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Test and Evaluation of Lighting System in High-Frequency AC Microgrids

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Test and Evaluation of Lighting System in High-Frequency AC Microgrids

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Abstract: **A 600Hz single phase high frequency AC microgrid is proposed to integrate the renewable source and load. In order to provide insights of how lighting systems can be adjusted to work more efficiently with high frequency power source. This paper is devoted to a study of the illumination intensity and efficiency changes of current household lighting systems under high frequency operating conditions. Comparisons of performance under different working frequencies are explained. Two types of lighting system, incandescent lamps and fluorescent lamps with magnetic ballast, were tested and evaluated. The experiments results of current & input power, illumination intensity and illumination efficiency, heat, power factor and starting voltage of lighting system have been obtained. It was determined that both types of lighting systems can function when directly plugged into 600 Hz AC source, and that they have superior performance and higher efficiency using a 600Hz than a 60Hz system.**

Keywords: ***Distributed generation, Microgrid, Lighting systems***

I. Introduction

Distributed generation (DG) has been considered as a promising alternative for the coordinated and flexible expansion of the present energy distribution system with reduced cost and improved reliability[1]. Distributed generation is a small-scale electric power source connected directly to the utility's distribution network or on the customer site of the meter, and it provides electric power at a site closer to customers than the central station generation. The capacity scale of DG typically ranges from 1 KW to 50MW. DG provides a multitude of services to utilities and consumers, including standby generation, peak shaving capability, base-load generation, or cogeneration. For businesses, DG can reduce peak demand charges, reduce overall energy use, ensure greater power quality and reliability, and reduce emissions. For large utilities and power producers, DG can augment overall system reliability, avoid large investments in transmission system upgrades, reduce transmission losses, closely match capacity increases to demand growth, and open markets in remote or environmentally constrained areas. Given continued technological and technical advances, Distributed generation can provide economic and environmental benefits well into the 21st century[2].

Various technologies are available for DG, including turbine generators, internal combustion engine/ generators, micro-turbines, photovoltaic/solar panels, wind turbines, and fuel cells. These small modular generation technologies interconnected to distribution systems can form a new type of power system, the microgrid[1]. The microgrid concept is a substantial step towards solving the controllability problems of distributed resources. In a microgrid, a cluster of loads and microsources operate as a single controllable system to provide power and heat in their local area. Power electronic converters are very important for the microgrid. Most of microsources must be power electronic based to provide required flexibility to ensure operation as a single aggregated system. In order to optimize system structure, a high-frequency AC link[4,5]has been used as the power electronic interface to achieve better utilization of the microgrid[3]. A single-phase 600 Hz high-frequency AC (HFAC) microgrid is used to combine the renewable sources with the loads and the grid in this project.

In a high frequency AC microgrid system, commercial lighting system should function when plug into a power socket. This test is dedicated to study the illumination benefits and efficiency of current household lighting systems under high frequency operation conditions. Comparisons of performance under different working frequencies will be presented. Two types of lighting systems, incandescent lamps and fluorescent lamps with ballast, were tested and are evaluated in this paper. The results are expected to provide insights of how current lighting systems can be adjusted to work more efficiently with high frequency power source. The configuration and specification of two types of lighting system are provided in Section II. In Section III, The characteristics including current & input power, illumination and illumination efficiency, heat of incandescent lamps in a 600Hz HFAC system are tested and explained. The experimental tests of performance, power factor and starting voltage of fluorescent lamps with ballast are evaluated in Section IV. Final conclusions are given in Section V.

II. Types of Lighting Systems

There are mainly two types of most prevalent household lighting equipment, the first kind is incandescent lamps and the other type is fluorescent lamps with ballast. Two typical incandescent and fluorescent lamps have been selected for testing at 50Hz, 60Hz, 400Hz and 600Hz.

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1) Incandescent lamp: FEIT Electric Company BP40A15/W/CF/WG
2) Fluorescent lamp (tube): Philips F30T12/ D/RS/ALTO
Fluorescent lamp (fixture): Philips CH230-120V Ballast: Philips RL140TP

The test circuit of incandescent and fluorescent lamps is shown in Fig. 1 and Fig. 2.

