International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:6, No:12, 2012

Harmonic Comparison between Fluorescent and WOLED (White Organic LED) Lamps

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***Abstract*—**Fluorescent and WOLED are widely used because it consumes less energy. However, both lamps cause a harmonics because it has semiconductors components. Harmonic is a distorted sinusoidal electric wave and cause excess heat. This study compares the amount of harmonics generated by both lamps. The test shows that both lamps have THDv(Total Harmonics Distortion of Voltage) almost the same with average 2.5% while the average of WOLED's THDi(Total Harmonics Distortion of Current) is lower than fluorescent has. The average WOLED's THDi is 29.10 % and fluorescent's THDi is 87. 23 %.

***Keywords*—**Fluorescent, harmonic, power factor, WOLED.

I. INTRODUCTION

NOWADAYS, more research effort is put on energy efficiency issues. Researcher has been doing research to find more energy-efficient lamps. Australia and Europe tried to eliminate the use of incandescent lamps in 2009, while China targets complete replacement in 2016. The underlying reason is because incandescent bulbs waste a lot of electrical energy into heat. Based on a research data incandescent lamp has efficacy 14 lm / w, halogen lamp has 20 lm / w, fluorescent has 60 lm / w, and WOLED has 100 lm / w [1].

Based on the data above, it is clear that fluorescent and WOLED are more efficient than incandescent bulb. Although fluorescent and WOLED has higher efficacy, both of them cause harmonic distortion due to the use of non-linear component. Fluorescent has non-linear component in the inverter [2], while WOLED using electronic drive to get the corresponding voltage obtained from the power [1]. Previous research has shown that the average fluorescent lamp has THDv rate of 4%, and THDi of 70% [3]. WOLED type resistor has a THD 39.5% [4].

The aim of this study is to compare the resulting harmonic distortion caused by fluorescents and WOLED. Harmonic is an indicator of the performance lamp to electrical energy consumption (power factor). The test is performed using the three-phase star arrangement.

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II. HARMONICS

A. Harmonics in Power Systems

Harmonic is a phenomenon arising from the operation of non-linear loads which is caused by a sinusoidal wave with a frequency of integer multiples of the frequency of the source [2]. For example if the source frequency is 50 Hz harmonics frequency is 100 Hz, 150 Hz, 200Hz, and so on.

Fourier theory mentions that any repetitive waveform can be defined in terms of summing sinusoidal waveforms which are integer multiples (or harmonics) of the fundamental frequency. For the purpose of a steady state waveform with equal positive and negative half-cycles, the Fourier series can be expressed as (1) [5].

$$f(t) = \sum_{n=1}^{\infty} An \,.\sin\,(n2\pi t/T) \tag{1}$$

where

f(t) is the time domain function

n is the harmonic number (only odd values of **n** are required)

An is the amplitude of the n-th harmonic component

T is the length of one cycle in seconds

Superposition of harmonic frequency and the source frequency causing defects (distorted) on the sine wave in power system. Sample images of sinusoidal wave and distorted wave due to harmonic signals can be seen in Fig. 1.

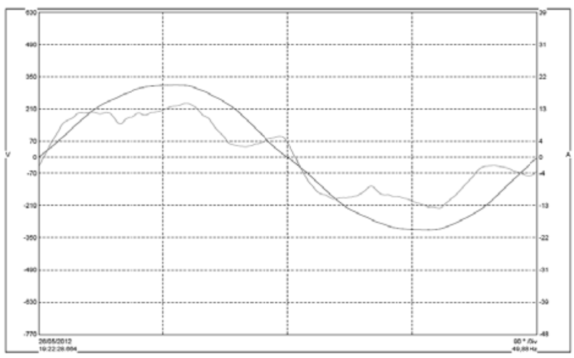


Fig. 1 Sinusoidal wave and distorted wave

B. Causes of Harmonic

Harmonic is caused by non-linear loads on the electrical system. Non-linear loads are electronic devices that have a semi-conductor component in the switching part. Some equipment that can cause harmonics are namely computer, TV, printer, CFL bulbs, and motors [6].

