EFFECTIVE ELECTRICAL LIGHTNING SYSTEM

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Abstract. Essentially the widely used incandescent lamps are good heaters, but a very uneconomical light source, as only 10-12 % of the consumed energy is converted to light. Therefore, according to the programs of resource saving the production of incandescent lamps has been fully or partially halted in the EU, USA, Canada and other countries. Wherewith more attention has been paid to special energy effective light bulbs with electronic ballast. Though, this type of light source still could not get into market widely because of its expensiveness. Accordingly it is absolutely reasonable to focus on improvement of tube-type low-pressure gas discharge (fluorescent) lighting installations, which are 4 – 5 times cheaper, as much economic as the economic light bulbs mentioned before and successfully approbated in practice. In this aspect the ballast-less fluorescent lighting installation developed by authors and designed to operate in an artificially created 3-phase fault situation has been discussed in this article.

Key words: fluorescent lamp, ballast choke, neutral point displacement voltage

Introduction

However, lighting installation with fluorescent lamps (FL) on standard constructive setup at defined operational modes has the following drawbacks [1].

The glass bulb of a lamp filled with gas has very low electrical impedance; therefore it should be used only with a series-connected inductive ballast choke (BC). Otherwise it will momentary burn out under voltage. Consequently BC is an integral part of standard circuits of fluorescent lamps and performs the following functions:

1. creates high self-induction voltage at the moment of starter closed contact breaking, thus ensuring reliable start-up of the lamp;
2. after starting the lamp the choke serves as an inductive ballast impedance and limits current flowing through the lamp.

However, BC has also several disadvantages:

- in the coils of BC about 20-25 % of active power is necessarily lost;
- low natural power coefficient ($\cos\varphi = 0.5$) forms a major part of the total electrical power consumption. Therefore special capacitors, which compensate the inductance of choke, should be used in the circuit of the lamp.

This reduces both energetic and economical effectiveness of fluorescent lamps.

In order to eliminate these drawbacks an innovative technological solution has been applied [2]. In a 3-phase four-wire system one phase line is removed and FL is connected in the neutral line. The operation of such circuit in theory can be described as follows [3]. The electrical load is distributed unevenly on the two remaining phases, which causes neutral point displacement voltage to appear at the ends of discontinuous neutral line. The voltage is high enough to start the FL momentarily (Equation 1).

$$U_{neutr} \geq U_{start} . \qquad (1)$$

This way the first function of BC is substituted.

According to the known formula of electrical engineering [3] the current flowing in the neutral wire and also in the bulb of FL is the geometrical sum of separate phase currents and with defined level of asymmetry of loads it is a constant value (Equation 2).

$$\dot{I}_o = \dot{I}_a + \dot{I}_b = const . \qquad (2)$$

Thus the second current limiting function of BC after FL start-up is complied. The natural power coefficient $\cos\varphi \approx 1$ in this case [4]. And it follows that FL can be operated without ballast and compensating capacitors in such circuit thus giving a significant economical effect. Moreover, the light intensity of FL is increased, as there is no voltage drop in the ballast [4]:

$$H = \frac{F}{P} \ . \tag{3}$$

The light intensity is the ratio of effective flow of light $F(lm)$ to the total power in the electrical circuit $P(W)$.

The circuit is shown in Figure 1. The neutral point displacement voltage between the points N and n turns on the fluorescent lamp 6 by help of the starter switch 3. In accordance with equation (2) the fluorescent lamp continues to light normally under nominal values of current I_n and voltage U_n and without BC and compensating capacitors.