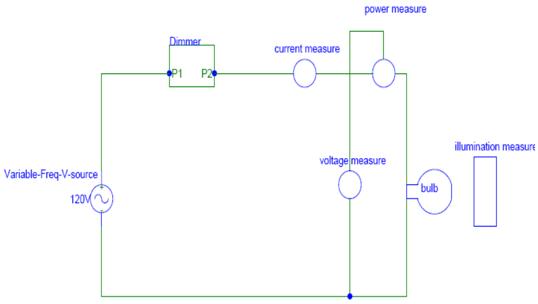

Fig. 1. Test Circuit for incandescent lamp

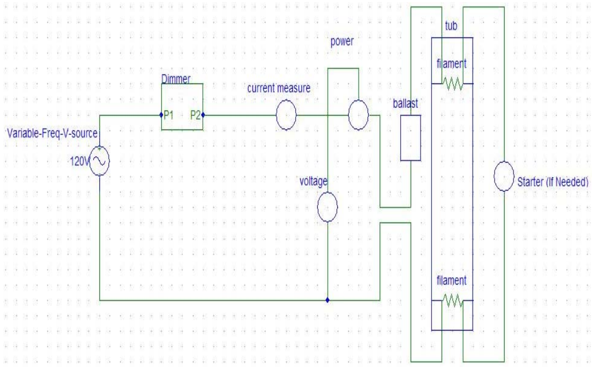

Fig. 2. Test Circuit for fluorescent lamp with magnetic ballast

The test content and specifics are given in Table 2.1.

Table 2.1 Test Specifics of Lighting System

Test of Lighting Apparatus at Different Frequencies	
Apparatus Category	Characteristics of Interest
Incandescent Lamps	Current & Power
	Luminous at Rated Voltage
	Luminous Efficiency at Rated Voltage
	Generated Heat
Fluorescent Lamps	Current & Power
	Luminous at Rated Voltage
	Luminous Efficiency at Rated Voltage
	Generated Heat
	Power Factor
	Lowest Start Voltage

1) The light intensity was measured 1 meter away from the bulb/tube.
2) Luminous efficiency is defined as

$$LUMINOUS\_EFF = \frac{ILLUMINATION[lumen]}{INPUT\_POWER[W]}$$

3) Power factor was measured at the output terminals of the voltage source.
4) The heat generated by the bulb/tube was measured with a remote heat sensor.

In addition to the desired 600 Hz, the lighting systems are tested operating at three other frequencies. They are 50 Hz, 60 Hz and 400 Hz. 50 and 60 Hz, which are commonly used as the base frequency of power systems. 400 Hz is usually employed in aircraft. The frequency variable AC power source used in the test is Pacific 345-ASX. The list of test equipment is:

Multimeters:	Fluke 8050A
	Fluke 79III
Power Analyzer:	Voltech PM300
Thermometer:	Lutron TM-909
Osclloscope:	Agilent 54624A
Sound Level Meter:	Simpson 886
Light Meter:	Velleman DVM1300

III. Test Results for Incandescent Lamp

The voltage across the lamp is set to 110 volts. The current through the lamp as well as the temperature of the lamp are measured at different time spots and at different frequencies. The environment temperature is recorded for every test as reference. The measurement of the illumination is conducted in a black box when the lamp is heated thoroughly (i.e. the current stays constant). The vertical distance between the reference level of the lamp and the light meter is 20 cm. Since the current no longer changes after 10 minutes during 400 Hz and 600 Hz operation, the current was not further measured and the illumination test is then carried out.

(1). Current

The current characteristic of incandescent lamp is shown in Fig. 3. The test results at different frequencies are shown in points of different color as in the legend. The trend lines of the characteristics at the four frequencies are of different color, which is also illustrated in the legend. All similar figures in the paper will use the same color pattern.

