ON THE MODEL OF A COMPACT FLUORESCENT LAMP AS LOAD OF A MIXED LV NETWORK

Mihaela Albu[1], Aurel–Ionuț Chirilă[1], Ioan–Dragoş Deaconu[1]

[1]"Politehnica" University of Bucharest, Faculty of Electrical Engineering,
060042 Bucharest, Splaiul Independenței 313, Romania

albu@ieee.org (Albu Mihaela)

Abstract

The need of an optimal integration of dispersed generation (mainly based on renewable sources, which are usually intermittent and provide electricity in DC form) led to a new distribution system, which includes DC layer as an active network (generation, storage and loads are all interconnected at direct voltage by means of uni- or bi-directional power electronics converters). At a first stage, these DC networks should operate interconnected with the AC distribution system. One main application in the near future is considered to be the use of a DC layer in office buildings. Therefore, models of the system components have to be developed, as to accurately simulate the network behavior for various states. In this paper, firstly a PSpice model of a CFL lamp was derived, as to allow different simulations conditions when supplied with DC at various voltage levels. Then a set of experiments conducted both in DC and AC enabled the model validation. For various CFLs, the I(U) characteristics were obtained and appropriate numerical model of the corresponding CFL impedance for DC supply were derived, as to be further implemented in complex grid models developed within Matlab workspace. Finally, conclusions regarding the efficiency of a DC supply grid are drawn, together with an assessment within the power quality frame.

Keywords: CFL, DC supply, Simulation, Experimental validation.

Presenting Author's biography

Mihaela Albu is from Craiova, Romania. She graduated from "Politehnica" University of Bucharest in 1987 and holds the Ph.D. degree (1998) from the same university. Since 2002 she is a Professor of Electrical Engineering. Her research interests include active distribution networks, DC grids, power quality, instrumentation, and remote experimentation embedded within on-line laboratories. Dr. Albu was spending a leave at Arizona State University as a Fulbright Fellow 2002 - 2003.

1 Introduction

Our society's future depends on a secure, affordable and sustainable electrical energy supply produced and sold to all customers at affordable prices, in the conditions of fulfilling the environment requirements. All renewable solutions have to be revised along with a new strategy for security of energy supply. However, despite the great promises of renewable use, major obstacles are still to be overcome: the most challenging among them is the lack of equipment and strategy to allow distributed energy resources (DER) connection with the existing power system, allowing the integration of dispersed generation (DG) into flexible energy networks.

One solution is to use DC at the distribution and the user layer. At the beginning of the electricity era, Edison developed the first distribution of electrical energy in a DC form, and the DC current supplied all loads. Later on, due to the difficulties concerning the transport at long distance and the invention of induction motor by Tesla, the AC replaced the DC solution. Due to the progress in the last 10-15 years in the field of power electronics (low-cost high voltage and large current IGBTs) and high performance DSP controllers, the DC solution became performant again and is expected to have a big impact in the future [1]. Considering all economically available forms of distributed renewable energy, one can use them as generating nodes within a grid feeding mainly the local loads (active networks). The distributed generation system becomes a hybrid one, including multiple power sources, which by an adequate control can improve the overall system performances [2].

The main reason for choosing DC technology for electrical energy distribution is the trend in the LV load characteristics. For most of the equipment high performance is required and is ITC labeled – i.e. hosting a DC power source accommodating an inverter due to the present AC-distribution. Anticipating the further extensive use of low-power, DC-based, intelligent devices [3] it might become more efficient to avoid losses in energy transfer at least where the energy is produced in a DC-form. Moreover, using DC grids in buildings is expected to be one of the main applications and challenges in the future. Most of the electrical equipment used in buildings operates with electrical energy in DC form (computers, mobile phones, and other mobile multimedia, lighting, air conditioning, other appliances etc.), as shown in Fig. 1. With a DC supply these components would not need an AC/DC adapter anymore. In combination with PV (included into the facade or on the roof), a battery system or fuel cell system, a sustainable DC energy system for buildings can be developed. In order to estimate the total systems efficiency and cost reduction, several DC installations on different voltage levels and power ranges have to be simulated [4, 5].

