Group Led Supply with A Real Three-Phase Converter of "Boucherot" Type

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Abstract

It is represented a real three-phase converter of "Boucherot" type for applications in indoor lighting installation with non-variant constant current supply of a group of luminaries connected in series to the output terminal of the converter. It is preset a regime of the light sources in the luminaries for work with similar current, independent of their number, with non-variant alternating voltage supply. The required inductance and capacitance of the converter for achieving the required steady-state values of the phase current and the light sources' current are chosen under ideal conditions. The researched model is with specified LED luminaries and the received output properties are defined with registering of the resistance of the circuits and the non-linearity of the reactors, realized with ferromagnetic core. The received results for the real three-phase converter of "Boucherot" type for group supply of LED light sources are analyzed.

Keywords: three-phase "Boucherot" converter; stable constant current; series circuit; LED.

Introduction

The modern tendencies in the lighting technology are for realization of the lighting installation with energy-efficient luminaries and supplying devices. Special object of interest is the reconstruction of present conventional lighting installations with more effective their alternatives. The complete reconstruction, offering a solution with new geometry of the installation, is connected with big investments. They can be reduced by:

- saving the present geometry of the lighting installation;
- using existent cable traces and/or connections.

In the present consideration the following problems state:

1. Replacement of luminaries with last generation halogen filament lamps with higher efficiency in a typical foyer [1] with modern luminaries, constructed with group glass optics at the same geometry and fulfilling the standard"s requirements for lighting in that kind of rooms;

2. Designing of a group supplying device for the used LED luminaries with a converter of "Boucherot";

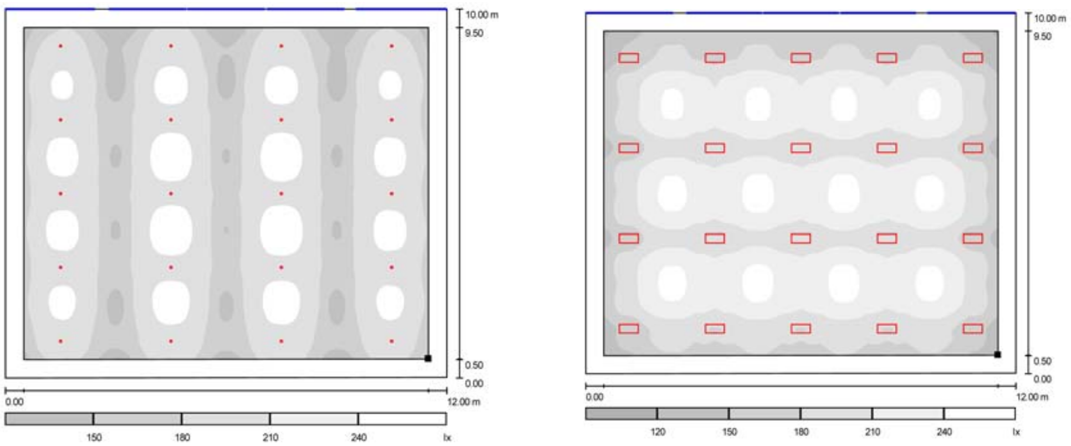
3. Mathematical modeling of the supplying device, made with real components, and its working characteristics.

Analysis of the working regimes of the device based on received results of a laboratory model and the conditions for constructing a real industrial sample are defined.

Expose

The foyer premise taken into consideration is with area 120m^2, height 3.6m, height of the working plane 0.75m and required average illuminance [2] 200lx, UGR<22, as the standard requirements for uniformity of the illuminance are fulfilled and the characteristics of the reflective surfaces are read. The received lighting calculations for both realization variants are shown on fig. 1.

The applied luminaires are with high efficiency light sources – halogen filament lamps last generation and power light emitting diodes (LED-s) with luminous efficacy 100 lm/W at 350mA working current (Rebel ES, Philips). The LED-s work at 700mA (due to the costruction solved heat dissipation system), which allows reducing the number of the elements (with lower luminous efficacy per 1W) and competitive prices for LED luminaire.



a) *b)*

Fig. 1 a) Realization with halogen filament lamp lumaire with infrared reflecting film 50W, 12V, η_o=29,48 lm/W; b) realization with LED luminaires with group glass optics and individual power supply 21W, η_o=42,86 lm/W

Note: η_o – luminous efficacy of the lumaires.