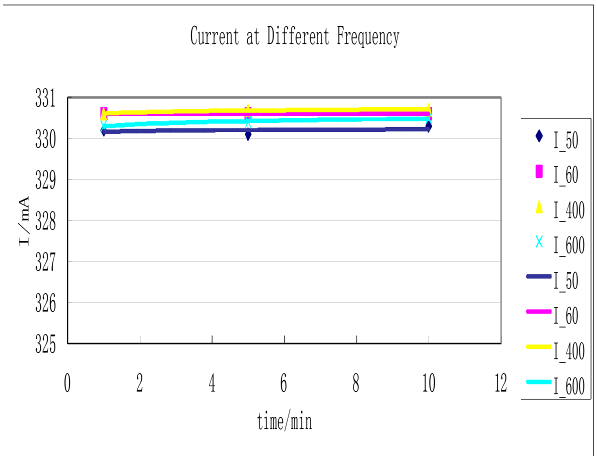

Fig. 3. Current of incandescent lamp.

From Fig. 3, it can be seen that the current of incandescent lamp at different frequency are close to each other. With the same input voltage, it is the input power are almost the same as well. This result means the frequency have no effect on the input current and power for incandescent lamp.

(2). Heat

The heat of the incandescent lamp was measured by the temperature degree in this test. The temperature characteristic of the incandescent lamp is shown in Fig. 4.

It can be concluded from the test data that the final temperatures are almost the same, even though the bulb is heated faster at higher frequencies. This result indicates that the heat efficiency at different frequency is the same, while the quicker transient response is achieved with higher frequency.

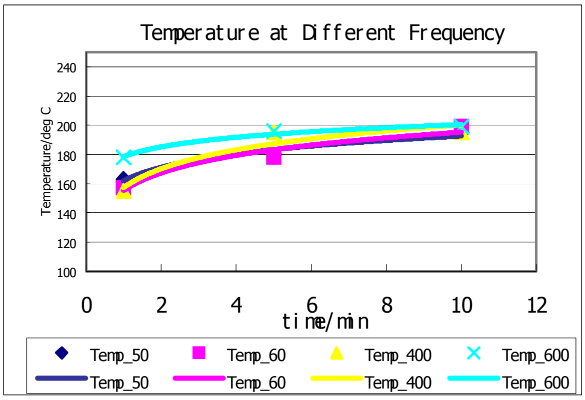

Fig. 4. Temperature of incandescent lamp.

(3). Illumination

The illumination of the incandescent lamp was measured by the light meter. The Illumination at rated voltage of the incandescent lamp with different impressed frequencies is shown in Fig. 5. The rated voltage is equal to 110 V.

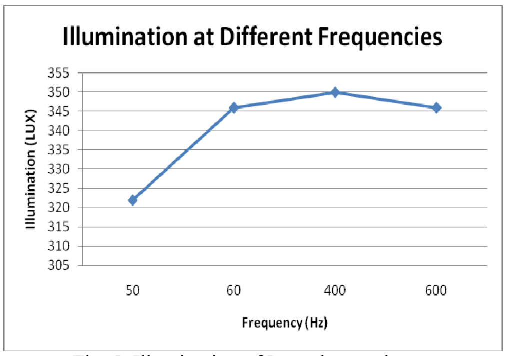

Fig. 5. Illumination of Incandescent lamp.

From Fig. 3, it can be seen that the increase of frequency impacts the illumination to some certain extent. Over the frequency range of the test, the highest illumination is achieved when the bulb is excited at 400 Hz.

(4). Illumination efficiency

The illumination efficiency of incandescent lamp at different frequencies is shown in Fig. 6. The abscissa is the ratio of the actual illumination at rated voltage to the input power in percentage.

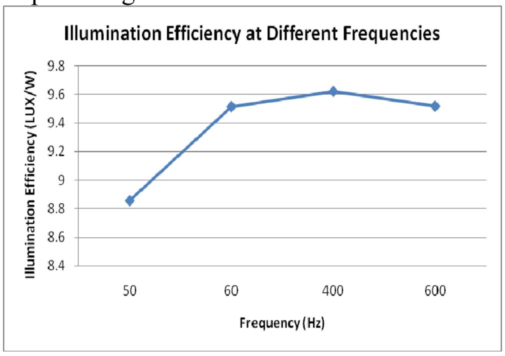

Fig. 6. Illumination Efficiency of incandescent Lamp.

It can be concluded from the test data that illumination efficiency increase with the increase of frequency, while the highest illumination efficiency is achieved when the bulb is excited at 400 Hz.

