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LED DRIVERS AND DISCHARGE LAMPS CONTROL GEARS: PRESENT STATE AND FUTURE DEVELOPMENT

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ABSTRACT

A review of up-to-date LED drivers and discharge lamps control gears is presented. Opportunities for further development are characterised. Circuit solutions are classified, and examples of principal diagrams are provided.

Key words: control gears, drivers, discharge lamps, LEDs (light emitting diodes), light sources, electric current sources, voltage sources, regulation

1. DISCHARGE LAMPS CONTROL GEARS

Depending on components, the control gears for discharge lamps may be electromagnetic or electronic.

1.1. Electromagnetic control gears (ballasts)

The control gears combine chokes, transformers, and capacitors. The current here is close to sinusoidal and alternates at the power line frequency of 50 or 60 Hertz. Electromagnetic ballasts are simple, inexpensive, manufactured for decades, and hence are highly durable.

A unified diagram of the control gear is presented in Fig.1. It comprises a coil ballast L (to stabilize lamp current), compensating capacitor C (to compensate reactive power), and ignitor (starter for fluorescent lamps, pulse-igniter for high-pressure gas-discharge lamps (mercury, sodium, metal-halide, etc.).

Average data for ballasts of various lamp types are given in Tables 1–3 in [1].

Due to its simplicity, durability, and low cost, this wiring diagram has been used to operate discharge lamps in alternate current (AC) supply lines for more than sixty years. But over the last 10–15 years electronic ballasts have provided strong competition.

Electronic ballasts

Although they are simple, durable, and low cost, electromagnetic ballasts have some disadvantages: significant weight, dimensions, power losses, as well as limited functional abilities that do not allow a light source to fit optimally with its power supply, thus making some operating and switching modes impossible. As a result, discharge lamps flicker too much (since phosphor radiation and gas discharge have low inertia, the instant luminous flux closely follows the half sine wave of an instant power of a lamp at 50 Hz frequency). Furthermore, there are problems associated with eliminating audible noise and regulating lamp current. The sinusoidal current alternating at 50 Hz frequency provided by magnetic ballast is not optimal for obtaining high values of luminous efficiency and service time. The supply of a discharge lamp by a current with rectangular shape or of higher frequency (>20 KHz) provided by an electronic ballast almost completely eliminates output pulsation and increases lamp service time. In the case of fluorescent lamps,

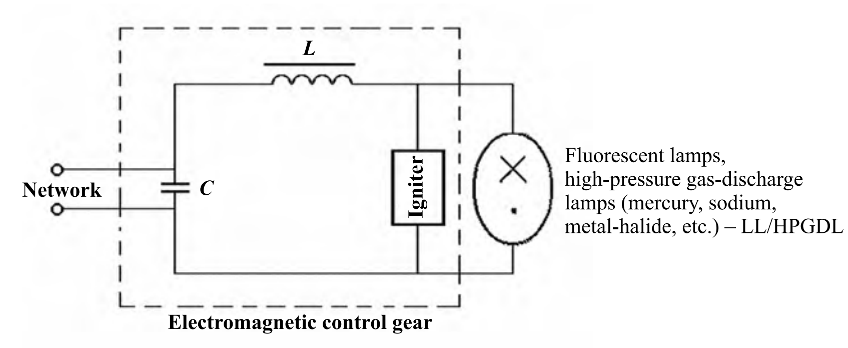

Fig. 1. Generalised scheme of electromagnetic control gears

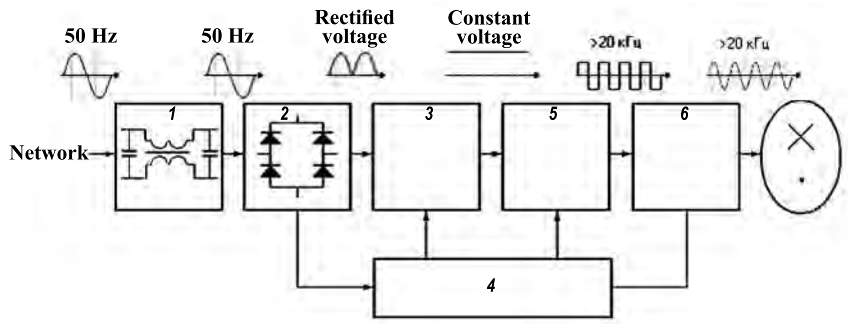

Fig. 2. Structural scheme of high-frequency electronic ballasts: 1 – radio-interference filter, 2 – rectifier, 3 – power factor corrector, 4 – control unit, 5 – inverter, 6 – output unit

