ANALYSIS OF POWER CONVERTER WITH COMPUTER SIMULATION

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Abstract

In the paper are given the results of computer simulations for power converter. The analyze is made for full bridge converter and half bridge converter loaded with serial resonant circuit. The simulations are made in PowerSim simulation program. Analyzed is operation of the converter with change the pulses width of the gate of IGBT transistors, voltage stress of the transistors and change of output voltage and current on the converter with change the dynamics of resonant circuit . Also here are analyzed harmonics, generated from operation of the converter.

Key words: *Simulation programs, power converter, wave forms.*

1. INTRODUCTION

Power Electronics is the art of converting electrical energy from one form to another in an efficient, clean, and compact manner for convenient utilization, [3]. 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, 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, [5]. The application of power thyristors and bipolar transistors, which were mostly used as switches in the previous period, slowly replaced by MOSFET and IGBT transistors. IGBT transistors are a combination of good feature of bipolar and MOSFET transistors. They are voltage managed and have small resistance in the on state. That makes them applicable in applications with high voltages 6500V and large current 2500A. IGBT are used in circuits with switching frequency up to 150kHz. Because they are voltage managing elements the circuits for their management are simple. The main target is IGBT transistor as a switch to operate with reduced losses of switching. The choice on the resonant circuit of the output of converter provides turn on and turn off of the transistors in the bridge to be done at the time of zero voltage or at zero current. So the losses of power from switching are reduced, [8],[9].

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, 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 serial resonant circuit in the mode of induction furnace, [4],[6],[7]. 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, [1],[2]. The main task to paper is the researching for operating of resonant converter with output loads whose dynamics are changing and is affecting of sizes on the resonant circuit.

2. ANALYSIS OF POWER CONVERTER

In the Fig. 1 is presented block diagram in the power electronic converter.

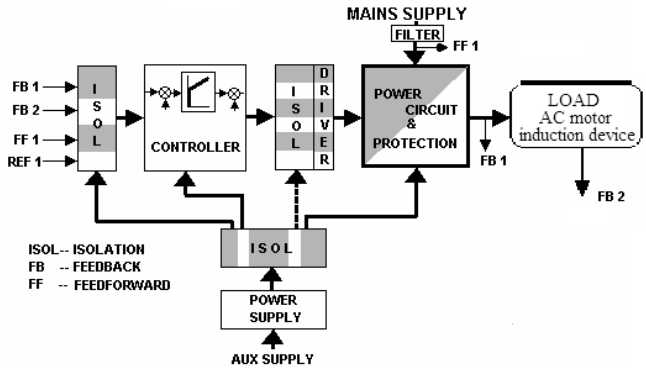


Fig. 1. Power converter

In applications where the dynamic of the process affects on the parameters of the converter are used resonant converters. Applications on the converter which are used often are full bridge and half bridge configuration. In the paper on the basis of a defined change on inductance on the resonant circuit from the dynamics of induction device obtained by ELTA simulation program, is analyzed the work of full and half bridge converter with serial resonant circuit, [1].

2.1 Definition of working conditions

We analyze the processing on the work piece metal with induction heating under follow operating conditions:

•Working piece

-metal 0.4% C steal 2T anneal

-shape-cylinder, length (Z):35cm, finite system length

- R_{int} = 3cm, R_{ext} = 8cm

-maximum temperature is 1000ºC

-time cycle is 600s.

• Maximum output power (Smax) is 100000VA.

• Switching frequency (fsw) 10 kHz was assumed for the design of maximum power.

• 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]. In the Fig. 2 is given temperature distribution of the work piece. From Fig. 2 concludes that the work piece after time from 600s is going to reach temperature from 950 to 1020 ° C. In the Fig. 3 are given diagrams of inductance, impedance, power, current, voltage efficiency, cosφ and capacitance for system inductor work piece.

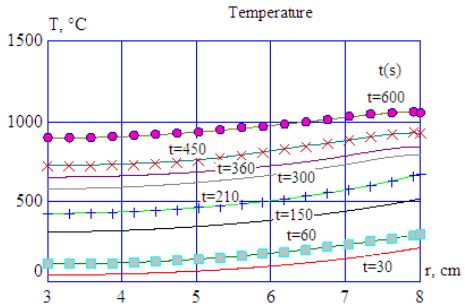
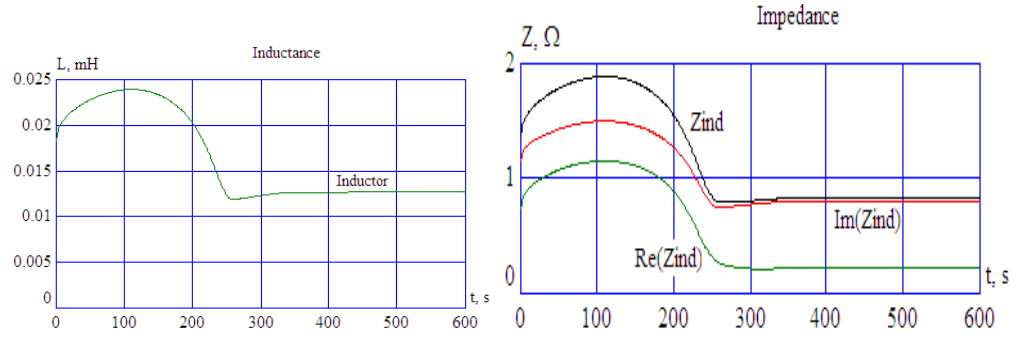
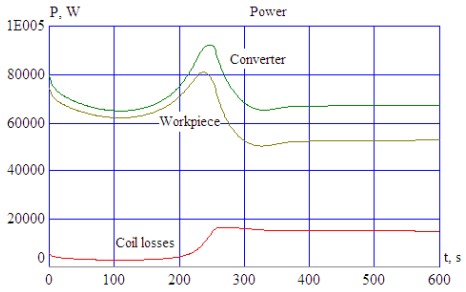