IV. TEST RESULTS FOR FLUORESCENT LAMP WITH MAGNETIC BALLAST

The voltage across the fixture was set to 110 volts. The temperatures of the ballast and the tube were measured at different time spots and at different frequencies. The environment temperature was recorded for every test as reference. The measurement of the illumination is conducted in a black box when the tube and ballast were heated thoroughly (i.e. the current stays constant). The active power and power factor was also measured at the same time. The vertical distance between the reference level of the tube and the light meter is 15 cm. The lowest instant start (within 2 seconds) voltage of the fluorescent lamp was tested at different frequencies.

(1). Current & Power

The current characteristic of fluorescent lamp with magnetic ballast at different frequencies is shown in Fig. 7.

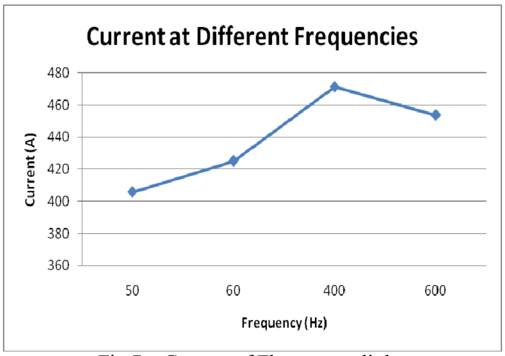

Fig.7 Current of Fluorescent light.

The input power of the fluorescent lamp with a magnetic ballast at different frequencies is shown in Fig. 8.

From Fig.7 and Fig. 8 it can be seen that the current of fluorescent lighting system at different frequency increase with the increase the frequency. It means more power consumption. The highest power consumption is achieved at 400Hz.

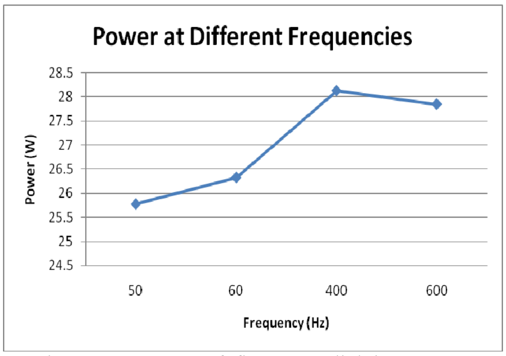

Fig.8 Input Power of fluorescent lighting system.

(2). Illumination

The illumination of the fluorescent lamp is measured by the light meter. The illumination at rated voltage of incandescent lamp with different frequencies is shown in Fig. 9. The rated voltage was again equal to 110 V.

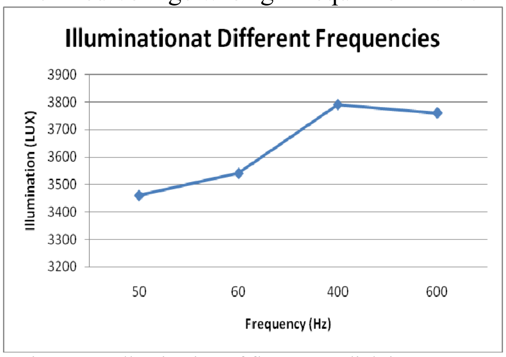

Fig.9 Illumination of fluorescent lighting system.

From Fig. 9, it can be seen that the increase of frequency impacts the illumination noticeably. Apparently, the highest illumination is achieved when the bulb is excited at 400 Hz.

(3). Illumination efficiency

The Illumination efficiency of Incandescent Lamp at different frequencies is shown in Fig. 10. The abscissa is the ratio of the actual Illumination at rated voltage to the input power in percentage.

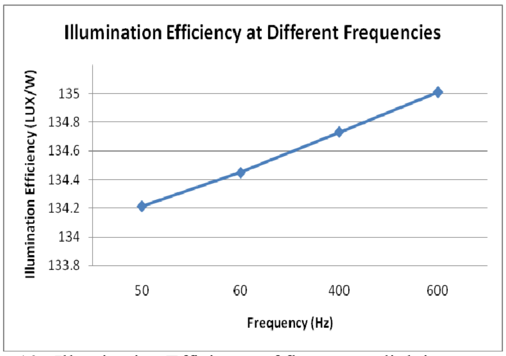

Fig.10 Illumination Efficiency of fluorescent lighting system.

