Electronic supply systems for fluorescent lamps

5.1 General

Fluorescent lamps with low pressure mercury vapors are the main sources of light used in indoor lighting installations. This extension of fluorescent lighting is a consequence of high luminous efficacy of the fluorescent sources compared to the incandescent ones. The fluorescent lamps are connected to the main grid via limited-stabilizing elements, which may be electronic or electromagnetic ballasts. The fittings with electromagnetic ballasts, although having a considerable luminous efficacy (η_m = 50 ... 70 lm/ W), have some disadvantages, such as higher cost of installation, a discontinuous spectrum light (flicker effect), considerable volume and weight, low power factor, upper current harmonic and an incompatibility for coupling to a data bus/control.

The above drawbacks disappear when electronic ballasts are used. These are AC/AC or DC/AC converters which provide an output voltage with high frequency, at the same time with the limitation of the current through the lamp at the prescribed value. Supplying the lamps at high-frequency leads to: increased luminous efficacy of the source, lower ignition voltage and increased lifetime of the light source.

5.2 Powering the fluorescent lamps at high-frequency supply

Increasing the voltage supply of the fluorescent lamps leads to positive effects such as:

a) *Increasing the luminous efficacy* of fluorescent lamps along with increasing the voltage's frequency, depends on the type of used ballast (Fig. 5.1). Significant differences are recorded in the 50 ... 300 [Hz]. At higher frequencies, the differences are less important and the lamps will have, regardless of the ballast used, a value of higher luminous efficacy η_{ln} superior to its nominal value, which corresponds to a 50 [Hz] supply.

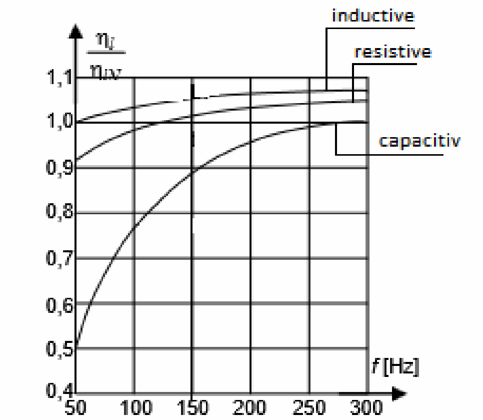

Fig.5.1 Supply voltage frequency influence on luminous efficacy

A correlated analyze of the luminous efficacy of the lamp, the ambient temperature and the supply voltage frequency will give optimum specific areas of the three types of ballast. Research carried out in this context showed that regardless of the type of ballast used, the influence of increasing the supply voltage is reduced at temperatures above 50°C and an increase in frequency above 3 kHz is negligible. Increased luminous efficacy of the fluorescent lamp along with power supply frequency is made due to the reduction of power losses in both electrical discharge column and the auxiliary equipment. Fluorescent lamps supplied at high frequency, f > 1 kHz, behave as purely ohmic resistance because the ionization phenomena in tube tends to be defined as quasi-stationary. At a given power of the lamp, the luminous flux (fig.5.2) increases proportional with the voltage frequency because it increases the radiated power and the percentage of the mercury resonance radiations having λ_2 = 253.7 nm.

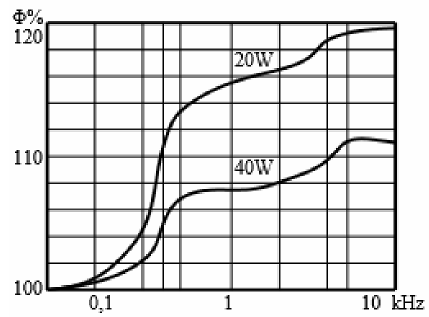

Fig.5.2 Lumen-frequency dependence for Pl = ct.

To highlight the power loss decreasing in the discharge column there are used the dynamic characteristics u = f(i_a) of the fluorescent lamp. This feature is shown in Fig.5.3 for the 50Hz fluorescent lamp with different ballasts and compared with 5 kHz inductive ballast.