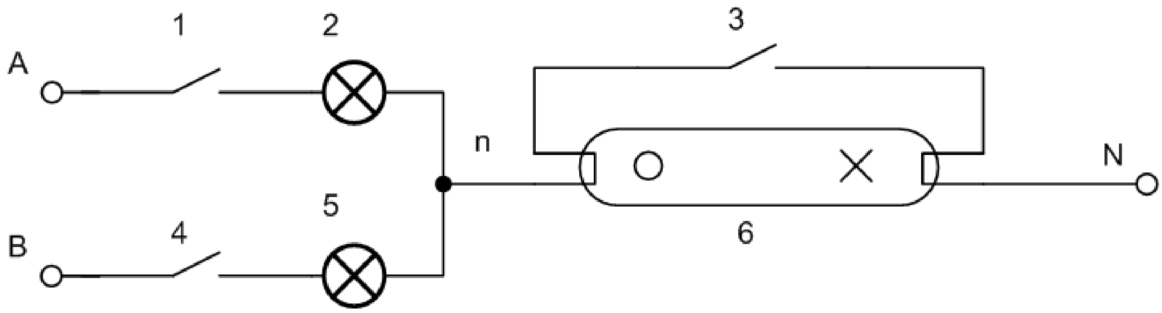

Fig. 1. **Electrical circuit of FL and incandescent lamps** (1, 4 – single pole switch; 2 – incandescent lamp of higher power; 3 – starter switch; 5 – incandescent lamp of lower power; 6 – fluorescent lamp of small power; A, B, N – two phases and neutral of electrical grid; n – common point of lamps)

It is purposeful to use such circuit in a combined lighting system where in accordance with the existing rules of exploitation of electrical equipment [5] it is allowed to operate FL in local lighting 6 only in combination with incandescent lamps of common lighting 2 and 5. By using of circuit in Fig. 1. it is also possible to perform modernization of the existing electrical installations of combined lighting (FL's and incandescent lamps).

However, this circuit also has certain disadvantages. In order to start high power FL, incandescent lamps with accordingly higher power difference should be used. But this in its turn can cause lower power lamp voltage drop that is higher than nominal (220V) and may lead to burn out of the lamp. Therefore use of this circuit is limited.

Figure 2 shows a circuit, which eliminates these drawbacks.

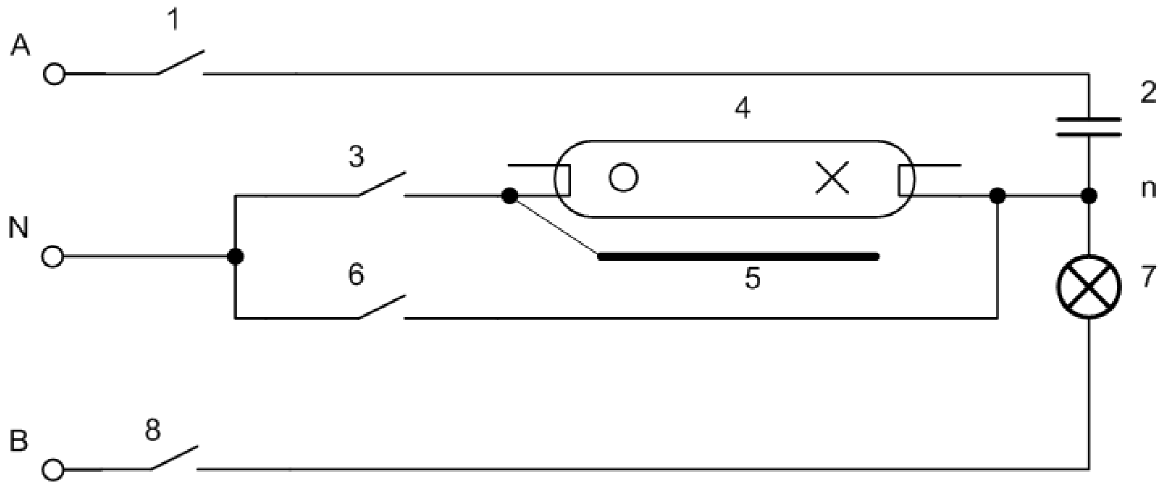

Fig. 2. **Circuit with capacitor and incandescent lamp** (1, 3, 6, 8 – single pole switch, 2 – capacitor, 4 – high power FL, 5 – additional electrode, incandescent lamp)

The low power incandescent lamp has been replaced with a capacitor 2 of appropriate capacitance and voltage that exceeds phase voltage a number of times in this circuit. It allows to increase the neutral point displacement voltage to the level of the starting high power fluorescent lamp 4 (e.g., 40..80 W).

