

PARTICULARITIES OF POWER LASER ELECTRICAL ENERGY SUPPLY

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Abstract: *Main electromagnetic pollution sources are the PWM controlled power converters, owing the strong non-linear characteristics of the devices from their structure. Power converters presence inevitable means harmonics in power supply current and consecutively, distortion factor weak. Power processing at a poor power factor may distortion the power supply voltages waveforms, disturbing in this way the operation of other equipment are powered in parallel by the same mains. This paper present some aspects resulted after analyses of harmonics in power supply current for voltage converters used to supply power lasers.*

Keywords: *LASER, harmonic pollution, distortion factor, “full bridge” converter*

1. INTRODUCTION

Power converters PWM (Pulse Width Modulation) controlled are often used by power supply of CO₂ and YG:Nd pulse and continuous power laser's used in laser processing installation.

The PWM power converters are the main harmonics pollution sources because of strong non-linear characteristics of the devices from their structure.

Switching power converters are placed between main power line and installation, acting like a load for power line and like a source for installation.

Because of this is necessary put in accord performances and parameters of these electronic systems with parameters of electrical power delivered and maximum disturbances allowed by main power supply.

In spite of the PWM convertors are well known, for each particular case it is necessary to took into consideration the condition of functioning, load cycle, electromagnetic compatibility conditions and technical parameters of design when we calculate and create such systems.

2. ANALYSIS OF QUALITY OF ELECTRICAL ENERGY USED TO SUPPLY LASER INSTALLATIONS

Laser processing installations are non-linear consumers which create important electromagnetic disturbances inside electrical distribution network.

Asymmetric current supply creates additional losses of energy with negative effect on energy transfer efficiency.

According with harmonics amplitude the total harmonic distortion (THD) is [6]:

$$\text{THD} = \frac{Y_d}{\sqrt{Y^2 - Y_0^2}} \quad (1)$$

where:

$$Y_d = \sqrt{\sum_{k=2}^n Y_k^2} \quad (2)$$

where:

Y_d – distortion residue;

Y – effective value of periodic distortion wave;

Y₀ – continuous component;

Y₁ – effective value fundamental component;

Y_k - effective value of k harmonic component.

A numerical method computing the currents and voltages RMS values and consecutively the power consumption and power factor is further presented (Fig. 1) [1].

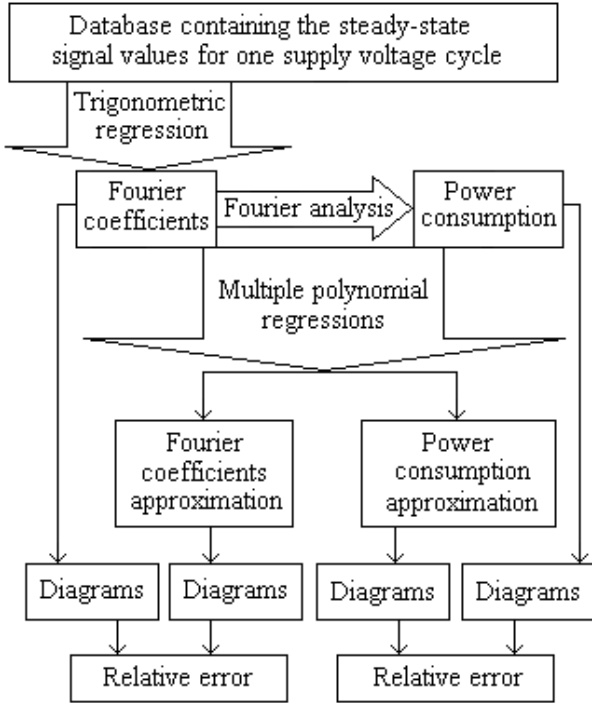


Fig. 1 Block scheme of the algorithm computing volt-amps

The proposed method is the following [4]:

- Approximating the analyzed quantities waveforms by using a trigonometric type regression function, containing n harmonics and based on the least squares method;
- Computing harmonic (sine) Fourier series coefficients;
- Computing volt-amps;
- Computing polynomial type approximating functions (polynomial regression) for volt-amps and harmonic Fourier series parameters (amplitudes, phase-shifts).