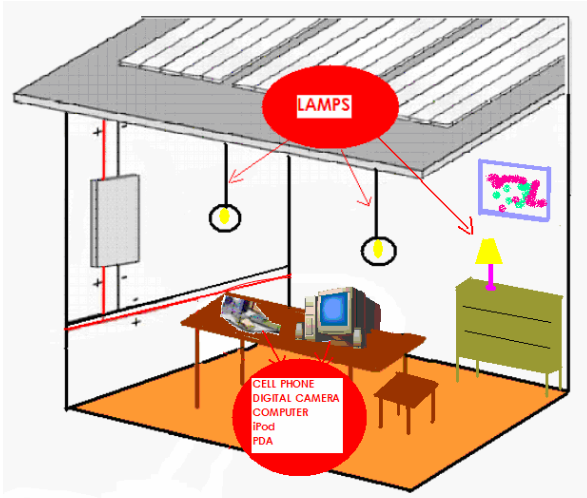


Fig. 1 Example of DC supply in residential buildings

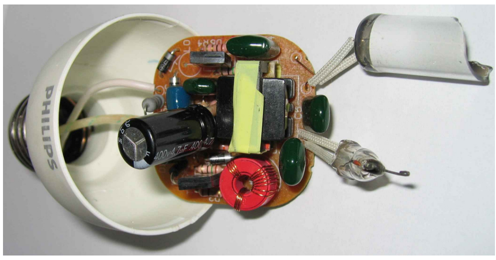
Referring to the electrical lighting systems, most of the world's population uses as their main artificial light source incandescent lamps. In many countries the Compact Fluorescent Lamps (CFL) or the so-called economical lamps are starting to be a strong competitor to the classic incandescent lamps. When compared with incandescent lamp a fluorescent lamp (CFL) has a longer lifetime and smaller energy consumption (for the same light intensity). Recently, the European Union Parliament was taking into account a proposal put forward by one of its ministers that all EU members should forbid the manufacturing of incandescent lamps which should be replaced with CFLs by the end of 2009. The main reasons are the low efficiency of incandescent lamps (about 5%) and the CO_2 emissions of the factories that manufacture incandescent lamps. Instead of eliminating incandescent light bulbs altogether, California lawmakers recently (June 2007) passed Assembly Bill (AB) 1109, which requires the state to set energy efficiency standards for light bulbs that by 2018 would reduce electricity consumption by 50% for indoor lighting and 25% for commercial and outdoor lighting.

2 The Compact Fluorescent Lamp

2.1 CFL model

In [6, 7, 8] numerical simulation results are presented for various CFL models. However, no schematics were available for studying various operation modes when the CFL is directly connected at direct voltage supply. Furthermore, in order to validate a model which can be used in numerical simulations developed for active DC networks (for both steady-state and dynamic control studies), we investigated simple schematics for an 18W CFL [9, 10, 11].

The resulting model we found for the above mentioned CFL was further used for numerical simulations in PSpice (see Fig. 2).



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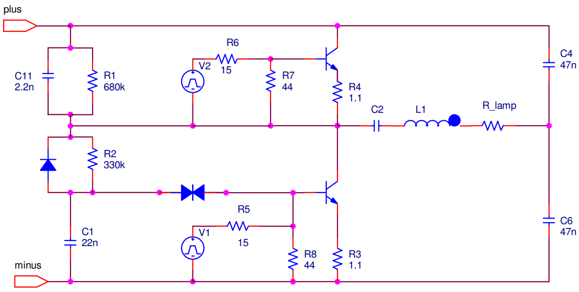


(b)

Fig. 2 The 18W CFL under study (a) and the corresponding PSpice model (b)

2.2 Experimental validation

In order to study and to compare the performances of the network components when directly supplied with DC, first the numerical models had to be developed for a collection of lamps, as they are designed only for AC supply. Then, for further investigation of the characteristics for DC conditions, a complete set of measurements was performed for the following lamps:

Compact fluorescent lamp, 9W, Philips (CFL_9)

Compact fluorescent lamp, 18W, Philips (CFL_18)

Compact fluorescent lamp, 15W, unknown producer (CFL_15x);

