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The Effects of Supply Harmonics on the Performance of Compact Fluorescent Lamps

by R. Arseneau and M.J. Ouellette

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THE EFFECTS OF SUPPLY HARMONICS ON THE PERFORMANCE OF COMPACT FLUORESCENT LAMPS

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Abstract - This paper describes a performance evaluation of ten compact fluorescent lighting systems operated with sinusoidal and distorted voltage waveform conditions. The lamps were either provided with an electronic ballast, a magnetic core ballast or a magnetic core ballast with a power factor correction circuit. The test results show that the electrical performance of the compact fluorescent lamps for both sinusoidal and distorted voltage waveform operation is related to the different types of ballast used. The cost of operation of these compact fluorescent lamps was calculated and compared to the cost of a conventional 60 W incandescent lamp.

INTRODUCTION

Compact fluorescent (CF) lamps represent new and promising alternatives to incandescent lamps. They are commonly reported to consume much less energy and last much longer than incandescent lamps with comparable luminous output [1]. As part of their energy conservation strategy, many utilities are promoting the use of CF lamps by offering rebates to their clients to partially offset the relatively high purchase price of these lighting systems. This has led to an increase in the demand for CF lamps.

The ballasts of compact fluorescent lamps can be an important source of harmonic current. Many compact fluorescent lighting systems also operate at a relatively low power factor [2,3]. Since it is estimated that lighting represents up to 30 percent of the energy consumed in North America, the increasing use of CF lamps could have serious power quality implications for the electrical systems [4].

Even though electric utilities strive to provide their customers with pure and stable sinusoidal voltages there appear to be ever increasing occurrences of waveform distortions, undervoltages and power interruptions. The frequency of end-user complaints in these regards is also increasing [5]. As a consequence, some CF lamp systems will likely be installed in locations where the voltage conditions are not always pure sinusoidal waveforms. It is therefore important to study the performance of CF lamps for both sinusoidal and distorted waveforms.

A research program was undertaken by the National Research Council of Canada (NRC) in cooperation with the Canadian Electrical Association (CEA) and Energy, Mines and Resources Canada, Centre for Mineral and Energy Technology (EMR/CANMET) to study the economic aspects and the lighting and electrical performance of the currently available CF lamp technology [6]. This paper reports some of the results of this program.

COMPACT FLUORESCENT LAMPS TESTED

Table 1 provides a brief description of the compact fluorescent lamps studied. They represent a wide range of products currently available. Samples include both T4 and T5 sized lamps. Twin Tubes, Quad. Tubes and other lamps configurations are included in the samples. The lamps are provided with a magnetic core or an electronic ballast. These ballasts are either built-into the lamp fixtures, separately wired, or adapted for operation in a conventional medium based socket.

All the compact fluorescent lamps are designed to operate at 120 V AC and have power consumption ratings of 13 to 28 Watts. The retail cost of lamps and ballasts ranged from about \$17 to \$55. For this study, Sample 13 is used as the reference lamp and is a tube shaped T10 long life incandescent lamp of approximately the same physical size as the CF lamps under tests. Samples 7 and 8 are provided with ballasts with power factor correction circuits and operate at a "high" power factor.

Each sample consisted of a group of seven new lamps and ballasts aged and stabilized for approximately 100 hours. During the aging period of each sample, the seven lamps were powered together and their luminous output, voltage, current, wattage and power factor were monitored. After aging, a final selection of three lamps from each sample were chosen for evaluation under sinusoidal and distorted voltage waveforms.

Table 1
Description of the lamps under tests

SAMPLE	LAMP	RATING	BALLAST	COST
1	Twin, T4	13 W	Magnetic, Separate	\$19.95
2	Misc., T4	16 W	Magnetic, Built-in	\$21.00
3	Quad., T4	20 W	Electronic, Built-in	\$26.50
4	Misc., T4	18 W	Electronic, Built-in	\$26.70
5	Quad., T4	13 W	Magnetic, adapter	\$20.70
7	Quad., T4	26 W	Magnetic, separate hp*	\$55.69
8	Twin, T5	24 W	Magnetic, separate hp*	\$45.03
9	Quad., T5	28 W	Magnetic, separate	\$26.61
10	Quad., T4	13 W	Magnetic, separate	\$35.00
11	Twin, T4	13 W	Magnetic, adapter	\$17.58
13	Incand., T10	60 W		\$0.88

* hp = high power factor

DESCRIPTION OF THE TESTS

A diagram of the test system is shown in Figure 1 [7]. The voltage waveforms used for the tests are obtained from a system consisting of a computer, a digital arbitrary waveform generator and a voltage amplifier. The voltage test conditions are entered from the computer keyboard. The program loads the required waveform into the arbitrary waveform generator and sets the appropriate magnitude at the output of the generator. This output is then amplified and supplied to the three lamps under tests for each sample.