The waveforms (voltages and currents) in discussion being no sinusoidal, their harmonic Fourier series are required for power consumption computing. The case involving a voltage and a current as analyzed quantities will be exemplified further:

$$u(t) = C_{u0} + \sum_{k=1}^m [C_{u_k} \cos(k\omega t) + S_{u_k} \sin(k\omega t)]$$

$$= C_{u0} + \sqrt{2} \sum_{k=1}^m [A_{u_k} \sin(k\omega t + \varphi_{u_k})] \quad (3)$$

$$i(t) = C_{i0} + \sum_{k=1}^m [C_{i_k} \cos(k\omega t) + S_{i_k} \sin(k\omega t)]$$

$$= C_{i0} + \sqrt{2} \sum_{k=1}^m [A_{i_k} \sin(k\omega t + \varphi_{i_k})] \quad (4)$$

By using a simple trigonometric transformation, the trigonometric series becomes a harmonic series, in sine or cosine [1,4]. The voltage and current RMS values are given by the relations:

$$U = \sqrt{C_{u0}^2 + \sum_{k=1}^m A_{u_k}^2} \quad (5)$$

$$I = \sqrt{C_{i0}^2 + \sum_{k=1}^m A_{i_k}^2} \quad (6)$$

Finally, the power consumption relationship comes out, introducing by that: the instantaneous power (p), volt-amps (S), the active power (P), the reactive power (Q), the deforming power (D) and the power factor (K):

$$p(t) = \left\{ C_{u0} + \sqrt{2} \sum_{k=1}^m [A_{u_k} \sin(k\omega t + \varphi_{u_k})] \right\} \cdot \left\{ C_{i0} + \sqrt{2} \sum_{k=1}^m [A_{i_k} \sin(k\omega t + \varphi_{i_k})] \right\} \quad (7)$$

$$S = \sqrt{C_{u0}^2 + \sum_{k=1}^m A_{u_k}^2} \cdot \sqrt{C_{i0}^2 + \sum_{k=1}^m A_{i_k}^2} \quad (8)$$

$$P = C_{u0} C_{i0} + \sum_{k=1}^{\infty} A_{u_k} A_{i_k} \cos(\varphi_{u_k} - \varphi_{i_k}) \quad (9)$$

$$Q = \sum_{k=1}^{\infty} A_{u_k} A_{i_k} \sin(\varphi_{u_k} - \varphi_{i_k}) \quad (10)$$

$$D = \sqrt{S^2 - P^2 - Q^2} \quad (11)$$

$$K = \frac{P}{S} \quad (12)$$

Power converters create current distortions which increase harmonic distortion coefficient. Each power convertor creates a unique harmonic spectrum.

The harmonic distortion coefficient is dependent by electric supply network topology. Based on harmonic distortion coefficient it is calculating the total harmonic distortion.

Usually the THD coefficient is below 5%, at this value are not necessary harmonic filters.

Based on static parameters of voltage supply the quality of voltage source is determinate and the installations for voltage adjustment can be chose accordingly.

To measure the parameters of electrical network it used „CA 8335 Qualistar Plus” analyzer and the DataWiever® Software.

It was measured the parameters of current, voltages, apparent power and current and voltage imbalance [2,6].

After analyses of recorded data the following parameters was calculated: the load factor, voltage fluctuation and flicker, current unbalance factor, voltage unbalance factor, current and voltage THD.

Rapid variation of parameters values according with this configuration create voltage fluctuation and flicker.

The values of current and voltage THD based on the load factor of transformer are displayed in fig. 1 and 2 [6].

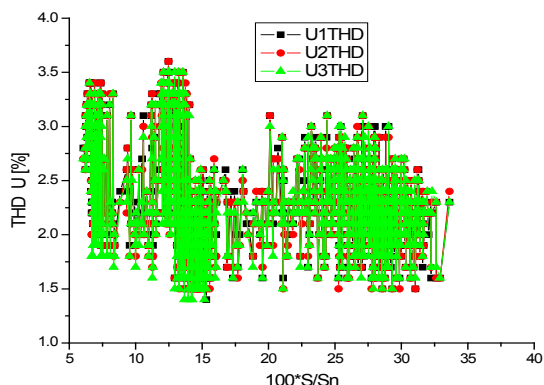


Fig. 1 Voltage THD for laser processing installations

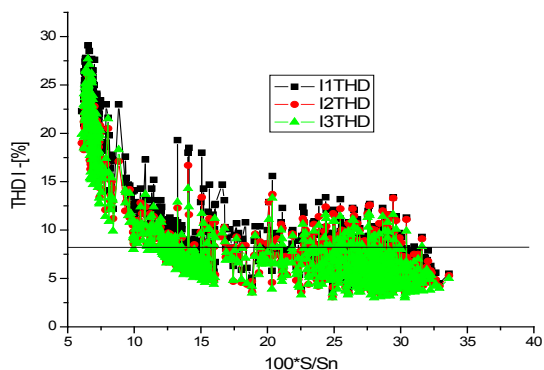


Fig. 2 Current THD for laser processing installations

The high values of current THD create additional losses inside the electric power network and linear loads.