The groups of LED luminaires are controlled per rows dependent on the daylight factor [3]. For the concrete geometry both groups consist of 2 rows per 5 luminaires, which are supplied via real three-phase converter of “Boucherout” type with the scheme, shown on figure 2. It is constructed with three singe phase converters, supplied via symmetrical three phase voltage source. To it’s out is connected two-way rectifier.

The symbols on the scheme are as it follows:

U_R, U_S, U_T – three phase supply, V;

L_{1R}, L_{2R}, L_{1S}, L_{2S}, L_{1T}, L_{2T} – three sets of identical reactors with ferromagnetic core, air gap and magnetic coupling between them m=1, H;

C_R, C_S, C_T – three identical capacitors, F;

J – three-phase two half-way rectifier;

n LED - load consisting of n LED luminaires;

I_{1R}, I_{2R}, I_{1S}, I_{LS}, I_{LT}, I_{LT} and I_{L0} – currents, A.

The project of three phase converter is realized on two stages [4]:

In the first stage are defined:

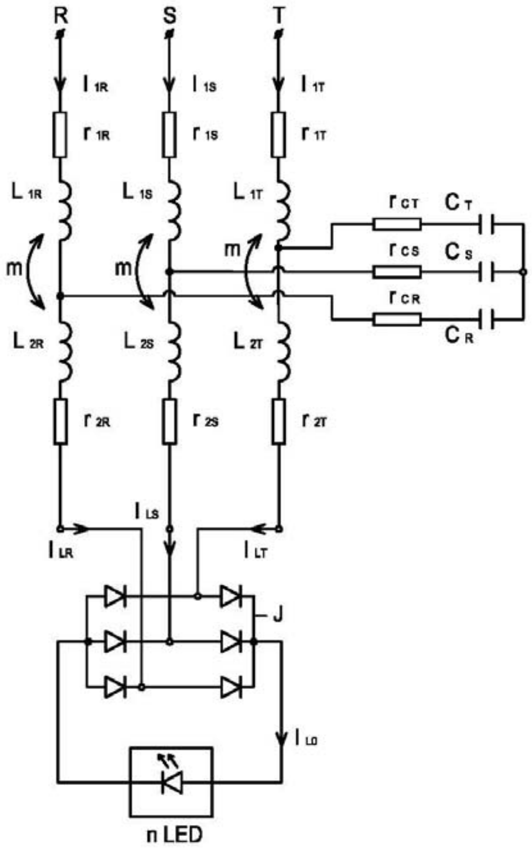


Fig. 1 Three phase converter for constant current load with independent reactors

- The necessary nominal data for the load according to a given function of the load current $i_{L0}(t)$;

- $I_{eff\ L0}$ at this function;

- The equivalent effective values of the phase currents $I_{eff\ LR}$ at given values for I_{effL0}, multiplied with numerical working coefficient k_{ph}.

The parameters of the phase converter are calculated.

In the second stage after defining the parameters of the phase converters it can be proceed to mathematical modeling of the three phase converter and the LED modules.

In the constructing of the real model of the three phase converter of "Boucherot" type the following proceedures are used:

- For modeling of the reactors with air gap – an existing curve-fitting function for their charachteristic of saturation magnetization, received from eksperimental data;

- The capacitors take part with their active resistance;

- The rectifier is with real parameters from catalogue data of the manufacturer;

- The LED modules are with V-A charachteristic for the real luminaire construction from catalogue data of the manufacturer.

For the specific case the following initial conditions are given:

- Load, consisting of 10 LED luminaires with per 7 LED-s Rebel ES each, all connected in series;

- Effective load current $I_{eff\ L0} = 0,7A$;

- To receive a stable load current with its given nominal value from the real laboratory model, realized with given elements with their characteristics a correction of the supply voltage is made. The preliminary analysis shows, that the required regime is achieved at effective phase supply voltage *241V* with frequency *f=50Hz*.

