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STUDY OF MAGNETIC AND ELECTRONIC BALLASTS

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Abstract. *This study compares the working principal and properties of magnetic and electronic ballasts used for fluorescent lamp lighting. A circuit simulation illustrates the benefit of a Power Factor Controller in electronic ballasts. Some comments are made on basic porperties as dimmability and efficiency.*
Keywords: *fluorescent lamp, magnetic ballasts, electronic ballasts, Power Factor Controller, dimming.*

Introduction

The working principle of magnetic ballasts.

This configuration consists of an magnetic ballast (an inductor) and a starter (figure 1.1). The starter is in essence an automatic switch. When the line voltage (230V, 50Hz) is applied, the switch is closed (figure 1.1.1) and the current flow through the ballast and the filaments of the fluorescent lamp.

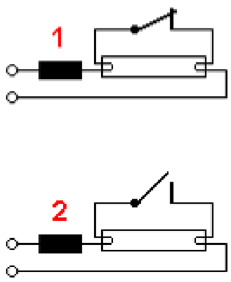

Figure 1.1. Basic circuit diagram of a fluorescent lamp with magnetic ballast.

This is the preheat phase; heating the filaments generate additional electrons reducing the breakdown voltage of the gas inside the lamp. But this does not suffice to reduce the breakdown voltage below the regular peaks of the mains alternating voltage (325V). A 58W tube for instance starts in cold state at 1300V sine wave, dropping to 550V with pre-heated filaments. For the ignition of the lamp, a voltage peak is generated by interrupting the inductive current (figure 1.1.2). The starter does this automatically. The inductive kick provides enough voltage to ionise the gas mixture in the tube and then the current in the tube keeps the filaments hot. In this stage of gas discharge the voltage required to sustain the current is shown in figure 1.2. [1]

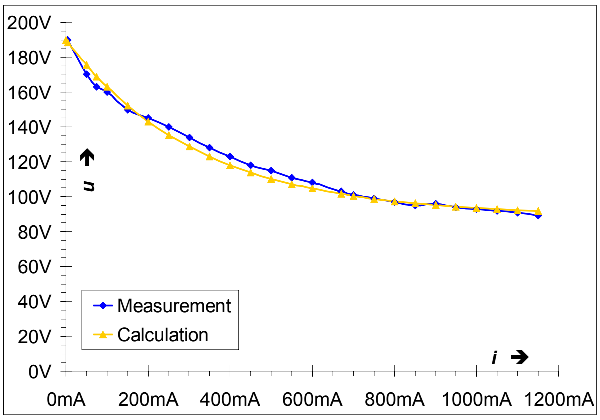

Figure 1.2. Voltage/current characteristic of a 58 W fluorescent lighting tube [1].

The non-linear behaviour of the lighting tube distorts the voltage measured across the two filaments very much, for while the current is highest the voltage drop is lowest. Yet this voltage is unable to distort the current to a worth mentioning extent because the distorting lamp load is connected in series with the very high inductance of the ballast, in this case ≈ 780 mH, which suppresses current distortion, respectively suppresses the flow of harmonic (higher frequency) currents. So the current curve looks nearly sinusoidal, apart from a crease at each zero crossing. Of course there is a long time lag between the voltage peak and the current peak, which means a high share of fundamental reactive power. This can be compensated with a series or parallel capacitor.