It can be concluded from the test data that the increase of frequency impacts the illumination efficiency noticeably. The lighting efficiency rises steadily as the frequency increases and peaks at 600 Hz.

(4). Heat

The heat of the incandescent lamp is measured by the temperature degree. The temperatures of fluorescent lamp and magnetic ballast were measured separately, since the temperature is different. Temperature characteristics at different frequencies are shown in Fig. 11 to Fig. 14.

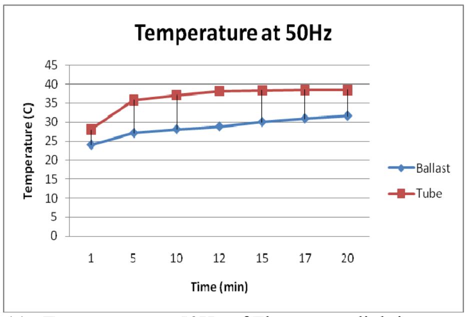

Fig.11. Temperature at 50Hz of Fluorescent lighting system.

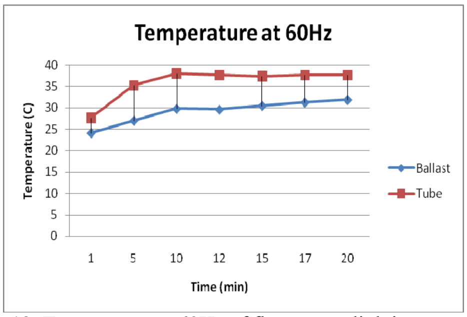

Fig.12. Temperature at 60Hz of fluorescent lighting system.

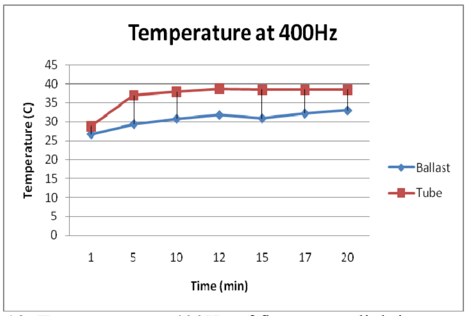

Fig.13 Temperature at 400Hz of fluorescent lighting system.

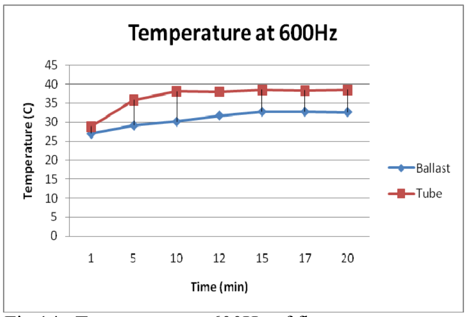

Fig.14. Temperature at 600Hz of fluorescent system.

It can be concluded from the test data that the temperatures curve are almost the same for Fluorescent tube. This result means that the heat efficiency at different frequencies is the same. With a ballast, even though the final temperatures are almost the same, the ballast is heated faster at higher frequencies. It is because the inductor is heated faster at higher frequency, due to the core loss.

(5). Power factor

The power factor of fluorescent lighting system with different frequencies is shown in Fig. 15.

From Fig. 15, it can be seen that the increase of frequency impacts the system power factor. At 400Hz, it is the point of lowest power factor. This result occurs because the fluorescent lighting system requires more power from the source with the increase of frequency, due to the inductor core loss. The highest power consumption is achieved at 400 Hz.

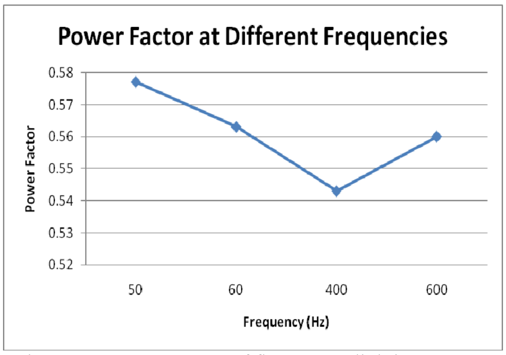

Fig.15 Power Factor of fluorescent lighting system.

