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Experimental Performance Analysis of Electronic and Magnetic Ballasts for Fluorescent Lamps

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Abstract: In this paper, the disadvantages of the electromagnetic ballasts (EMB) are discussed and approved by experimental results. Although this type of ballast is used widely for driving the fluorescent lamps (FL) in Iran, it has many harmful effects on the power network and other nearby appliances. Moreover, EMBs are not dimmable, which in turn makes them less effective for power-saving purposes. Total harmonic distortion (THD) and power factor (PF) associated with typical EMBs are compared with those of the electronic ballasts (EB). The effects of using a capacitor for PF correction in the case of EMB on power quality are experimentally analyzed. Laboratorial tests regarding the energy consumption have been done in three cases including the application of EMB, non-dimmable EB and dimmable EB. The results show that the power consumption is unacceptably high in the case of EMB. Light quality of FLs driven by different types of ballasts is also measured and compared. It is finally concluded that replacing the EMBs with dimmable EBs has an impressive impact on power quality and consumption, which would be of interest for the power system operators.

I. INTRODUCTION

Regarding the present efforts for reducing the power consumption and improving the power quality, electromagnetic ballasts (EMBs) are of crucial importance among the low-voltage consumers. This fact is more serious in our country, Iran, because of the wide penetration of EMB during the previous decades which still continues. This possibly has happened due to the lower initial cost and lack of sufficient awareness of later costs and destructive impacts on power network. Furthermore, the dimmability feature of electronic ballasts (EB), if applied, can effectively reduce the power consumption, while the EMB doesn't easily support such capability.

A relatively similar study was previously done in [1] which has reported some of the issues discussed in this paper. However, other subjects are still to be studied. Among these subjects are the impact of power factor (PF) correction using a capacitor on the total harmonic distortion (THD), light intensity of differently-driven fluorescent lamps (FL) and its variation with time, and comparison of power consumption of different ballasts type.

The ballast efficacy standards mandated by the U.S. Department of Energy (DOE) in 2005 officially outlawed the manufacture of magnetic ballasts for standard FLs. This decision clearly describes the importance of the matter and similar policies are needed to be applied in our country. As stated in these standards, T12 electronic ballasts are up to 20% more efficient than magnetic ballast technology and can reduce energy consumption by an average of 10 watts per ballast.

From an economic point of view, in a typical application where lights are operated for 4000 hours per year at an average cost of 8 cents per kWh, an upgrade to electronic T12 ballasts can reduce energy costs by $3.20 per ballast per year, or by an estimated $40 per ballast over its lifespan.

In the following subsections, a brief introduction to FLs and their performance is given.

A. Fluorescent Lamp

The tubular FL is one of the gas-discharge lamps. Their popularity is due to high efficiency (up to 104lumen/w) in comparison to the incandescent lamps and higher light quality. The availability of tubular FLs in wide ranges of wattages, lengths and shapes makes it a flexible light source that provides wide range of freedom in illumination design.

Common types of FLs are T5, T8, and the traditional T12 with 16, 26 and 38mm bulb diameters, respectively. The thinner the diameter, the more energy-saving the lighting system is. For example, a 32-watt T8 lamp uses %20 less energy to provide the same light output as a 40-watt T12 lamp, and T5 lamps provide more efficiency than T8 FLs [2]. The operation procedure of FLs is described in detail in [3], [4].

B. Electromagnetic Ballasts

A typical EMB circuit is shown in Fig. 1. To limit the current flowing through the FL, an inductor is used. The starter is a device used to ignite the gas-discharge lamp. After lamp ignition, the starter becomes an in-active element in the system. The PF of this circuit is rather low and adding a capacitor can solve this problem.

C. Electronic Ballasts

In EBs, the half-bridge switching method is employed to control the frequency of lamp's input current. Figure 2 depicts a general topology of a typical EB circuit. A control system will switch two MOSFETs which are connected in half-bridge topology. These ballasts have three modes of operation, as magnetic ones have, but here the frequency of switching determines the voltage on the lamp and in turn, the operation mode. A resonant RLC output stage is used to control the FL. The resonant behavior of the circuit is used to preheat, ignite and dim the lamp. During the preheating, the lamp does not conduct and the circuit is a high-Q series LC. To impose high voltage on the FL, the frequency is decreased. At the ignition point, the voltage meets a peak and then the Q level changes resulting in lower voltage. Decreasing the frequency again, the voltage increases till the lamp reaches its full brightness [5]-[7].