1. Defining of the quantities of stage 1:

1.1. From the preliminary analysis is defined, that $k_{effph} = \sqrt{\frac{2}{3}}$ at a given load current and $k_{effph} = 1{,}11 * \frac{2}{3}$ at a given average load current, respectively:

(1) $$I_{effLR} = \sqrt{\frac{2}{3}} * I_{effL0}\ ; \qquad I_{effLR} = 1{,}11 * \frac{2}{3} * I_{avgL0}$$

1.2. From the condition for receiving a current source for each of the converters [4, 5],

(2) $$j(x_{1R} - x_{CR}) = 0;\; x_{1R} = x_{CR};\; \omega L_{1R} = \frac{1}{\omega C_R},$$

The parameters of the single phase converter are:

(3) $$x_{L2R} = x_{CR} = x = \frac{U_{ph}}{(m+1) I_{effLR} k_c} = 211.5\Omega;$$

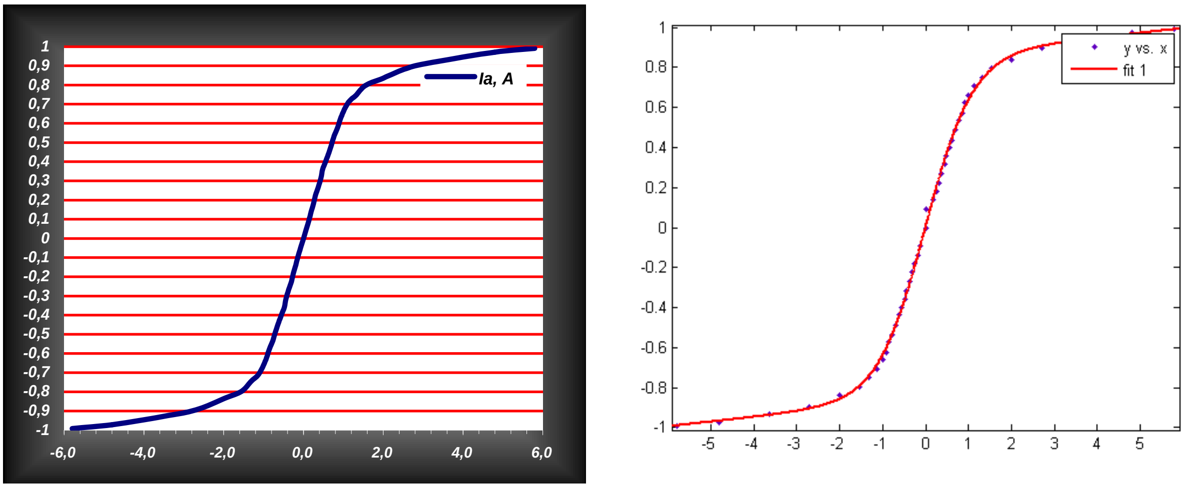
$$L = \frac{x}{\omega} = 673mH; \qquad C = \frac{1}{\omega x} = 15\mu F,$$

where the correction coefficient k_c is defined from the characteristics of a real laboratory converter.

2. Modeling of the real elements, parts of the scheme.

The realization of the mathematical modeling is realized with standard programs ORCAD PSpice and Matlab with the required supplements.

2.1. For the considered case are given the same initial quantities as the reactor is with experimentally defined characteristic $\Psi_{L21}(i_{L21})$ and $\Psi_{L22}(i_{L22})$, shown on fig. 2.



a) b)

Fig.2 a) experimentally received characteristic of the reactor;
b) calculated characteristic, received by mathematical modeling

For correlation of the magnetic induction of the core on fig. 3 is shown it's equivalent characteristic of magnetization $B=f(H_{eq})$ with figuring on the air gap, which is 0,1mm and it's real size.

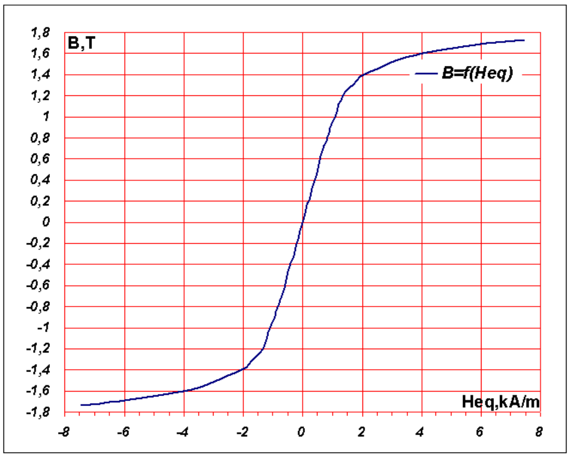
Ferromagnetic core reactors are modeled with curve-fitting function [5] with the following expression:

(4) $\psi_{L1} = \psi_{L2} = f(i_2) =$ a*tanh((b*x)/a)+c*x=a*tanh((b*i_2)/a)+c*i_2 ,

where a = 0.8809; b = 0.7947; c = 0.02383.

