Energy Efficiency Testing of Fluorescent and WOLED (White Organic LED)

Hari Maghfiroh, and Harry Prabowo

Abstract**—**WOLED is widely used as lighting for high efficacy and little power consumption. In this research, power factor testing between WOLED and fluorescent lamp to see which one is more efficient in consuming energy. Since both lamps use semiconductor components, so calculation of the power factor need to consider the effects of harmonics. Harmonic make bigger losses. The study is conducted by comparing the value of the power factor regardless of harmonics (DPF) and also by included the harmonics (TPF). The average value of DPF of fluorescent is 0.953 while WOLED is 0.972. The average value of TPF of fluorescent is 0.717 whereas WOLED is 0.933. So from the review of power factor WOLED is more energy efficient than fluorescent lamp.

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].

Power Factor (PF) showed how effectively energy is transferred from the power source to the load [3]. Resistive load has PF = 1 because all the energy is absorbed by the load while the inductive load and capacitive load has PF with range of value between 0 and 1. The closer value of PF to 1 the more efficient an appliance of consuming energy. This research is to test the efficiency of fluorescent lamps and WOLED with PF parameters. Because fluorescent and WOLED have semiconductor components that give rise to harmonic then TPF (True Power Factor) is used in the calculation of power factor which has two components, DPF(Displacement Power Factor) and DF(Distorting Factor). The test is performed using the three-phase star arrangement.

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II. POWER FACTOR

A. Power Factor (PF)

AC power has low losses in the transmission if the current isn't distorted and it's synchronous with the voltage (no shift angle). Incandescent bulbs have resistive properties that the current is synchronized and proportional to the voltage. On the other hand, fluorescent and WOLED have semiconductor components that causes a phase shift and distortion of current (harmonics).

The ratio of the actual power transmitted (real power) to the apparent power that could have been transmitted if the current was undistorted is known as the power factor [4] as (1). PF can also be calculated from the cosine of phase angle between current and voltage (ϴ) as (2).

$$Power\ Factor(PF) = \frac{real\ power(P)}{apparent\ power(S)} \quad (1)$$

$$Power\ Factor(PF) = \cos \quad (2)$$

The relationship between the apparent power, real power and reactive power (Q) can be seen in Fig. 1. Fig. 2 shows the phase shift between current and voltage. This shift led to a valuable component of apparent power to be negative, negative component of apparent power is called reactive power that will be returned to the line power.

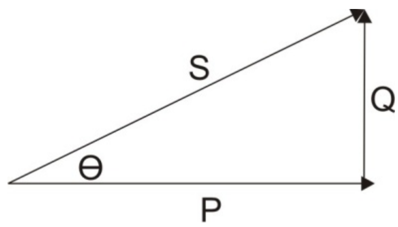


Fig. 1 Power triangle

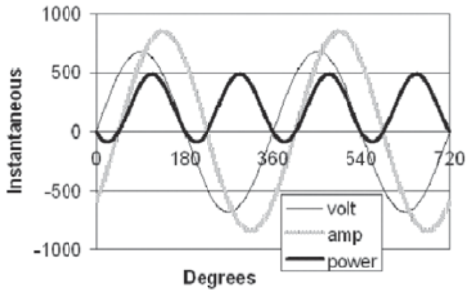


Fig. 2 Phase shift between current and voltage [4]

PF has no units and its value is between 0 and 1. PF value = 1 means for supplying 1kW required 1 kVA apparent power (1kW / 1 = 1 kVA, as (1)), whereas if PF = 0.5 then for supplying 1kW required 2kVA apparent power (1kW/0.5 = 2 kVA). Thus the closer PF to 1 make supply of electric energy more efficiently.

Before the development of semiconductor components, current distortion is a minor problem, resulting in the calculation of PF is sufficient from phase shift. The used of semiconductor components that give rise to the harmonic also affect the value of the power factor. Rated power factor which only affected by the phase shift is called Displacement Power Factor (DPF), while the presence of harmonics causing Distortion Factor (DF). Power factor values are calculated from the phase shift and harmonic called True Power Factor (TPF) which is the result of multiplication between DPF and DF.

1) DPF (Displacement Power Factor)

DPF is the value of active power divided by the apparent power with sinusoidal current (fundamental current).

$$DPF = \frac{P}{V_1 I_1} \tag{3}$$

2) DF (Distortion Factor)

DF describes how the harmonic distortion of a load current decreases the average power transferred to the load [5].

$$DF = \frac{I_{1,rms}}{I_{rms}} = \sqrt{\frac{1}{1+THD^2}} \tag{4}$$

3) TPF (True Power Factor)

TPF is the value of active power divided by the apparent power value with non-sinusoidal currents (having harmonics).

$$TPF = DPF * DF \tag{5}$$

B. Harmonics

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. 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. 3.