The rectifier can be thought as a harmonic current source and produces roughly the same amount of harmonic current over a wide range of power system impedances. The characteristic of the current harmonics that are produced by a rectifier are determined by the pulse number. The following equation allows determination of the characteristic harmonics for a given pulse number [5]:

$$h = (k * q) \pm 1 \tag{2}$$

where

h is the harmonic number
k is an integer (1, 2, 3, …)
q is the pulse number of the converter

This means that a 6-pulse(or 3-phase) rectifier will exhibit harmonic at the 5th, 7th, 11th, 13th, 17th, 19th, 23rd, 25th, etc. multiples of the fundamental.

C. Effect of Harmonic

Harmonics can lead to power system inefficiency. Some of the negative ways that harmonics may affect equipment are listed below[5]:

- ***Conductor Overheat:*** a function of the square rms current per unit volume of the conductor. Harmonic currents on undersized conductors or cables can cause a "skin effect", which increases with frequency and is similar to a centrifugal force.
- **Fuses and Circuit Breakers:** harmonics can cause false or spurious operations and trips, damaging or blowing components for no apparent reason.
- **Transformers:** have increased iron and copper losses or eddy currents due to stray flux losses. This causes excessive overheating in the transformer windings. Typically, the use of appropriate "K factor" rated units are recommended for non-linear loads.
- **Utility Meters:** may record measurements incorrectly, resulting in higher billings to consumers.
- **Drives/Power Supplies:** can be affected by misoperation due to multiple zero crossings. Harmonics can cause failure of the commutation circuits, found in DC drives and AC drives with silicon control WOLED rectifiers (SCRs).

The likelihood of such ill effects occurring is greatly increased if a resonant condition occurs. Resonance occurs when a harmonic frequency produced by a non-linear load closely coincides with a power system natural frequency [5].

D. Harmonic Index

1) Individual Harmonic Distortion (IHD)

IHD is the ratio between the rms value of the individual harmonics to the rms value of fundamental.

$$IHDn = \frac{In}{I1} \; x\,100\% \tag{3}$$

$$IHDn = \frac{Vn}{V1} \; x\,100\% \tag{4}$$

2) Total Harmonic Distortion (THD)

THD is the percentage of total harmonic voltage distortion calculated or measured at PCC(Point of Common Coupling). Some books mention it as THDv(Total Harmonic Distortion of Voltage) and here we use THDv.

$$THD = THDv = \frac{\sqrt{\sum_{h=2}^{\sim} Vh^2}}{V1} \tag{5}$$

3) Total Demand Distortion (TDD)

TDD is the percentage of total harmonic current distortion calculated or measured at PCC. Some books mention it as THDi(Total Harmonic Distortion of Current) and here we use THDi.

$$TDD = THDi = \frac{\sqrt{\sum_{h=2}^{\sim} Ih^2}}{I1} \tag{6}$$

E. Standard Harmonics IEEE 519 - 1992

IEEE 519-1992 titled *"IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power System"* establish recommended guidelines for harmonic voltages on the utility distribution system as well as harmonic currents within the industrial distribution system. This standard give limits for voltage and current harmonic, see Table I for voltage harmonics limits and Table II for current harmonics limits.

TABLE I
VOLTAGE DISTORTION LIMITS [7]

Bus Voltage at PCC	Individual Voltage Distortion (%)	Total Harmonic Voltage Distortion(%)[1]
69 kV and below	3.0	5.0
69.0001 kV through 161 kV	1.5	2.5
161.001 kV and above	1.0	1.5

[1]High voltage systems can have up to 2.0% THD where the cause is an HVDC terminal that will attenuate by the time it is tapped for a user.

