HARMONIC DISTORTION ANALYSIS OF COMPACT FLUORESCENT LAMPS WITH INTEGRATED ELECTRONIC BALLAST

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Abstract: *Non-linear Volt-Amper characteristic of compact fluorescent lamps is a basic reason for the non-sinusoidal form of the current passed through them. Using electronic ballast limits this current during its work, but at the same time it generates high harmonics to the supplying electrical network. In the paper are made time and frequency analysis of compact fluorescent lamps with different power (7,8,9,15 and 20 W) about electro-magnetic compatibility. The results show that each analyzed lamp is up to the requirements of the standard for possible deviation of the coefficient THD and with sufficient precision of 7% it deviates from the standard for power factor λ.*

Key words: *compact fluorescent lamps, high harmonics, electromagnetic compatibility*

1. INRODUCTION

Compact fluorescent lamps (CFL) cannot work in direct connection to the supplying network. In this reason it uses electronic ballast (EB), which has a key role for their effective and optimal work. Main disadvantage of these lamps is generating the high harmonics to the network as a result of the using electronic scheme.

In admissible variation of the supplying voltage the parameters of the scheme and electric parameters of the lamps in working mode (current and power) have not exceed admissible limits [1, 2, 4].

Construction of the analyzed CFL with electronic ballast is shown on Fig. 1, but their block [5] and electric schemes – on Fig. 2a and 2b.

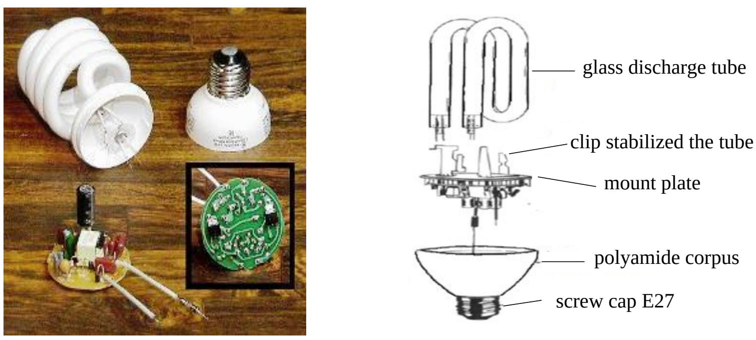


Fig. 1. CFL with electronic ballast

Decreasing harmonic distortion in admissible limits defined in international standards realizes by filter for reducing the disturbances. In practice, there are different schemes for power factor correction (Fig. 2) [4].