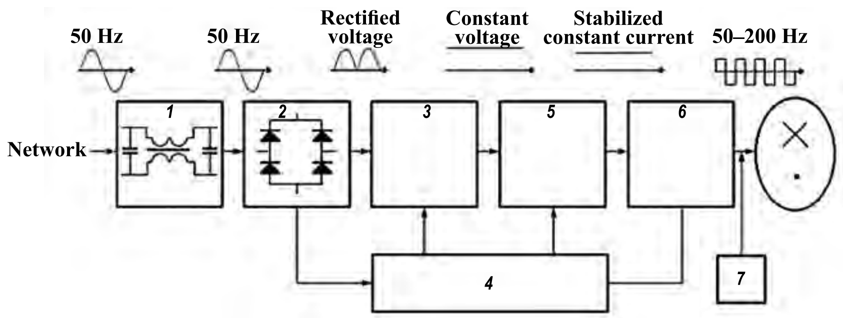

Fig. 3. Structural scheme of low-frequency gears with a rectangular shape of output voltage: 1 – radio-interference filter, 2 – rectifier, 3 – power factor corrector, 4 – control unit, 5 – current stabiliser, 6 – inverter, 7 – igniter

electronic ballast increases lamp output (efficiency) by 10–25 %.

Structural diagrams of electronic ballasts are provided in Figs. 2 and 3.

• The diagram in Fig.2 is designed mostly to feed the fluorescent lamps by high-frequency current (higher than 20 kHz). It is rarely used in HID circuits, because of the problems related to acoustic resonance. The scheme contains the following main parts.

Radio-interference filters (the П-shape or double П-shape filters consisting of chokes and capacitors) are used to suppress high-frequency noise made by electronic ballast in the mains;

Rectifier unit: this is used when the ballast operates with an AC power supply.

Power factor corrector: this is used in case of AC power supply. It provides the shape of an input current being close to sinusoidal, raises the power factor to nearly 1, and decreases harmonic distortions of input current. The active power factor correcting units, namely transistor pulse regulators based on voltage increasing or decreasing converters (Figs. 4a and 4b), are the most promising. Both schemes of correctors contain transistors *T*, diodes *VD*, chokes L, capacitors *C* and controlling integral chips (IMC) located in the control unit *4*. In addition to correcting power factor and shaping sinusoi-

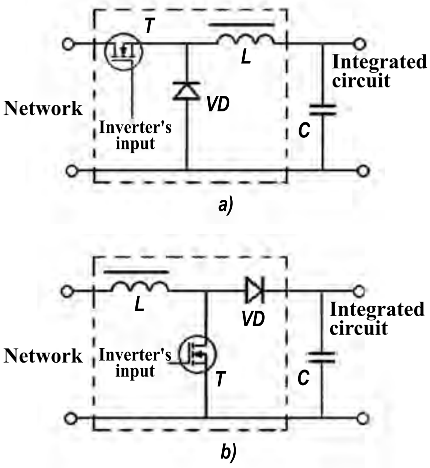

Fig. 4. Schemes of active power factor corrector based on decreasing (*a*) or increasing (*b*) pulse regulators

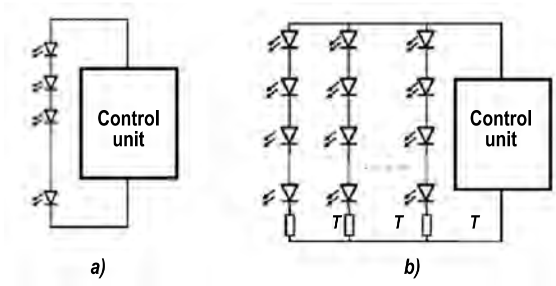

Fig. 5. Connections between LEDs and drivers

dal input current the above-mentioned schemes may stabilise and regulate a rectified line voltage.