Fig. 2 Temperature distribution on the working piece

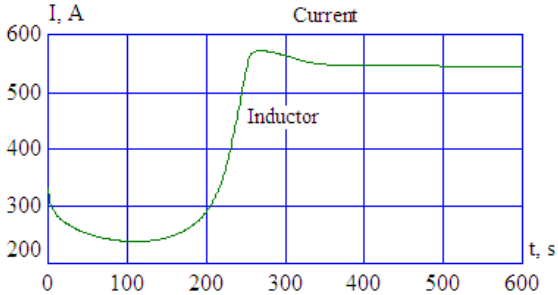


a)

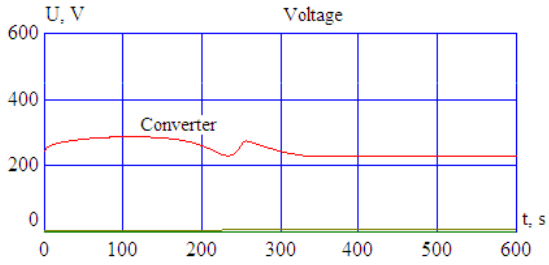
b)



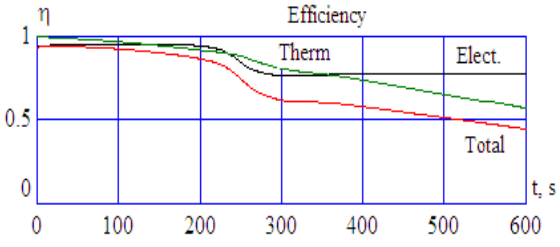
c)



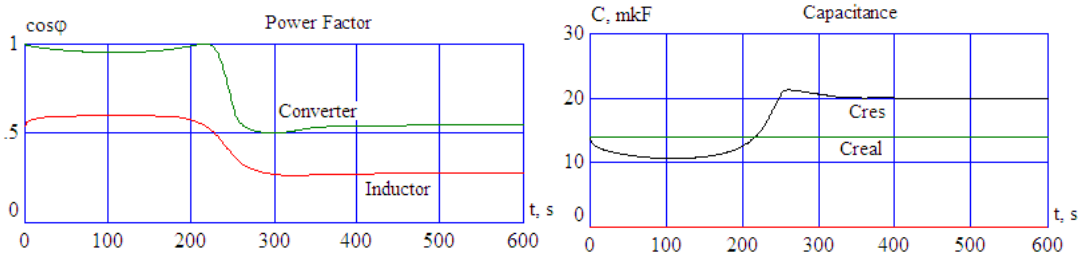
d)



e)



f)



g) h)

Fig. 3. Wave forms on the: a) inductance , b) impedance, c) power, d) current, e) voltage, f) efficiency, g) power factor and h) capacitance of the system inductor work piece

From the diagrams on the Fig. 2 and 3 is seen that the process of induction heating on the work piece steel is a dynamic and parameters of the system inductor work piece are changing. The change of the parameters is the summary given in table 1 and 2. In the table 1 is given temperature distribution of the work piece during time interval from 600s.

Table 1

	r(cm)	3	3.551	4.122	4.663	5.224	5.776	6.337	6.888	7.449	8
t(s)											
0		20	20	20	20	209	20	20	20	20	20
66.13		123.1	125.6	133.1	145.1	161.8	182.5	208	237.7	272.8	311.3
133.5		274.6	277.1	285	297.4	314.6	336	362.6	393.9	431.4	473
199.6		403.5	406.1	414.4	427.7	446.4	470	400.9	536.2	581.9	633.4
266.9		521.8	524.9	534.7	550.4	572.7	601	637.1	681	736.1	769.3
333.1		618.8	621.5	629.9	643.1	661.4	684.1	712.4	746.5	787	807.8
400.4		685.4	687.7	694.8	706.3	722.6	744.6	777.3	788.8	806.4	828..4
466.5		732	734.5	742.6	757.5	783.5	797.2	805.5	811.7	828.6	835.9
533.9		781.4	789.8	809.4	820.5	845.3	855.6	863.4	878.3	886.3	895.4
600		896.4	899.2	906.3	912.4	923.5	938.9	973.2	1003	1012	1020

From table 1 is seen that after time interval from $t = 600s$ the temperature of the work piece is from 896 º C to 1020 º C. It is a temperature for thermal processing of work piece. In table 2 are given the results for changing the parameters of the system inductor work piece.

Table 2

	L (mH)	Creson (μF)	Creal (μF)	|Zind| (Ω)	Im(Zin) (Ω)	Re(Zind) (Ω)	Iind (A)	Uconver. (V)	P conv (kW)	η ele. (%)	Cosφ conv (º)
	0.01189	21.4	13.9	0.79	0.75	0.37	571	225	92.3	0.76	0.5
	0.02393	10.6	13.9	1.8	1.5	1.14	238	285	65	0.96	1
% (min/max)	49.6	49.5		43.8	50	18.4	41.7	79	70.4		50

From table 2 is concluded:

- The changing on temperature of the work piece from 20 to 1000 º C produces change on the inductance for 49.6%.
- Creson is value on capacitance required for compensate of changes of inductance for preserve the resonance frequency from 10000Hz.
- Creal is a real value of the selected capacitor.
- $|Z_{ind}| = \sqrt{R_e^2 + I_m^2}$ is a module of impedance of the inductor.
- 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 maintaining on constant output power.

2.2 Construction of converter

From the results for the parameters of the induction device obtained by ELTA simulation program, in PowerSim program with computer simulations analyzes the operating of the converter for two usually used configurations: full and half bridge converter, [2],[4],[6].

2.2.1 Full bridge converter

In the Fig. 4 is given the circuit for simulation of the full bridge converter with serial resonant circuit.