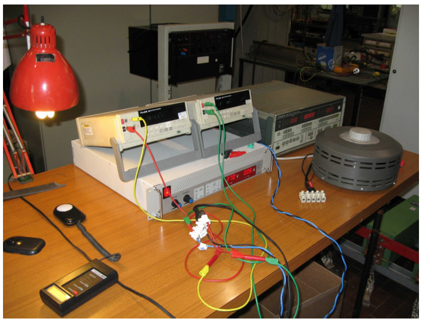
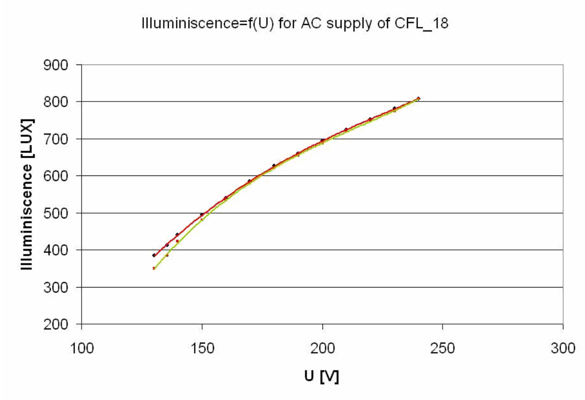


Fig. 3 Measurement set-up for the CFL

The measurement set-up shown in Fig. 3 comprised: digital multimeters (Fluke 45; Hewlett Packard 34401A); power analyzers (Yokogawa 2533; Fluke 454); luminescence meter (Mitek MK5330). Fig. 4 presents a comparative results for luminescence of the compact fluorescent lamp, for both supplying cases (AC and DC), increasing the voltage from the minimum value at which the lamp started to glow to a maximum of 300 V (peak voltage in AC case) and then decreasing the voltage in order to highlight possible hysteresis effect.



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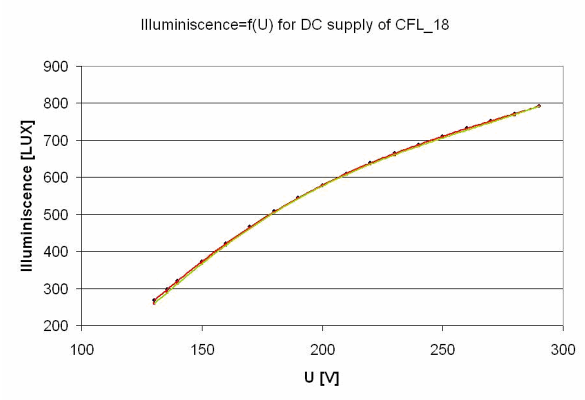


(b)

Fig. 4 Illuminance of the CFL_18 lamp when supplied with AC voltage (a); DC voltage (b)

Considering the alternative supply voltage (230 V rms) and the circuit in Fig. 2b, a good concordance between the simulated and the measured waveforms was obtained, see Fig. 5.

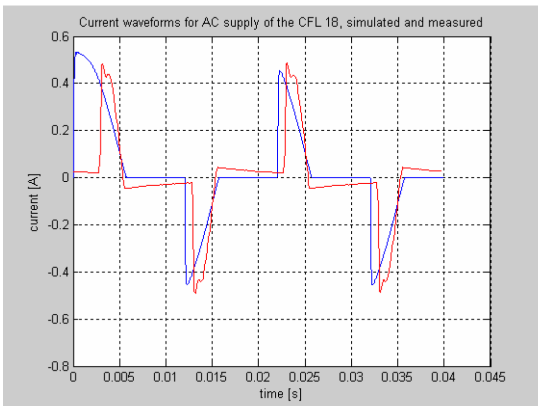
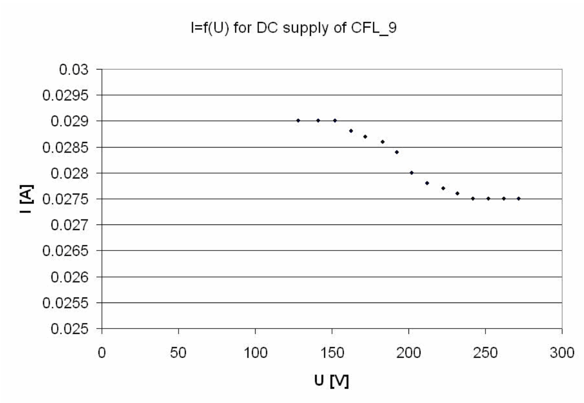