TABLE II
MAXIMUM HARMONIC CURRENT DISTORTION IN % OF I_L INDIVIDUAL HARMONIC ORDER (ODD HARMONICS)[2,3] [7]

I_{SC}/I_L	<11	11≤h≤17	17≤h≤23	23≤h≤35	35 ≤ h	TDD
< 20[4]	4.0	2.0	1.5	0.6	0.3	5.0
20 < 50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

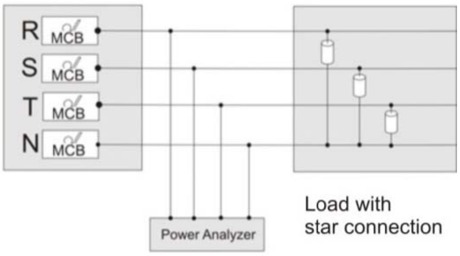
[2] Even harmonics are limited to 25% of the odd harmonic limits above.

[3] Current distortions that result in a DC offset, e.g., half-wave converters are not allowed.

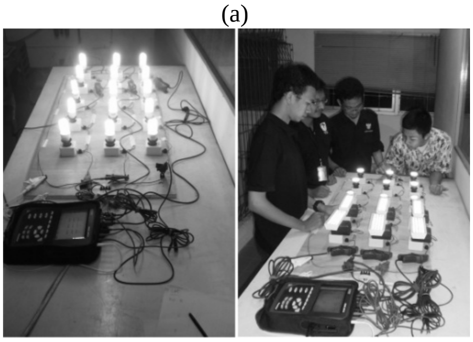
[4] All power generation equipment is limited to these values of current distortion, regardless of actual I_{SC}/I_L where ISC = maximum short circuit current at PCC and IL = maximum demand load current(fundamental frequency component) at PCC.

III. Research Method

In this study, the circuit used for testing is a star connected three-phase source as seen in Fig. 2.



(a)



(b)

Fig. 2 (a) Star composition, (b) Test-bench

The test is done by placing a fluorescent lamp and WOLED alternately on each phase wire. The total of lamp's wattage in each phase is made equal to create a balance connection. Harmonics that occurs in this series is observed through a Power Analyzer which is connected to the circuit. The flowchart on this research can be seen in Fig. 3.