In table 1 and 2 are displayed the first 20 values of voltage and current unbalance factor [6].

Table 1 Value of current unbalance factor

Ora	IR [A]	IS [A]	IT [A]	K2I [%]
7:10:00.000 PM	2.64	3.08	2.688	9.895
7:00:00.000 PM	2.664	3.096	2.696	9.839
7:10:00.000 AM	2.856	3.272	2.824	9.651
2:50:00.000 AM	2.792	3.224	2.808	9.610
12:30:00.000 PM	2.808	3.232	2.816	9.485
7:20:00.000 PM	2.632	3.048	2.672	9.483
12:40:00.000 PM	2.912	3.392	3	9.372
2:20:00.000 PM	2.744	3.136	2.728	9.294
7:30:00.000 PM	2.632	3.024	2.656	9.143
7:00:00.000 AM	2.864	3.256	2.832	9.115
10:30:00.000 AM	2.752	3.2	2.848	9.091
10:40:00.000 AM	2.856	3.344	3	9.043
12:20:00.000 PM	2.784	3.184	2.8	8.942
3:00:00.000 AM	2.824	3.224	2.832	8.919
6:50:00.000 AM	2.88	3.264	2.848	8.897
2:40:00.000 AM	2.824	3.232	2.848	8.895
6:40:00.000 AM	2.888	3.28	2.872	8.850
7:40:00.000 PM	2.632	3.024	2.68	8.829
8:00:00.000 PM	2.584	3.04	2.76	8.779
2:40:00.000 PM	2.744	3.128	2.76	8.712

Table 2 Value of voltage unbalance factor

Ora	UR [kV]	US [kV]	UT [kV]	K2U [%]
6:10:00.000 PM	21.2	21.48	21.3	0.719
6:50:00.000 PM	21.24	21.58	21.38	0.841
7:10:00.000 AM	20.64	20.9	20.78	0.610
5:40:00.000 PM	20.88	21.14	21.02	0.603
11:20:00.000 PM	20.82	21.12	21.02	0.635
1:20:00.000 PM	21.02	21.32	21.16	0.724
1:30:00.000 PM	21.06	21.36	21.2	0.723
5:10:00.000 AM	20.76	21.02	20.9	0.606
6:30:00.000 AM	20.86	21.16	21.06	0.634
10:40:00.000 AM	21.06	21.36	21.2	0.723
10:50:00.000 AM	21	21.3	21.18	0.662
12:30:00.000 PM	20.86	21.16	21.06	0.634
12:40:00.000 PM	20.86	21.14	21.02	0.635
1:10:00.000 PM	20.84	21.14	21.02	0.667
4:40:00.000 PM	21.14	21.42	21.3	0.626
4:50:00.000 PM	21.12	21.4	21.28	0.627
7:30:00.000 PM	21.14	21.44	21.32	0.657
2:30:00.000 AM	20.92	21.2	21.1	0.601
2:40:00.000 AM	20.88	21.2	21.1	0.665
2:50:00.000 AM	20.9	21.22	21.14	0.632

Based on this analysis the following results are obtained:

The value of voltage unbalance factor is according with standards;

The value of current unbalance factor is above standards for a load below 30%;

The value of voltage THD is according with standards;

The value of current THD is raising when the load factor of transformer decrease;

The value of current THD is over limit in 400 cases from 1000 measurements.

3. THE ANALYSIS OF HARMONICS OF CURRENT FROM POWER GRID

The main modules for CO2 laser power supply (high voltage starting pulse 20kV, voltage 8...10kV) are (fig. 3) [3,5]:filter to reduce harmonics from/to power grid; voltage rectifier and filter module; auxiliary power supply; trigger circuit for achieving discharge starting voltage; power modules; the command circuit and operation mode achievement.

