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ELECTRONIC HIGH FREQUENCY FLUORESCENT BALLASTS
(Past, Present & Future)

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Abstract

Based upon the years of development and manufacture as well as a documented three and one-half year life test the reliability of the electronic high frequency ballast concept has been established. There are several characteristics that can be used to assess a ballasts performance with respect to cost effectiveness, lamp life and power quality. The higher cost of the electronic ballast is due to the demand exceeding the supply. With more competition in an expanding market the price of ballasts will be significantly reduced.

Introduction

This paper presents the present status of the electronic high frequency ballast and its important characteristics to assess the product as well as important issues that have arisen with its introduction. In order to establish the technologies credibility a brief history of its development is presented. The paper concludes by describing what we can expect in the future with respect to the product cost as the demand for the electronic ballast increases.

Past

There is a growing segment of the lighting community that realize the electronic high frequency ballasts for fluorescent lamps have demonstrated reliable performance. Yet there are many who are still uncertain about the electronic ballast's reliability, recalling many of the problems with early production units that occurred in the early 1980's. To address this issue we shall briefly review the history of the technology.

Figure 1 shows some of the participants and their years of activities in the ballast's development and/or production over the past 13 years. The time of their activity are approximate and based upon the author's personal experience. This partial list shows at least 26 different organizations have participated in developing the technology. Of these 26,14 different organizations have proceeded to the manufacturing stage. Of particular is the length of time a manufacturer has made electronic ballasts available; 5 groups have had production units available between 6 to 8 years. Thus, the early production models problems that faced all manufacturers were overcome by 5. Initially the group of relatively small manufacturers were able to supply the entire market demand with suitable products. The length of time some groups have manufactured product is indicative of the quality since it is unlikely that these small manufacturers could remain solvent for six or more years with an unreliable product. The manufacturers that produced unreliable electronic ballasts or were too expensive would last no longer than a couple of years. Today there about 9 manufacturers supplying the US market. The 1989 electronic ballast market was about 2 million units which is about 3 to 4% of the market. Today all of the major ballast manufacturers, Advance Transformer and Universal-Magnetek have electronic ballast products. With their entry it is clear that an electronic ballast industry will grow rapidly in the next 3 to 4 years.

While most of us have heard of the horror stories of failed electronic ballasts which have occurred; the successful installations attract little attention. The results of one of the few carefully monitored installations of electronic ballasts was recently was presented at an IEEE-IAS meeting at the Production and Application of Light Session. The paper [1] was presented by the energy facility management staff of the University of California (UC). They had installed over 32,000 electronic ballasts in the UC Berkeley campus and tracked the ballast failures for over 3.5 years. Table II summarizes their results. The table has two parts, the upper part lists the number and types of ballasts that were purchased as well as their average purchase and installation costs. The bottom part lists the number of ballasts installed from three (A, B and C) manufacturers and the number of failures. About 70% of the ballasts were operating 'energy saving' 34 watt F40 fluorescent lamps the remaining 30% operated standard 40 watt F40 fluorescent lamps.

The ballasts obtained from two of the manufacturers (A and B) have a failure rate of 1 and 0.5%, respectively, after three and one-half years of operation. This is about the same expected failure of standard core-coil ballasts (about 0.5%). Manufacturer C's ballasts had a failure rate of 6.2%. The ballasts from manufacturer C sometimes started slowly and were removed by the maintenance staff as defective. Thus the failure rate of 6.2% was reported to be much higher than actually occurred.Based upon these results the University of California at Berkeley has expanded its retrofit program and now has installed over 50,000 electronic ballasts on the Berkeley Campus.

This data is convincing evidence that the electronic ballast technology has been developed to the stage where reliable products are available. However, some caution should be still exercised since not all manufacturers may have addressed some of their initial production problems.

Table II is a summary of some of the data presented in reference [2] for ballasts operating two standard 40 watt F40 T-12 cool white fluorescent lamps. The table lists the ranges of performance of the important ballast parameters. These electrical parameters are essential for assessing the quality of the power, effect upon lamp life and the necessary lighting design. The first column was obtained for product available in 1982-83 and the second column is for ballasts available in 1985. The parameters of a standard core-coil is listed as the base case for comparison. The last column is for an electronic ballast operating two 32 watt F032 T-8 fluorescent lamps. The range of values listed represents the performance variations of the current electronic ballast products.

Present

From the past we have learned a great deal about the performance of electronic ballasts. With this variety of available product one can select an electronic lamp-ballast system best suited for a particular application. This section will describe some of the essential features of the electronic ballasts required to understand and assess the products. In addition some recent issues effecting the use of electronic ballast systems that have recently emerged.