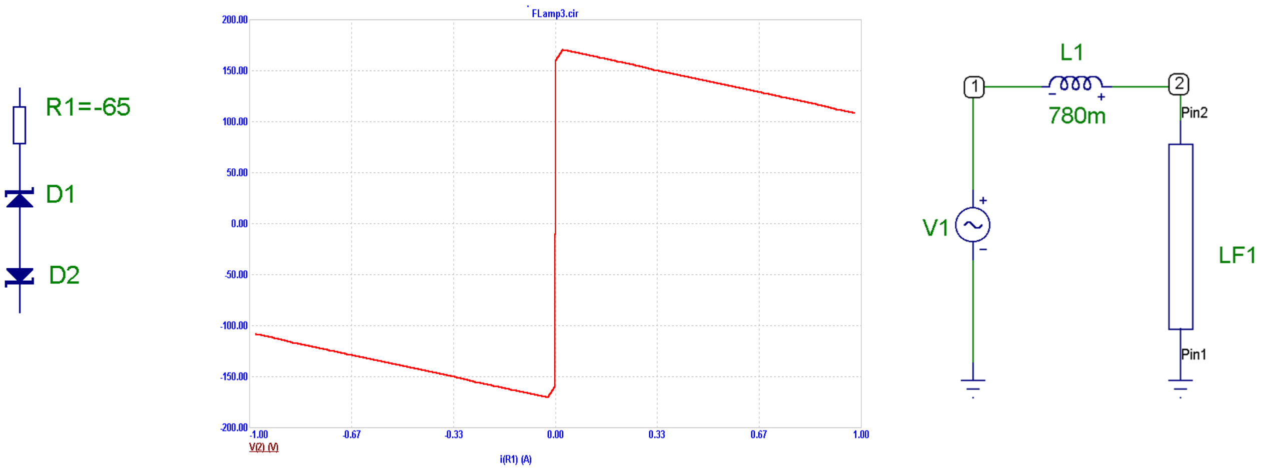

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Figure 1.3. a. Model for 58 W fluorescent lamp; b. resulting u/i characteristic; c. fluorescent lamp circuit.

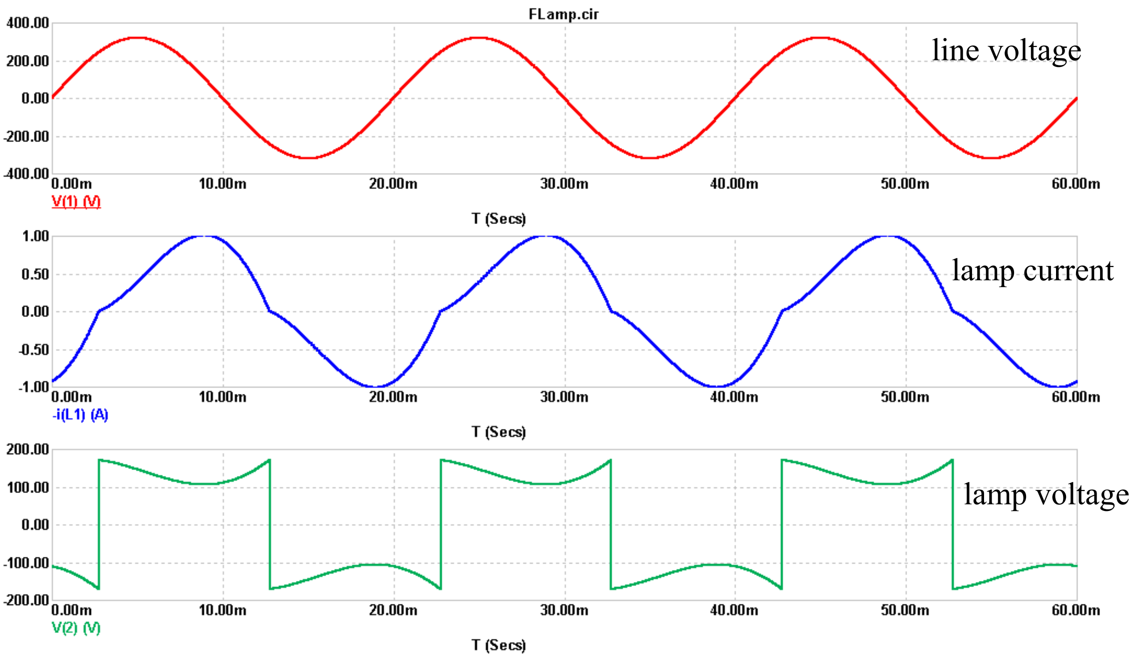


Figure 1.4. Voltage and current simulation for a 58 W fluorescent lamp.

The voltage/current characteristic of a 58 W fluorescent lighting tube was simulated with an electronic circuit analysis program Micro-Cap8 as a series connection of two 170V Zenerdiodes and a negative resistance equal to –65 Ω (figure 1.3.a). The resulting u/i characteristic is shown in figure 1.3.b. The resulting voltage and current with a 780 mH inductor are shown in figure 1.4.

