ANALYSIS OF PARALLEL RESONAT CONVERTERS WITH COMPUTER SIMULATIONS

Assist. prof. Dr. Eng. Stefanov G.[1] , Assos. prof. Dr. Eng. Sarac V.[2], Assist. Msc. Eng. Kukuseva Paneva M.[3]
Faculty of Electrical Engineering-Radovis, University 'Goce Delcev'-Stip, Macedonia [1,2,3]
goce.stefanov@ugd.edu.mk, vasilija.sarac @ugd.edu.mk, maja.kukuseva@ugd.edu.mk

Abstract: *In this paper analysis of power converters with parallel resonant circuit by using of computer simulations is made. The full bridge IGBT power converter is analyzing. The simulations are made in PowerSim simulation program. Calculation is the efficiency of the converter and is made harmonic analysis of the output voltage and current. Also, is made and compare on the obtained results of the parallel resonant converter with the results of the serial resonant converter in applications with variable RL-load.*

Keywords:POWER CONVERTER, EFFICIENCY, HARMONIC DISTORTION

1. Introduction

Power converters have great application in power electronics as in the devices for consumers (UPS, amplifiers) such and in industrial applications (driver converter, DC converter, and converter for induction heating). Basic elements in the power converter are semiconductors switching elements: diodes, thyristors, bipolar transistors, MOST transistors, IGBT transistors and GTO thyristors, [1], [2], [3]. The main target is semiconductors switching elements to operate with reduced losses of switching. The choice on the resonant circuit of the output of converter provides turn on and turns off of the switching elements in the bridge to be done at time as the voltage is zero or the current is zero. So the losses of power from switching are reduced, [1], [2].

Load resonant converters which used at devices for induction heating are with serial or parallel resonant circuit [1]. The resonant converters with serial *RCL* circuit are supply by a source of direct voltage. Output power in them is regulated by the control on difference between switching (operating) and resonant frequency. The output current of these converters, for switching frequency close to the resonant, has the shape close to a sine wave form and then transmitted energy is greatest. The resonant converters with parallel *RCL* circuit are supply by a source of the constant current. In these converters, output power is also regulated by control on difference between switching and resonant frequency. The output voltage of these converters, for switching frequency close to the resonant frequency has a shape close to a sine wave form and then transmitted energy is greatest [1].

The process on design of the power converter is defined with the purpose of the converter, and output load. Output load of converter defines the required output power, output voltage, output current, and output frequency. From the physical state of the output load on the converter depends configuration of hardware and software part of managing electronics. The work is simple if the output load is a stationary, time able not changed, such as output load in the mode of motor or regulated source of voltage. But the design of converter is complicated if the physical state of the output load is a dynamic, time-variable process and its dynamic affects on output variables of the converter: impedance, voltage, current, power, frequency. Such output load has in power converter burdened with parallel and serial resonant circuit in the mode of induction furnace, [1], [5], [6]. The mode of induction furnace changes the impedance of resonant circuit and it affects on the voltage, current and power on the converter. So the design on the converter with such load requires knowledge of the dynamics of the process. The design of converter is facilitated by using on the computer simulation programs, [5],[7].

The main task in this paper is the researching for operating of parallel resonant converter with output loads whose dynamics are changing and is affecting of sizes on the resonant circuit.

2. Power Converters at Devices by Variables RL Load

In the Fig. 1 is presented block diagram in the power converter at device to inductions headings.

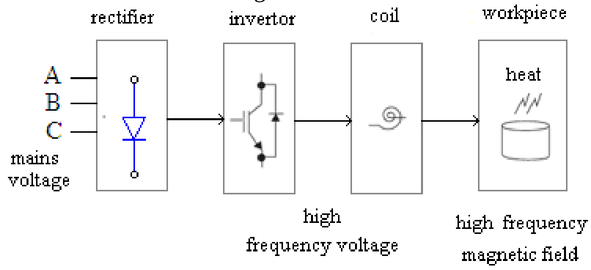


Fig. 1. *Power converter at device to inductions headings.*

The resonant converters used in applications where the dynamic of the process affects on the parameters of the converter. In the paper on the basis of a defined change on inductance and resistance on the resonant circuit, determined of the dynamics of induction device obtained by ELTA simulation program, is analyzed the work of full bridge IGBT converter with parallel resonant circuit, [5].