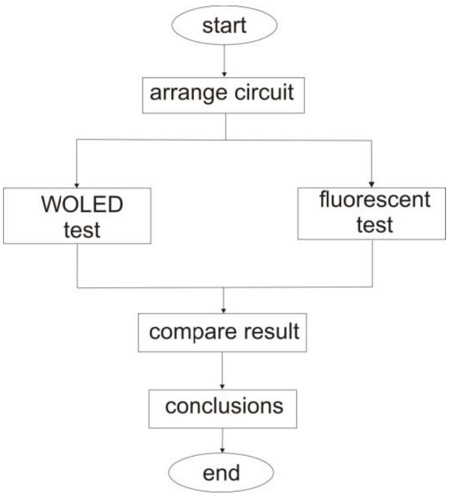


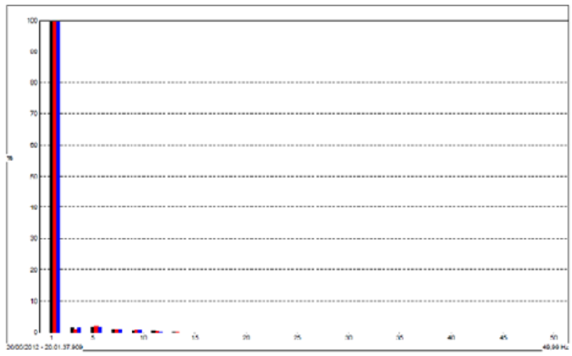
Fig. 3 Flowchart

IV. Results and Analysis

A. Voltage Harmonics

The result of harmonic voltage test shows that both lamps have a small value of the voltage harmonics. Graph of harmonic voltage spectrum can be seen in Fig. 4. As seen on the graph (a) and (b), the percentage of the first value is 100%, is the fundamental frequency. Then the second and so on are the harmonics frequency that became smaller. Power Analyzer measurement results show that the percentage of average THDv at each phase of testing with fluorescent lamps is 2.7%, 2.5%, 2.6% with the average THDv is 2.6% . On the other hand, the average percentage THDv at each phase of testing with this WOLED lamp is 2.4%, 2.5%, 2.7% with the average THDv is 2.53%. It can be inferred that the value of THDv between fluorescents and WOLED is almost equal with the difference 0.07%. The calculation of THDv is use 49 sample that is from 2nd harmonic to 50th harmonic. From Table I, we know that THDv standard from IEEE 519-1992 is 5 %, so THDv of both lamps are within the limits.

The small value of THDv in both lamps means that sinusoidal voltage wave form is minorly distorted. The voltage waveform image can be seen in Fig. 5.



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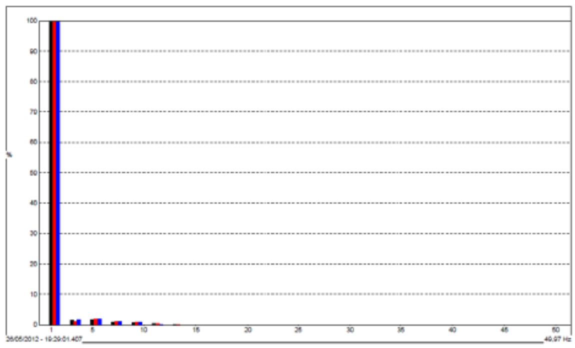


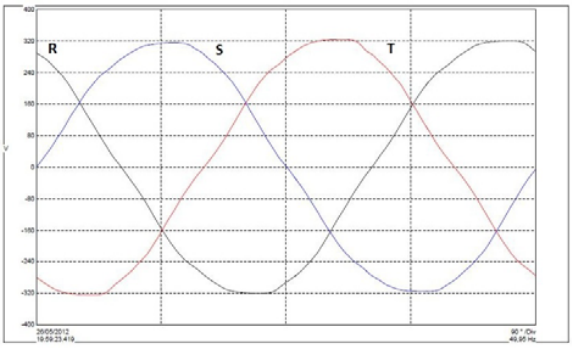
(b)

Fig. 4 Spectrum of voltage harmonic: (a) fluorescent, (b) WOLED

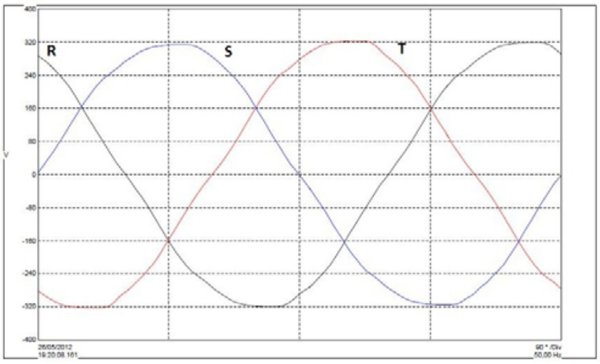
B. Current Harmonic

The maximum circuit current at PCC(I_{SC}) used in this test is 16A and the maximum demand load current(fundamental frequency component) at PCC(I_L) is 9.3A so I_{SC}/I_L is 1.7. From Table II, limits for THDi(TDD) is 5%.

Harmonic current testing results show that both lamps have considerable THDi value. THDi percentages chart can be seen in Fig. 6. THDi value of fluorescent lamp for each phase is 83.8%, 89.2%, and 88.7%, respectively, thus the average THDi of fluorescent lamp is 87, 23%. On the other hand, the THDi of WOLED for each phase is 28.4%, 29.9%, and 29.0%, therefore the average THDi of WOLED lamp is 29.1%. Thus we conclude that both lamps have THDi that exceed the IEEE 519-1992 standard, but these results clearly show that WOLED has lower THDi than fluorescent lamp.