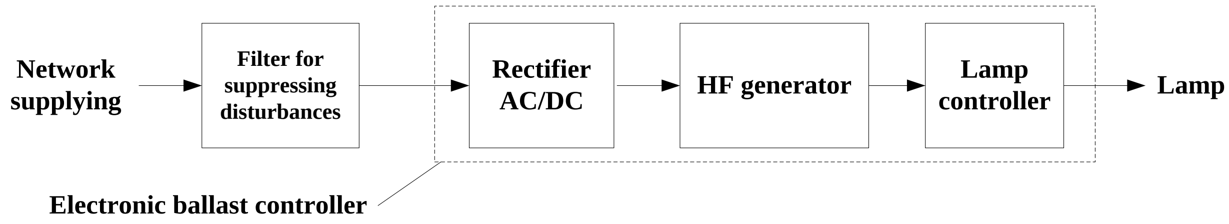


Fig. 2a. Block scheme of electronic ballast

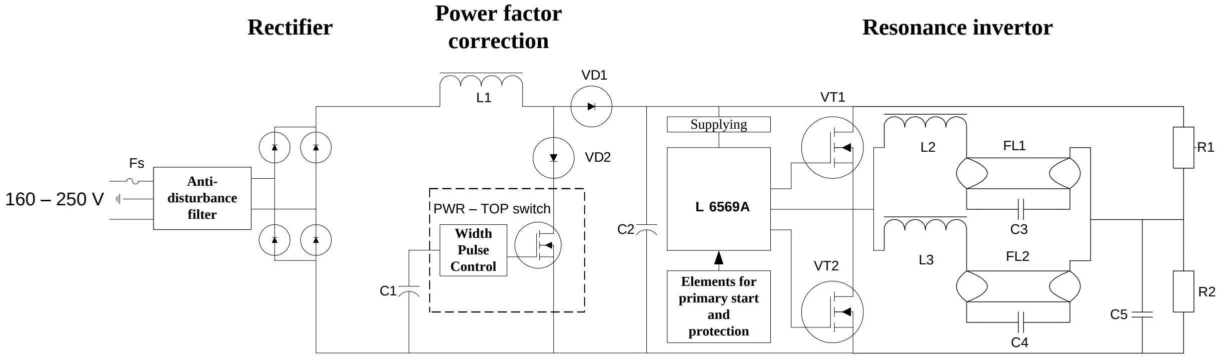


Fig. 2b. Electric scheme of electronic ballast

Main requirement to CFL with electronic ballast is the generated to the network disturbances to satisfy the standard БДС EN 55015, defining the conditions for electromagnetic compliability (EMC) [3].

Present paper is organized as follows. In section 2 are defined the coefficients of *Total Harmonic Distortion* (*THD*) and *power factor* (λ), which are indexes for quality assessment of the signal distortion with respect to the idea sine wave. In section 3 are presented requirements to the lighting devices for decreasing the high current's harmonics generating of them. In section 4 are analyzed different models CFL with electronic ballast in time and frequency domains. In first case are calculated the coefficients of the amplitude and the form of the current, passed through them, but in the second one are determined coefficients *THD* and λ. In conclusion are made some deductions about satisfying EMC standards from studied CFL with electronic ballast.

2. PROBLEM STATEMENT

Analysis of the existing in the system periodical non-sinusoidal signals can be made as in the time as in the frequency domains. The French physicians Fourier is proved that each time periodical function $x(t) = x(t + kT),\ k \in Z$ with period T can be presented as a sum of periodical harmonic (sinusoidal) functions as follows:

$$x(t) = x_0 + \sum_{k=1}^{n} x_{m(k)}.\sin\left(k\omega t + \psi_k\right),\ n \in Z^+ \tag{1}$$

Then it uses appropriate filters which have to minimize the influence of the high harmonics $x_{(k)}(t) = x_{m(k)}.\sin(k\omega t + \psi_k),\ k \in Z^+$. In practice, the influence of the main harmonic $x_{(1)}(t) = x_{m(1)}.\sin(k\omega t + \psi_1)$ has a key role, because the harmonics variations fade away, i.e. the amplitude of the high harmonics decreases with increasing their number.

The form of the current from supplying network is as pulses (Fig. 3), i.e. non-sinusoidal form, as a result of rectifying and existing of the buffer capacitor.

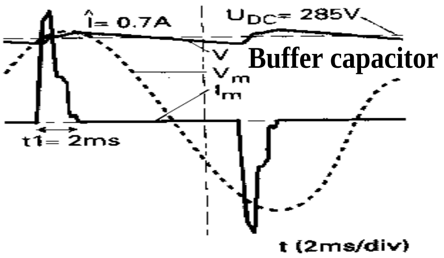


Fig. 3. Form of the current and voltage for two-way rectifier

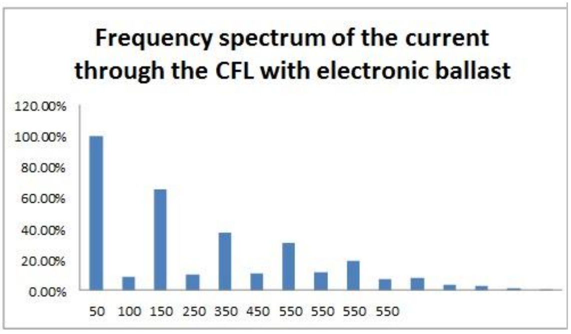


Fig. 4. Frequency spectrum of the current through the CFL with electronic ballast

Therefore, the respective frequency spectrum in Fourier series will be as shown on Fig. 4, where the amplitude of main harmonic is 100 %, but the respective maximums of high harmonics are presented as associated parts of it.

