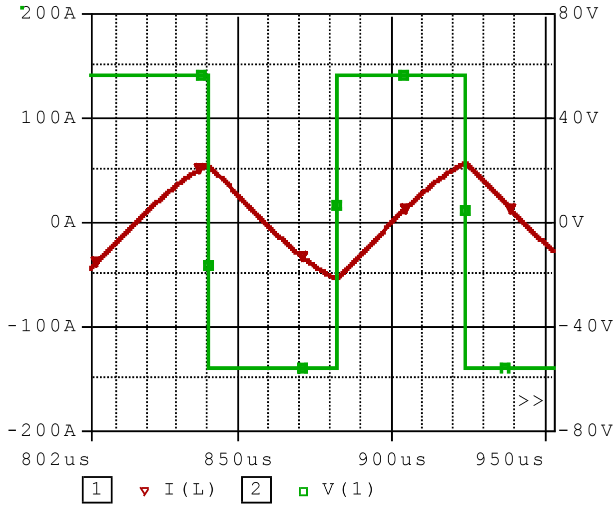
$f_s = 0{,}5 f_0$ = 2 979 Hz



f_s = 0,8 f_0 = 4 761 Hz

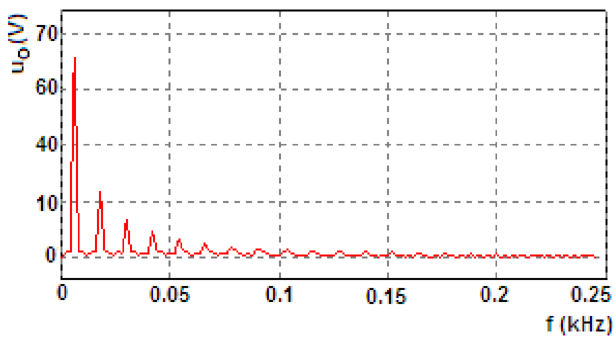


fs = 1,0 f0 = 5 951 Hz

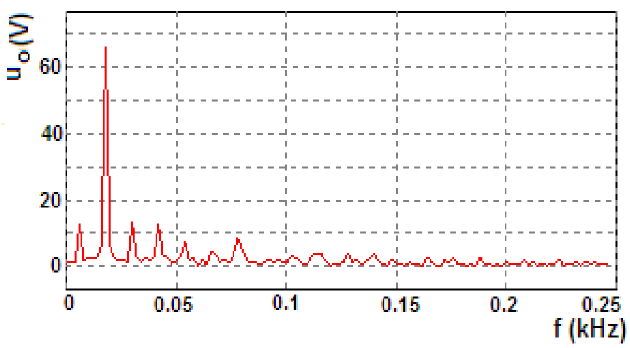


fs = 2,0 f0 = 11 902 Hz

Fig. 3 Steady state voltage and current waveforms below and above resonance (R = 0.24 Ω, L = 26.5 μH, C = 26.6 μF and Q = 4).



a)



b)

Fig.4 Harmonic specter of the output converter voltage: a) for duty cycle 0.5 and b) for duty cycle 0.2.

3. *Determination on the active power from phase difference and duty cycle*

In this paper calculate output power of the serial resonant bridge converter is give as:

$$P_o = \frac{I_o U_o}{U_o} \frac{4U_{DC}}{\pi\sqrt{2}} \sin(D\pi)\cos\varphi = I_o \frac{4U_{DC}}{\pi\sqrt{2}} \sin(D\pi)\cos\varphi \qquad (11)$$

The equation (11) gives the dependence of the output power of a bridge resonant converter from the output current I_o, the voltage of DC source U_{DC}, the phase difference φ and the duty cycle D.

In serial resonant converter, the output voltage is with square waveform and in such a case phase differences is [8], [10]:

$$\varphi = \operatorname{arctg}\left(\frac{\sin(\pi \frac{\omega_d}{\omega_s})}{e^{+\frac{\pi}{2Q}\frac{\omega_0}{\omega_s}} + \cos(\pi \frac{\omega_d}{\omega_s})} \right) \qquad (12)$$

When (12) is replaced in (11), for active power of converter is are obtained:

$$P_o = I_o \frac{4U_{DC}}{\pi\sqrt{2}} \sin(D\pi)\cos\left(\operatorname{arctg}\left(\frac{\sin(\pi \frac{\omega_d}{\omega_s})}{e^{+\frac{\pi}{2Q}\frac{\omega_0}{\omega_s}} + \cos(\pi \frac{\omega_d}{\omega_s})} \right)\right) \qquad (14)$$

Table III: Data for *fs*/*fd*, U_{DC}, *Io*, and *Po* for $D = 0.5$, $D = 0.4$ and $D = 0.2$ base on (14)

			D= 0.5		*D*= 0.4		*D*= 0.2	
f_s/f_d	U_{DC} [V]	φ [o]	I_o [A]	P_o [kW]	I_o [A]	P_o [kW]	I_o [A]	P_o [kW]
0.1	60	-0.02	57	2.88	25	1.26	18	0.91