A glow tube starter contains a small gas (neon, etc.) filled tube and an optional RFI suppression capacitor. The glow tube incorporates a switch which is normally open. When power is applied a glow discharge takes place which heats a bimetal contact. A second or so later, the contacts close providing current to the fluorescent filaments. Since the glow is extinguished, there is no longer any heating of the bimetal and the contacts open. The inductive kick generated at the instant of opening triggers the main discharge in the fluorescent tube. If the contacts open at a bad time - current near zero, there isn't enough inductive kick and the process repeats. [6]

Working principal of electronic ballasts.

With an electronic ballast, the fluorescent lamp is placed in a LC-resonant circuit driven by a high-frequency voltage (about 40 kHz). Frequency modulation of this high-frequency voltage controls the preheat, ignition and run mode of the fluorescent lamp. The block diagram of an electronic ballast is shown in figure 2.1.[2].
The incoming AC voltage is rectified via a bridge rectifier and smoothed with an electrolytic capacitor, resulting in a 300 V DC voltage; figure 2.2.

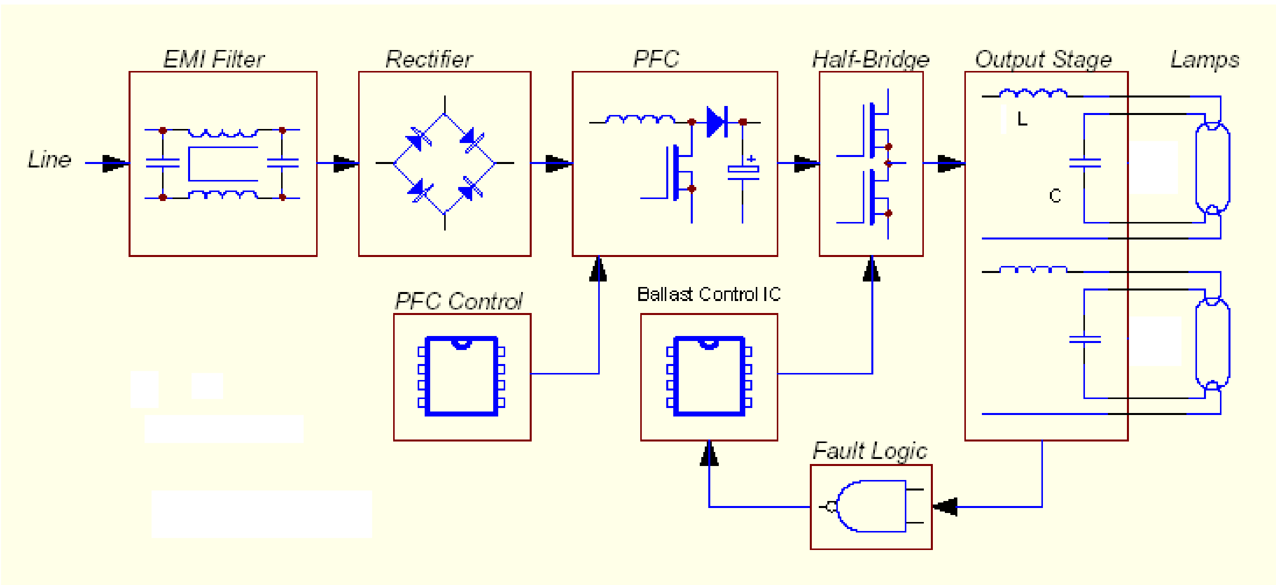
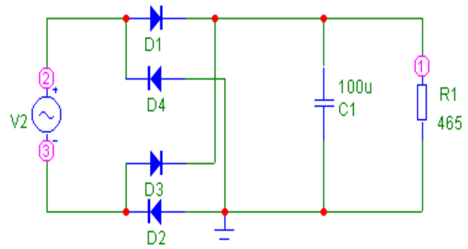


Figure 2.1. Block diagram of an electronic ballast [2].