Energy Efficiency/Cost

The input power and the ballast factor are the factors that determine the operating cost of the system. The ballast factor determines the relative light output that the lamp will provide relative to the rated catalog value. The figure shows that the ballast factors are as low as 0.81 and as high as 1.00. If one is retrofitting an over illuminated space a lower ballast factor would be most appropriate. The high ballast factor may be the best solution if it is a multiple retrofit that requires increased light output from the lamp. For new construction or renovation a high ballast factor (more light output from the lamp) is more effective since fewer fixtures (lamps and ballasts) will be required to provide the specified illumination level. This will reduce first cost as well operating cost making them still more economically attractive. Today the most efficient lamp-ballast four foot system is the instant start T-8 lamp with the electronic ballast. Table II show that this system's efficacy is 90 lumens/watt. With a ballast factor of 1.00 this can be an excellent choice for new construction.

Lamp Life

The filament voltage and the lamp current crest factor are ballast design factors that influence the life of the lamps. Lamps operated at lower current crest factor (peak current/rms current) have longer lives. The industry has established the published lamp life of 20,000 hours for 40 watt F40 lamps when operated with ballasts at crest factors equal to 1.7. Normal lamp life is also to be expected with an applied filament voltage between 2.5 and 4.1 volts. The table shows that some 1983 ballasts removed filament power to increase the system efficacy after starting but later models restored it to maintain rated lamp life. There are both magnetic and electronic systems that remove filament power after the ignition of the discharge. This improves the system efficacy while somewhat reducing lamp life. This tradeoff is usually cost effective.

Power Quality

There has been some concern about the power quality in the secondary circuit and/or reflected back onto the line from high frequency lighting systems. Power quality problems emerge from electromagnet radiation, low power factor and/ or high harmonic content. There is a FCC regulation that sets limits on the EM radiation that can be emitted by lighting systems. Electronic ballasts must be certified to show that they meet the FCC requirements. Most electronic ballast on the market today have a high power factor of about 0.90 or more. There are no standards for the harmonic content although the American National Standards Institute's (ANSI) lamp and ballast committee have temporarily agreed on a limit of 27% for the total odd harmonics and 33% for total harmonics. The odd triplet harmonics are the most important since they can overload the neutral in a three phase system. The higher order harmonics contribute more to the line voltage distortion which is the other adverse effect of harmonics. From Table III one can see that there are electronic ballasts that can meet all of the above criteria.

The allowable harmonic levels for lighting equipment are still being examined by the utilities, and the lamp and ballast committees of the American National Standards Institute (ANSI). There are programs which will measure the effects of harmonics generated by lighting equipment in buildings which will be important data to determine the allowed harmonic limits for lighting equipment.

Illumination Quality

The operation of lamps at high frequency have virtually no influence on most lighting quality parameters (color temperature, color rendering etc.) However, there has been an interesting result from an experiment in England [3] which indicated that workers under high frequency lighting had fewer complaints of headaches and eye strain than when working under low frequency fluorescent lighting (50 Hz). This would suggest that high frequency lighting could be a factor for improving productivity. There is an effort to repeat the experiment to confirm the results comparing high frequency lighting and 60Hz lighting.

Argon/ Krypton Filled Fluorescent Lamps

At present there are some conflicting reports concerning the performance of standard argon filled lamps and the 'energy saving ' krypton filled lamps. Table III summarized from ref. [2], lists the parameters of the two systems operated at 60 Hz with standard ballasts and at high frequency with an electronic ballast. The 34 watt energy saving lamp in this study had a lite white phosphor which is about 7% more efficient than the cool white phosphor because of its different spectral composition. The lite white phosphor contains more green-yellow than the cool white phosphor increasing its efficacy while reducing its color rendering index. This color has not been as popular as the cool white.

Table III shows that the 'energy saving' lamp-ballast system is only as efficient as the standard lamp-ballast system by virtue of the higher efficient phosphor material. For lamp systems with the same phosphor the standard 40 watt system would be about 5 to 7% more efficient. While the energy saving system is a sound option for a retrofit if a space is over illuminated, the standard system is the most effective choice for new construction because of the greater light output(higher ballast factor) and higher system efficacy. The 'energy saving' 34 watt F40 lamp-ballast system is less efficacious because the lamps operate at a higher current increasing the ballast losses; see the change in ballast efficiency in the first two columns in figure 4. A survey [4] of 18 newly constructed buildings showed that 30% of the buildings used the 'energy saving' lamps. This is evidence to show that there is a trend to favor the 'energy saving' lamps in new construction applications over standard lamps. If an analysis was made they would have found that the initial costs as well the operating costs was probably greater for the 'energy saving' lamp-ballast system.

