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Properties of high-pressure sodium lamp by different supply methods

Streszczenie. *W artykule przedstawiono charakterystyki prądowo – napięciowe oraz przebiegi czasowe prądu, napięcia i mocy wysokoprężnej lampy sodowej przy zasilaniu z sieci elektroenergetycznej ze statecznikiem indukcyjnym oraz przy zasilaniu poprzez falownik wymuszający prostokątny przebieg prądu. Przedstawione wyniki mogą być przydatne przy projektowaniu nowych konstrukcji układów zasilających wysokoprężne lampy sodowe (**Właściwości wysokoprężnej lampy sodowej przy różnych sposobach zasilania**).*

Abstract. *This article presents current-voltage characteristics and waveforms of instantaneous values of current, voltage and power of the high-pressure sodium lamp when it is powered from the mains with inductive ballast or from inverter by force rectangular current. The presented results may be useful for designing a new construction of high-pressure sodium lamps.*

Słowa kluczowe: wysokoprężna lampa sodowa, statecznik energoelektroniczny.
Keywords: high-pressure sodium lamp, electronic ballast.

Introduction

In recent years there has been a dynamic development of light sources, especially LED light sources. Typically, the light efficiency of LED lamps does not exceed 100 lm/W, although the efficiency of 300 lm/W has been achieved (already in 2014) [1]. However, sodium and metal halide high-pressure discharge lamps remain attractive as high-efficiency light sources. According to [2, 3] the light efficiency of the high-pressure sodium lamps (HPS) reaches 150 lm/W and is comparable with the luminous efficiency of commonly used LEDs. The literature on high-pressure discharge lamps (sodium and metal halide) and their control methods is rich. Overview of the commonly used methods and control systems is shown, inter alia, in the following references [4 - 12]. Recently, special attention has been paid to systems in which the high intensity discharge (HID) lamp is powered by a rectangular current wave [6-12]. Typically, this power supply consists of components: a PFC forming a sinusoidal supply current [7-12], a step-down converter working as a DC source and an inverter generating a rectangular current wave at the output with frequency several hundred, typically 200 Hz. Some control systems have the ability to adjust the luminous flux by changing the current value [13, 14].

Methods of supplying high pressure sodium lamps

Figure 1 shows diagrams illustrating how to power high-pressure sodium lamps. In the classical arrangement (Fig. 1a), the so-called "inductive ballast" is used to limit the current (choke with a core made of transformer steel sheets). Due to the presence of the choke, it is necessary to compensate the reactive power, using the capacitor connected from the power supply side.

Drawings 1b and 1c show diagrams illustrating the power electronics supply systems of sodium or metal halide lamps (HID) [9-12]. The system includes components such as: EMI (radio frequency disturbance) filter, PFC (power factor corrector) and inverter. In the circuit of Figure 1b, the rectangular wave of the output current is shaped by an inverter. In spite of the fact that the inverter shapes the current wave of frequencies of several hundred Hz, the transistors of this inverter switch with frequency of several dozen kilohertz. In addition, the coil that restricts the ramp of rising or falling of the current is located at the output of the inverter.

In the circuit shown in Figure 1c, current wave is forming by means of an additional step-down DC/DC converter. The transistors of the inverter switch only with a frequency of several hundred Hz (eg. 200Hz) while the transistor in DC/DC converter switches with a frequency of several tens of kilohertz. In this arrangement the choke which limits the rise / fall of the current is located at the output of the DC/DC converter (at the input of the inverter).