For fluorescent lamps with a power rating above 25 W a Power Factor Controller (PFC) is provided. This will be explained later in this paper. The DC voltage is converted to a high frequency square wave of 300V peak to peak, usually using a half-bridge topology. The ballast control IC controls the frequency of the high frequency square wave. Figure 2.3 shows the ratio of the lamp voltage to the DC voltage as function of the frequency [3].



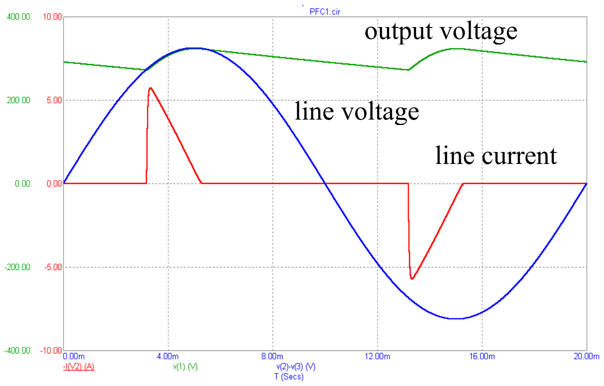


Figure 2.2. Rectifying and smoothing of the main AC voltage.

At start up the ballast is running at a frequency higher than the resonance frequency of the LC-circuit. This makes the impedance of the capacitor low and the voltage across the lamp below the strike voltage. This prevents a cold start of the lamp. The frequency is than shifted down to the preheat frequency and provides a current through the cathodes large enough to heat them while maintaining the voltage across the lamp below the strike potential. After the pre-heat time the frequency is moved to the final running frequency. At this point the voltage across the lamp becomes large enough to strike the arc and the resonant point of the circuit shifts lower and the current in the lamp is limited by the output stage inductor.

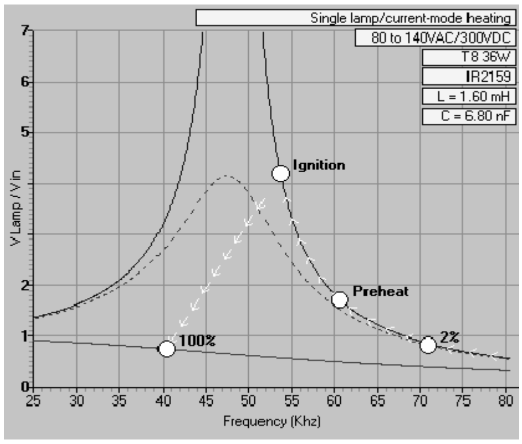
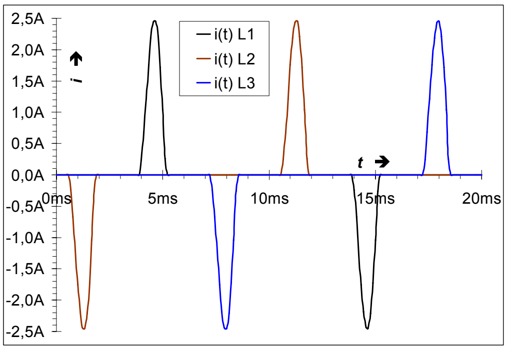


Figure 2.3. Lamp voltage/DC voltage as function of frequency [3].

As mentioned earlier, ballasts with ratings above 25 W are provided with a Power Factor Controller (PFC). As shown in figure 2.2 the direct rectification of the incoming AC, generates extreme periodic current peaks somewhere in the proximity of the voltage maximum, while during the rest of each semi wave no current flows at all. This current waveform includes a high harmonic content, especially of the third and its multiples, which add up on the neutral instead of cancelling out and cause a bunch of problems: neutral overload, transformer overheating, substantial distortion of voltage waveforms if network impedances are high, magnetic stray fields, EMI, etc. Figure 2.4 shows the line currents on the 3 phases (a) and the resulting neutral conductor current (b).
In ballasts with PFC the smoothing capacitor in the rectifier circuit is charged periodically during the entire cycle of the main voltage. This can be accomplished using a boost converter topology as shown in figure 2.5. The boost converter MOSFET (switch SW in figure 2.5) is turned on and off resulting in an energy transfer from inductor to smoothing capacitor during the entire cycle of the main voltage. Using a line filter this results in an input current in phase with the main voltage. Figure 2.6 compares the harmonic content of a rectifier circuit with and without PFC.



