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New Program for Investigating the Performance of Compact Fluorescent Lighting Systems

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NEW PROGRAM FOR INVESTIGATING THE PERFORMANCE OF COMPACT FLUORESCENT LIGHTING SYSTEMS

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***Abstract* -- This paper describes a new research program aimed at investigating the performance and energy-conservation potential of different types of conventional- and electronically-ballasted compact fluorescent lighting systems under a range of environmental conditions. Participants include key lighting and electrical research laboratories from Canada, the U.S.A., and the United Kingdom. The research team will conduct laboratory and field investigations of lighting efficiency, reliability, and both thermal and power quality considerations. The results will help electrical utilities, government bodies, manufacturers, consumers and others more effectively judge the benefits of compact fluorescent technology in energy conservation programs.**

I. INTRODUCTION

Compact fluorescent (CF) lamps are promising alternatives to incandescent sources. They are commonly reported as consuming up to 5 times less electricity and lasting 13 times longer than incandescent sources of comparable luminous output [1]. Such impressive reports, together with generous rebate incentives [2] and rigorous retail promotion [3], have led to a rapidly increasing demand for CF systems. Lighting manufacturers have developed a wide range of new products in response to this demand.

Compact fluorescent, and indeed all fluorescent systems, are fundamentally more complex than the incandescent technology they are designed to replace. As with all fluorescent technology, power consumption, luminous output, and lifetime varies as a function of ambient temperature [4]. Some CF lamps are 10 mm diameter, others are 15 mm diameter with fundamentally different operating characteristics. Some are dimmable, others are not. Some are enclosed by nonremovable diffusers and are subject to higher temperature operation. Regardless, all CF lamps require ballasts for establishing and maintaining operation. Ballasts, themselves, consume electricity and generate heat. Some ballasts are disposable and are built into the lamp, others are designed for longer use and are wired separately. Ballasts may be simple magnetic chokes operating one or more lamps at line frequency. They may also consist of electronic systems exceeding 80 components and they may operate nonlinearly at high frequency. Some may include thermal protection, power factor correction, radio interference suppression and other features foreign to the domain of incandescent technology.

Some electronic ballasts may significantly increase harmonics in the power system. In many cases, harmonics have little or no effect on connected equipment operation. In other cases, harmonics can lead to such problems as capacitor and transformer failure, poorer operation of electric motors and electronic equipment, computer problems and failures, incorrect power measurement, circuit breaker failures, excess neutral loading in 3-phase circuits and other safety hazards. The potential for problems increases as more electronic and nonlinear loads [5] are, including other electronic lighting and control systems, are connected. Some electronic ballasts are equipped with harmonic suppression filters. Hence, power quality issues demand serious consideration before undertaking large scale installation of electronically ballasted systems.

CF systems greatly expand one's opportunities in energy efficient lighting design. As with all new freedoms, they arrive at the expense of a significantly more complicated decision process. Not all CF systems are equally suitable for all applications. Consequently, one requires more detailed technical information on all aspects of CF system performance in order to effectively target and advise on retrofit applications, thereby ensuring the success of current energy conservation programs, and facilitating consumer acceptance and market penetration of CF technology. This paper presents the highlights of a research program aimed at investigating the key economic and performance aspects of currently available compact fluorescent technology.

II. THE RESEARCH PROGRAM

A. Samples

The widest possible range of product types will be studied. Samples will include what are known as ***Twin Tubes***, ***Quad Tubes***, and other lamp configurations. They will include both T4 and T5 sized lamps. Lamps with built-in diffusers will be studied in comparison with bare-lamp systems. Nondimmable systems will be studied in comparison with dimmable ones operating at full and at half output. Three types of ballasts will be included: built-in, separately wired, and ballasts adapted for operation in conventional medium based sockets. Both magnetic core/coil ballasts and electronic ballasts will be investigated. All samples will be studied in multiples of seven. This will partially compensate for random variations within individual sample types.