The arrangement of Figure 1b has a simpler structure in

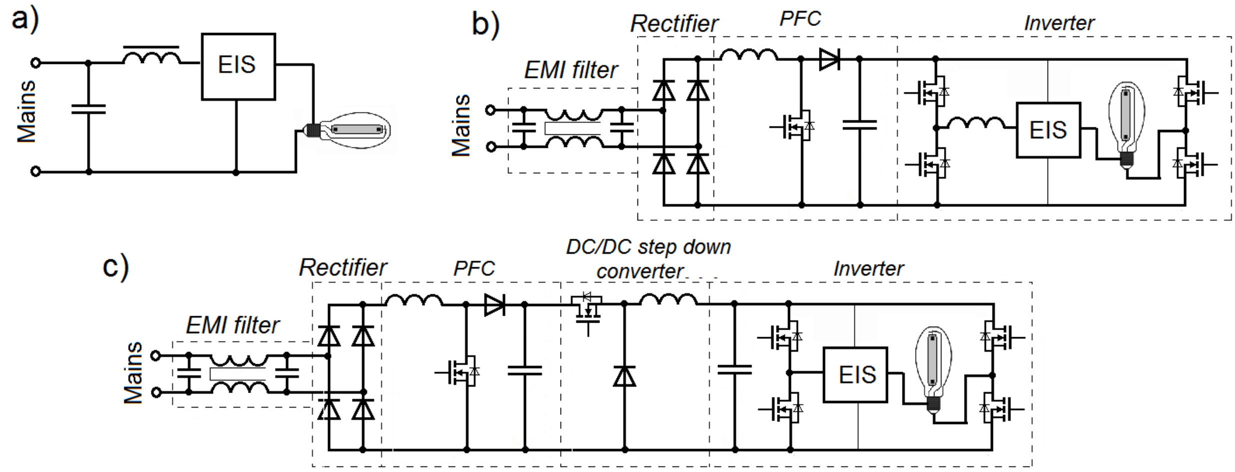
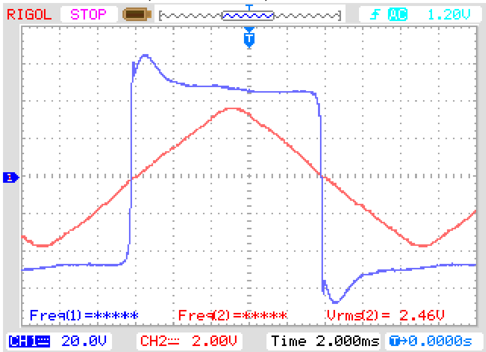


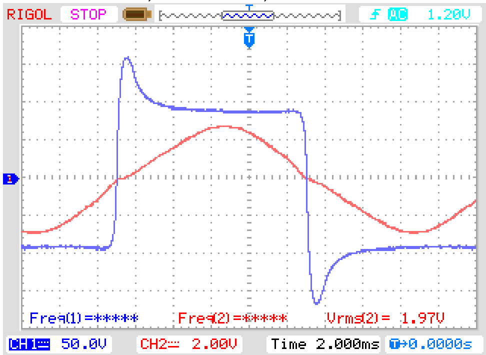
Fig.1. Schemes illustrating the methods of supplying high-pressure sodium lamps: a) classical system, with inductive ballast, b), c) systems with an electronic power converter; (EIS - electronic ignition system)

comparison to the system of Figure 1c, while slightly more complex control algorithm. Due to the wide range of commercially available specialized integrated circuits designed to control elementary converters (PFC, DC/DC, inverter), the layout of Figure 1c is often selected for the implementation. Each of the power supply for high-pressure discharge lamps is equipped with an electronic ignition system (EIS). The structure of the ignition system from Figure 1a differs from that from the drawings 1b and 1c.

a) CH1 u 20 V/u, CH2 i 2A/u, t 2ms/u



b) CH1 u 50 V/u, CH2 i 2A/u, t 2ms/u



c)

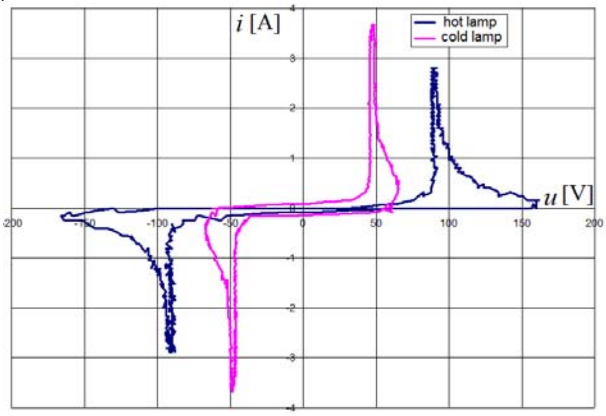


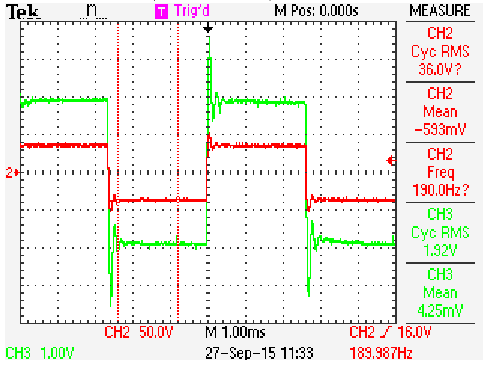
Fig. 2 Current and voltage waveforms of the lamps Master Son-T (PIA Plus 150 W) when it is powered from mains: a) cold lamp, a few seconds after power on, b) hot lamp, steady state, c) trajectories i = f (u) for the waveforms from Figures a) and b); The voltage is fixed after approx. 2 ms since the change of current direction

Selected research results of high-pressure sodium discharge lamp

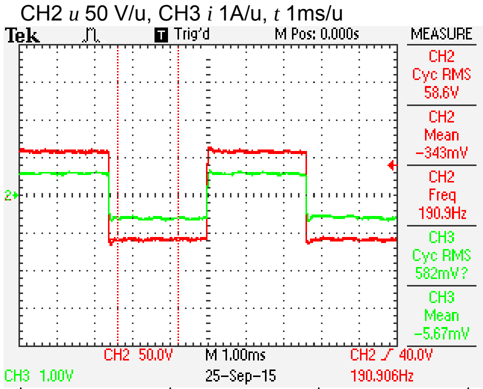
Figure 2 shows waveforms of current and voltage of the lamp Philips Master Son-T PIA Plus, with a power rating of 150 W (I_N = 1.8 A, 17500 lm, 110 lm/W, 2000K) when it is powered by the power grid through ballast inductor [14].