Invertor: this is designed to invert constant voltage into alternate voltage with a frequency higher than 20 kHz (exceeding audible range). It comprises transistors **operating** in half-bridge or bridge circuits.

Control unit: usually comprises a chip that controls the transistors in both power factor corrector and inverter modes.

Output unit: adjusts output characteristics of an inverter with starting and operating characteristics of a discharge lamp. As a rule, the output unit comprises resonance LC-circuit where a choke is connected serially while a capacitor – in parallel with a lamp. In switching mode the scheme provides a start of a lamp, and in running mode – stabilisation of lamp current.

The wiring diagram shown in Fig.3 is commonly used in electronic ballasts for metal-halide and high-pressure sodium lamps. Acoustic resonance problem are overcome here by operating at frequencies “free” from that effect, namely at 50–200 Hz, that is at low frequencies. Besides, for linearisation of dynamic current-voltage characteristic of a discharge lamp a rectangular shape current is applied. In contrast to the high-frequency scheme (Fig.2) the low-frequency scheme (Fig.3) has an additional block – current stabilizer made by the scheme of a high-frequency pulse regulator, while the inverter serves to change polarity of lamp current periodically (at frequency of 50–200 Hz) so that electrodes could operate symmetrically and cataphoresis is prevented. In several cases the inverter performs the ignition function for a discharge lamp, hence a separate igniter is not required.

2. LED DRIVERS

Since the rated power of a single LED is low, light-emitting diodes are usually grouped and then

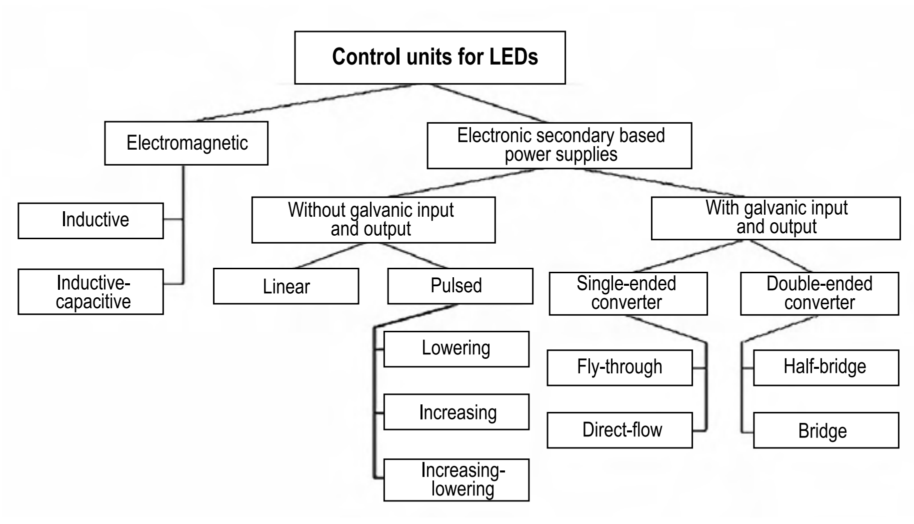

Fig. 6. Classification of LED drivers

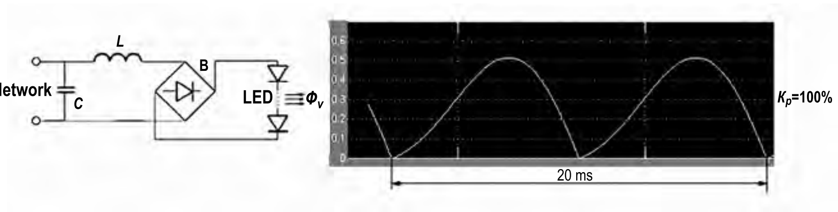

Fig. 7. Inductive scheme of connecting light-emitting diodes:
B – ballast, R – rectifier, C – compensating capacitor