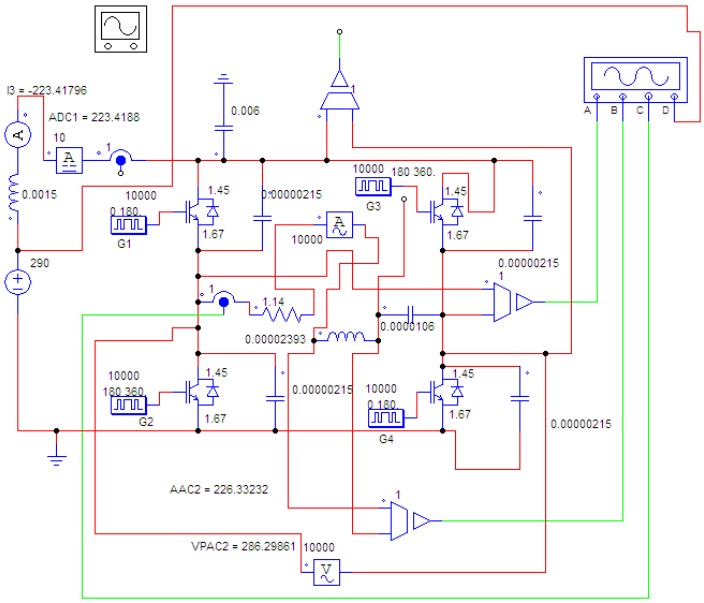


Fig. 4. Circuit for simulation of the full bridge converter

a) maximum inductance

From the diagrams in Fig. 3 and table 2 could 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. 5 are given wave shapes of the voltage and the current of output from the converter for full output load RCL load.

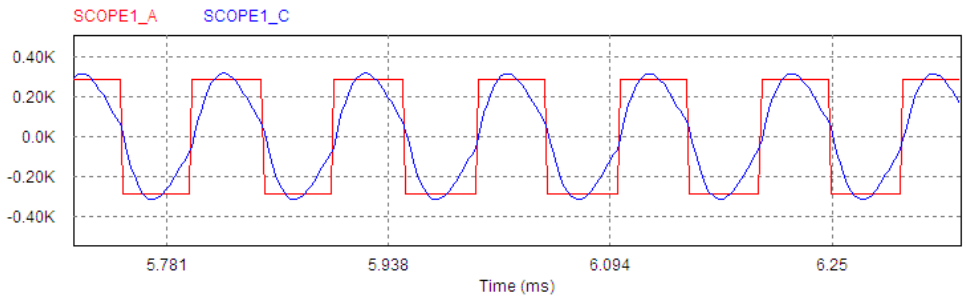


Fig. 5. Wave forms of the voltage and the current of output from converter for maximum inductance

In the Fig. 6 and 7 is given the harmonics distribution of the output voltage and output current at full bridge converter for maximum inductance.

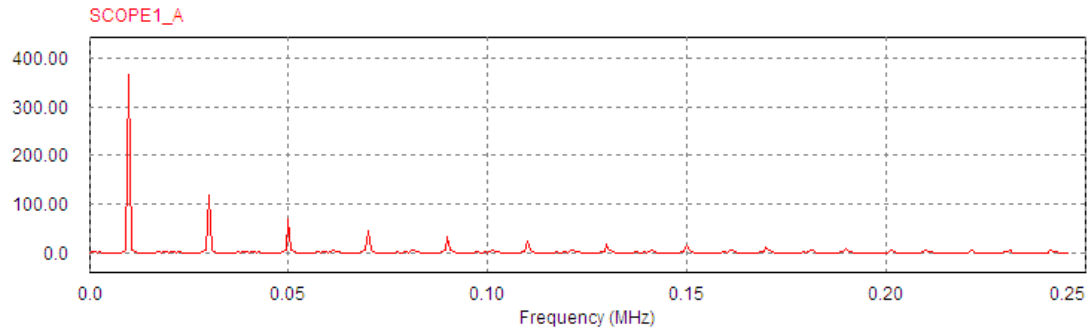


Fig. 6. Harmonics distribution of the output voltage

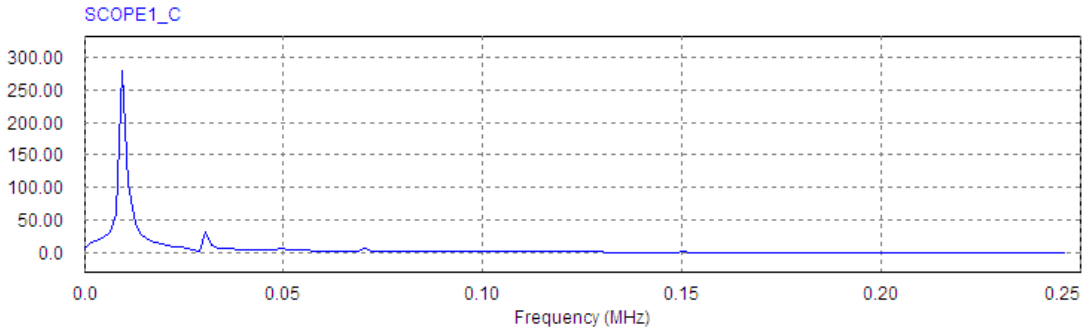


Fig. 7. Harmonics distribution of the output current

The voltage total harmonic distortion of the output on the power converter calculates with the equation, [9]:

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

Where: $U_{outrms(1)}, U_{outrms(3)}, ...U_{outrms(13)}$ are effective values on the first, second,…..thirteenth harmonic. The effective values are given in the table 3.