Waveforms and the corresponding current-voltage trajectories show that in each half-cycle of the current flowing through the lamp (after ignition) it behaves as a voltage source. The voltage waveform has a constant value (positive or negative) from the moment of ignition to the discharge end. The value of this voltage depends on the temperature of the lamp, which is a function of the power.

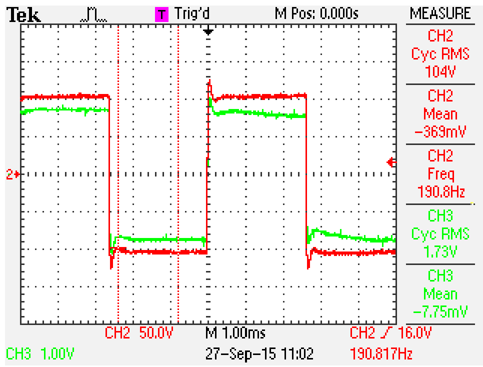
a) CH2 u 50 V/u, CH3 i 1A/u, t 1ms/u



b) CH2 u 50 V/u, CH3 i 1A/u, t 1ms/u



c) CH2 u 50 V/u, CH3 i 1A/u, t 1ms/u



d)

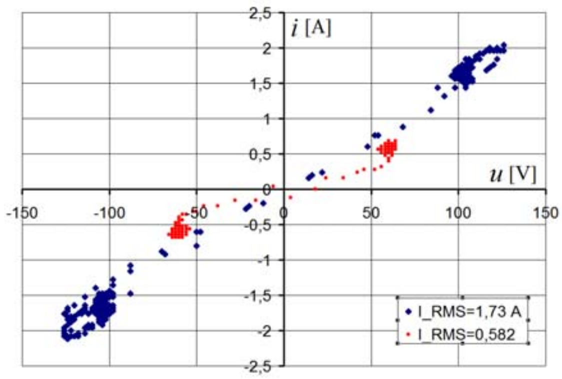
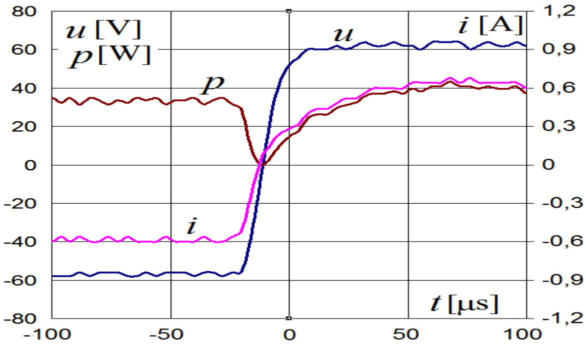


Fig. 3 Current and voltage waveforms of the lamps Master Son-T (PIA Plus 150 W) when it is powered from inverter by the current of a rectangular waveform: a) cold lamp, b) hot lamp in steady state, I_{RMS} = 1.73 A, c) trajectories i = f (u) for the waveforms from Figures a), b) and c)

Figure 3 shows the oscillograms of current and voltage of the same lamp when it is powered from an inverter (designed and built by the author [14] based on Figure 1c), which forces a rectangular current waveform.

Figure 4 shows the instantaneous values of current, voltage, and power of the lamp in the extended time scale, corresponding to those in Figures 3b and 3c. Voltage and current are rectangular waveforms, but the voltage is established after several tens of microseconds (Figs. 3b, 3c, 4a, 4b), so several dozen times faster than in Figure 1. The discharge in the lamp is practically not quenched what is shown by the trajectory of the Figure 3d. Taking into account the above described phenomena, the stroboscopic effect is unnoticeable when a discharge lamp is powered using the converter.

a)



b)

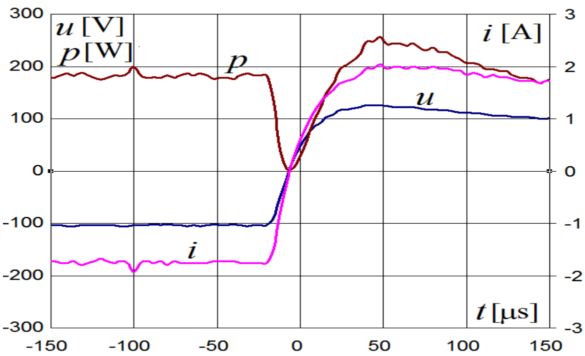


Fig. 4. Current, voltage and power waveforms of the lamp when it is powered from the inverter with rectangular current - hot lamp in steady state: a) I_{RMS} = 0.58 A, b) I_{RMS} = 1.73 A