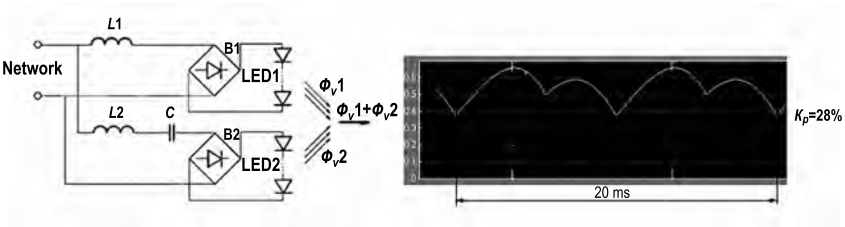

Fig. 8. Split phase scheme

connected to a driver. Options for connections are shown in Fig.5.

In the case shown in Fig.5a the LEDs are connected in series and a common current is running through them. A driver here shall have the features of a source of current. In specific cases, in order to eliminate extinction of a whole group when a single LED fails, the LEDs may be bypassed with relays (not shown in Figure) that complete the circuit when LED fails. For instance, *ON Semiconductor* active shunts may be used for this purpose [2].

In the case shown in Fig.5a several serial groups of LEDs are connected in parallel to the output of a driver. The driver here may be both the current source and the voltage source, but to balance current values in parallel circuits one shall use current limiting elements *T*. Up to 20 mA, resistors are being used for this purpose. Under higher currents it is reasonable to use linear current stabilizers (see below).

2.1. Classification of drivers

Classification of LED drivers is shown in Fig.6.

2.1.1. Electromagnetic drivers

In applications where luminous flux stability and flicker limitation are less of an issue, as well as the driver's weight, and where the major requirements are low price and high reliability – electromagnetic drivers may be used [3]. In addition to simplicity, low cost, reliability, and ability to operate under low temperatures (down to –60 °C) these drivers are environmentally friendly, since they can be totally recycled (remelted). In fact, electromagnetic drivers are just “the store of copper and steel placed at the ceiling”, while electronic drivers end up as rubbish that cannot be recycled.

An additional advantage of electromagnetic drivers is their technological succession with respect to choke ballasts for discharge lamps which are underpinned by a developed manufacturing baseline.

Electromagnetic drivers are produced in two configurations – inductive (Fig.7) and inductive-capacitive with split phase (Fig.8).

Inductive scheme provides high power factor (>0,9), but at the same time – high flickering of luminous flux (flicker factor $K_п \approx 100$ %). To reduce pulsation, the split phase scheme is used, which operates two groups of LEDs (Fig.8).

It should be noted that the optimal performance for both schemes can be reached under m = 0.67, where m is the ratio between the voltage on the LEDs chain to the mains voltage. Under this condition the power transfer from the mains to the electric load reaches its maximum and output pulsation in the latter scheme is minimal (25–30 %), while the stability factor is at an acceptable level (1,5–1,75).

2.1.2. Electronic drivers

Electronic drivers are much more widely used in operating LEDs. In fact, they represent secondary power supply sources (in accordance with the