Table 3

$U_{outrms(1)}$ (V)	$U_{outrms(3)}$ (V)	$U_{outrms(5)}$ (V)	$U_{outrms(7)}$ (V)	$U_{outrms(9)}$ (V)	$U_{outrms(11)}$ (V)	$U_{outrms(13)}$ (V)
258	72	22.9	22.7	15.5	13.5	8.1

So voltage total harmonic distortion of the output is:

$$THDV = 31.7\% \tag{2}$$

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

$$THDC = \sqrt{\frac{\left|I^2_{outrms(3)}\right| + \left|I^2_{outrms(5)}\right| + \left|I^2_{outrms(7)}\right| + \left|I^2_{outrms(9)}\right| + \left|I^2_{outrms(11)}\right| + \left|I^2_{outrms(13)}\right|}{\left|I^2_{outrms(1)}\right|}} \tag{3}$$

Where: $I_{outrms(1)}, I_{outrms(3)}, ...I_{outrms(13)}$ are effective values on the first, second,…..thirteenth harmonic. The effective values are given in the table 4.

Table 4

$I_{outrms(1)}$ (A)	$I_{outrms(3)}$ (A)	$I_{outrms(5)}$ (A)	$I_{outrms(7)}$ (A)	$I_{outrms(9)}$ (A)	$I_{outrms(11)}$ (A)	$I_{outrms(13)}$ (A)
199	22.2	5.2	0	0	0	0

So current total harmonic distortion of the output is:

$$THDC = 11.5\% \tag{4}$$

In the table 5 are given the results from analyze on the tables 3 and 4 and the equations (1) and (3).

Table 5

THDV(%)	THDC(%)
31.7	11.5

In the table 6 are given the results from analyze in the Fig. 3, 4, 5 and table 2.

Table 6

L (mH)	Creson (μF)	Re(Zind) (Ω)	Ioutrms (A)	Uoutrms (V)	Sconv. (kVA)	I_{DC} (A)	U_{DC} (V)	P_{DC} (W)	Ψ (º)	cosψ	Pconv. (W)	$\eta_{conv.}$ (%)
0.02393	10.6	1.14	226	286.4	64.7	223.4	290	64.8	8	0.99	64	98.7

In the table 6 sizes are:

- $U_{outrms} = \sqrt{\frac{1}{T}\int_0^T u_{out}{}^2(t)dt} = U_{DC} - 2V_{cesatIGBT} = 290 - 3.34 = 286.4V$
- Ψ is phase angle among Uout and Iout
- $P_{conv} = S_{conv}\cos\psi$
- $\eta_{conv} = \frac{S_{conv}\cos\psi}{P_{DC}}100\%$ is efficiency on the full bridge converter

b) minimum inductance

From the diagrams in Fig. 3 and table 2 could be seen that when the inductance and the resistance are minimum, the capacitance is maximum, the output voltage is the minimum and the output current is maximum. For this state in Fig. 8 are given wave forms for the voltage and the current of the output in the converter for full load RCL load, obtained in PowerSim simulation program.

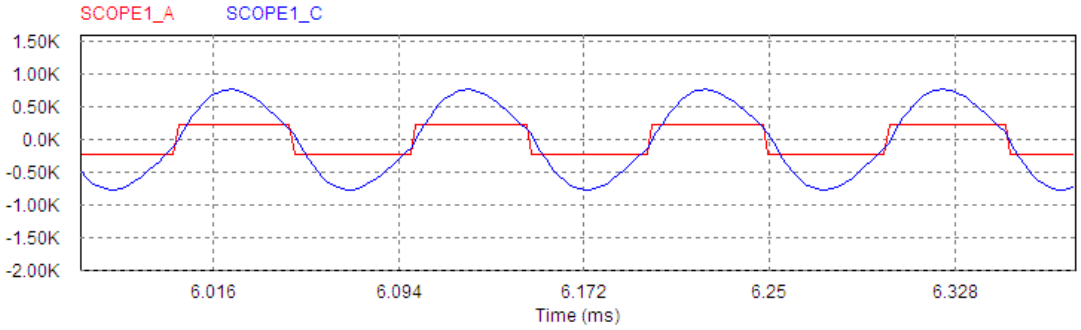


Fig. 8. Wave forms of the voltage and the current on output from converter for minimum inductance

In the Fig. 9 and 10 are given the harmonics distribution for the voltage and the current of the output from the converter for minimum inductance.

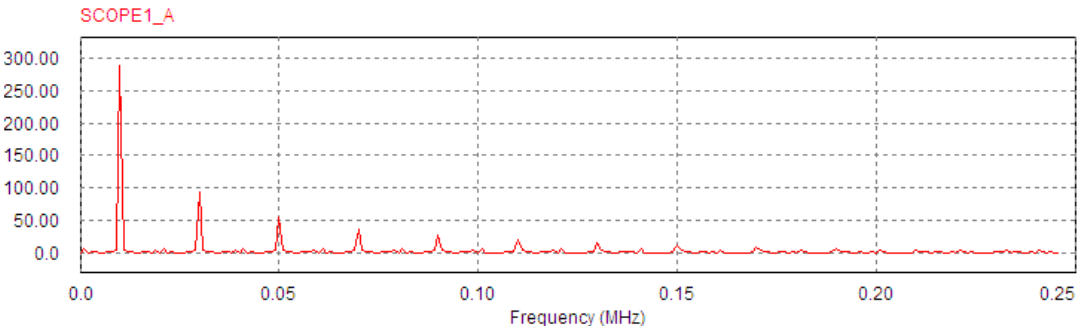


Fig. 9. Harmonics distribution of the output voltage

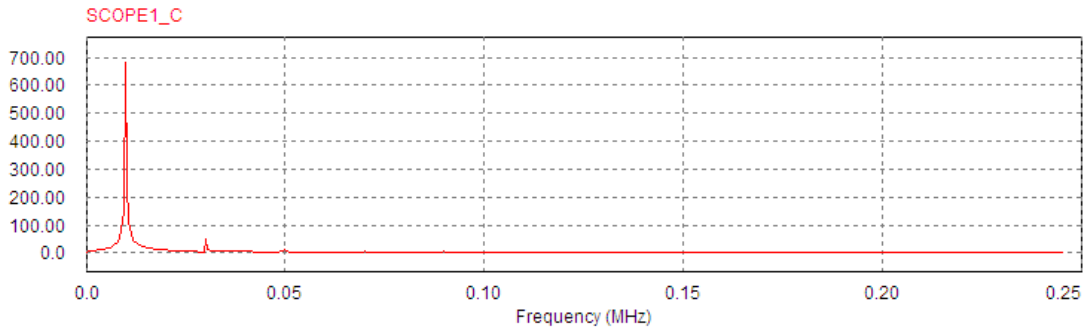


Fig. 10. Harmonics distribution of the output current

In the table 7 are given effective values on the harmonics in the output voltage.