In International standards (IEC 555-2 and БДС EN 61000-3-2 [1]), are defined the limits about the quantity of the returning current's electro-magnetic disturbances to the supplying network. In some of electronic ballasts in Bulgarian market miss network filter and the harmonics with numbers upper than 3 exceed the requirements defined in these standards [1]. In Europe (till 1998) didn't allow limits about harmonic distortions resulting of the electronic ballasts for fluorescent lamps (with power $\leq$ 25 W) [4]. Therefore, the structure and parameters of the filters chose in this way, that the generated harmonics signals to satisfy standards for EMC.

For this reason defines the coefficient for total harmonic distortions (*THD*) [5] as follows:

$$THD = \sqrt{\frac{\sum\limits_{k=2}^{\infty} I_k^2}{I_1^2}} = \sqrt{\frac{I_2^2 + I_3^2 + I_4^2 + \ldots}{I_1^2}} \qquad (2)$$

In lighting devices used the term *Power factor* (λ), which quality evaluates the degree of harmonic distortions, instead of *Power coefficient* ($\cos\varphi$). Because of that always on the electronic ballast have to be written the value of λ. Usually the supplying network voltage has almost sinusoidal form. Then the consumed active power is: $P = U_N . I_N . \cos\varphi$.

Remark: U_N and I_N are RMS values of the main harmonics of the supplying voltage and the input current for the considered electric circuit, respectively.

In practice, in electric circuits with CFL $0.93 \leq \cos\varphi \leq 1$. When determines the power factor λ, it is significant the angle between supplying voltage and main input current as well the coefficient of total harmonic distortion *THD*. If supplying voltage is sine wave, then power factor λ calculates as follows [2]:

$$\lambda = \frac{\cos\varphi}{\sqrt{1+THD^2}} \tag{3}$$

Therefore, electric circuits with different $\cos\varphi$ can have the same power factor λ.

Remark: In schemes with electronic ballast without power factor's correction λ*, the phase difference* φ is nearly to 0 and therefore $\cos\varphi = 1$. *Because of the fact that main input current has a large number of harmonics then* $THD \approx 1.44$ *and* $\lambda = 0.57$.

3. STANDARDS FOR LIGHTING DEVICES

Lighting devices are devices of class C with respect to the limitation of the harmonic distortion of the currents, passed through them. The requirements to these devices [1] are shown in Table 1 for cases when the consumed active power exceeds 25 *W*. In Table 2 are given the necessary limits in working of the fluorescent lamps with electronic ballast as a result only odd numbers' harmonics.

Table 1. Standard for current's harmonics for technic devices of class C

№	$K_{I_{r(k)}} = \frac{I_{(k)}}{I_{(1)}}.100,\ \%$
2	2
3	30.λ*
5	10
7	7
9	5
$11 \le № \le 39$	3

Table 2. Fluorescent lamps with electronic ballast

№	***f*, *Hz***	***I(k)* , *mA***	$K_{I_{r(k)}} = \frac{I_{(k)}}{I_{(1)}}.100,\ \%$
1	50	96	100
2	100	0	0
3	150	89	92
5	250	74	77
7	350	57	59
9	450	40	41
≥ 11	550	25	26