Definition of working conditions

We analyze the processink on the work piece metal with induction heating under follow operating conditions [5]: 1.Working piece metal 0.4% C steal 2T anneal, shape-cylinder, length 35cm, finite system length, R_{int} = 3cm, R_{ext} = 8cm, maximum temperature is 1000ºC, time cycle is 600s; 2. Maximum output power (Smax) is 100000VA; 3. Switching frequency (f_{sw}) 10 kHz was assumed for the design of maximum power; 4. IGBT devices are used.
With these conditions in ELTA simulation program is define the dynamics of the parameters (power, current, voltage, frequency, inductance, impedance) important for the design of the converter, [1], [5]. In Table 1 are given the results for changing the parameters of the system converter-inductor-work piece.

Table 1. *Parameters of the system converter-inductor-work piece*

	L (μH)	C_{reson} (μF)	C_{real} (μF)	R (Ω)	I_{ind} (A)	U_{conver} (V)	P_{conv} (kW)	η_{ele} (%)	PF
	11.89	21.4	13.9	0.37	571	225	92.3	0.76	0.5
	23.93	10.6	13.9	1.14	238	285	65	0.96	1
% (min/max)	49.6	49.5		18.4	41.7	79	70.4		50

From Table 1 can be concluded:

- The changing on temperature of the work piece from 20 to 1000 ^{o} C produces change on the inductance for 49.6%.
- C_{reson} is value on capacitance required for compensate of changes of inductance for preserve the resonance frequency from 10000Hz.
- C_{real} is a real value of the selected capacitor.
- The changing on the inductance produces change of power of the converter for 30%.
- When the inductance is minimum, the power and the current have a maximum value.
- The changing on power of the converter shows that in such variable loads is necessary to build a system for controlling on output power.

Construction of converter

From the results for the parameters of the induction device obtained by ELTA simulation program, in PowerSim program with computer simulations the operating of the converter is analyzes [4].

Full bridge parallel resonant converter

In the Fig. 2 is show the circuit for simulation of the full bridge IGBT converter with parallel resonant circuit.

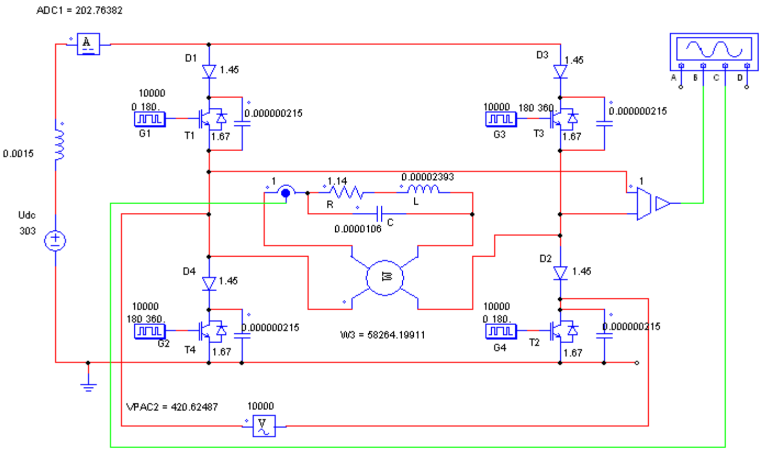


Fig. 2. *Circuit for simulation of the full bridge IGBT parallel resonant converter.*

In this paper the results to the parallel converter are comparing with the results for full bridge converter with serial resonant circuit obtained in [5]. In the simulation of the two types of converters took into consideration output power in both cases be the same.

Maximum inductance

From Table 1 can be seen that when the inductance and the resistance of the circuit are maximum, the capacitance is minimum, the output voltage of the converter is maximum and the output current is minimum. For this state, in Fig. 3 are given wave forms of the voltage and the current of output from the converter for full (100 %) output *RCL* load. In the Fig. 3a is shown wave forms for the converter by serial resonant circuit obtained to paper [5], and in the Fig.3b is shown wave forms for the converter by parallel circuit obtained by simulations in PowerSim program of the circuit of the Fig. 2.