Table 7

$U_{outrms(1)}$ (V)	$U_{outrms(3)}$ (V)	$U_{outrms(5)}$ (V)	$U_{outrms(7)}$ (V)	$U_{outrms(9)}$ (V)	$U_{outrms(11)}$ (V)	$U_{outrms(13)}$ (V)
203.5	60.4	36.3	23.8	18.4	12	10.8

In the table 8 are given effective values on the harmonics in the output current.

Table 8

$I_{outrms(1)}$ (A)	$I_{outrms(3)}$ (A)	$I_{outrms(5)}$ (A)	$I_{outrms(7)}$ (A)	$I_{outrms(9)}$ (A)	$I_{outrms(11)}$ (A)	$I_{outrms(13)}$ (A)
497	27.3	3.7	3.5	0	0	0

In the table 9 are given the results for the voltage total harmonic distortion and the current total harmonic distortion obtained with analyze on the table 7 and 8 and the equations (1) and (3).

Table 9

THDV(%)	THDC(%)
37.3	5.5

In the table 10 are given the results from analyze in the Fig. 3, 4, 8 and table 2.

Table 10

L (mH)	Creson (μF)	Re(Zind) (Ω)	Ioutrms (A)	Uoutrms (V)	Sconv. (kVA)	I_{DC} (A)	U_{DC} (V)	P_{DC} (W)	Ψ (º)	cosψ	Pconv. (W)	$\eta_{conv.}$ (%)
0.01189	21.4	0.37	543	226.4	123	541	290	124.5	8.5	0.989	121.6	97.7

In the table 10 sizes are:

- $U_{outrms} = \sqrt{\frac{1}{T}\int_0^T u_{out}{}^2(t)dt} = U_{DC} - 2V_{cesatIGBT} = 230 - 3.34 = 226.4V$
- Ψ is phase angle among Uout and Iout
- $P_{conv} = S_{conv}\cos\psi$
- $\eta_{conv} = \frac{S_{conv}\cos\psi}{P_{DC}}100\%$ is efficiency on the full bridge converter.

c) affection on the pulse width of gate from IGBT of total harmonic distortion

In the Fig. 11 are given wave forms on the output voltage and the output current for 50% load RLC load in the full bridge converter in case of maximum inductance, [9].

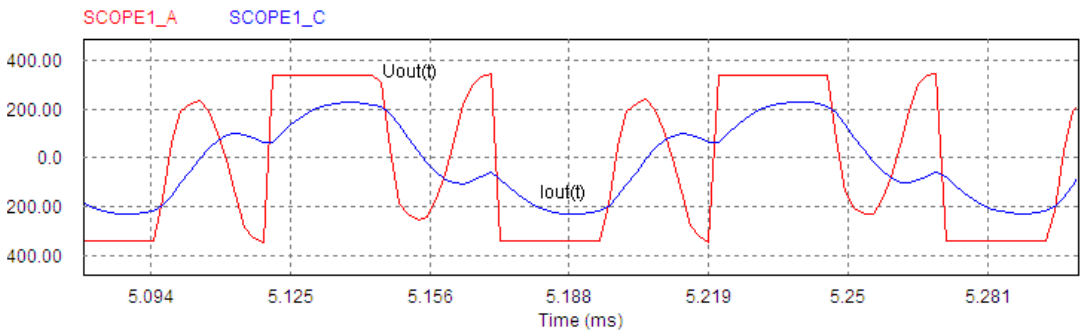


Fig. 11. Wave forms of output voltage and current for 50% load RLC load in the full bridge converter

From Fig. 11 is seen that for pulse width on the gate from IGBT with 50% load RLC load, the output voltage is distorted and harmonics distortion is expand, Fig. 12 and 13.