Fig. 5 Comparison between the simulated (blue) and measured (red) current waveforms for the CFL_18 lamp when supplied with AC voltage

2.3 Numerical models

Complex analysis of a DC network requires numerical models of all elements, for different voltage levels. An

I-U characteristic of each load was derived [12] from measurements performed in DC and AC. Figure 6 shows such characteristics obtained for the three lamps under study. As for comparison, Fig. 7 shows the I-U characteristic of a fluorescent lamp, 8W (FL).



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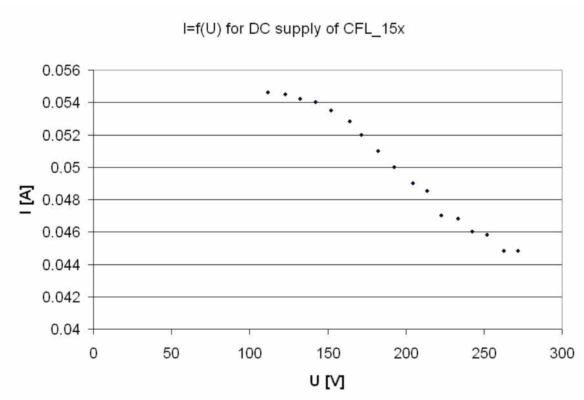

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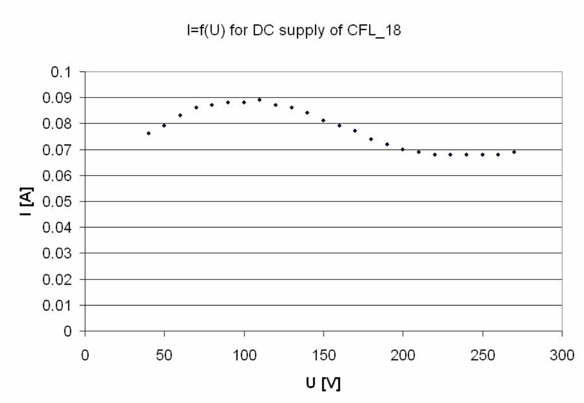


(c)

Fig. 6 Steady-state characteristic of different CFL supplied with direct voltage: CFL_9 (a); CFL_15 (b) and CFL_18 (c)

From the measurement set, after applying a minimal pre-processing, an equivalent of the nonlinear impedance of the CFL was derived, as a polynomial equation I(U).

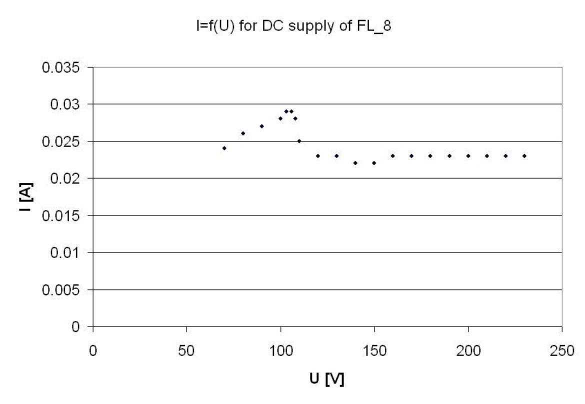


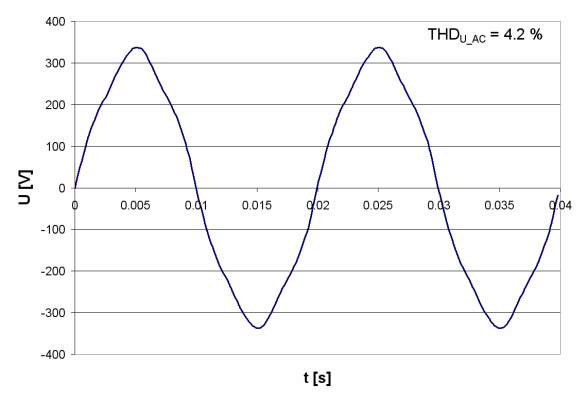
Fig. 7 Steady-state characteristic of a 8 W fluorescent lamp (FL_8) with DC supply