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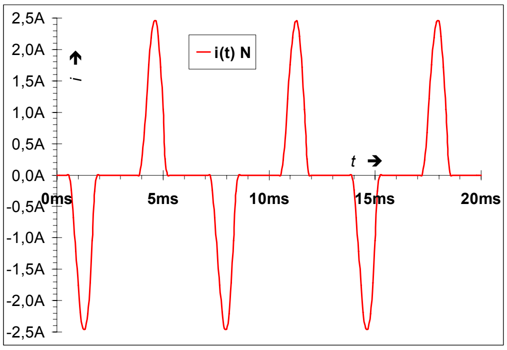
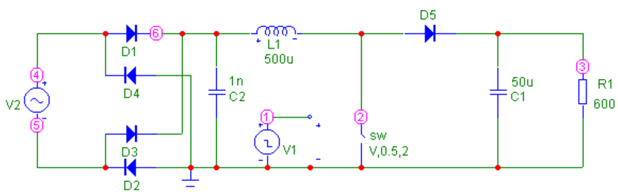


b

Figure 2.4. Line currents on the 3 phases (a) and the resulting neutral conductor current (b) without PFC [4].

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.MODEL A PUL (VONE=1 P1=0N P2=0N P3=8u P4=8.0001u P5=50u)
.MODEL D1 D (IS=1N RS=0.1)
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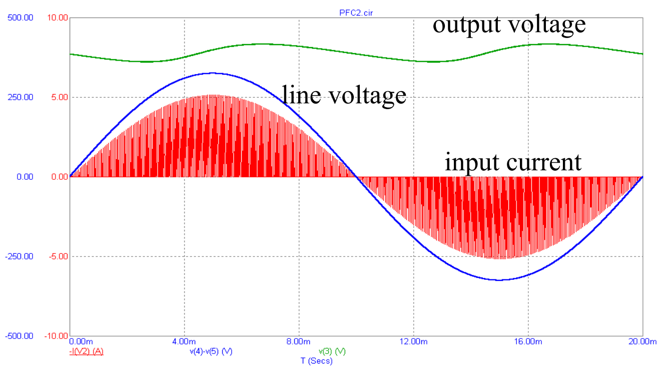

Figure 2.5. PFC using a boost converter topology.

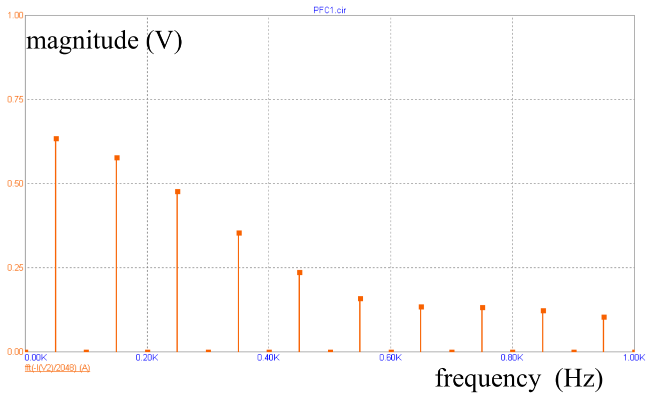

Figure 2.6.a. Harmonic content of a rectifier circuit without PFC .

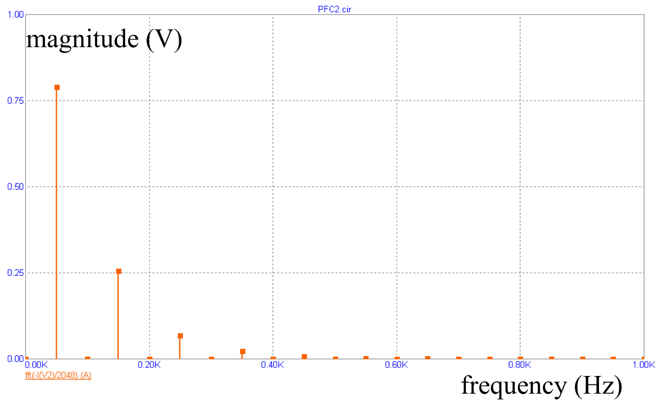

Figure 2.6.b. Harmonic content of a rectifier circuit with PFC.