2.2. The capacitors are with active resistance $r_c = 1.34\ \Omega$.

2.3. For modeling of the real neutral-white and cool-white Rebel ES LED-s is used an existing program algorithm in ORCAD PSpice, as the V-A characteristic shown on figure 4 is set for Thermal Pad temperature = 25° C.



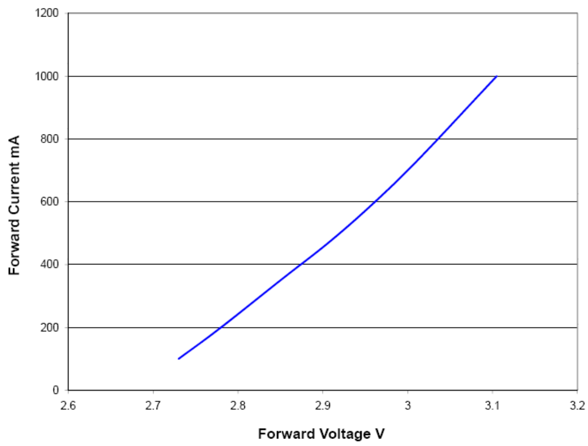


Fig. 3 Fig. 4

The numerical characteristics for ideal constructive elements (without active resistances and non-linearity) and the received with mathematical modeling give for steady-state regime the results shown on fig. 5 and 6:
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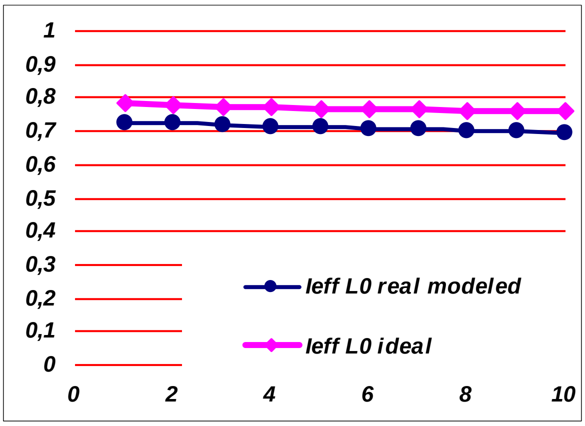

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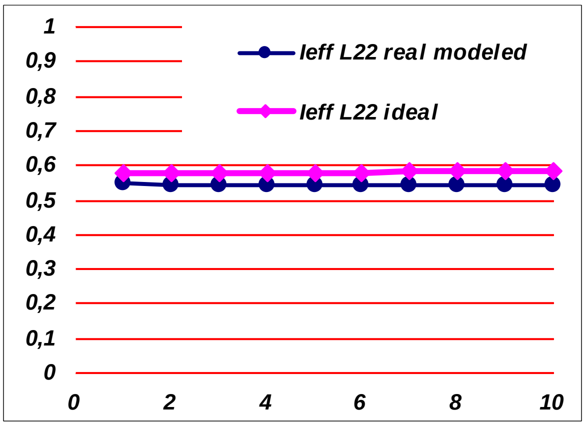