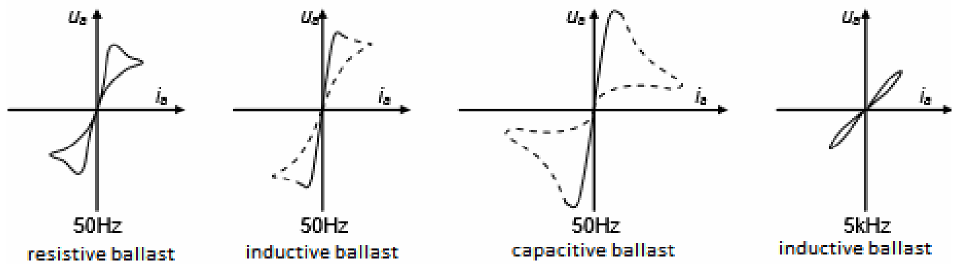

Fig.5.3 Dynamic Characteristics u = f (ia) of fluorescent lamp with different ballasts and power at 50Hz and 5kHz.

Regardless of the type of ballast used, the area enclosed by the dynamic characteristic of the lamp depends on the size of losses on the electrical resistance of the plasma. Its value depends on the state of ionization of mercury vapors and has a linear variation. The high frequency power amplifies the degree of ionization of the mercury vapors (lower number of recombination) and the positive column of the electrical discharge extends in detriment of the space between it and the cathode. Thus the ohmic resistance and the column losses decrease, and the radiation emitted by the discharge power increases.

b) *Low voltage of ignition*. The lamp ignition voltage U_a is a function that depends on the power supply frequency f, the ambient temperature θ_a (and, therefore, the temperature of the wall glass), ballast type and the amount of current used for heating the filament of the fluorescent lamp. Also the ignition voltage depends on the diameter of the glass tube and the nature or of the gas mixture inside the tube, both constructive parameters directly influencing the thermal regime of the lamp.
In general, the lamp ignition voltage decreases with increasing the frequency of the voltage supply. Therefore, all power systems at high frequency operate without a starter, and the ballast is no more dimensioned to provide the ignition voltage.
For example, the inductive ballast weight used to 3 kHz is 30% and at 30 kHz is 3% from the similar ballast used at 50Hz. Instead, the magnetic core material (tola or ferrite) must be of high quality. In turn, the capacitor used in the capacitive ballast at 1 kHz has a value with plus 1μF to that used in 50Hz, which tends to 4μF.
The miniaturization of the electronic ballasts led to the apparition of the compact fluorescent lamps (CFLs), which tend to replace traditional incandescent lamps being 3-4 times more efficient and having a lifetime of 5 times higher.

c) *Increasing the life time* with increasing the frequency of the voltage is accompanied by lumen maintenance at a longer baseline (reduction factor depreciation).
In conclusion, the advantages of high-frequency fluorescent lamps are:
- Luminous efficacy increases by approx. 10% from the 50 Hz power;
- Ignition voltage decreases and facilitates the operation of no starter assemblies;
- Decrease the size and weight of the ballast;
- Increase the life time of the lamp;
- Is eliminated the flicker phenomenon (rapid oscillations of the luminous flux which are harmful to health) because of the plasma thermal inertia that prevents rapid changes of plasma pursue).
- Heat radiation heat is reduced.

The main disadvantages are the higher cost price; sometimes the occurrence of disturbing noise (ringing), particularly at 1 kHz.

5.3 High-frequency power supplies

Powering the high-frequency fluorescent lamps is done by groups or individually.
The simultaneous supply is suitable for the separated groups with high frequency A.C. distribution (e.g. ships, aircraft or trains). In these cases is used directly the frequency distribution (usually 400Hz) obtained from own sources of the vehicle.
Power group is also found in some special cases in which, although is present the industrial power grid of 50Hz, it is preferred the centralized supply at high frequency with the adjustment possibilities of the luminous flux (theaters, auditorium etc.) in which case the sources are practical power inverters.
The individual supply is preferred for the isolated installation of low power (≤ 200W) where the energy source is a DC (cars, buses, trains are used where voltages of 12, 24 or 36 A.C.). We can also consider as individual supply the compact fluorescent lamps (CFLs). In this case, each lamp is provided with its own inverter, connected when necessary, with a voltage step-up transformer.
Load circuit of the high frequency power supply is basically a resonant circuit consisting of two reactors, one inductive and one capacitive, both mounted in series and in parallel with the lamp (fig.5.4).