II. IMPACT OF MAGNETIC BALLASTS ON POWER NETWORK

The current waveform of FLs is highly non-sinusoidal due to their gas-discharge mechanism. The harmonic injection into the network may result in serious problems such as distortion in the voltage waveform and interfering with the operation of other equipments that are sensitive to these harmonics [8]-[10].

When the FL is driven by the EMB, the inductive impedance of the circuit will result in a poor PF. As a solution, a capacitor is usually added to improve the PF. However, this leads to much higher THD, as will be shown in Section III.

Adding the dimmability feature to the EMBs is very difficult and inefficient, while the EBs can be dimmed much easier which leads to save the energy [11]. EMBs are not able to drive several lamps by single ballast, while the EBs have the capability to drive, for example, 4 lamps using single ballast. Thus, the space that the ballasts occupy is reduced.

EMBs emit electromagnetic radiations mostly in the AM frequency band during the starting period. This radio frequency interference (RFI) can cause distortion in telecommunication systems in the AM band [12], [13]. For instance, in the radio substations, this kind of ballasts should not be used due to the mentioned reason. Besides, this may make noises on the radio and television sets. These waves are created because of several strikes happening during the ignition stage.

Moreover, EMBs reduce the lamp lifespan. There is no efficient preheat stage in this method and thus the filaments are continuously under sudden stress during each ignition. This causes the filaments to become mechanically weaker and so the lifespan of the lamp decreases. It is experimentally approved that the lifetime of a FL may increase noticeably by EBs in comparison with the EMBs [14], [15].

III. Experimental Results and Discussion

A. Power Quality

In the first test, a 36W lamp was driven by an EMB with PF correction using different capacitors. The results are shown in Table I and Fig. 3. The EMB without a capacitor provides a low PF about 0.5. The external capacitor cannot be selected to be large because of increasing in THD. Table I also shows the harmonic components of the input current measured by the power analyzer (PQA450 Power Quality Analyzer, HOTEK Technologies).

As seen in Fig. 3, PF can be improved by adding external capacitor. However, the THD would increase. Therefore, it seems that the performance of these ballasts cannot be improved even by the aid of an external capacitor.

The same lamp was driven by an EB and the results are reported in Table II. Comparable improvements in THD and PF are achieved by the EB.

B. Energy Consumption

In the second test, in order to obtain the amount of energy saved using different ballasts, a 6m*5m room was illuminated by twelve T8 40W lamps with three different driving systems. In the first case, each lamp was driven by an EMB equipped with a PF correction capacitor of 10uF. In the second case, the EMBs were replaced with non-dimmable EBs (NDEB). Finally, in the third case, a dimmable EB (DEB) was employed. In this part, a light sensor is installed near each lamp so that when natural light presents, each lamp is automatically dimmed based on the amount of available natural light. The power consumption of each lamp varied from 0.78W to 40W for different dimming levels.

A brief report of the obtained results is shown in Fig. 4. If the power consumed by the EMB-driven lamps is considered as the base of the power consumption, then the NDEBs use %22 less power.

When a FL is driven by EMB, it is run at 50Hz. In such a circuit, a considerable amount of input power is dissipated near the electrodes, where it does not produce any radiation, but merely serves to heat them.

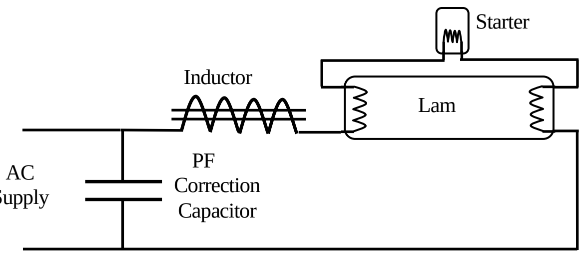


Fig. 1. Typical electromagnetic ballast circuit.