Costs

In Table I the average purchase prices of the two lamp F40 ballast were listed. These were the prices that the University of California paid. As the demand for electronic ballasts have increased the pricing structure has changed. Today, if they are specified they are directly installed by the fixture manufacturers. The premium price charged to the end user for a fixture with an electronic ballast with respect to a standard core-coil ballast is about $20.00 to $30.00. These prices are for relatively large volumes, probably in the hundreds. Direct sales of electronic ballasts through distributors have lower $10.00 to $15.00 premiums.

The annual return in reduced operating cost is $7,40, assuming an annual use of 3500 hours; system efficacy of a standard ballast is 63 lm/W and the electronic ballast is 80 lm/W; and energy cost of $0.10 /kWh. The simple pay back period is 2.9 years for the electronic ballast with respect to the standard core-coil ballast. The fixture manufacturer charges much more to install an electronic ballast in a fixture than a standard core-coil ballast which does not reflect his actual costs.

The premium price of an electronic ballast obtained through a distributor also depends upon the size of the order. Because of the range of prices payback periods are as short as 2 years and as long as 5 years. It is particularly wise to price ballasts from different manufacturers since some companies may have lower overhead and operating costs, hence, lower prices with equally good product.

While there has been a reduction in the manufacturing costs due to experience, the price to the end user has not experienced a large reduction. Initially most ballasts were sold directly from the factory with no added handling costs, (OEM, distributors or representatives), as well as below costs (direct , development and research) to help develop a market. Today, there is are OEMs (fixture manufacturers) and distributors that add there overhead and profit. Furthermore the demand of electronic ballasts (about 2 million units in 1989 or nearly 6 % of the market electronic ballasts serve) exceeds the supply so there is no pressure on the electronic ballast manufacturers or the OEM fixture manufacturers to price their product to reflect their costs and a reasonable profit. This will continue for a short period as the electronic market continues to grow and the major ballast manufacturers enter the market to meet the supply. When there is more competition the price of electronic ballasts should be substantially reduced.

Dimmable Electronic Ballasts

Although one of the first ballasts brought to the marketplace was a dimmable unit, clearly demonstrating the ultimate capability of the electronic ballasts, most of the ballasts developed were dedicated to compete directly with the existing ballast market. Today, nearly eight years later we see the dimming electronic ballast being reintroduced. Control systems are being designed to operate these ballasts to dim the fluorescent lamps over a large range of light levels. The use of lighting controls is another area where there is a large potential energy savings.

Future

After over ten years of research, development and manufacturing, the electronic ballast has an established credibility and gained a small but permanent foothold in the ballast market. Although there have been attempt by foreign companies to introduce product, the U.S. electronic ballast industry, which has played the leading role in its development, are leading their international competitors. In fact, some U.S. manufacturers are supplying major foreign companies with product.

With the growing demand of product and the entry of major corporations in the manufacture of electronic ballast we anticipate a more competitive industry. This will result in addition investment in product development to reduce the manufacturing costs. This will entail applying first hybrid integrated circuit technologies, higher frequencies systems and eventually the 'smart' chip technology (integration of power and signal devices). Electronic ballasts will someday become an integral part of the fixture. The above technologies will further increase the efficacy of the fluorescent lamp-ballast system to well over 100 lumens per watt.

In the near future there will be advances in electronic dimming ballasts and there will be control systems designed to incorporate them in the system. Eventually these lighting control systems with power line carrier communications will be able to independently control the light level of each luminaire. These systems will be the ultimate in good quality, comfort and energy efficient lighting.

Conclusion

i) Reliable electronic high frequency ballasts are presently available on the market.

ii) There are a variety of products with different performances each of which may be best suited for a particular application.

iii) There are still some issues surrounding the electronic ballast that do not affect most products today but should be fully resolved for future performance requirements.

iv) The cost of todays ballasts do not reflect actual manufacturing and distribution costs since demand exceeds supply, with more competition we can expect drastic decreases in the price of electronic ballasts.

v) The advantages of the electronic high frequency ballast are more than simply higher system efficacy. There is evidence that there is improved comfort and performance due to reduced flicker .

Finally the ability to easily dim the fluorescent lamps in a continuous manner, with low voltage wiring, will permit the proper illuminance levels in spaces with changing visual needs. This will improve productivity and save more energy than the present dedicated lighting systems.