Tab. 1 Derived I(U) polynomial functions for DC supply of the CFL

Lamp	Poly-nomial degree	Coefficients
CFL_9	3	[2.05e-09 -1.20e-06 2.15e-04 1.68e-02]
CFL_18	10	[3.29e-22; -5.14e-19; 3.51e-16; -1.38e-13; 3.44e-11; -5.68e-09; 6.24e-07; -4.50e-05; 2.02e-03; -5.07e-02; 6.06e-01]
CFL_15x	3	[4.76e-09 -2.82e-06 4.67e-04 3.09e-02]

3 Power Quality considerations

Measurements of the PQ parameters (voltage and current THD) were performed by using a Fluke 434 monitoring device. In Fig. 8 the corresponding AC waveforms are presented.



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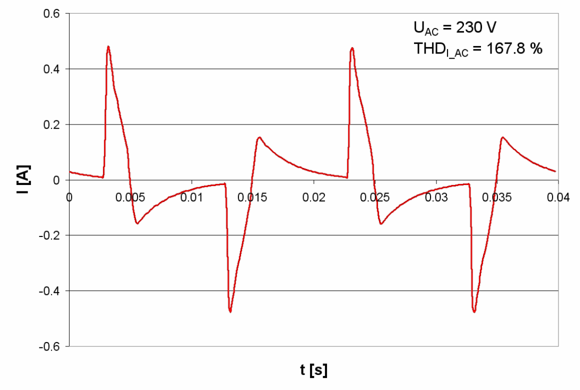
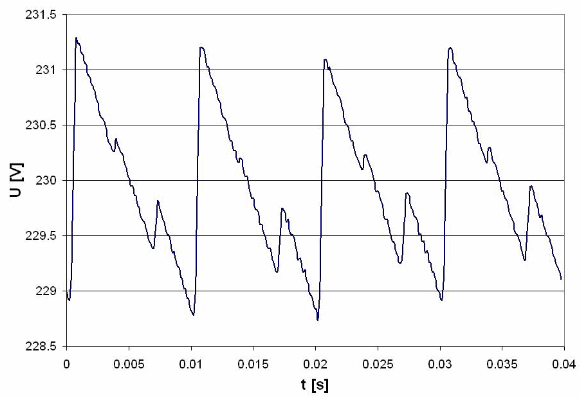


(b)

Fig. 8 Total Harmonic Distortion of the voltage (a) and current (b) waveforms for the CFL_18 lamp supplied with alternative voltage (230 V rms)

When directly connected to a DC voltage source, the corresponding waveforms are presented in Fig. 9.



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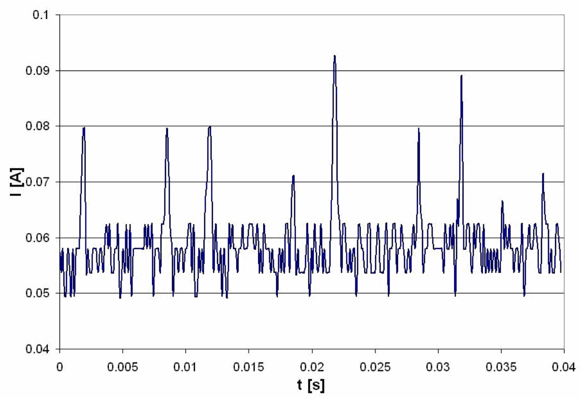


(b)