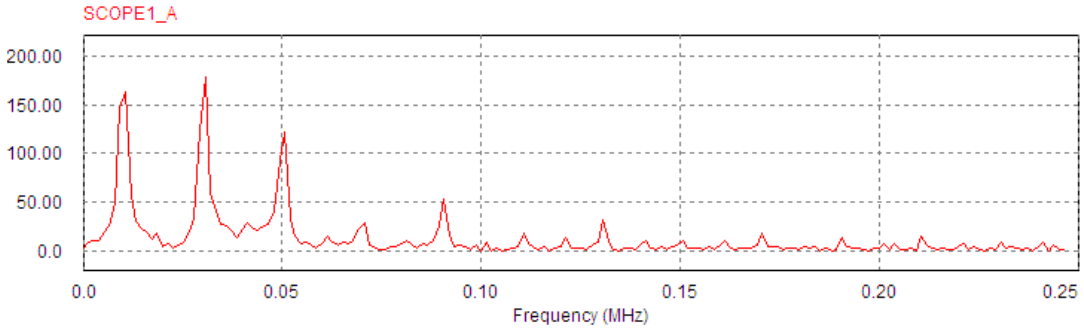


Fig. 12. Harmonics distribution on output voltage for 50% load RLC load

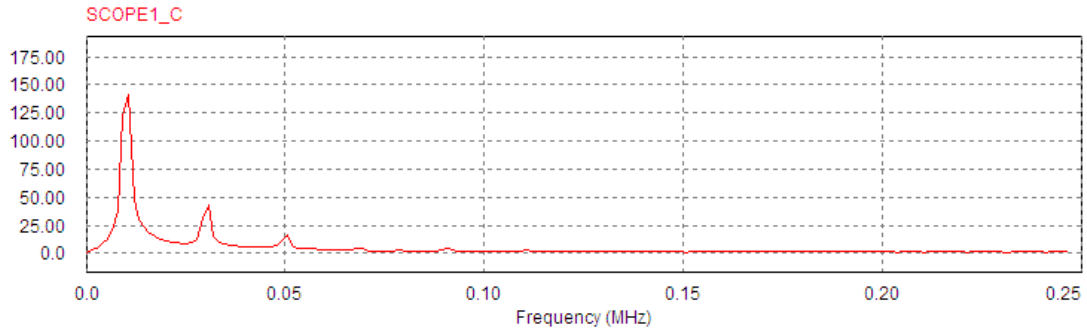


Fig. 13. Harmonics distribution on output current for 50% load RLC load

In the table 11 are given effective values on the harmonics in the output voltage.

Table 11

$U_{outrms(1)}$ (V)	$U_{outrms(3)}$ (V)	$U_{outrms(5)}$ (V)	$U_{outrms(7)}$ (V)	$U_{outrms(9)}$ (V)	$U_{outrms(11)}$ (V)	$U_{outrms(13)}$ (V)
109	126.5	82.9	20.9	34.3	12.9	20.2

In the table 12 are given effective values on the harmonics in the output current.

Table 12

$I_{outrms(1)}$ (A)	$I_{outrms(3)}$ (A)	$I_{outrms(5)}$ (A)	$I_{outrms(7)}$ (A)	$I_{outrms(9)}$ (A)	$I_{outrms(11)}$ (A)	$I_{outrms(13)}$ (A)
130.9	32	3	2	0.9	0	0

In the table 13 are given the results for the voltage total harmonic distortion and the current total harmonic distortion obtained with analyze on the table 11 and 12 and the equations (1) and (3).

Table 13

THDV(%)	THDC(%)
145	24.6

2.2.2 Half bridge converter

In the Fig. 14 is given the circuit for simulation on the half bridge converter with serial resonant circuit, [2],[4],[6].

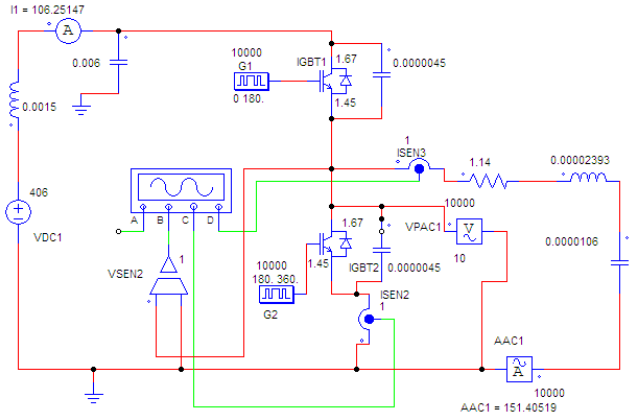


Fig. 14. Circuit for simulation in the half bridge converter

a) maximum inductance

For values of the RLC, which corresponds to maximum inductance, defined in the table 2, the wave forms of the output voltage and the output current for full load RCL load, are given on the Fig. 15.

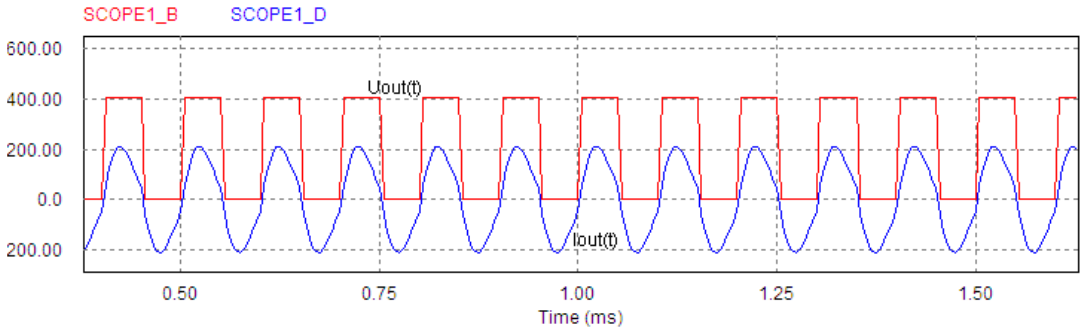


Fig. 15. Wave forms of output voltage and output current at half bridge converter

In the table 14 are given values on sizes for half bridge converter with maximum inductance of induction device.

Table 14

L (mH)	Creson (μF)	Re(Zind) (Ω)	Ioutrms (A)	Uoutrms (V)	Sconv. (kVA)	I_{DC} (A)	U_{DC} (V)	P_{DC} (W)	Ψ (º)	cosψ	Pconv. (W)	$\eta_{conv.}$ (%)
0.02393	10.6	1.14	151.7	284.6	43.44	107	406	43.44				

In the table 14 sizes are:

- $U_{outrms} = \sqrt{\frac{1}{T}\int_0^T u_{out}^2(t)dt} = \frac{U_{DC}}{\sqrt{2}} - 2V_{cesatIGBT} = 287.9 - 3.34 = 284.6V$
- Ψ is phase angle among Uout and Iout
- $P_{conv} = S_{conv}\cos\psi$
- $\eta_{conv} = \frac{S_{conv}\cos\psi}{P_{DC}}100\%$ is efficiency on the half bridge converter.

The value for power of output from the converter shows that the configuration of the half bridge converter with selected DC link voltage 406V does not satisfy the condition for required power defined with the table 2, (65kW).