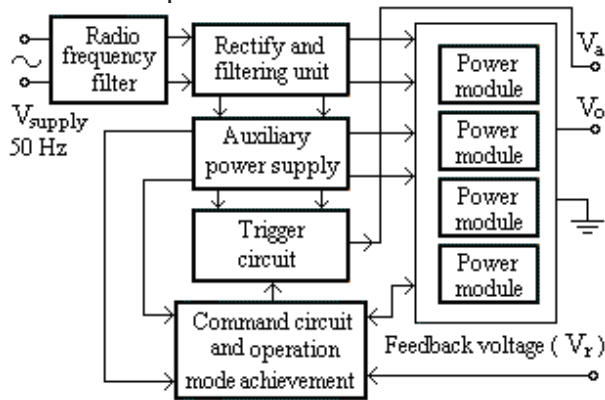


Fig. 3 The main modules for CO2 laser power supply

In order to power a CO2 laser with 1 kW the pulse power supply should have 4 parallel power modules with following parameters (for a minimum efficiency of conversion of electric energy into laser energy of 12,5%):

Power grid with 50Hz, 380V, 3 phase;

Rated output voltage $V_o = 8...10kV$;

Rated load current $I_o = 200mA$;

Voltage adjustment for current $V_r = 0...10Vdc$;

Rated output $P_o = 2kW$;

Pulse repetition frequency $f_r = 0...1kHz$;

Pulse width $t_i = 0,2ms$;

Maximum current pulse $I_{oi\max} = 0,8A$;

Minimum efficiency $\eta = 0,75\%$;

Discharge starting voltage $V_a = 20kV$;

Pulse shape: Train half circle redressed without any special waveform to the converter.

The circuit of Full Bridge voltage converter, for the presented parameters is displayed in Fig.4.

The waveform of the output voltage are shown in Fig. 5 and the waveform of the output current in the primary winding of high voltage transformer and primary winding voltage are shown in Fig. 6 and 7.

The Fourier analysis for the current drawn from the power supply is shown in Fig. 8.

The analysis was performed for several values of load converter (10kΩ; 20kΩ and 50kΩ), the required output voltage is 9kV.