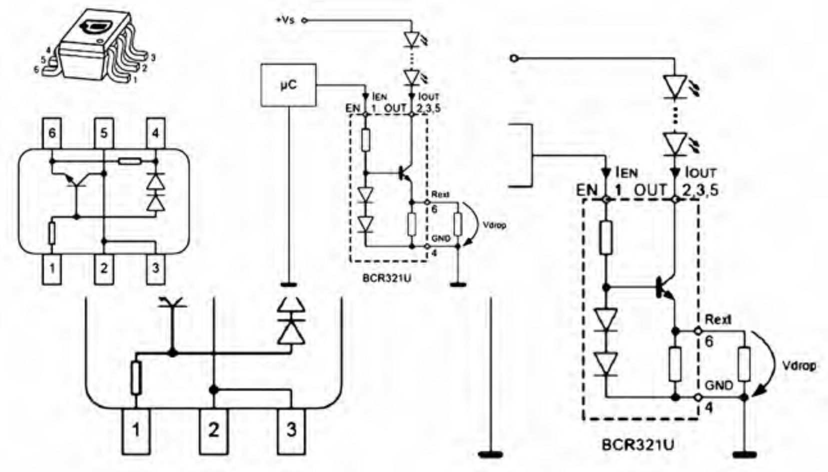

Fig. 9. Linear regulator *BCR321U*

definition accepted in converter engineering, this is a device designed to transform the electrical input of alternate or constant voltage into a power supply with requested features as an output) for operating such a specific load as LEDs.

Electronic drivers need to have functional capabilities that enable transforming power and provide optimal conditions to run and/or regulate LEDs, as well as to meet EMC (electro-magnetic compatibility) with the mains and other requirements of an end user.

Wiring diagrams of electronic drivers look very much like those for secondary power supply sources; in this way the design if the drivers reflects the achievements of contemporary converter engineering.

The most common wiring diagrams of LED electronic drivers are as follows (Fig.6).

2.1.2.1. Devices without galvanic isolation

Linear regulators are the simplest kind of electronic drivers that comprise only three elements: transistor, resistive sensor, and a source of threshold voltage. The transistor operates in an active mode and serves as a variable current-limiting resistor. It is reasonable to use linear regulators for current limiting elements *T* in LED circuits connected in parallel to the output of power supply source (Fig. 5, *b).* In this case, in addition to aligning of current levels in parallel circuits, they play two more important roles: increase dynamic resistance of LED circuits (i.e. enabling a significant decrease in the requirements to the flickering of driver output voltage), and also make it possible to provide pulse-width regulation of a current in LEDs when a relevant digital input signal is applied. Such stabilisers are designed especially for LED circuits and manufactured in series.

For instance, *Infineon* company produces linear regulators under name of «*BCR*» for currents ranging from 10 mA to 2 A (with external transistor) and voltage up to 40 V. Fig. 9 shows the view of the product and its wiring diagram. The main features of this regulator are as follows: current – up to 250 mA, voltage – up to 24 V, maximal dissipating power – 1 W, housing SC74 *with* 6 pins, pulse-width regulation when a digital signal from outer controller is applied to the input *1*.

Pulse regulators are built on a single transistor key. They are cheap, compact, and used mainly in retrofit LED lamps with a screw base.

The scheme of the most widely spread product of that kind (operating as a decreasing regulator) is given in Fig. 10. The scheme comprises radio-interference filter, rectifier, passive diode-capacitor corrector of power factor, and pulse lowering power regulator. The latter is built on the base of highly efficient and not expensive pulse width modulation (PWM) controller *Supertex HV9910* (or *HV9961*), which is able to work under a voltage range from 8 V to 450 V. Brightness constancy of LEDs is provided by a stabilised output current either by its peak (*HV9910*) or average (*HV9961*) value. The direct output current has a saw tooth high-frequency flicker (20–100 kHz), the range of which is controlled by a choke *L2* and usually taken as 20–40 %. If required, the flickering can be reduced to several percent by connecting a capacitor in parallel to LEDs chain.