Therefore, to obtain power on the output of the converter defined with requirements in the table 2, DC link voltage increases. The values on the sizes which satisfy the conditions for operating of the converter from table 2 are given in the table 15.

Table 15

L (mH)	Creson (μF)	Re(Zind) (Ω)	Ioutrms (A)	Uoutrms (V)	Sconv. (kVA)	I_{DC} (A)	U_{DC} (V)	P_{DC} (W)	Ψ (º)	cosψ	Pconv. (W)	$\eta_{conv.}$ (%)
0.02393	10.6	1.14	184.6	348.1	64.3	132	494	65.2	0.07	1	64.2	98.6

In the Fig. 16 and 17 are given harmonics distribution on the output voltage and the output current for half bridge converter with increased DC link voltage.

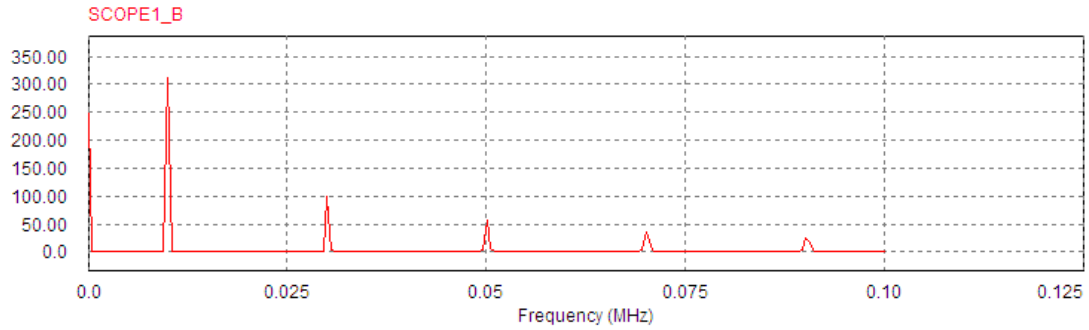


Fig. 16. Harmonic distribution of the output voltage for half bridge converter

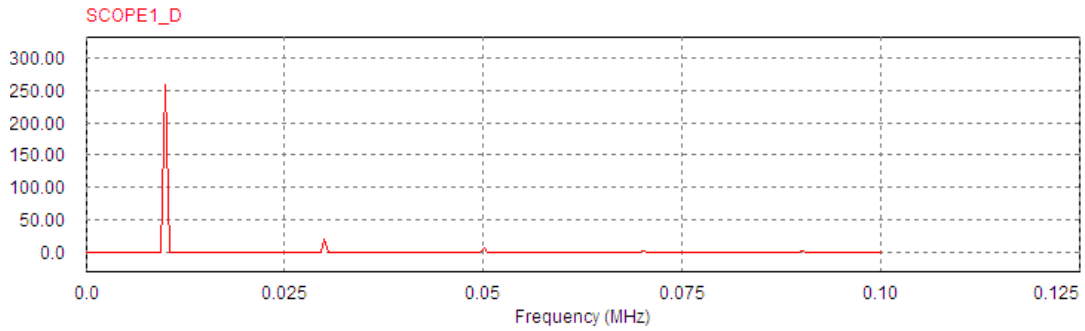


Fig. 17. Harmonics distribution of the output current for half bridge converter

In the table 16 are given effective values on the harmonics in the output voltage.

Table 16

$U_{outrms(1)}$ (V)	$U_{outrms(3)}$ (V)	$U_{outrms(5)}$ (V)	$U_{outrms(7)}$ (V)	$U_{outrms(9)}$ (V)	$U_{outrms(11)}$ (V)	$U_{outrms(13)}$ (V)
192	70	36	20.5	16.3	0	0

In the table 17 are given effective values on the harmonics in the output current.

Table 17

$I_{outrms(1)}$ (A)	$I_{outrms(3)}$ (A)	$I_{outrms(5)}$ (A)	$I_{outrms(7)}$ (A)	$I_{outrms(9)}$ (A)	$I_{outrms(11)}$ (A)	$I_{outrms(13)}$ (A)
193.6	9.9	4.4	1.98	0	0	0

In the table 18 are given results for the voltage total harmonic distortion and the current total harmonic distortion obtained with analyze on the table 16 and 17 and equations (1) and (3).

Table 18

THDV(%)	THDC(%)
43.2	5.6

b) *affection on the pulse width of gate from IGBT of total harmonic distortion*

In the Fig. 18 are given wave forms on the output voltage and the output current for 50% load RLC load in case of maximum inductance for half bridge converter, [9]. In the Fig. 19 and 20 are given harmonics distribution for 50% load RLC load of half bridge converter.

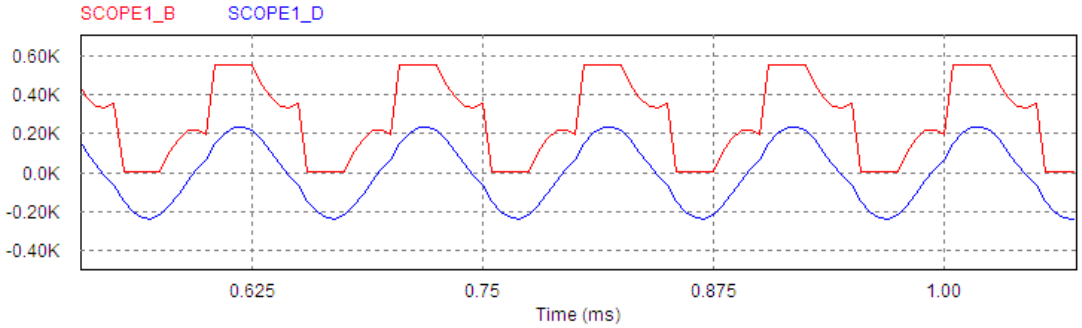


Fig. 18. Wave forms of output voltage and current for 50% load RLC load at half bridge converter