(6). Start voltage

The start voltage of fluorescent lighting system with a range of frequencies is shown in Fig. 16.

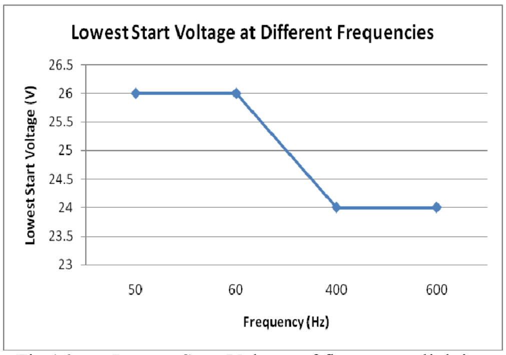

Fig.16 Lowest Start Voltage of fluorescent lighting

From Fig. 16, the lowest instant-start voltage decreases as the frequency increases, which indicates that the start voltage range is wider at the higher frequencies. However, a power supply as low as 15 volts is still able to start and run the lamp if given sufficiently long time to start (more than 10 seconds). This result also suggests that faster transient response is achieved with higher frequency.

It can be concluded from the test data that the increase of frequency impacts the illumination as well as the efficiency noticeably. The light is capable of extracting more power from the source and providing more illumination at higher frequencies with the same terminal voltage. The highest power consumption and the highest illumination are both achieved at 400 Hz, although it is also the point of lowest power factor. The lighting efficiency rises steadily as the frequency increases and summits at 600 Hz.

It should be noted that the significant efficiency difference between the incandescent lamp and the fluorescent lamp is not only caused by their nature but also by the test distance of the light meter, therefore, the result of this test does not provide insightful comparison between the two lighting apparatus.

V. Conclusion

Two typical kinds of commercial lighting system, incandescent lamps and fluorescent lamps with ballast, were tested and evaluated for use in a high frequency AC microgrid system. The experimental results for current & input power, illumination and illumination efficiency, heat, power factor and start voltage of lighting system have been obtained. It was determined that both types of lighting system can not only function properly when directly plugged into 600 Hz AC source but have superior performance and high efficiency in when compared with a 50 Hz or 60Hz system.

It was found that

1) The illumination and illumination efficiency are higher at higher input frequency.
2) For both the incandescent lamp and the fluorescent lamp, 400Hz excitation produces the highest illumination.
3) The highest illumination efficiency appears at 400Hz for the incandescent lamp and 600Hz for the fluorescent lamp.
4) The increase of the frequency does not increase the highest temperature of either the incandescent lamp or the fluorescent lamp.
5) The incandescent lamp is heated faster at higher frequencies.
6) The lowest instant-start voltage decreases as the frequency increases. It also suggests that quicker transient response is achieved with higher frequency.

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REFERENCES

[1] R. H. Lasseter, “MicroGrids,” Proc. PES Winter Meeting, Jan. 27–31, 2002, vol. 1, pp. 305–308.

[2] H.Xu, L.Kong, X.Wen, “Fuel Cell Power System and High Power DC-DC converter”, IEEE Trans on Power Electronics, vol. 19, no.5, pp 1250-P1255, Sep 2004.

[3] S. Chakraborty, M.D. Weiss, and M. G. Simões, “Distributed Intelligent Energy Management System for a Single-Phase High-Frequency AC Microgrid”, IEEE Trans on Industrial Electronics, vol. 54, no.1, pp.97-108, Feb. .2007.

[4] P. K. Sood and T. A. Lipo, “Power conversion distribution system using a high-frequency ac link,” IEEE Trans. Ind. Appl., vol. 24, no. 2, pp. 288–300, Mar./Apr. 1998.

[5] P. K. Sood and T. A. Lipo, “A versatile power converter for high-frequency link systems” IEEE Trans. on Power Electronics, vol. 3, no. 4, pp. 383-490, Oct. 1988.

[6] I. Takahashi and G. J. Su, “A 500 Hz power system-applications,” Proc. IEEE–IAS Annu. Meeting Conf. Rec., Oct. 1–5, 1989, vol. 1, pp.996–1002.