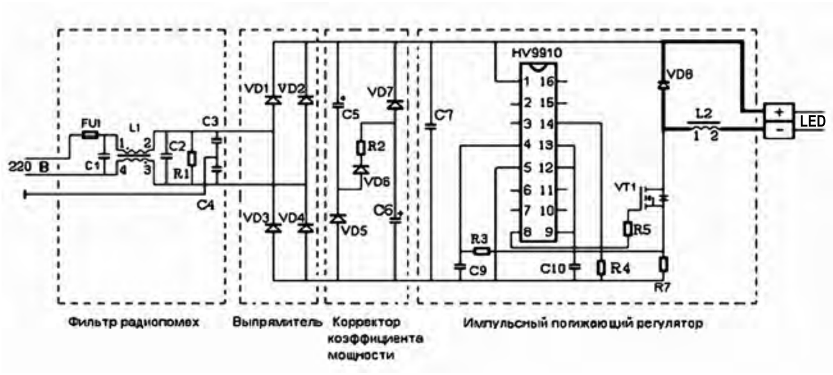

Fig. 10. Standard scheme of pulse decreasing regulators

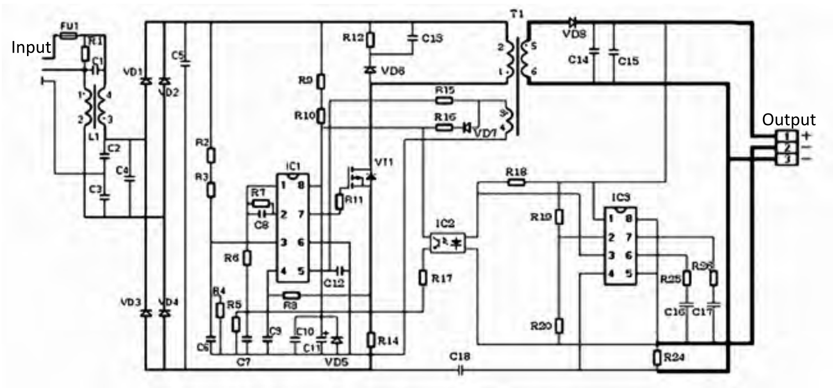

Fig. 11. Electronic ballast on reverse voltage converter

Other chips, e.g. *IRS2540* (*International Rectifier*), may be used as PWM controllers in that scheme. And active power factor corrector may be applied to provide a high power factor and a low value of harmonic distortion of a current consumed from the mains.

Electronic drivers based on pulse regulators are widely applied with a load up to several dozen Watts in condition that the galvanic separation between their input and output is not needed. In the opposite case, when galvanic separation is needed, other drivers are used, i.e. based on 1- or 2-stroke voltage converters (Fig.5).

2.1.2.2. Electronic drivers with galvanic separation between input and output

A distinctive feature of such drivers is the usage of transformers that provide galvanic separation between input and output.

One-stroke schemes are applied for powers up to 80W (*NXP Semiconductors* allows to use this kind of apparatus for powers up to 250W), and two-stroke schemes (half-bridge and bridge) shall be used for higher powers.

A device based on a reverse-stroke voltage converter, the scheme for which is shown in Fig.11 [4], is the most common product of this kind. Its scheme comprises radio interference filter, rectifier, and return-stroke voltage converter driven by a power factor controller *IC1.* This low cost 8-pin chip (*TDA4853* produced by *Infineon*) performs two important functions: first, it provides a high power factor and a low level of harmonic distortions of input current; second, depending on the type of feedback (either by voltage or load current), any output characteristic can be provided, thus a driver can be both a current source or voltage supply. To perform the second function, additional elements, i.e. current-voltage regulator *IC3* (*TLE4305 chip* produced by *Infineon)* and a decoupling optical transistor *IC2,* shall be introduced in the scheme. A signal proportional to input voltage is being delivered to the input of regulator *IC3* from a voltage divider *R19–R20*, while a signal proportional to output current is taken from a resistive current sensor *R24.* The device serves as a voltage stabilizer when a load is connected to its output terminals 1 and 3, and as a current stabiliser when connected to terminals 1 and 2.

Table 1. Power losses in ballasts for fluorescent lamps

Ballast class	Power losses, W, with lamp power		
	18 W	36 W	58 W
D	12	10	14
C	10	9	12
B2	8	7	9
B1	6	6	8