For the tests all lamps were mounted base-up in a uniform circular arrangement of radius of 60 cm. They were enclosed within a dark room to eliminate stray light. The dark room was ventilated from above by natural convection. The temperature inside the enclosure was monitored during the tests. Following stabilization, the lamps were tested at room temperature for a pure sinusoidal waveform and with three nonsinusoidal voltage waveforms. The voltage was set at 120 V_{rms} for all test conditions. The nonsinusoidal waveforms and their frequency spectrum are shown in Figure 2. These waveforms have been previously recorded in the field at harmonic problem locations. They were selected for testing the CF lamps as they represent typical voltage waveforms of low (4.6%), medium (15.5%) and high (36.4%) total harmonic distortion amongst the hundreds of examples stored in the NRC library of field recorded waveforms. The lamps were therefore tested under simulated field conditions.

A calibrated 12 bit dual channel digital oscilloscope was used to record the voltage and current waveforms of the lamps under tests. The stored digital samples were later transferred via the IEEE Bus to a computer for harmonic analysis and calculation of the electrical quantities shown in Table 2. The sampling clock of the digital oscilloscope was synchronized with the fundamental frequency of the test voltage waveforms. The harmonic content of the test waveforms was limited to 100 harmonics. The sampling frequency was therefore set at 1024 times the fundamental frequency, more than ten times the maximum harmonic frequency.

The values of V_{rms}, I_{rms}, Power (P), voltage total harmonic distortion THD_V and current total harmonic distortion THD_I were calculated directly from the harmonic components obtained with a Fast Fourier Transform of the sampled data of the voltage and current waveforms of the lamps under tests. These quantities were calculated as:

$$V_{rms} = \sqrt{\sum_{h=1}^{100} V_h^2} \quad (1)$$

$$I_{rms} = \sqrt{\sum_{h=1}^{100} I_h^2} \quad (2)$$

$$P = \sum_{h=1}^{100} V_h I_h \cos \phi_h \quad (3)$$

$$THD_V = \left[\frac{\sqrt{\sum_{h=2}^{100} V_h^2}}{V_{rms}} \right] \times 100\% \quad (4)$$

$$THD_I = \left[\frac{\sqrt{\sum_{h=2}^{100} I_h^2}}{I_{rms}} \right] \times 100\% \quad (5)$$

where V_h, I_h, φ_h are magnitudes and phase shift of the voltage and current h order harmonics.

The apparent power S and power factor PF were calculated as shown in equation (6) and (7).

$$S = V_{rms} \times I_{rms} \quad (6)$$

$$PF = \frac{P}{S} \quad (7)$$

It is estimated that the accuracy of the values obtained from equations (1) to (7) are better than 0.25%.

Figure 1 Diagram of the test system

Figure 2 Frequency spectrum and waveforms of the test voltages

During the tests, a true RMS multifunction meter with a bandwidth of 20 kHz was used to independently monitor the values of voltage, current and consumed real power of the lamps under tests. Comparison of the readings of the multimeter with corresponding calculated values based on the sampled data of the digital oscilloscope showed close agreement between the two systems for all test conditions.

Illuminance measurements of the three lamps under test were collected with an illuminance photometer at a location equidistant to each lamp, in a plane 1 m below the lowest point of the lamps. The illuminance meter was calibrated against the responses of a portable spectroradiometer for each of the different compact fluorescent samples. This procedure corrected for errors due to inexact matches between photometer relative spectral responsivity and human spectral luminous efficiency [8].

TEST RESULTS AND DISCUSSION

The results of the tests are summarized in Table 2. The measurements of current, real power and apparent power represent the average values for one lamp in each sample tested. In the Table, the eleven samples have been regrouped in five sets (I to V) each having similar electrical characteristics.

Samples 1, 2, 5, 9, 10, and 11 are in Set I. They all have magnetic ballast and operate at a power factor close to 0.5 for all test voltage waveforms. The THD values of their current waveforms are on average slightly above 10% except for test waveform NRC 1362 where it rises to slightly below 14%. The illuminance output of the lamps in this set is relatively constant for the sinusoidal and waveforms NRC 0002 and NRC 0004. Samples 1, 2, 5, and 9 experience a 7 to 10% drop in light output when supplied with test waveform NRC 1362.