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3. A.J. Wilkins et al, Fluorescent Lighting Headaches and Eye Strain, Lighting Res. Technol. 21, (1) 11-18, (1989).

4. Survey by New England Power Company and Fred Davis Corporation, (1989)

Table I. University of California Monitoring of Ballast Failures [1]

Purchased Ballasts

Type	Number	Average Unit Cost ($)	Average Installation Cost ($)
2F40	34,174	21.00	12.30
2F96	7,926	32.00	18.00
2F96 (HO)	878	35.00	23.00
3F40	100	27.00	17.00
4F40	3,798	48.00	18.00
	46,876		

Ballast Failures (1985-1989)

Manufacturer	Type	Installed	Failure (%)	
A	2F40	13,026	0.8	(104)
A	2F96	4,119	1.6	(66)
		17,145	1.0	(170)
B	2F40	9,883	0.5	(49)
B	2F96(HO)	229	1.3	(3)
B	2F96	1,136	0.5	(6)
		11,248	0.5	(58)
C	4F40	2,745	4.8	(132)
C	2F96	1,323	9.2	(122)
		4,068	6.2	(254)
		32,461	1.5	(482)

Table II. Solid-State Ballast Performance Range (2 lamp F40) [2]

Parameter	1983 T-12 Lamp	1985 T-12 Lamp	Standard Core-Coil	1985 T-8 Lamp
Power (W)	67 - 82	63 - 75	96	65
Power Factor	0.99 - 0.89	0.98 - 0.89	0.98	0.89
Harmonics				
3rd (%)	9 - 33	10 - 36	12	43
5th (%)	1 - 18	5 - 23	10	6
Filament Voltage (V)	0 - 3.6	1.4 - 3.6	3.5	0
Lamp Current Crest Factor	1.4 - 1.9	1.5 - 2.0	1.7	1.5
Light Output (lm)	5330 - 5800	5120 - 5940	6100	5820
Ballast Factor	.85 - .92	.81 - .94	.96	1.00
Regulation (%)	1 - 23	1 - 10	4	8
Flicker (%)	0 - 33	0 - 30	30	1
System Efficacy (lm/W)	77 - 80	74 - 83	63	90

Table III. Ballast Operating Two 40W and 34W F40 Lamps [2]

	Core-Coil (60 Hz)		Change (%)		High Frequency	
	40W (Cool White)	34W (Lite White)			34W (Lite White)	40W (Cool Whte)
Power (W)	93	79	-15	-13	63	72
Power Factor	0.98	0.92	-6	-2	0.93	0.95
Lamp Voltage (V)	100	82	-18			
Lamp Current (I)	0.42	0.46	+10			
Cathode Volts (V)	3.5	3.5	0	0	3.1	3.1
Ballast Factor	0.97	0.88	-9	-6	0.87	0.93
Light Output (lm)	5970	5160	-14	-14	5060	5870
Flicker (%)	30	21	-30	-27	11	15
Harmonics						
3rd (%)	12	20	+40	0	24	24
5th (%)	10	14	+29	-7	13	14
Ballast Efficiency (%)	0.80	0.76	-5			
Lamp Efficacy (lm/W)	81	87	+7			
System Efficacy (lm/W)	64	65	+2	0	81	81

Figure 1. Solid-State High Frequency Fluorescent Ballast History

1977	1979	1981	1983	1985	1989	1990	Manufacturing Years

EBT (IOTA)—(Excel)—(EE Tech)—M—M—M—EBT—6
Luminoptics—M—M—M—M—Luminoptics—7
(Steven's)
Magnetek—Triad—M—M—M—Mag-Triad—6
-Triad—Utrad
Electrides—X
Zia Assoc.—X
Thomas Inc.—M—M—X—Thomas Inc. (M)-Thomas Inc.—4
Genesis—M—M—M—Genesis—6
(Aztec) (Universal Mfg.)
Quietlite—X
Data Power—X
XO—M
Toshiba—M—M—M—M—Toshiba—8
OY Helvar—X
Hunt (M)—M
Solatron (M)—M
General Aero—X
Energy Devices—X
Valmont (M)—M—Valmont—4
(GE)
Fyrentics (M)—X
Diablo—X
Advance—Advance
Trans. (M)—M—Trans.—4
Siemens (M)
American
Ballast Corp.
PanTech (M)—PanTech—1
ETTA—ETTA—1
Braydon
Royconn

Total 47 yrs.

	1977	1979	1981	1983	1985	1989	1990
Developers	7	10	10	14	14	16	2
Manufacturers	0	0	3	8	11	10	10

X - Stopped development/manufacturing
M - Manufacturing

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