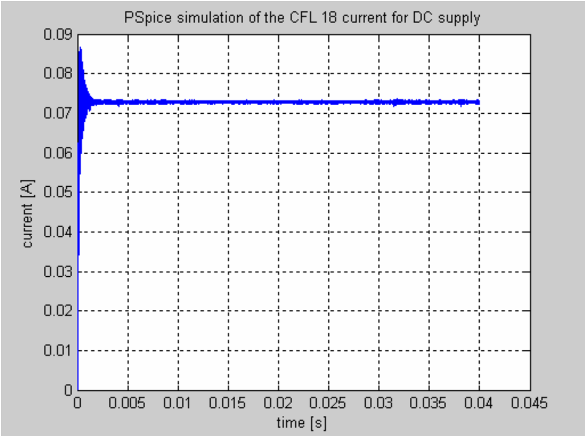
Fig. 9 The voltage (a) and current (b) waveforms for the CFL_18 lamp supplied with DC voltage (230 V)

Table 2 synthesizes the functional parameters found for the three CFLs when supplied with AC and DC respectively. In this table, U_o, I_o and P_o represents the voltage, current and power when the lamp starts to glow, while U_s, I_s and P_s represents the voltage, current and power when the lamp does not illuminate anymore. PF is the power factor and cosφ is the displacement power factor (computed from the 50 Hz components of the current and voltage waveforms).

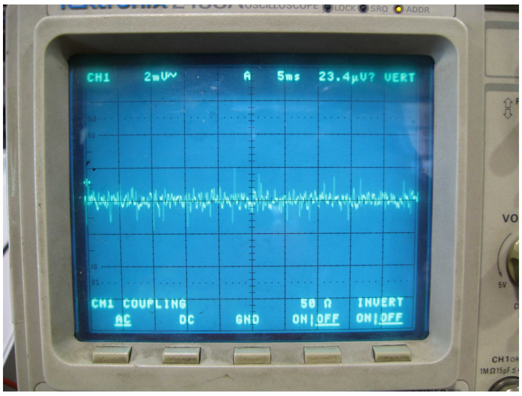
Tab. 2 Comparison of DC and AC supply of the CFL

Lamp		AC		DC	
		1 min	3 min	1 min	3 min
CFL_9 9W, 230V50Hz	U_o [V]	102.3	102	130.9	130
	I_o [A]	0.047	0.047	0.029	0.028
	U_s [V]	55.6	58.6	43.5	47
	I_s [A]	0.027	0.028	0.027	0.029
	P_o [W]	3	3	3	3
	P_s [W]	1	1	1	1
	cosφ	0.85	0.85	-	-
	PF	0.65	0.65	-	-
	THD [%]	67	67	-	-
CFL_18 18W, 230V 50Hz	U_o [V]	76	76	107	107
	I_o [A]	1.22	1.22	0.21	0.21
	U_s [V]	60	60	46.4	46.4
	I_s [A]	1.16	0.16	0.18	0.18
	P_o [W]	3	3	3	3
	P_s [W]	1	1	1	1
	cosφ			-	-
	PF			-	-
	THD [%]	169	167	-	-
CFL_15x 15W, 230V	U_o [V]	87	84.8	106	105.6
	I_o[A]	0.117	0.118	0.055	0.055
	U_s[V]	37	36.6	35.6	34.7
	I_s [A]	0.082	0.081	0.047	0.047
	P_o [W]	6	6	7	8
	P_s [W]	2	2	1	1
	cosφ	0.86	0.86	-	-
	PF	0.55	0.55	-	-
	THD [%]	126.5	126.5	-	-

One can observe that DC supply can dramatically improve the overall power quality, although additional studies on power quality definitions and quantitative descriptors for dc grids have to be carried out. The current waveform is very much depending on the ability of the voltage source to keep constant level. In this case, the current variations are les then 1%, as the oscillogram in Fig. 10b presents. Fig. 10a shows the current waveform as obtained with the PSpice model.



(a)



(b)

Fig. 10 The current waveform of the CFL_18 supplied with DC voltage. PSpice simulation (a) and the AC component of the measured current (b)

4 Conclusions

In this paper a CFL is analyzed by identifying its steady-state parameters from measurements performed with AC and DC supply, respectively. One reason for such a test was to determine if the use of CFLs in DC grids will eliminate the waveform distortion of the CFL current when fed by a classical AC system. The CFL's scheme was modeled into PSpice. The PSpice model was validated by matching the experimental results. With the help of this model a study can be carried out concerning the functional parameters, including protection, of a building's lighting system that uses CFLs connected into an AC or a DC distribution grid, respectively.

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