Samples 3 and 4, the lamps provided with electronic ballasts are grouped in Set II. They operate at a power factor of 0.55 for the sinusoidal and NRC 0004 waveforms, and of 0.35 and 0.4 for waveforms NRC 0002 and 1362. The THD values of their current waveforms are approximately 82% for the sinusoidal and NRC 0004 waveforms and 94% for the other two test waveforms. The light output of these two samples rises with the harmonic distortion of the test waveforms.

Set III, IV, and V have only one sample each, Samples 7, 8, and 13 respectively. Sample 7 has a magnetic ballast with a power factor correction circuit. It operates at a power factor of 0.97 with a current THD of 21% for the sinusoidal test voltage. The electrical performance of Sample 7 changed significantly when it was supplied with the three distorted test waveforms. Its power factor even dropped to less than 0.1 and the THD of its current waveform reached 99.8% for waveform NRC 1362.

Sample 8 also has a magnetic ballast with a power correction circuit. However the three distorted voltage waveforms used during the tests have only a slight effect on the performance of this sample. It operates at a power factor larger than 0.95 and has a current THD of approximately 13% for all voltage waveform conditions. The illuminance output of this sample is also relatively constant for all test conditions.

Sample 13 is the reference incandescent lamp. As expected it operates at a power factor of 1.0 and with a current THD slightly higher than the voltage THD of the test waveforms it is supplied with. Its illuminance does not vary significantly with the test voltage conditions.

The test voltage waveforms and corresponding current waveforms for a typical lamp from each set are shown in Figure 3. The shape and harmonic content of the current waveforms for Set I and Set IV lamps are the least affected by changes of

Table 2
Performance comparison of the lamps under tests

Test Voltage	Sample	1	2	Set I Magnetic		9	10	11	Set II Electronic		Set III hp*	Set IV hp*	Set V inc.*
				5					3	4	7	8	13
Sine 120 V _{rms} THD _v = 0.1%	III.(L)	70.6	157.1	87.3	187.2	90.8	76.4		158.0	94.1	165.1	135.4	50.3
	I(A)	0.28	0.25	0.24	0.62	0.29	0.25		0.28	0.22	0.25	0.29	0.44
	S(VA)	33.8	30.3	28.6	74.5	35.1	29.6		33.6	26.4	30.4	34.6	53.4
	P(W)	16.6	16.0	14.7	33.7	18.6	14.5		18.5	15.2	29.6	34.2	53.4
	PF	0.49	0.53	0.51	0.45	0.53	0.49		0.55	0.58	0.97	0.99	1.00
	THD _i (%)	12.8	11.1	9.5	8.6	10.4	9.2		82.9	78.7	20.9	12.5	0.7
NRC 0004 120 V _{rms} THD _v = 4.6%	III.	70.1	158.2	87.7	188.1	90.2	76.4		160.2	95.8	166.8	134.8	50.1
	I(A)	0.27	0.25	0.24	0.62	0.29	0.24		0.29	0.22	0.45	0.29	0.44
	S(VA)	33.0	30.3	28.6	74.0	35.5	29.4		35.1	26.4	54.6	34.6	53.4
	P(W)	16.3	15.9	14.6	33.8	18.7	14.5		19.0	15.5	29.5	34.1	53.4
	PF	0.49	0.53	0.51	0.46	0.53	0.49		0.54	0.59	0.54	0.98	1.00
	THD _i (%)	12.8	11.3	9.5	8.6	10.1	9.0		84.3	79.8	87.8	14.0	4.61
NRC 0002 120 V _{rms} THD _v = 15.5%	III.(L)	70.7	157.1	86.9	184.8	88.5	74.2		162.4	98.4	165.7	134.8	50.1
	I(A)	0.27	0.25	0.23	0.61	0.29	0.24		0.50	0.41	2.24	0.29	0.44
	S(VA)	32.9	29.7	28.2	73.2	35.1	29.7		59.7	49.7	269.5	34.4	53.4
	P(W)	16.3	15.7	14.4	33.2	18.4	14.2		20.1	17.5	31.0	33.7	53.4
	PF	0.49	0.53	0.51	0.43	0.52	0.48		0.33	0.35	0.11	0.98	1.00
	THD _i (%)	12.9	11.2	9.5	8.6	10.2	8.6		95.1	94.4	99.5	11.3	15.4
NRC 1362 120 V _{rms} THD _v = 36.4%	III.(L)	63.3	144.3	81.6	176.1	89.9	74.8		166.9	103.7	154.8	137.0	50.0
	I(A)	0.23	0.22	0.21	0.54	0.24	0.21		0.41	0.41	2.58	0.29	0.44
	S(VA)	27.7	25.9	24.9	64.6	28.9	24.8		49.3	49.1	310.7	35.2	53.4
	P(W)	14.1	14.0	12.9	29.7	15.8	12.8		20.5	18.1	28.4	33.6	53.4
	PF	0.51	0.54	0.52	0.46	0.55	0.51		0.42	0.37	0.09	0.95	1.00
	THD _i (%)	16.8	14.1	12.8	12.4	14.3	13.2		92.8	94.1	99.8	15.0	34.4