0.25	60	-0.06	33	1.67	23	1.16	32	1.62
0.3	60	-15.13	62	3.03	52	2.54	34	1.66
0.4	60	20.53	52	2.46	28	1.32	41	1.94
0.5	60	-0.06	42	2.13	41	2.07	41	2.07
0.6	60	-19.72	55	2.62	55	2.62	42	2
0.7	60	-32.56	62	2.64	76	3.24	57	2.43
0.8	60	-37.36	89	3.58	110	4.42	58	2.33
0.9	60	-29.32	157	6.93	155	6.83	47	2.07
1.0	60	0.19	211	10.7	186	9.41	43	2.18
1.1	60	31.10	169	7.32	174	7.54	42	1.82
1.2	60	43.88	129	4.71	128	4.67	33	1.2
1.3	60	47.70	86	2.93	90	3.06	29	0.99
1.4	60	48.17	76	2.57	73	2.46	28	0.95
1.5	60	47.31	62	2.13	62	2.12	26	0.89
1.6	60	45.90	55	1.94	53	1.86	24	0.85
1.7	60	44.29	46	1.67	47	1.70	26	0.94
1.8	60	42.63	41	1.53	44	1.63	23	0.86
1.9	60	40.99	40	1.53	37	1.41	19	0.73
2.0	60	39.42	35	1.37	36	1.40	18	0.7

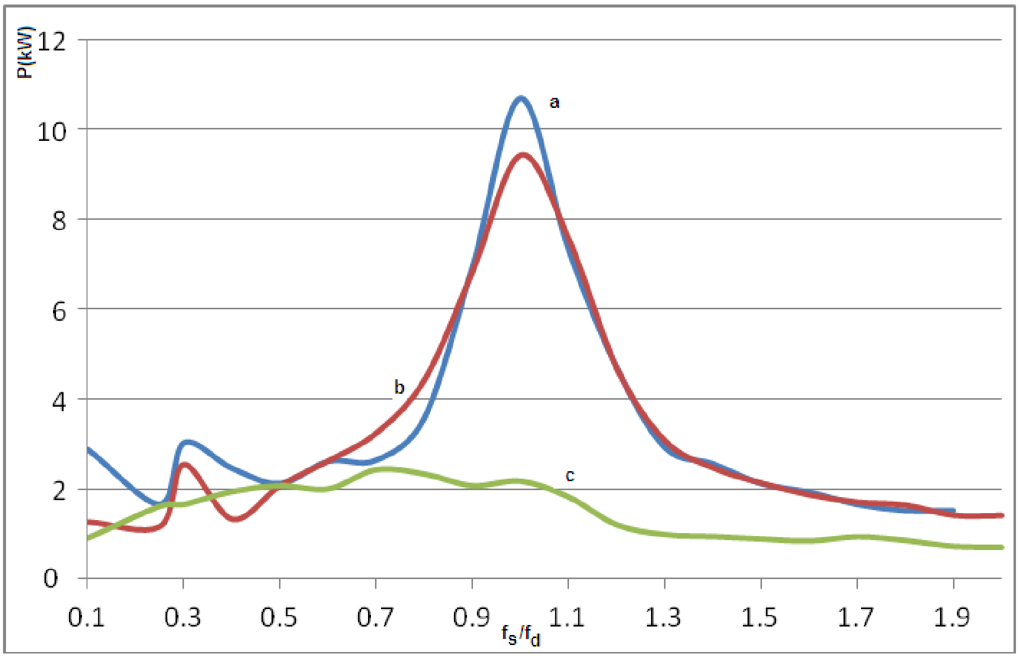


Fig. 6. Waveforms on the output power of the resonant converter for three value on duty cycle: D = 0.5, D = 0.4 and D = 0.2.

From Table III and Fig. 6 can be seen that: first, the output power is maximal for $fs = fd$ and duty cycle $D = 0.5$, second, the output power for $D = 0.4$ and $fs = fd$ is reduced for 15 % in ratio on the power for $D = 0.5$.

Also, can be noted that for frequencies larger than $fs = 1.1\ fd$, the waveforms on the output power for $D = 0.4$ and $D = 0.5$ are almost the same.

The waveform on the output power for $D = 0.2$ shows that in this case is greatly reduced with maximum value for fs = 0.7fd.

5. Conclusion

- The serial resonant bridge converter have output voltage with square waveform and output current with sinusoidal form when switching frequency is same with the resonant frequency. When this converter operates in mode on induction device RL parameters are changed and this is change the output converter power.
- To maintain a constant power transfer from the converter to the load, it is necessary to know the dependence of the power on the phase difference and duty cycle. In this paper, an exact equation is derived for the dependence of the output power of the converter from the phase difference and duty cycle. This equation can be used for development of an algorithm for the operation of the converter with constant power.