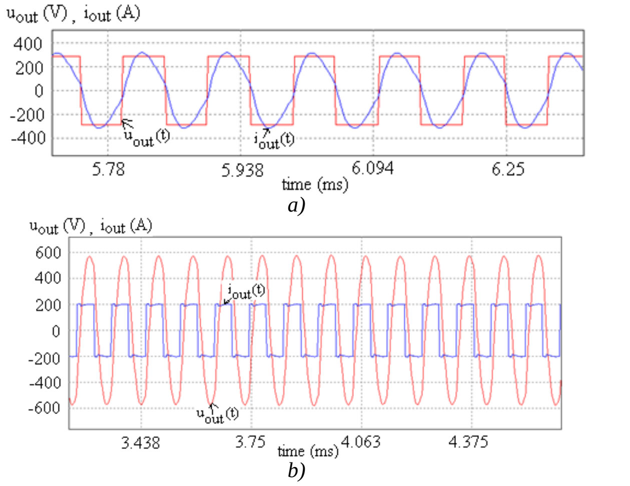


Fig. 3. Wave forms of the voltage and the current of output from converter for maximum inductance and 100 % *RLC* load: a) wave forms for the converter by serial resonant circuit in paper [5], b) wave forms for the converter by parallel circuit from Fig. 2.

From Fig. 3 can be seen that the output voltage in the converter by serial resonant circuit is with rectangular form, and the output current is with sine form, and in the converter by parallel circuit the output voltage is with sine form and the output current is with rectangular form.

The harmonics distribution of the output voltage (voltage amplitude spectrum) for maximum inductance and 100 % *RLC* load for serial resonant converter is shown in the Fig. 4a, and for parallel converter is shown in the Fig. 4b.

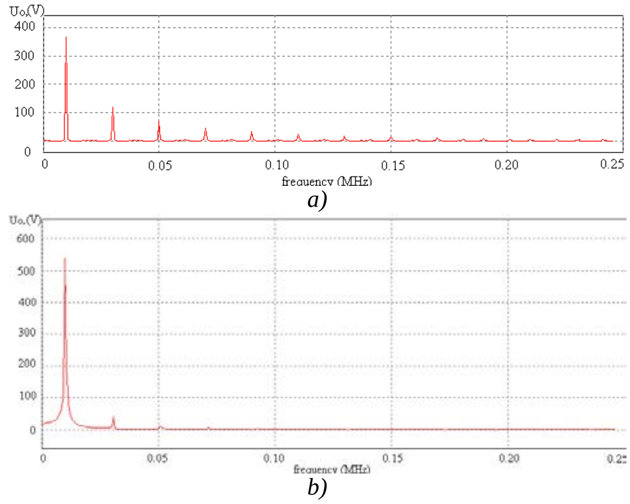
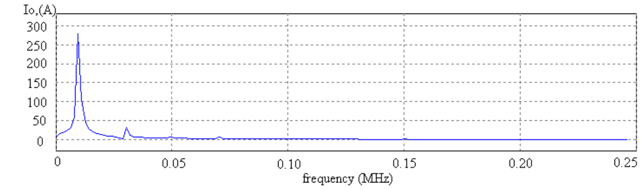
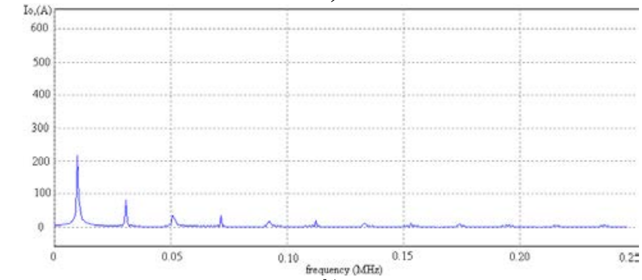


Fig. 4. *Harmonics distribution of the output converter voltage for maximum inductance: a) for serial resonant converter, and b) for parallel resonant converter.*

The harmonics distribution of the output current (current amplitude spectrum) for maximum inductance and 100 % *RLC* load for serial resonant converter is shown in the Fig. 5a, and for parallel converter is shown in the Fig. 5b.



a)



b)