NOTE: hp* = high power factor, inc.* = incandescent

harmonic distortion in their supply voltage. The current waveforms of the incandescent lamp Set V are, as expected, of the same shape as the supply voltage waveforms.

The current waveforms of the Set II and Set III lamps changed significantly when they were supplied with the distorted voltage waveforms. The current waveforms of the Set II lamps are nonsymmetrical and are particularly affected by spikes and dips near the peaks of the NRC 0002 and NRC 1362 voltage waveforms. The current waveforms of the Set III lamp observed under the distorted voltage waveform conditions bear no resemblance to its current waveform for a sinusoidal voltage. This lamp malfunctions in the presence of harmonics in its supply voltage.

ECONOMICS OF COMPACT FLUORESCENT LAMPS

A brief review of the power consumption and illuminance output data of Table 2 clearly indicates that the compact fluorescent lamps studied produced more light per watt than the incandescent lamp. These CF lamps will therefore cost less to operate than the incandescent lamp. In order for CF lamps to gain general acceptance in the market place, it must also be shown that this reduction in operating cost is sufficient to enable the customer to recover, in a reasonable time, the initial high retail cost of a new CF lamp and ballast.

The pricing policies and rate structures for electricity vary greatly in North America. However in most utilities residential customers are only charged for their energy use while commercial and industrial clients are billed for both energy and demand. These demand charges are increasingly based on apparent power measurements of kVA meters.

The cost of operation at room temperature of the lamps studied in this project has been calculated for their first 10,000 hours of operation, their estimated lamp life. Cost equations (8) and (9) for residential and commercial customers are based on the retail cost of a new lamp and ballast, a residential (Res.) energy rate of 7¢ per kW-h, a commercial (Com.) energy rate of 6¢ per kW-h and demand charges of \$6.00 per peak kVA. Labor cost for installing a new lamp system or replacing a burned lamp have not been included in the calculations. The effects of reduced lamp life due to switching have not been considered. The cost calculations have been adjusted for a common illumination output of 100 lux.

$$\text{Cost (Res.)} = \left[\text{R.C.} + \frac{P}{1000} \times 10000 \times 0.07 \right] \times \frac{100}{\text{Ill.}} \quad (8)$$

$$\text{Cost (Com.)} = \left[\text{R.C.} + \frac{P}{1000} \times 10000 \times 0.06 + \frac{S}{10000} \times \frac{10000}{720} \times 6.00 \right] \times \frac{100}{\text{Ill.}} \quad (9)$$

where the values of P, Ill. and S are the measured values reported in Table 2 and R.C. are the Retail Cost shown in Table 1.

The second term of the cost equations represent the energy costs of operating the lamps for 10,000 hours. The last term of equation (9) is an estimate of the demand charges for the lifetime of the lamp. It assumes that the lamp is always on when the monthly peak demand occurs and that the billing cycle is 30 days, i.e. 720 hours.

Total costs of operation shown in Table 3 have been calculated for all the lamps under consideration and for a conventional A19, 60W, 120 V, 2500 hours incandescent lamp known to have twice the light output of Sample 13. These calculations were done for both the sinusoidal and NRC 1362 voltage waveforms.

These calculations indicate that on average the costs were only slightly higher for the distorted waveform except for sample 7 where the cost under distorted conditions are more than 20% higher. This is due to the relatively high values of apparent power measured for this sample under distorted conditions. In general the cost under the commercial rate are also slightly higher than residential.