Increase of neutral point displacement voltage also allows to start FL with cold electrodes, in other words, the circuit can be used without an electrode-heating starter thus simplifying the circuit and increasing reliability of the lighting system. It also becomes possible to operate FL with burned out thread of one of the terminal electrodes using this configuration. In this case an additional electrode 5 should be placed on the surface of the light bulb. A metallic spiral or band can be used [1, 4].

The capacitor used allows not only to create the necessary conditions of starting of FL's, but also improves the power coefficient of the overall system and results in the economy of electrical energy. Besides, the capacitor as a capacitative reactive impedance causes the third harmonic, which triples the frequency of the current flowing in FL and additionally improves operation of the lamp.

In a local case the circuit can be used with contacts 6, 8 shorted and 1, 3 open, which will result in operation of incandescent lamps only.

The technical solution described in [18] can be applied to FL's with high levels of starting voltage or with terminal electrodes burned out. It relates to the use of voltage doublers and a circuit for this case is shown in Figure 3.

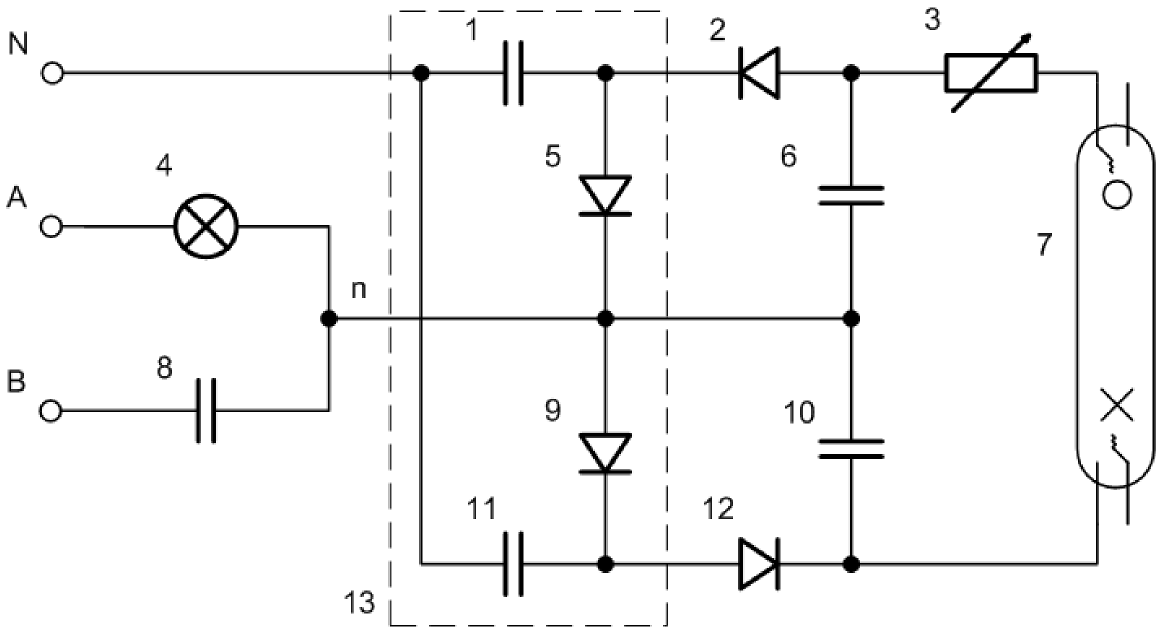

Fig. 3. **Circuit with burn out terminal electrodes of FL** (1, 6, 10, 11 – capacitors; 2, 5, 9, 12 – diodes; 4 – incandescent lamp; 8 – grid capacitor; 3 – adjusting rheostat; 7 – fluorescent lamp; 13 – voltage doubler; A, B, N – two phases and neutral of electrical grid)

Results and discussion

In order to illustrate the functionality of ballast-less installations of fluorescent lamp lighting systems an experiment was carried out. A circuit shown in Figure 2 was assembled.