Fig. 5. *Harmonics distribution of the output converter current for maximum inductance: a) for serial resonant converter, and b) for parallel resonant converter.*

The voltage total harmonic distortion of the output on the power converter is calculates with the equation, [1]:

$$THDV = \sqrt{\frac{\left|U^2{}_{o(3)}\right| + \left|U^2{}_{o(5)}\right| + \left|U^2{}_{o(7)}\right| + \left|U^2{}_{o(9)}\right| + \left|U^2{}_{o(11)}\right| + \left|U^2{}_{o(13)}\right|}{\left|U^2{}_{o(1)}\right|}} \qquad (1)$$

Where: $U_{o(1)}$, $U_{o(3)}$,$\cdot\cdot U_{0(13)}$ are effective values on the first, second,…..thirteenth harmonic.

The harmonic effective values of the output voltage for serial and parallel converter base in figure 4 are given in the Table 2.

Table 2. *The harmonic effective values of the output voltage for serial and parallel converter and 100 % RLC load*

	$U_{o(1)}$ (V)	$U_{o(3)}$ (V)	$U_{o(5)}$ (V)	$U_{o(7)}$ (V)	$U_{o(9)}$ (V)	$U_{o(11)}$ (V)	$U_{o(13)}$ (V)
serial circuit	258	72	22.9	22.7	15.5	13.5	8.1
parallel circuit	381	26.01	6.20	3.84	2.05	0	0

So voltage total harmonic distortion of the output for both converters is:

THDV = 31.7 % for power converter by serial circuit

THDV = 7.11 % for power converter by parallel circuit (2)

The current total harmonic distortion of the output on the power converter is calculates with the equation:

$$THDC = \sqrt{\frac{\left|I^2{}_{o(3)}\right| + \left|I^2{}_{o(5)}\right| + \left|I^2{}_{o(7)}\right| + \left|I^2{}_{o(9)}\right| + \left|I^2{}_{o(11)}\right| + \cdot\cdot + \left|I^2{}_{o(19)}\right|}{\left|I^2{}_{o(1)}\right|}} \qquad (3)$$

Where: $I_{o(1)}$, $I_{o(3)}$, $\cdot\cdot I_{o(19)}$, are effective values on the first, second,….. nineteen harmonic. The harmonic effective values of the current for serial and parallel converter base in Fig. 5 are given in the Table 3.

Table 3. *The harmonic effective values of the output current for serial and parallel converter and 100 % RLC load*

	$I_{0(1)}$ (A)	$I_{0(3)}$ (A)	$I_{0(5)}$ (A)	$I_{0(7)}$ (A)	$I_{0(9)}$ (A)	$I_{0(11)}$ (A)	$I_{0(13)}$ (A)	$I_{0(15)}$ (A)	$I_{0(17)}$ (A)	$I_{0(19)}$ (A)
serial circuit	199	22.2	5.2	0	0	0	0	0	0	0
parallel circuit	153	44.53	25.12	21.16	11.16	10.50	9.84	7.40	6.84	3.95

So current total harmonic distortion of the output for both converters is:

THDC = 11.5 % for power converter by serial circuit

THDC = 38.73 % for power converter by parallel circuit (4)

In the Table 4 are given the cumulative results from analyze on the tables 2 and 3 and the equations (1) and (3), and in the Table 5 are given the results from analyze in the Fig. 3, 4, 5 and Table 1.

Table 4. *Total harmonic distortion on output voltage and current at serial and parallel converter for full (100 %) RLC load*

	THDV(%)	*THDC*(%)
serial circuit	31.7	11.5
parallel circuit	7.11	38.73

Table 5. *Parameter of the resonant circuit and output parameter at serial and parallel converter and 100 % RLC load*

	L (mH)	*C* (μF)	*R* (Ω)	I_{out} (A)	U_{out} (V)	S_{conv} (kVA)	I_{DC} (A)	U_{DC} (V)	P_{DC} (kW)	*PF*	P_{conv} (kW)	$\eta_{conv.}$ (%)
serial circuit	0.02393	10.6	1.14	225.68	287	64.77	207.18	290	60.08	0.90	58.34	97.10
parallel circuit	0.02393	10.6	1.14	197.80	431.73	85.40	202.76	303	61.45	0.68	58.26	94.81