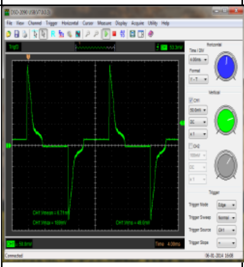
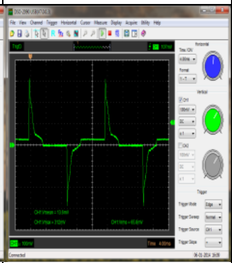
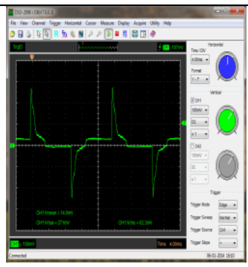
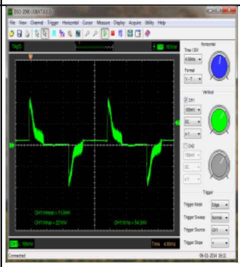
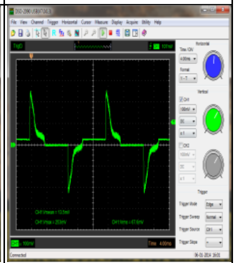
Remark: № – number of the harmonic; $K_{I_{r(k)}}$ *– ratio of the maximum admissible values of the k*th *harmonic and the main harmonic of the consumed current, %; λ* – power factor. Usually the harmonics with numbers upper than 11 and even numbers almost don't influent on the current form. On this reason the standards of IEC define limits in respect of their total effect.*

4. ANALYSIS OF COMPACT FLUORESCENT LAMPS WITH ELECTRONIC BALLAST FOR DIFFERENT POWERS

It is analyzed different models CFL with electronic ballast. The graph of the input voltage and input current in time and frequency domains are experimentally measured. Current $i_N(t)$ have highly marked non-sinusoidal form.

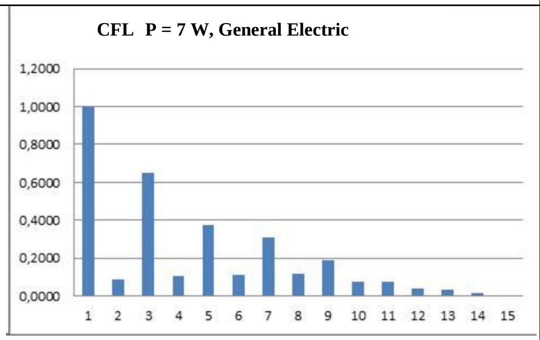
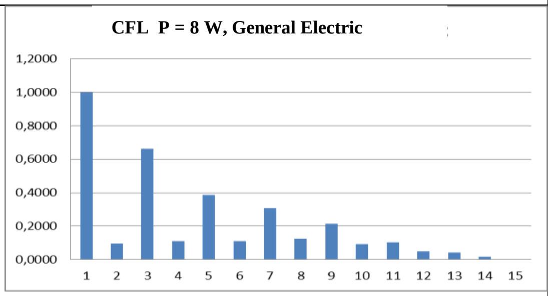
Quality assessment of the results from time domain analysis are amplitude coefficient ($k_A = I_m / I$, -) and form coefficient ($k_f = I / I_{cp.}$, -) of this current, which are shown in Table 3. These coefficient are not given with respect to the supplying voltage because it has almost sinusoidal form and $k_A \approx \sqrt{2} \approx 1.41$ and $k_f \approx 1.11$.

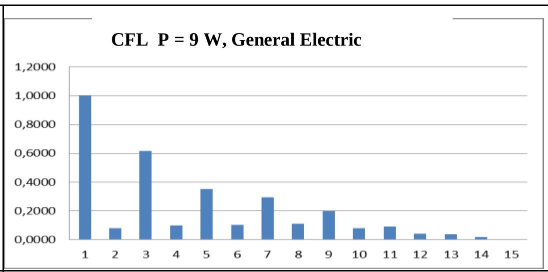
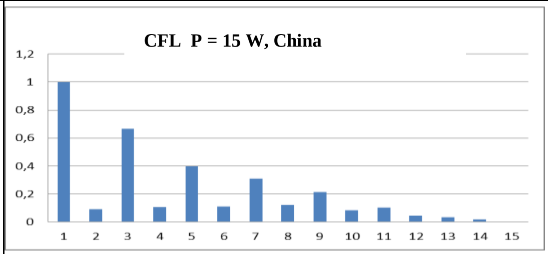
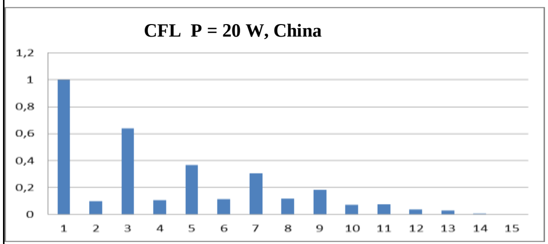
Table 3. Time analysis of CFL with electronic ballast