Table 2. HID ballasts parameters

<table>
<tr><th rowspan="2">Lamp power, W</th><th rowspan="2">Power losses, W</th><th rowspan="2">Power factor</th><th colspan="3">Dimensions, mm</th><th rowspan="2">weight, kg</th></tr>
<tr><th>L</th><th>B</th><th>H</th></tr>
<tr><td>70</td><td>14,2</td><td>0,39</td><td rowspan="2">111</td><td rowspan="3">66</td><td rowspan="3">53</td><td rowspan="2">1,5</td></tr>
<tr><td>100</td><td>16</td><td>0,43</td></tr>
<tr><td>150</td><td>19,5</td><td rowspan="2">0,42</td><td>133</td><td>2</td></tr>
<tr><td>250</td><td>28</td><td rowspan="2">135</td><td rowspan="2">85</td><td rowspan="2">70</td><td>3,15</td></tr>
<tr><td>400</td><td>29</td><td>0,5</td><td>3,18</td></tr>
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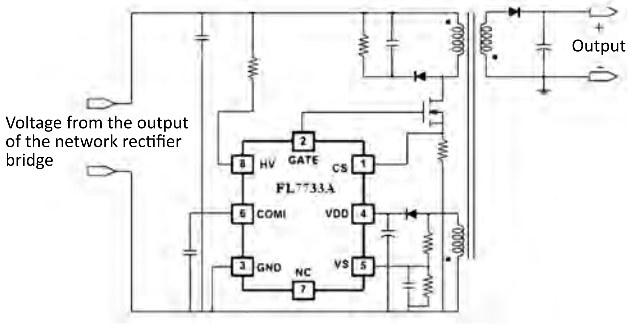

Fig. 12. One-stroke device scheme with regulation on the primary side

The device is attractive due to its relative simplicity and low cost, since it contains only one power switch *VT1* and one coil element *T1* (as well as the radio-interference filter coil) which performs a function of a cumulative throttle and transformer. Many other companies use the same scheme to produce drivers, only chips may differ. For instance, *Texas Instruments* applied *UCC28810* chip as a power factor controller, while *ST Microelectronics – L6562A/AT, ON Semiconductor – NCL30000,* and *NXP Semiconductors – SSL1750*.

The drivers of this group are being constantly improved. As an example, *Fairchild* company released controller *FL7733A* several years ago which manages operation of a reverse-stroke voltage to a converter by using feedback signal taken from the primary side of the scheme. The driver scheme became simple and low cost when previously used optrones, which transmitted information about current and voltage by taking signals from sensors on the secondary part of the scheme (Fig.12) [5] were rejected.

Direct-way devices are less common, since they have a degauss coil that makes a transformer more complex and, thus, more expensive.

There were numerous attempts to combine the direct and reverse schemes where during a direct move the power was transformed and released into the output circuit and during reverse move – the power accumulated in the transformer was released back into the same circuit. The corresponding wiring diagram (Fig.13) described in details in [6] was a result of such attempts. The diodes *8–9*, a choke *10* and capacitor *11* form the direct

Table 3. SON ballasts parameters

Lamp power, W	Power losses, W	Power factor	Dimensions, mm			weight, kg
			L	*B*	*H*	
70/50	14/9	0,39	111	66	53	1,5
100	16	0,43				
250	28	0,42	135	70	85	3,15
400	32	0,40	165			4,3
1000	55	0,43	196	105	90	10,0

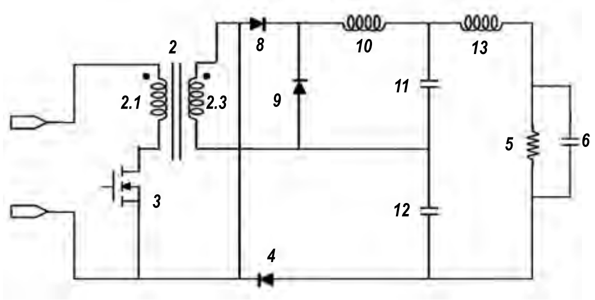

Fig. 13. Functional scheme of converter with a combination of direct and reverse circuits

scheme, while a diode *4* and capacitor *12* – the reverse scheme. Testing of this circuit showed that the voltage on transistor decreased by 1.3 times and heating of transformer – by (10–12) % in comparison with the scheme of the reverse converter.