Since the performance of CF systems can vary with mounting position, all lamps will be mounted base-up, the position most common in overhead applications. Since the performance of most fluorescent systems continually decreases with accumulated duration of operation [4], only new lamps and ballasts will be considered, and they will all be aged for the same duration. Throughout the aging period, the following parameters will be monitored for groups of seven replicate samples powered together: relative luminous intensity, voltage, current, wattage, and power factor. In addition, a harmonic analysis will be performed on both current and voltage waveforms. After aging, samples will be similarly evaluated on a balanced 3-phase supply, with particular emphasis on neutral loading.

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B. Instrumentation

In the presence of harmonic and other distortions, the accurate measurement of electrical consumption can be a difficult problem. Measurement equipment may give seriously inaccurate readings for waveforms distorted, in part, by certain ballasts, other connected equipment and possibly even by the measurement equipment itself [6]. To ensure accuracy, all electrical monitoring equipment will be true RMS responding within a bandwidth of 0 - 3 kHz or wider. In addition, all samples will be powered, in turn, by the same regulated and conditioned AC power supply.

Accurate photometric measurement is also not a straight forward matter with CF systems. Even the highest quality illuminance meters may respond differently to equal illuminances of different spectral composition. The effect is often negligible for such broad-band sources as incandescents, but it may become significant for narrow-band triphosphor, CF sources. Suitably calibrated spectroradiometers are not, however, susceptible to this measurement problem. The extent of this effect will be determined for each illuminance meter to be used in the study under each of the unique CF systems. Results will be compared with illuminance readings derived from a high quality laboratory spectroradiometer. Ratios between illuminance meter readings and spectroradiometer readings under each of the lighting systems will be used, if necessary, to correct all subsequent readings obtained with illuminance meters.

C. Effect of Ambient Temperature and Humidity

Unlike incandescent sources, the efficiency of all fluorescent lamps varies considerably with the vapour pressure of the contained mercury, a function of temperature [4]. Electrical properties are also affected [4]. As a consequence, most general purpose fluorescent lamps are designed to operate at peak efficiency within normal indoor environments. Unless otherwise stated, one should only assume that quoted performance specifications [1] are in terms of ideal ambient conditions. The following measurements will delineate the performance of CF systems when exposed to unfavourable conditions of temperature and humidity.

CF samples will, in turn, be equilibrated at 6 different temperatures spanning the range under which CF lamps may be expected to operate: from subzero outdoor wintertime temperatures to the high temperatures that a CF lamp may experience when installed in recessed luminaires blanketed with thermal insulation [7]. Humidity will be maintained at dew point, except at one of the lower temperatures where humidity will be both above and below dew point to assess the effects of lamp wall frosting. Under these conditions, the following performance parameters will be measured: 1) lamp starting time or failure, 2) time for luminous and electrical stabilization, 3) relative luminous intensity, 4) luminous flicker index, 5) minimum lamp wall temperature, 6) power consumption, and 7) relative luminous efficacy.

D. Effect of Power Quality

Power Quality may be operationally defined as "the degree to which both the utilization and delivery of electric power affects the performance of electrical equipment" [5]. This may involve the extent to which current and voltage deviate from the perfect sinusoid, but it may also involve such other disturbances as undervoltage situations.

Electric utilities have always strived to provide clean and reliable bulk power suitable for running electric motors and other more traditional loads. Although no electric utility customer was ever immune to occurrences of wave distortions, undervoltage and power interruption, the frequency of end-user complaints are increasing in these regards [5]. Judging from the recent proliferation of such highly sensitive devices as computers and other electronic equipment, one might conclude that end-users are redefining their definition of clean and acceptable power. Traditional linear loads are more tolerant of brief or subtle deviations from ideal power. These same blemishes, however, have the potential of shutting down or even destroying sensitive modern digital equipment. To a computer or a digital clock, even a brief microsecond disturbance may be as fatal as a long interruption in service [8,9]. Likewise, the performance of some CF systems may be sensitive to the variations in power quality. The following describes the measurements which will be conducted in order to gain a greater insight into the effect of power quality issues upon the performance of the wide range of CF systems.