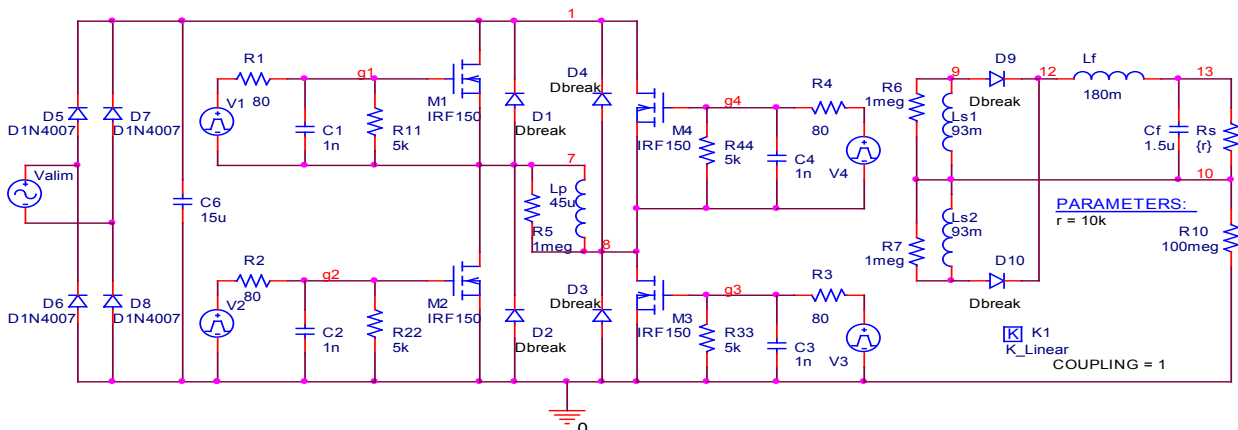


Fig. 4 Full Bridge voltage converter

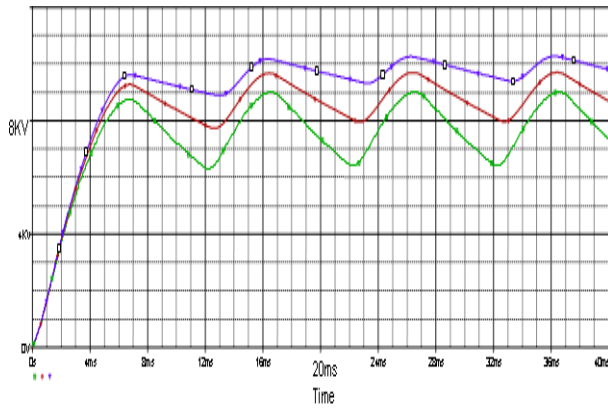
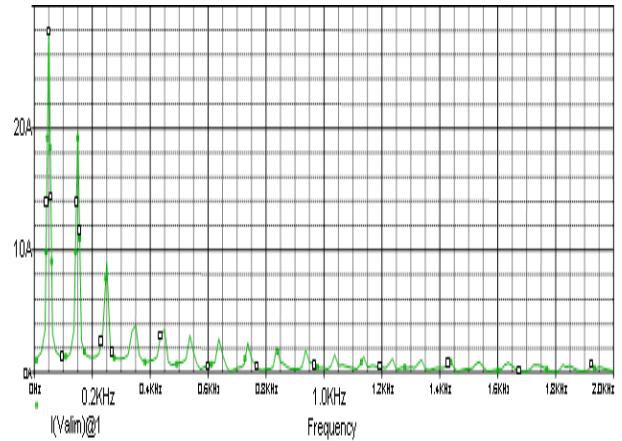


Fig. 5 The waveform of the output voltage (RS = 10k; RS = 20k; RS = 50k)



$R_S = 10k\Omega$

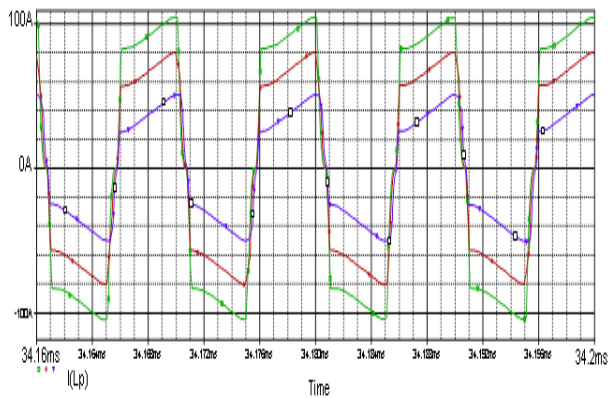
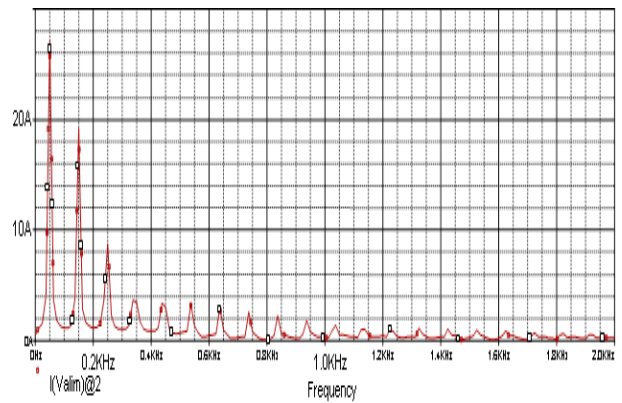


Fig. 6 The waveform of the output current in the primary winding of high voltage transformer I(Lp) (RS = 10k; RS = 20k; RS = 50k)