The supply of the HID lamp by the inverter makes it easy to adjust the lamp power by means of pulse width modulation (PWM). The waveforms in Figure 3 were obtained by changing the modulation factor of control signal of the DC/DC converter (witch work with frequency of several tens kilohertz). Power regulation was obtained in range from about 34 W (Figure 3b) to approx. 180W (Figure 3c) at voltage and current of 104 V, 1.73 A $< I_N$ = 1.8 A. During power-up, voltage and current were: 36 V, 1.92 A (Figure 3a).

Figure 5 shows the characteristics of the effective value of the lamp voltage U, power P, and U / I quotient (static resistance) as a function of the effective value of rectangular lamp current. Pay attention to the variation of the static resistance of the lamp as a function of its current (or as a function of power). For the lamp under test, the static resistance varies between about 110 and 60 Ω with increasing the current (power). The dynamic resistance (du/di) remains much smaller for the given power, as shown by the oscillograms in Figure 2 (currents and voltages after ignition).

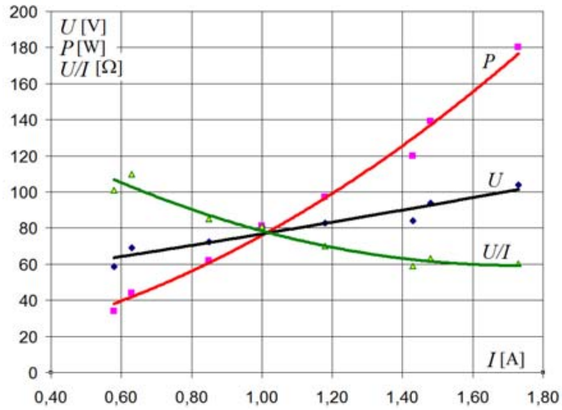


Fig. 5. Characteristics of the effective value of the lamp voltage U, power P, and U / I quotient (static resistance) as a function of the effective value of rectangular lamp current

Figure 6a shows a view of a prototype of the converter system for supply a high power sodium lamp. This layout was used for registration these oscillograms, which are listed above. The thermogram (Fig. 6b) registered during operation of this circuit shows that the losses of energy in certain components should be reduced. This prototype was used to design a fully functional device that could be produced industrially.

a)

b)

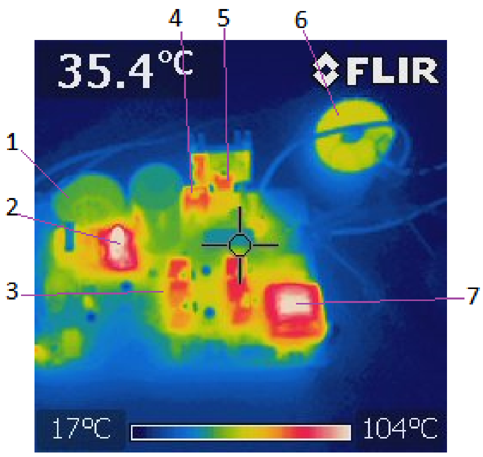


Fig. 6. View of the test board for feeding the high-pressure sodium lamp (a) and its thermogram (b); 1, 6 – chokes, 2 - NTC thermistor, 3, 4, 5 - power semiconductors, 7 - ignition transformer

Conclusions

1. The article presents waveforms of current, voltage and trajectories $i = f(u)$ of high-pressure sodium lamp at various power supply methods. Significant differences in the control method have been shown, for example there is practically

no stroboscopic effect when the lamp is powered by current which has a rectangular shape. This is related to continuous, strong gas ionization. Under these conditions, the ignition and setting of the instantaneous voltage in the hot lamp occurs several times shorter than when supplied from the mains via the choke ballast (Figures 2 and 3).

2. The described layout was designed and built in accordance with Figure 1c, using commercially available specialized integrated circuits. Each of the elementary converter had a separate integrated control circuit. The setting of the lamp current can be performed by setting the internal or separated external PWM signal.

3. Supply of the discharge lamp through the inverter has enabled the control of lamp power in a wide range, from about 34 W to 180 W (rated power is 150W) without exceeding the rated current of the lamp. In this case, the current value of the rectangular waveform was given. When using an external, master control the controlled value could be, for example, power.

In the near future, the author plans to carry out further comparative studies (eg illumination and spectrum of different types of lamps) using magnetic and power electronics ballasts.

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