Investigated quantity	*CFL for different power*				
	7 *W*	**8 *W***	**9 *W***	**15 *W***	**20 *W***
$i_N(t)$					
k_A ,-	3,8579	4,7416	4,3499	4,1386	3,7426
k_f ,-	7,3025	4,8382	4,4501	3,8696	5,0074

The results from frequency analysis of the studied CFL are shown in Table 4.

Table 4. Frequency analysis of CFL with electronic ballast

CFL	Investigated quantity		
	$I_N(f)$	***THD***	λ
7 *W*		**1.325**	**0.602**
8 *W*		**1.341**	**0.599**

9 *W*		**1.298**	**0.6103**
15 *W*		**1.346**	**0.5963**
20 *W*		**1.316**	**0.605**

Main input current in the studied electric circuit has non-sinusoidal form (see Table 3). The respective amplitude and form coefficients have value in the following intervals: $3.7416 \le k_A \le 5.6186$ (for ideal sine wave $k_A \approx \sqrt{2} \approx 1.44$) and $2.9755 \le k_f \le 7.3025$ (for ideal sine wave $k_f \approx 1.11$), which requires frequency analysis of this current. Results of this analysis (see Table 4) show, that generates high harmonics in the spectrum of the main input current in the circuit including CFL. The most considerable influence has the harmonics with odd numbers. It is sufficient to consider only these which have a number smaller or equal than 15. Result about the total harmonic distortion coefficient for analyzed CFL are in the interval $1.298 \le THD \le 1.396$. This satisfies the requirements for admissible value of $THD = 1.44$, defined in the EMC standards. Calculated values for power factor are in the interval $0.596 \le \lambda \le 0.610$. This result shows the variation of 7 % up the admissible value $\lambda = 0.57$ according to the EMC standards.

5. CONCLUSION

Usually in practice the disturbances suppresses by using limiting elements, filters, inductors and transformers. On the other side when the ballast constructs it sizing in such way that to minimize the generated disturbances, standing in normal work of the other devices in the network.

It studies the generated periodical non-sinusoidal signals as a result of the CFL's work. Analysis is made in both domains - time and frequency. Results show that when increases the number of harmonic the amplitude of the respective sine wave fades away. Based on the quality assessments from the harmonic analysis it calculates the values of *THD* and λ for each analyzed CFL. The results (according to the EMC standard) show that the values of *THD* are in admissible range, but these for λ deviate from its admissible value with 7 %. These results interpret with the fact that studied CFL are produced from large-scale manufacturers.

References

[1] БДС EN 61000-3-2 Електромагнитна съвместимост (EMC). Част 3-2: Гранични стойности. Гранични стойности за излъчвания на хармонични съставящи на тока (входен ток на устройства/съоръжения до и включително 16 А за фаза) Electromagnetic compatibility (EMC) - Part 3-2: Limits - Limits for harmonic current emissions (equipment input current $\leq$ 16 A per phase).

[2] БДС EN 61547: 1996 Equipment for general lighting purposes – EMC immunity requirements.

[3] БДС EN 55015:2007 Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment.

[4] Анчев М. Х., Иванов З. А., Електронен пускорегулиращ апарат за луминесцентни лампи с висок фактор на мощност, сп. ”Осветителни системи”, бр. 3, 2001, “ABC Техника “ООД.

[5] Иванов З. А., Пускорегулиращи апарати за разрядни лампи, ISBN 954-998-347, 229 стр., ТУ - София, 2003.

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