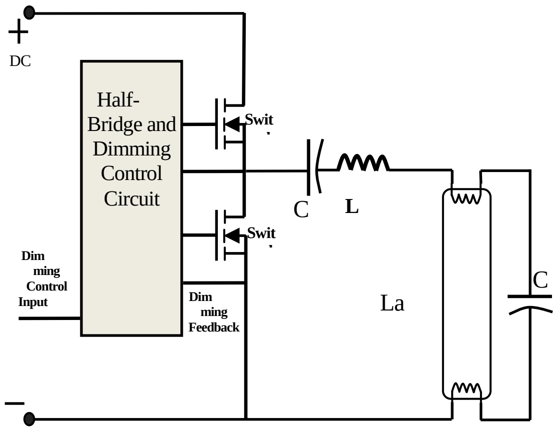


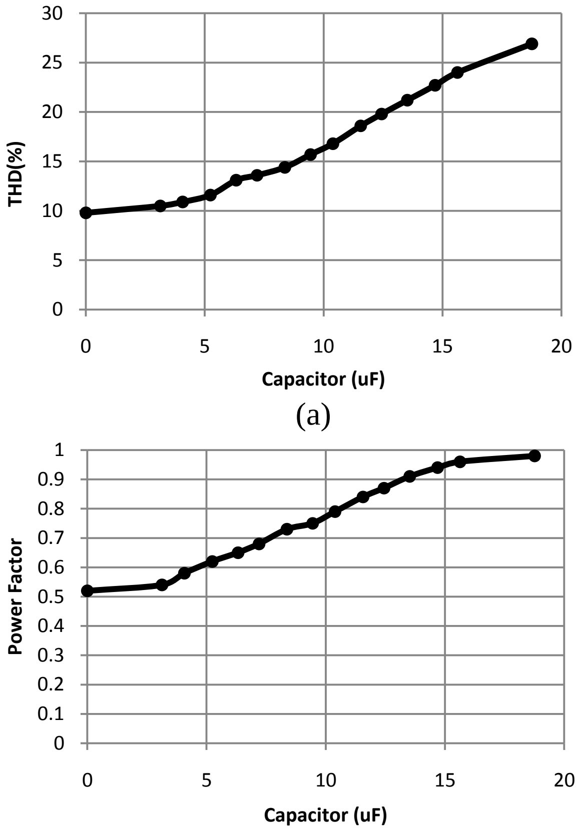
Fig. 2. Typical electronic ballast circuit.

Table I Measurement results of current harmonics and PF of EMB for 4 values of capacitor

C(μF)	PF	THD (%)	I(1st)(A)	I (3rd) (%)	I (5th) (%)	I (7th) (%)	I (9th) (%)
-	0.553	12.53	1.18	12.34	1.95	0.65	0.6
10	0.79	16.8	0.86	13.54	4.24	7.56	4
15	0.94	23.1	0.74	16	6.48	11.35	7.65
18.3	0.98	27.6	0.69	16.41	8.44	15.1	10.76

Table II Measurement results of current harmonics and PF of EB

PF	THD (%)	I(1st)(A)	I (3rd) (%)	I (5th) (%)	I (7th) (%)	I (9th) (%)
0.96	2.3	0.31	2.12	0.32	0.14	0.09



(b)

Fig. 3. (a) THD versus PF correction capacitor size; (b) PF versus the capacitor size.

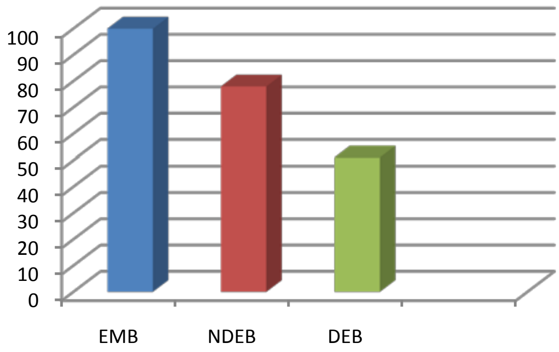


Fig. 4. Power consumption for 3 types of ballasts during 11 hours a day; values are in percent with the EMB power consumption to be the base value.

On the other hand, a lamp driven by a high frequency EB is run typically at around 28 kHz, 560 times greater than the frequency of the input. At such high frequencies, less energy is wasted near the electrodes and more power is available for light generation.