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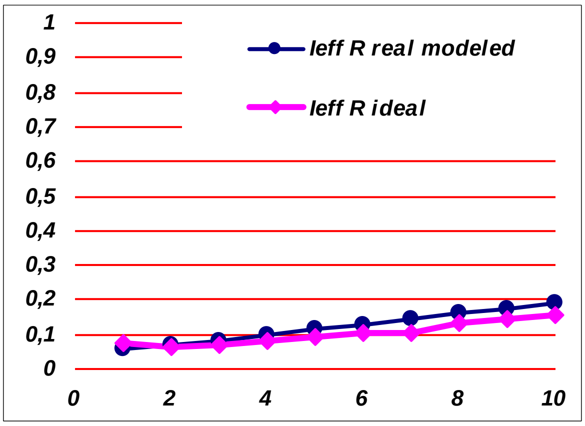
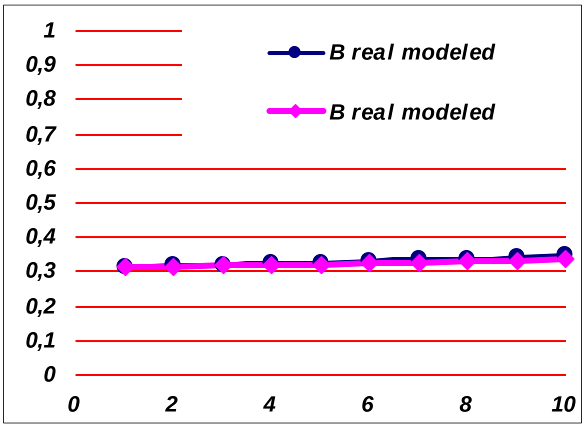
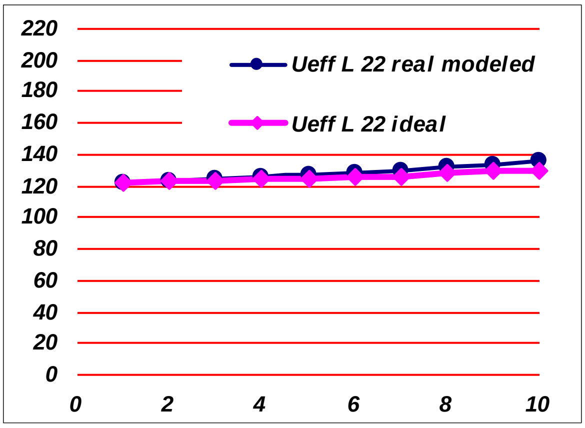


c)

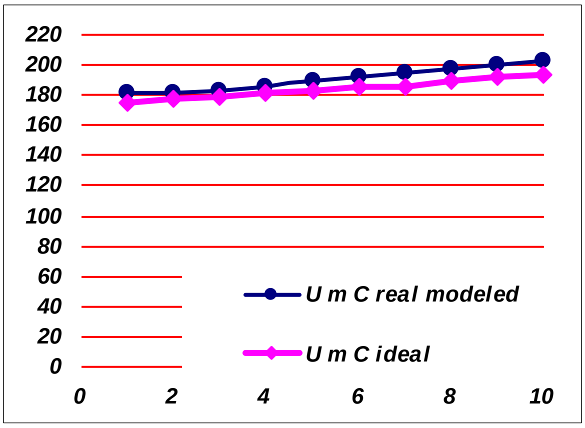


d)

Fig. 5 a) $I_{eff\ LO}$=f(nLED), A; b) $I_{eff\ L22}$=f(nLED), A; c) $I_{eff\ phR}$=f(nLED), D; d) B= f(nLED), T;



a)



b)

Fig. 6 a) $U_{eff\,L22}$=f(nLED), V; b) $U_{m\,V}$=f(nLED), V

The explored models with the produced reactors in the examined load range operate with magnetic inductances of the magnetic core, defined from fig. 3 and figure 5d) and show that with maximum load the saturation limit of the magnetic core material is not reached.

Conclusion

With the examined methodology of projecting is realized three-phase converter with out-going characteristic of a current source and can be defined one-valued all nominal parameters for constructing the reactors and for choosing of the capacitors.

With real constructive elements and figuring on the active resistance and the non-linear characteristics of the reactors with ferromagnetic cores are received methodology errors which can be reduced to acceptable minimum limits.

As it can be expected with increasing of the magnetic inductances in the magnetic cores, the end errors for maximum load voltages, connected to the out of the converter, increase. The upper limit of these voltages is limited from the material saturation limit.

At minimum load regime of the three phase converter the current to the supplying source is relatively bigger from the current of a single phase converter and with zero load becomes minimum, but not equal to zero. This obviously is due to increasing the influence of harmonics, which appear as a result of joint operation of the three-phase rectifier, the reactors and the capacitors.

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