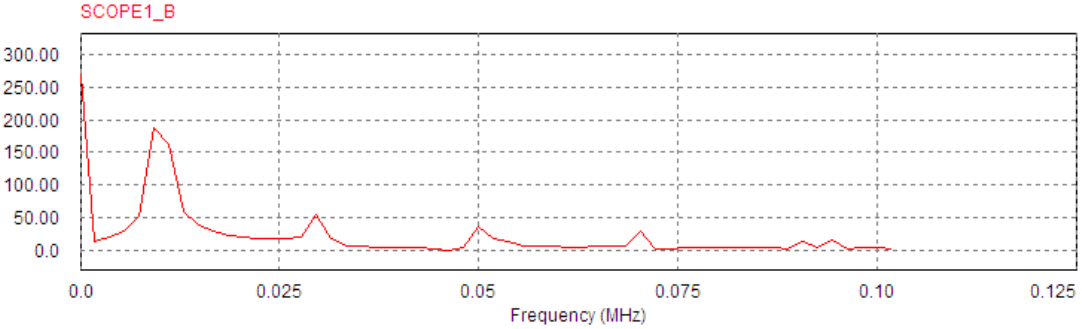


Fig. 19. Harmonics distribution on output voltage with 50% load RLC load at half bridge converter

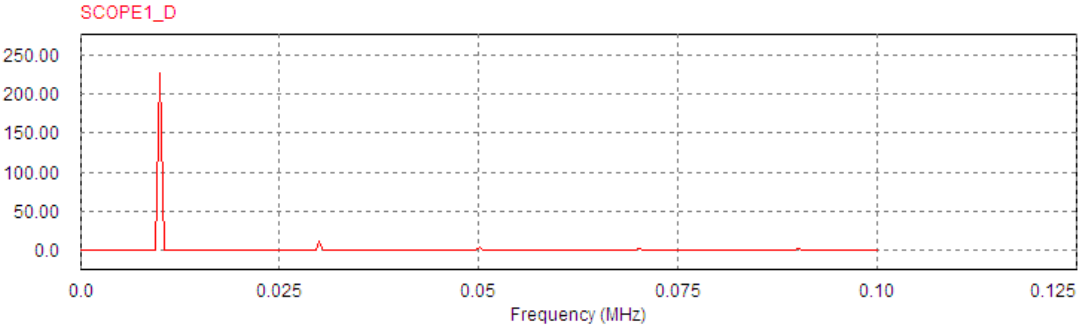


Fig. 20. Harmonics distribution on output current with 50% load RLC load at half bridge converter

In the table 19 are given effective values on the harmonics in the output voltage.

Table 19

$U_{outrms(1)}$ (V)	$U_{outrms(3)}$ (V)	$U_{outrms(5)}$ (V)	$U_{outrms(7)}$ (V)	$U_{outrms(9)}$ (V)	$U_{outrms(11)}$ (V)	$U_{outrms(13)}$ (V)
169.7	40	30.5	16.6	13.2	0	0

In the table 20 are given effective values on the harmonics on the output current.

Table 20

$I_{outrms(1)}$ (A)	$I_{outrms(3)}$ (A)	$I_{outrms(5)}$ (A)	$I_{outrms(7)}$ (A)	$I_{outrms(9)}$ (A)	$I_{outrms(11)}$ (A)	$I_{outrms(13)}$ (A)
161	5.3	3.4	1.5	0.95	0	0

In the table 21 are given the results for the total total harmonic distortion and the current total harmonic distortion obtained with analyze on the table 19 and 20 and the equations (1) and (3).

Table 21

THDV(%)	THDC(%)
32.2	4

2.2.3 Analysis of results

Based of the results in point 2 could be concluded:

- The full bridge converter satisfies the requirements for power and current defined in the table 2.
- The full bridge converter has greater voltage total harmonic distortion then current total harmonic distortion.
- In the full bridge converter with 50% load RCL load the voltage total harmonic distortion is increased. The sum on effective values on harmonics is greater than effective value on basic harmonic.
- In half bridge converter, the value for power of output from the converter shows that the configuration of the half bridge converter with selected DC link voltage 406V does not satisfy the condition for power defined with table 2, (65kW).
- Therefore, to obtain power of output of the converter defined with requirements in the table 2, DC link voltage increases.
- For full load RLC load, the half bridge converter has greater voltage total harmonic distortion than full bridge converter.
- For full load RLC load, the half bridge converter has smaller current total harmonic distortion than full bridge converter.
- For 50% load RLC load, the full bridge converter has greater voltage total harmonic distortion than the half bridge converter.
- For 50% load RLC load, the full bridge converter has greater current total harmonic distortion than half bridge converter.
- In the full bridge converter has 4 IGBT transistors.
- In the half bridge converter has 2 IGBT transistors.

- In the half bridge converter, IGBT transistors operate with greater voltage (greater voltage stress) than the full bridge converter for same output power.
- In the half bridge converter, IGBT transistors operate with smaller current than the full bridge converter for same output power.
- The half bridge converter and the full bridge converter have same efficiency for same output power.
- Since the mode of inductiion device has a variable dynamic the converter which operates with such a device in applications where is required constant output power must monitore and regulate the output power with adequate methods of management.
- The methods of management on these converters are with frequent and phase control.

3. CONCLUSION

In the paper are given researchs for construction of full bridge and half bridge power converter with computer simulations. Here are researched power converter with output load in mode of the induction device. Output load of power converter is design with computer simulation program ELTA. In the analyse of the power converter is used PowerSim simulation program. The operation of the converter is analyzed for full load RCL load and 50% load RCL load. Also analyzed is the operation of the converter with change on the pulse width of the gate of IGBT transistors, the voltage stress on the transistors and change of the output voltage and the current on the converter with change on the dynamics of resonant circuit . It is made analyze of the Harmonics generated from the operation of the converter.

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