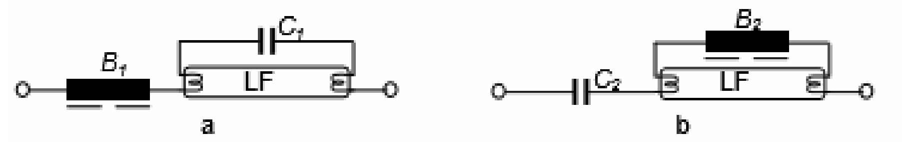

Fig.5.4 High-frequency resonant circuit

Irrespective of being inductance or capacitance, the series element also serves as ballast.
There are therefore two types of electronic sources (electronic ballasts), depending on the type of the energy source: DC/AC inverters for the DC power sources and AC/AC converters which permit to connect the lamp directly to the main grid (230V, 50Hz). Their topology is usually of two types:

- Fly-back schemes (fig.5.5) that are not very used because of the important overvoltage occurring in the transient regime and require the use of high voltage power transistors, relatively expensive. In addition, this topology does not allow the limitation of transistors switching power losses and therefore has a low efficiency.
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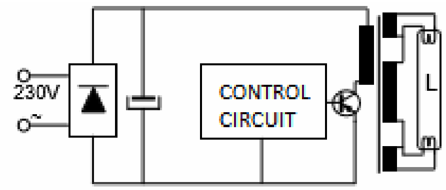

Fig.5.5 Typical fly-back circuit

- Resonant scheme as voltage source (fig.5.6) which is relatively simple and easy to put into practice without major inconveniences. They are the most used and use a "half-bridge" structure which supplies LC series resonant load circuit. The control of the switching elements of the "half-bridge" structure can be achieved with both discrete elements (the control switch being made by a transformer, usually toroidal) and, more recently, with specialized integrated circuits. The circuit oscillates undamped, resulting a square wave with a frequency of 10…80 kHz which supplies the resonant load circuit. The energy required for controlling the transistors is taken from the load circuit. The choice of the semiconductor devices has a great influence on the size and nature of the electronic ballast losses and they are considered the following parameters: the operating voltage, the current collector and the current gain, the switching times and the junction temperature.

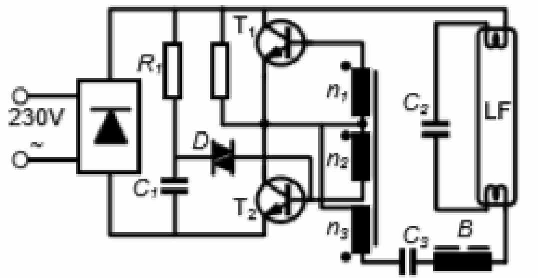

Fig.5.6 Typical scheme for resonant circuit voltage

In the past, very widespread were the inverters made with thyristors, devices which, in high voltage applications, combines the advantage of a reduced cost with the disadvantage of the most expensive solutions for the switch. It is limited in frequency, but has a highest capacity for overload.
The control circuits for bipolar transistors are complex and require negligible power consumption. Currently there are block devices capable to switch to 1200 V and currents up to several hundred amperes.
Modern MOSFET (Metal-Oxide-Silicon-Field-Effect-Transistor) transistors type are characterized by very short switching times (< 500 ns), thus allowing very high switching frequencies (above the audio range) with moderate switching losses. They do not require a steady state control current, and so the gate control circuits consume virtually no power.
For devices that work with large DC voltages (≥ 300 V D.C.) and high value for the current, IGBT's (Insulated Gate Bipolar Transistor), which combines the features of rapid bipolar transistor conduction and switching facilities control grid of field effect transistors, offers a viable alternative and cost to power MOSFET transistors.

5.3.1 DC/AC Inverters

When the power source is a D.C. one, there are using DC/AC converters. To supply a fluorescent tube from a 12V battery requires the use of an inverter capable of generating a sufficiently high voltage ignition.

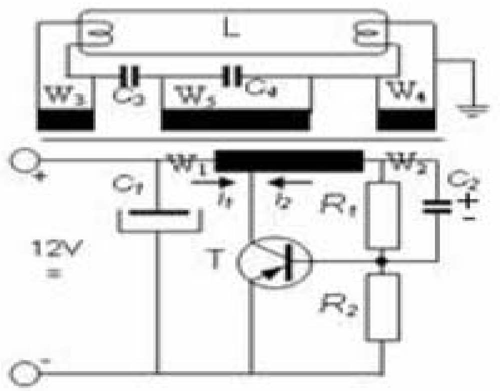

Fig.5.7 Fluorescent lamp powered at 12 V

The scheme in Fig. 5.7 is relatively simple and consists of an autopilot oscillator.
When it is supplied, the transistor T is blocked due to positive potential of the divider R_1-R_2. A current i_1 is set through the ferrosilicon sheets of the transformer primary, which charges the capacitor C_2 with the polarity in the figure. At one moment, the C_2 potential ensures a negativity of the base of the transistor T, it goes into conduction and causes the discharge of C_2 through winding W_2, establishing the current i_2. Thus, in the transformer primary they appear some opposed A.C. currents generating an AC voltage in the secondary. The scheme operates at the resonance frequency of the W_5-C_4 group.