Dealing with power greater than (80–100) W, the drivers shall be built by using the schemes of two-stroke voltage converters. For instance, the *Infineon* company implements the scheme in LED drivers for road luminaires with rated power exceeding 100 W. A scheme of such driver (Fig.14), [7] contains a radio interference filter *L*, rectifier *BR1*, half-bridge inverter based on transistors *MHS* and *MLS*. The latter brings into current and voltage agreement an isolating transformer T, an output rectifier, and a feedback block. Drivers of this kind are highly efficient and have practically no upper power limit.

3. FUTURE DEVELOPMENTS OF CONTROL GEARS AND DRIVERS

The future development of control gears and drivers totally depends on the market of light sources. The dynamics of the latter in Russia is given in Table 4 [8]. It shows that the production of discharge lamps will decrease by 10–100 times compared to 2013 levels in the nearest future, while production of LED products will increase 5–8 folds. That is why the new developments of electromagnetic and electronic ballasts for discharge lamps have been practically stopped. But since a lot of HID lamps (mainly, metal-halide and sodium) are still in use, the corresponding ballasts are in demand and will continue to be produced for a long time for such applications as road and horticulture lighting. A sufficient drop in production took place only in the following product groups: conventional ballasts for fluorescent lamps, integrated electronic ballasts for compact fluorescent lamps (retrofitted by LED lamps with screw base), and electromagnet-

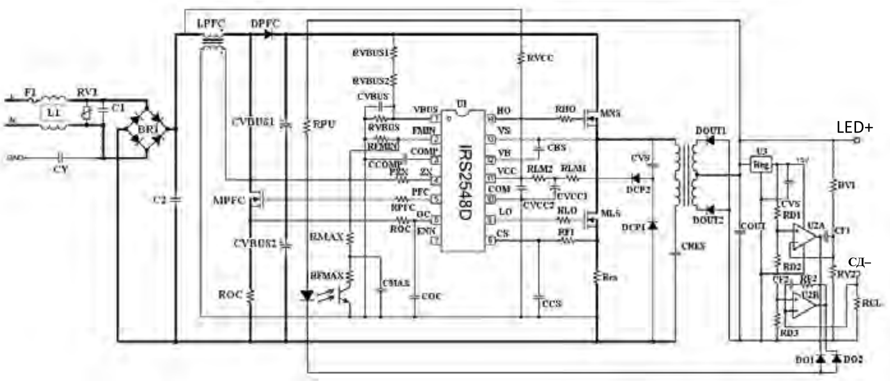

Fig. 14. Scheme of control unit based on two-stroke voltage converter

Table 4. Market trends for light sources in Russia (production and import), million pieces

Light source type	2013	2014	2015	2016	2017	2018	2019	2020
Fluorescent lamps	121	88,5	80	64	38	29(19)	22(10)	16(5)
Compact fluorescent lamps	124	106	58	37	18	4	3	2
High-pressure mercury lamps	9	6	2,5	1,5	0,5	0,3	0,2	0,1
High-pressure sodium lamps	2,4	2,2	1,4	1	0,8	0,6	0,4	0,2(0,1)
Metal-halide lamps	1,5	1,4	1	0,7	0,5	0,3	0,2	0,2
Light-emitting diodes	54	124	99	123	168	209(309)	240(375)	265(421)

Remark: values given in brackets are under discussion in the countries of the Eurasia economic union.

ic ballasts for high-pressure mercury lamps (HPL) replaced by sodium lamps (SON).

In contrast to ballasts for HID, the LED drivers are at the peak of development. The main directions of growth for these are as follows:

• New designs that correspond with the classification given in Fig.6;

• Use of new up-to-date components, namely, highly efficient semiconductor devices based on silicon carbide, gallium arsenide, etc.; special chips, planar high-frequency transformers and chokes, ceramic and film capacitors (instead of electrolytic);

• Since dynamic lighting systems are in great demand, the drivers shall be supported by wide range of analogue and digital interfaces in order to cooperate with lighting controls.

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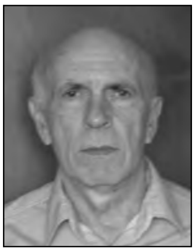

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