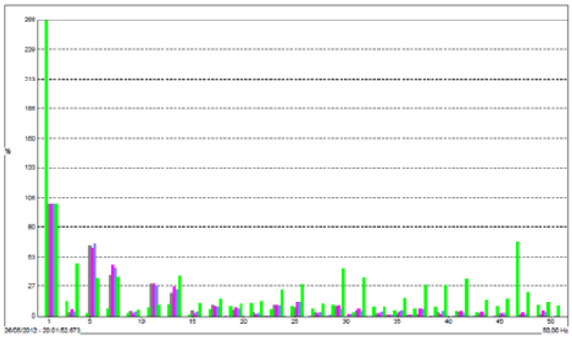
(a)



(b)

Fig. 5 Harmonic Voltage Waveform : (a) fluorescent, (b) WOLED

The value of THDi on both lamps have a large effect on the current waveform as seen in Fig. 7. Because THDi value of fluorescent lamp is greater than the THDi value of WOLED, current waveform distortion of fluorescent is larger. This is evident from the results of the experiment according to Fig. 7. It appears that the fluorescent lamp current waveform is no longer in sinusoidal form, while the WOLED current waveform of WOLED has considerably less distortion than fluorescent lamp.



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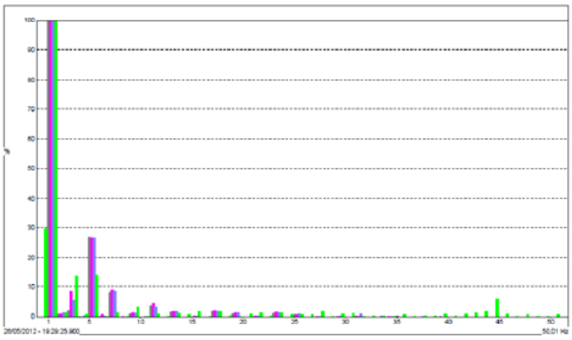
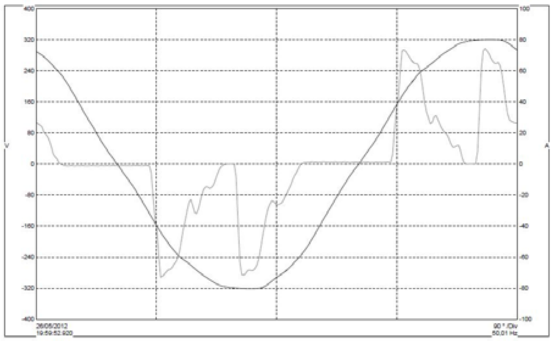


(b)

Fig. 6 Spectrum of current harmonic: (a) fluorescent, (b) WOLED



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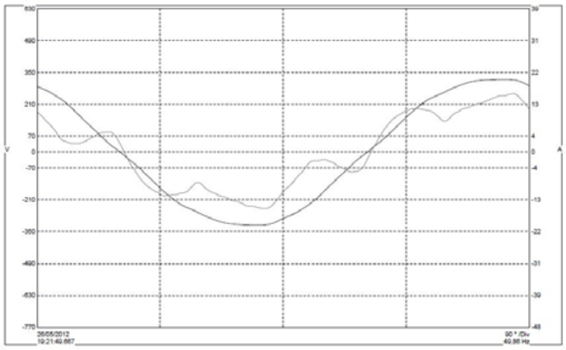

(b)

Fig. 7 Harmonic Current Waveform: (a) fluorescent, (b) WOLED

V. CONCLUSION

This experiment obtains the harmonics produced by fluorescent lamp and WOLED and analyzes them. Based on the obtained results, we are able to say that the THDv value of both lamps is within the limits of IEEE 519-1992 standard. On the other hand, both lamps has THDi that exceed this standard limits, but WOLED has lower THDi than fluorescent lamp. To reduce the harmonics we can use passive filter, active filter, isolation transformers, etc.

ACKNOWLEDGMENT

Thanks to the Department of Electrical Engineering and Information Technology, Gadjah Mada University (GMU) for their cooperation with useful resources during research.

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