Dimmability

Various methods were developed to achieve the dimmability of fluorescent lamps with magnetic ballasts but these performed not too smart and are out of date.

Fluorescent lamps are dimmable by control of the output frequency. As can be seen in figure 2.3, the lamp voltage decreases with increasing frequency. This frequency can be controlled by adjusting the dimming control voltage on the ballast control IC. The control range (100% to 2%) is limited as the cathode current must be sufficient in order to prevent the lamp from extinguishing.

Efficiency

The EU classified fluorescent lamp ballasts by the overall power intake of the ballast and lamp circuit. The classes and limits for linear lamps are displayed in table 1. A comparison of the energy efficiency for 5 different classes of ballasts is shown in figure 4.1 [5].

Table 1. Classes and limits for linear lamps.

Lamp Power		Maximum input power of ballast & lamp circuits					
50Hz (mag-netic)	HF (elec-tronic)	Class D	Class C	Class B2	Class B1	Class A3	Class A2
15W	14W	>25W	25W	23W	21W	18W	16W
18W	16W	>28W	28W	26W	24W	21W	19W
30W	24W	>40W	40W	38W	36W	33W	31W
36W	32W	>45W	45W	43W	41W	38W	36W
38W	32W	>47W	47W	45W	43W	40W	38W
58W	50W	>70W	70W	67W	64W	59W	55W
70W	60W	>83W	83W	80W	77W	72W	68W

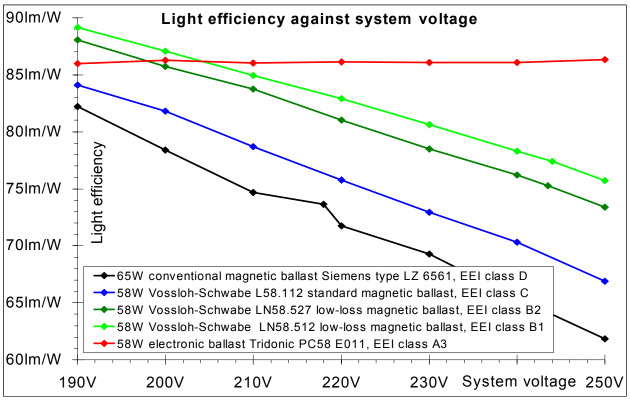

Figure 4.1 A comparison of the energy efficiency for 5 different classes of ballasts [5] .

At 230 V the electronic ballast have the best energy efficiency, but at lower voltages, magnetic ballasts can perform better. Therefore some producers developed voltage reduction systems in order to operate fluorescent lighting at reduced voltages. In installations with dedicated power lines for the lighting the use of magnetic ballasts in combination with a voltage reduction system can have energy saving results.

On the other hand, dimmable electronic ballasts provide the possibility to adapt the luminous flux to actual needs with automatic daylight dependent control systems. But in energy saving calculations one has to take into account the standby power consumption, since dimmed operation requires permanent filament heating.

So the energy saving function of magnetic or electronic ballasts should be evaluated for each case individually.

References

[1] *** http://lighting.copperwire.org/Files/Ballasts.pdf p.3

[2] *Powerlight reference design: lineair ballast*, IRPLLNR1, International Rectifier, p.1

[3] *Low Voltage DC Supply Dimmable Ballast for 1 x 36W T8 Lamp, Applicatuon Note International Rectifier* AN-1038 p.2

[4] *** http://lighting.copperwire.org/Files/Ballasts.pdf p.18

[5] *** http://lighting.copperwire.org/Files/Ballasts.pdf p.29

[6] *** *Fluorescent Lamps, Ballasts, and Fixtures: Principles of Operation, Circuits Trouble-shooting, Repair* ;Version 1.90; Samuel M. Goldwasser.