DEBs save %49 of the power used by the EMBs. The tests were done when natural light was available about 11 hours in a day. Using sunlight as a light source during the day would result in less power consumption. This procedure is handled by the sensors and the dimming systems used for the EB.

These results show that EB is also more economic for customers. Due to lower energy consumption, EB is cheaper to operate during a long time, although its initial price is slightly higher than EMB. EBs provide flicker free light because they operate at 25 kHz while EMBs operate at 50Hz. The high frequency operation prevents stroboscopic effect and perceptible flickers.

C. Light Quality

In the third test, three types of lamps were driven by different ballasts and important characteristics were measured using the power analyzer and the Integrator Sphere (Ulbricht Sphere) with 3 meters diameter. This device was calibrated with standard normal lamp described in Table III. After collecting measured data, the luminous flux of the tested lamp can be calculated as:

$$\frac{\varphi_N}{\varphi_x} = \frac{E_N}{E_x} \quad (1)$$

The measurement results are reported in Table VI. The efficiency of the EB-driven lamps is significantly higher than the EMB-driven ones. In this test, no capacitor was added to the circuit.

Besides, the time for the lamp to reach its final light intensity was measured for one lamp driven by two different ballasts and the results are shown in Fig. 5. Because of the fast rate of rise in EMB-driven lamp, the filaments are under severe stress and the lifespan of the lamp will be reduced.

Besides the mentioned issues about EMBs, radio frequency interference (RFI) is another associated problem. RFI is any signal, either radiated from the lamps or conducted on the power line, interfering with radio or television receptions. EB is equipped with special filters that meet the FCC (Federal Communication Commission) guidelines for RFI and electromagnetic interference (EMI) for prohibiting these unwanted signals.

Although the EB is more efficient than EMB, some preceding research have shown disadvantages of the early EB because of the poor design in the manufacturing [16].

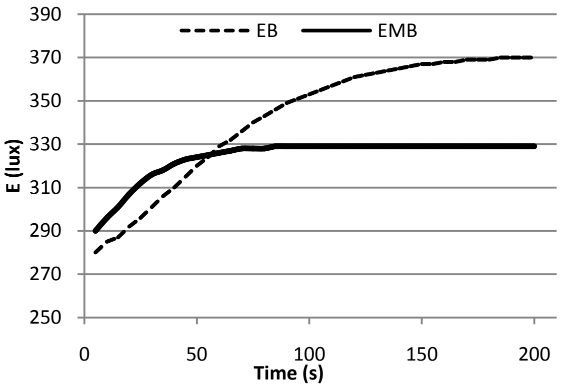


Fig. 5. Luminance versus time for a 40W fluorescent lamp driven by EB and EMB.

Table III Measured Characteristics of the Normal Lamp
(40W, 24V, Radium Co. Production)

E_N(lux)	$\varphi_N(lumen)$	V(volt)	I(mA)
85.01	575.3	24	1.700

Table IV Measured Electrical and Light Parameters for 3 Types of EBs (Steady-State Values).

	Type1*	Type 2**	Type 3***
E (lux)	371	364	431.5
V (V)	230	230	230
I (mA)	165	183	166
P (W)	37.3	41.4	37.8
PF	0.99	0.98	0.99
Φ (lumen)	2511	2465	2920
Efficiency (lumen/W)	67.32	59.54	77.24

Table V Measured Electrical and Light Parameters for 3 Types of EMBs (Steady-State Values).

	Type 1*	Type 2**	Type 3***
E (lux)	328.5	315.7	385.2
V (V)	230	230	230
I (mA)	364	319	365
P (W)	41.5	43	41.9
PF	0.495	0.586	0.497
Φ (lumen)	2223	2136	2607
Efficiency (lumen/W)	53.56	49.67	62.21

* T8-36W-Pras Shahab
** T10-40W-Pars Shahab
*** T8-36W-Phillips

IV. Conclusions

Electric features of EMBs were compared to those of EBs in driving FLs. Higher values for THD and power consumption, and lower light quality and lifespan of the lamp are experimentally approved in case of EMB. Adverse impacts of PF correction using a fixed capacitor on THD for EMBs were reported. The impact of dimmability of EBs on power consumption was shown and the deficiency of EMBs was shown due to the lack of dimmability. It is highly recommended to aware the people about these issues, which is up to the media and the ministry of power.

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