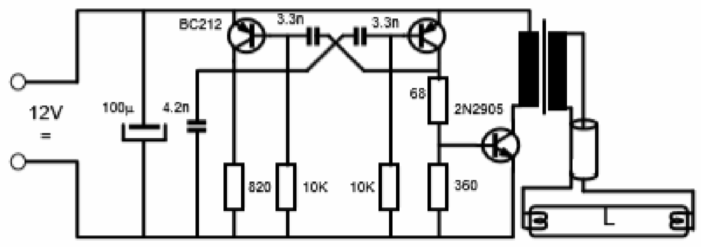

Fig.5.8 Multivibrator diagram powered at 12 V

Another type of inverter (Fig.5.8) uses a schema designed for a fluorescent lamp of 40W supplied from a 12V battery. A multivibrator generates rectangular pulses with frequency of 20 kHz which controls a power transistor which is responsible for a step up transformer. The transformer is coupled to a fluorescent lamp through a shielded

cable to minimize the emitted electromagnetic disturbances.
In Fig. 5.9 is presented a common lighting scheme CFR- passenger car that works at 5 kHz and has the features:
- The choice of the operating point on the static characteristic of transistors T_1, T_2, is made with divider P-R_1;
- The peaks of the voltage induced in the windings n_2, n_2^* are limited by the capacitor C_2, and the C_3 capacitor protects the emitter-collector junctions of the switching overvoltage;
- The winding n_5 provides the ignition of the lamp (LFB 40, LFR 40), namely, when the diode D_2 is on, to the ends of the lamp it appears a high voltage, and with it a considerable potential difference between the outside lane and the opposite electrode (increases and levels the field in the lamp). After ignition of the lamp, the role of the winding n_5 is negligible because the resistance R_2 is much greater than the capacitive reactance of C_4, which functions as a ballast.

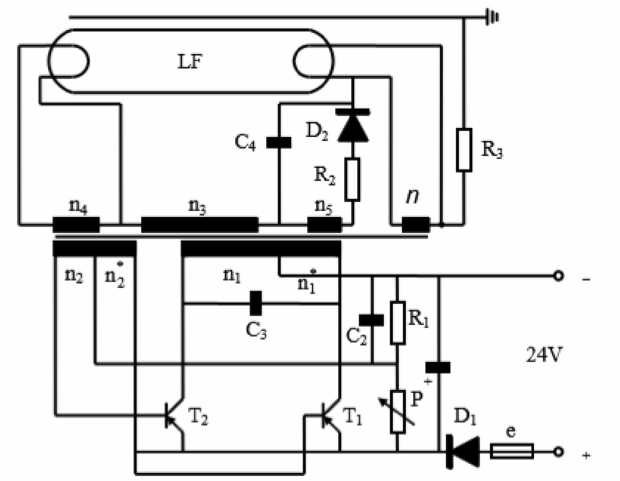

Fig.5.9 Power inverter for fluorescent lamps

5.3.2 AC/AC Converters

The AC/AC Converters or electronic ballasts (Fig. 5.10) allows a directly connection of the lamp to the provider's power grid (230V, 50Hz). It is carried out in a half-bridge structure, and generally they have a series LC resonant circuit which connects the light source. The operating frequency is high (20 ...80 kHz) and to avoid the deformant regime, the assembly is provided with the input harmonic filters L_fC_f. Bipolar transistors T_1, T_2 can be controlled with discrete elements or specialized circuits and the initialization of the operation is done by the triac D_c.

5.4 Conduct of the laboratory

In the laboratory classes consider the following theoretical and practical problems:
- Electronic ballasts schemes in the laboratory will be studied;
- Comparative measurements will be made regarding the luminous flux, luminous efficacy and time of ignition for the assemblies made with several sizes of ballasts;
- Oscilloscope waveforms of electrical parameters;
- Record the conclusions of the study.