The used parts:

- fluorescent lamp “Pila”, nominal power $P_n = 40\ W$, current $I_n = 0.41\ A$, voltage $U_n = 108\ V$;
- incandescent lamp with nominal power $P_n = 100\ W$;
- capacitor with capacitance $C = 0.5\ \mu F$;
- phase voltage of electrical grid $U_p = 228\ V$.

As it can be seen from the results of the experiment (Table 1) the operating parameters of the FL are close to the nominal values. More adequate operating parameters can be easily achieved by adjusting the characteristics of incandescent lamps and/or capacitors.

Table 1

Results of the experiment

Quantity	Designation	Value	Units
Starting voltage	U_{start}	234	V
Operating voltage	U_o	111	V
Operating current	I_o	0.34	A
Power	P	38	W

In order to prove the deviation of the experimental results calculation has been performed according to the formulae in the complex form [2-3, 15, 17], argument of which gives the numerical value of the examined parameters.

Starting voltage of FL:

$$\dot{U}_{start} = \frac{y_a \dot{U}_a + y_b \dot{U}_b}{y_a + y_b}, \tag{4}$$

where $\dot{U}_a = 228\ V$ – phase A vector,

$\dot{U}_b = \dot{U}_a e^{-j120°} = 228(-114 - j197.45)\ V$ – phase B vector.

The conductivity of phases y_a and y_b was determined in experimental way before starting up the fluorescent lamp:

$$y_a = \frac{I_a}{U_a}, \tag{5}$$

$$y_b = \frac{I_b}{U_b}. \tag{6}$$

Operating voltage of FL after starting:

$$\dot{U}_o = \frac{y_a \dot{U}_a + y_b \dot{U}_b}{y_a + y_b + y_0}, \tag{7}$$

where y_0 – conductivity of the bulb, which is also determined experimentally:

$$y_0 = \frac{I_o}{U_o}. \tag{8}$$

Voltage U_o and current I_o are related to the operating mode of FL and are calculated using the formulae (5) and (6).

The value of the operating current of the lamp is verified using the formula:

$$\dot{I}_0 = \dot{I}_a + \dot{I}_b\ . \tag{9}$$

where $\dot{I}_a, \dot{I}_b$ – corresponding complex phase points.

The power of the lamp:

$$P = I_o U_o\ . \tag{10}$$

The results of analytical calculations proved those obtained in the experiment (relative inaccuracy did not exceed 2.6 %).

Conclusions

1. The dominating opinion that low-pressure gas discharge lamps cannot be operated without traditional chokes or other ballasting impedances has been disproved. It is proved by

unconventional technological solutions described in this article that it is still possible if lamps are operated in artificially created fault conditions of a 3-phase electrical grid.

2. In ballast-less systems there is also no need for compensating capacitors and starters of fluorescent lamps, the lamps can be operated even with terminal electrodes burned out.
3. The use of such approach in lighting systems gives decrease of the actual cost by 50 % and gives energy economy of 25 % in comparison to traditional solutions.
4. The principle of ballast-less fluorescent lighting can be used not only in living spaces [7, 8, 15], but also in such agricultural areas as animal production [9-11], gardening [12], installations of microclimate improving the production facilities [13, 14] etc.
5. The operating capabilities of all scientific developments have been verified in laboratories of the LUA and the most significant ones were broadcasted on Latvian television [16].

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