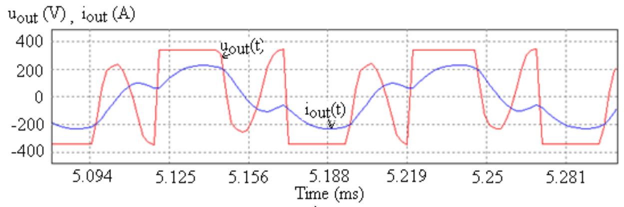
In the Table 5 sizes are:

- U_{out} and I_{out} are effective values of the output converter voltage and current
- *PF* is power factor of the converter

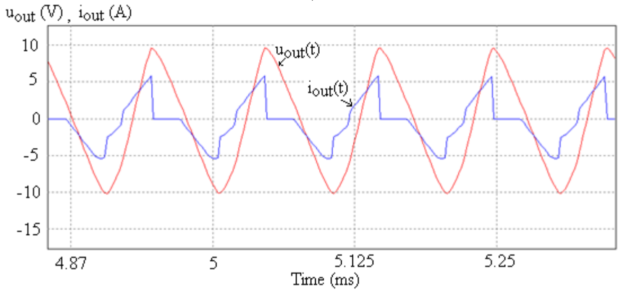
- $S_{conv} = U_{out}I_{out}$ output apparent power
- $P_{conv} = S_{conv}PF$ is output power of the converter
- $\eta_{conv} = (P_{conv}/P_{DC})100\%$ is efficiency on the full bridge converter

Affection on the pulse width of gate from IGBT of total harmonic distortion

In the Fig. 6a are shown wave forms on the output voltage and the output current in serial resonant converter by 50% load *RLC* load in case of maximum inductance, [5], and in the Fig.6b wave forms in parallel resonant converter for same case. This wave form are obtained with simulations on the circuit from Fig. 2 in PowerSim program.



a)



b)

Fig. 6. *Wave forms of output voltage and current for 50% load RLC load in case of maximum inductance: a) for the serial resonant converter, b) for the parallel resonant converter.*

In the table 6 are given the results for the voltage total harmonic distortion and the current total harmonic distortion obtained with same analyze as for full output *RCL* load and used on the equations (1) and (3).

Table 6. *Total harmonic distortion on output voltage and current at serial and parallel converter and 50 % RLC load*

	THDV(%)	THDC(%)
serial circuit	145.0	24.6
parallel circuit	6.5	29.9

3. Analysis of results

Based of the results in point 2 can be concluded:

- Both types' resonant converters, parallel and serial satisfy the requirements for power and current defined in the Table 1.
- For same output power the parallel resonant converter works with more voltage and less current of serial converter.
- Also, for same output power in parallel resonant converter power factor *PF* and efficiency η are smaller from serial converter.
- In the parallel resonant converter current total harmonic distortion is greater, and in serial converter voltage total harmonic distortion is greater.
- In the converter with 50% load *RCL* load the voltage total harmonic distortion in serial resonant converter is increased. The sum on effective values on harmonics is greater than effective value on basic harmonic.
- It should be noted is that in parallel resonant converter to 50% load *RCL* load, the output power is significantly reduced.
- In the serial resonant converter, IGBT transistors operate with greater current (greater stress) than the parallel resonant converter for same output power.
- Since the mode of inductiion device has a variable dynamic, the converter which operates with such a device must monitore and regulate the output power with adequate methods of controlling.

4. Conclusion

In the paper is shown the procedure for construction of IGBT bridge parallel resonant converter with computer simulations. Here is analysis power converter with output load in mode of the induction device. Operation of the parllel converter is compared with the operation of the serial converter. The parameter of the resonant circuit and the required output power is obtained in the program package ELTA, with simulation of device for induction heating. In the analyse of the power converter is used PowerSim simulation program. The analyzed is the operation of the converter with change on the pulse width of the gate of IGBT transistors, as and changes of the output voltage and the current on the converter with change on the dynamics of resonant circuit. Also are analyze harmonics generated from the operation of the converter and is determined total harmonic distortion of the output voltage and current.

5. References

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