$R_S = 20k\Omega$

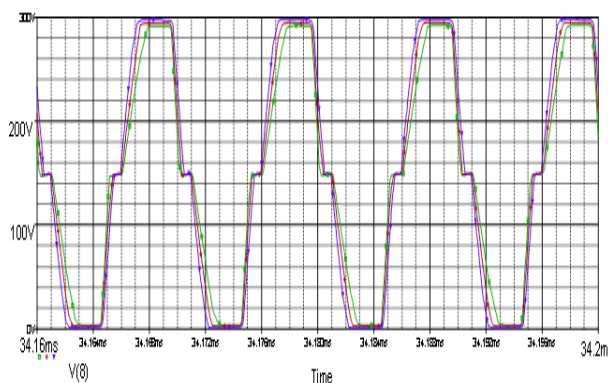
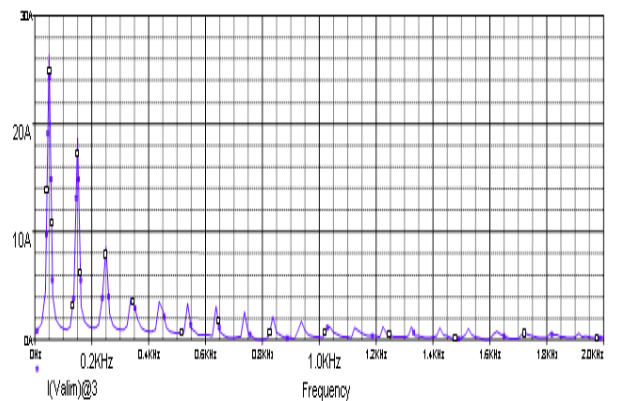


Fig. 7 The waveform of the primary winding voltage of high voltage transformer



$R_S = 50k\Omega$

Fig. 8 The Fourier analysis for the current drawn from the power supply

In Fig. 5 shows both a strong dependence of the output voltage maximum value and the value of its ripple's load module.

For Full Bridge converter the transient regime is lower in comparison with Half Bridge [5], and is approximately 10ms.

From Fig. 8 it is seen that it is generated both even and odd harmonics, the most significant being the fundamental frequency harmonic.

CONCLUSIONS

Equipment supply power lasers are composed of switching power converters, leading to the presence of harmonics in the current drawn from the mains.

Total harmonic distortion factor is calculated based on the harmonic factor that depends on the type of mains and consumer characteristics.

The introduction of harmonic currents in the supply network has the effect of waveform distortion of the system voltage phase electric supply.

From the analysis showed result that the voltage THD value remains at admissible parameters, but current THD value increases with decreasing load factor of the transformer, this imposing and analysis of electromagnetic pollution phenomena for laser processing plants and in particular of PWM power converters in the composition of power sources analyzed.

Following the results obtained by Fourier analysis of voltage Full Bridge converter resulted existence of both even and odd harmonics of the current drawn from the mains, but the amplitudes of harmonics are reduced and do not depend on the converter load and varies quite slightly depending on the type of the converter.

The amplitudes of the odd harmonics strongly depend both on the load and the type of converter.

It follows that the presence of power converters inevitably lead to the presence of harmonics in the current drawn from the mains and therefore distortion of degradation factor, and each type of power converter have its distinct harmonic spectrum.

BIBLIOGRAPHY

1. Constantinescu, C. (2004). Contributions in AC Switching Mode of the Electrical Circuits with Applications on Current Rectifiers inner Transformers Designing; PhD Thesis, "Transilvania" University, Braşov.
2. Mihai, C.; Holom, R.; M., Pearsică, M.; Constantinescu, C.G. & Strîmbu, C. (2011). Analiza fenomenelor de poluare electromagnetica în cazul instalațiilor de prelucrare cu laser. Conferința Națională și Expoziția de Energetică, Sinaia, pp. 391-398.
3. Pearsică, M.; Băluță, S.; Constantinescu, C.; Strîmbu, C. & Mihai, C. (2009). A method to obtain the pulse operation of a power CO2 laser working in continuous regime. Optoelectronics and Advanced Materials, vol. 3, pp. 1264-1268.
4. Pearsică, M.; Constantinescu, C.; Strîmbu, C. & Miron, L. (2008). A Study Concerning the Decrease of Harmonic Pollution in Supply Networks of the Electric Systems with PWM Control. Proceedings of the 5th Int. Conf., „Janos Bolyai” Military Technical Academy, Budapest, Hungary, pp. 53-62.
5. Pearsică, M.; Constantinescu, C.; Strîmbu, C. & Miron, L. (2007). Discharge Current Modulation to Obtain the Pulse Operation of a Power CO2 Laser, with Continuous Flow of the Gas. Proceedings of the IEEE International Symposium on Industrial Electronics, Vigo, Spain, June 4-7, pp. 550-554.
6. Pearsică, M.; Nedelcu, Șt.; Constantinescu C.; Strîmbu, C.; Mihai, C. & Bența, M. (2011). Interacțiunea radiației laser cu substanța: modelarea fenomenelor fizice și tehnici de depoluare electromagnetica, GRANT CNCSIS PN-II-ID-PCE-2008, ID_2291.