The cost of all the CF lamps systems during the initial 10,000 hours of operation were lower than Sample 13 the reference lamp. When compared to a conventional 60W lamp, Samples 2, 3, 4, 5, 9 and 11 had lower costs.

After the first 10,000 hours, the retail cost in the calculation for the remaining lamp systems (Samples 1, 7, 8, 10) can be reduced to only the cost of a new replacement lamp. As such all these CF lamp systems will reach a break even point during their second 10,000 hours of operation.

Table 3
Cost of operation of the lamps for their initial 10,000 hours
(\$/100 Lux)

Sample	Sine		NRC 1362	
	Res.	Com.	Res.	Com.
1	44.72	46.34	47.11	48.53
2	20.49	21.08	21.34	21.87
3	24.96	25.56	24.47	25.71
4	39.68	40.40	37.96	40.16
5	35.50	36.54	36.43	37.40
7	46.28	46.02	48.82	63.71
8	50.93	50.54	50.04	49.72
9	26.81	28.33	26.91	28.28
10	52.88	54.05	51.23	52.16
11	36.29	37.63	35.48	36.53
13	76.06	74.29	76.52	74.74
A-19	44.00	43.00		

VOLTAGE WAVEFORMS

Sine

NRC0004

NRC0002

NRC1362

CURRENT WAVEFORMS

Set I
Sample 1

Set II
Sample 3

Set III
Sample 7

Set IV
Sample 8

Set V
Sample 13

Figure 3 Test voltages and current waveforms for a typical lamp from each set

CONCLUSIONS

In recent years, the levels of harmonic distortions of the voltage and current waveforms in power systems have steadily increased. As a consequence, compact fluorescent lamps, which are increasingly being used as alternatives to incandescent lamps, will likely be installed in locations where the voltage waveforms are not always pure sinusoids. It is therefore important to study the performance of these new lamps for both sinusoidal and distorted voltage waveforms previously observed in power systems.

The results of the tests indicate that the electrical performance of the lamps for both sinusoidal and distorted voltage waveform conditions is related to the type of ballast used (magnetic or electronic) and whether or not these ballasts are provided with a correction circuit to achieve high power factor operation. The lamps with magnetic ballasts without correction circuits (Set I) produced the least harmonic current and were the least affected by supply voltage harmonics. The Sample 7 lamp (Set III) malfunctioned in the presence of harmonics in its supply voltage.

Economic analysis showed that six of the ten CF lamp systems studied would reach their break even point during their first 10,000 hours of operation, i.e. their lamp life. The other four CF lamp systems would only achieve their break even point during their second 10,000 hours of operation. Harmonics in the supply voltage have relatively little influence on the economics of CF lamp systems.

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REFERENCES

- [1] J. Cherfas, "Skeptics and visionaries examine energy saving", Science, vol. 251, pp. 154-156, Jan. 1991.
- [2] R.R. Verderber, O.C. Morse and W.R. Alling, "Harmonics from compact fluorescent lamps", IEEE Industry Applications Society 1991 Conference, Dearborn, Michigan, Sept. 28 - Oct. 4, 1991, pp. 1853-1858.
- [3] M. Etezadi-Amoli, T. Florence, "Power factor and harmonic distortion characteristics of energy efficient lamps", IEEE Trans. Power Deliv., Vol. PWRD-4, pp. 1965-1969, July 1989.
- [4] T. Jednacz, "Power quality design implications of high frequency lighting ballasts and controls", IEEE Industry Applications Society 1991 Conference, Dearborn, Michigan, Sept. 28 - Oct. 4, 1991, pp. 1833-1835.

- [5] M.C. Ryan, "Power Quality Reference Guide", Ontario Hydro, Toronto, Ontario, 1988.
- [6] M. Ouellette, R. Arseneau, M. Siminonvitch and S. Treado, "New program for investigating the performance of compact fluorescent lighting systems", IEEE Industry Applications Society 1991 Conference, Dearborn, Michigan, Sept. 28 - Oct. 4, 1991, pp. 1895-1897.
- [7] R. Arseneau, P. Filipski, "Application of a three phase nonsinusoidal calibration system for testing energy and demand meters under simulated field conditions", IEEE Trans. Power Deliv., Vol. PWRD-3, pp. 874-879, July 1988.
- [8] Commission internationale de l'éclairage, "Light as a true visual quantity: principles of measurement" CIE publication No. 41 (TC-4.1), Paris 1978.

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