Each CF system will be powered, in turn, by a unique 3-phase AC generator capable of supplying a wide assortment of waveforms sampled from within a diversity of commercial, residential, and industrial building sites across Canada [10]. Relative luminous intensity and luminous flicker index [4] will be measured under each supplied waveform. Voltage to the CF systems will then be reduced, and the following parameters will be iteratively determined: 1) the minimum voltage for lamp starting, and 2) the minimum voltage for sustaining lamp operation. Thus, the effects of waveshape and brownout conditions will be determined.

E. Effect on Power Quality

Power quality complaints have risen in proportion to the increasing use of such disturbance-producing equipment as arc welders, electric variable speed drives, solid state switching semiconductors and other nonlinear loads [5,8]. Electronic ballasts, too, are commonly blamed [9]. While electric utilities and other groups are actively assessing and redirecting their goals, installers and specifiers of lighting equipment bear the responsibility of ensuring their equipment does not propagate the problem more than necessary. The following measurements will provide the technical background for evaluating the various types of CF systems in terms of their effects on power quality.

Each CF system will be powered, in turn, by a clean 60 Hz, 115 V supply. Following stabilization, the following parameters will be measured: true watts, volt-amperes, and power factor. In addition, a harmonic analysis will be conducted on both lamp current and voltage waveforms.

F. Field Study

Controlled laboratory studies (Sections II.A to II.E) are essential for accurately quantifying and rank ordering the various CF systems in terms of the parameters of interest. Nevertheless, laboratory measurements cannot necessarily predict performance in field situations where a diversity of dynamically changing loads may act and interact to affect the operation of the samples in question.

In a public office building, two different CF systems will, in turn, be retrofitted into circuits initially loaded with incandescent lamps. The following parameters will be monitored both before and after the retrofits: true wattage, volt-amperes, power factor, and average illuminance at the workplane or floor level, wherever appropriate. In addition, a harmonic analysis will be conducted both before and after each retrofit. The resulting data will be used to assess the true energy conservation and performance potential of the tested CF systems.

G. Developments in Thermal Control Devices

A number of thermal control devices have been reported for improving the thermal operation of CF lamps [e.g., 11]. These include solid and liquid heatsinks and thermal jackets for lamp cooling, and different reflector and diffuser designs for lamp warming.

This phase of the project will explore the potential and implications of controlled thermal management in CF systems.

H. Psychological Effects

Good electrical, photometric and economic performance together do not guarantee a suitable result. Success or failure depends ultimately upon end-user satisfaction and acceptance. It has been reported that the physical appearance of light sources can affect one's impressions of the brightness of interior spaces [12]. Bare CF lamps appear, by nature, different from bare incandescent ones. Their light is typically diffused more uniformly over a larger surface area than that from incandescent filaments. Drawing from the earlier work of Bernecker and colleagues [12] one might draw the hypothesis that spaces illuminated with bare incandescent lamps would appear brighter than they would if illuminated in the same manner by CF lamps of equal rated luminous intensity. If true, CF systems might require yet higher electrical loads to achieve a suitable sensation of brightness.

A series of psychophysical experiments will be conducted to evaluate the ability of CF systems to provide equal brightness of comparable incandescent lamps. The experiments will involve test subjects rating and adjusting the brightness of ambient lighting in two adjacent offices, one illuminated with CF lamps, the other with incandescent ones. Data analysis will reveal the economic implications of any differences in illumination needed to achieve equivalent brightness.

III. DISCUSSION

Presentation of this new research program highlights the diversity of important issues regarding the evaluation and implementation of compact fluorescent products. While the program may well be the most thorough investigation of its kind for CF systems, it is far from complete. Practical considerations prevent the study, at this early stage, of lamp life as a function of temperature, power quality, switching frequency, voltage fluctuations [13] and other operational parameters. These and other issues require further study.

Results from this research program will be published as they become available. In the meantime, it is hoped that this announced program will serve as a model for the design and enhancement of evaluation programs of electrical discharge lighting systems.

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