Harmonics caused by non-linear loads on the electrical system. Non-linear load is electronic equipment that has semi-conductor components in the switching part. Some of the equipment can causing harmonics are namely computers, TVs, printers, CFL bulbs, and motors [6]. As a result of this harmonic then the value of PF was down which means losses increase. Comparison between linear load losses (which not affected by harmonics) with non-linear loads (which affected by harmonics) can be seen in Fig. 4.

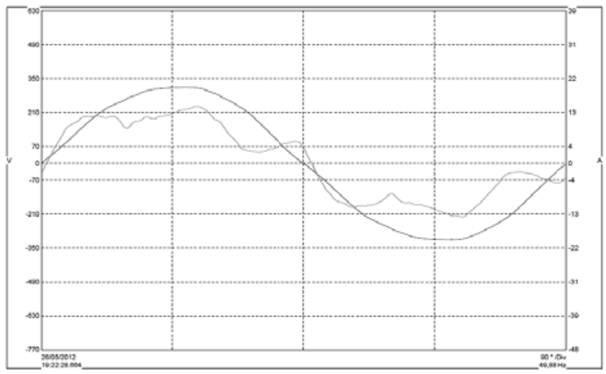


Fig. 3 Sinusoidal wave and distorted wave

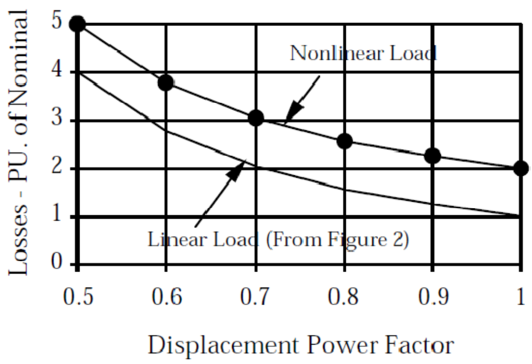


Fig. 4 Comparison of Losses of Linear and Non-Linear Load [7]

1) Total Harmonic Distortion (THD)

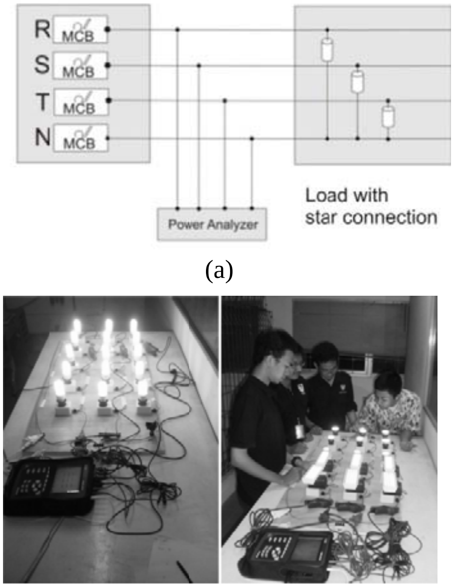
THD is the ratio of the rms value of all harmonics components and the rms value of the fundamental. THD represent the current and voltage waveform distortion. THD for current in some book is mention as TDD(Total Demand Distortion).

$$THDv = \frac{\sqrt{\sum_{h=2}^{\sim} Vh^2}}{V1} \tag{6}$$

$$THDi = TDD = \frac{\sqrt{\sum_{h=2}^{\sim} Ih^2}}{I1} \tag{7}$$

III. Research Method

In this study the circuit used for testing is Star(Y) connection of three-phase source as seen in Fig. 5.



(a)

(b)

Fig. 5 (a) Star composition, (b) Test-bench

The test is done by placing a fluorescent lamp and WOLED alternately at each phase wire. The total of lamp's wattage in each phase is made equal to get a balance connection. Phasor graph and power factor values observed through the Power Analyzer which is connected to the circuit. Flowchart on this research can be seen in Fig. 6.

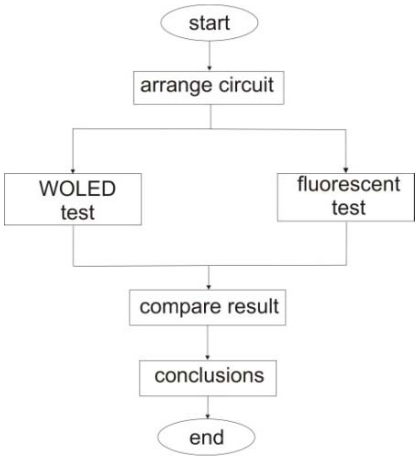


Fig. 6 Flowchart

IV. Results and Analysis

A. Without Harmonics

The results of testing without harmonic components can be seen in Table I. The first column is parameter that measured, second column is result from phase 1, third column result for phase 2, forth column result for phase 3, and fifth column is result from the average of all phase. Table I.A show the result of fluorescent, seen the value of active power, reactive power, and apparent power almost the same in each phase that shows a balance connection of each phase. Reactive power has negative value means that this system includes a capacitive load it is also indicated by the negative phase angle value. Phase angle with negative value means the current leading the voltage. Average value of DPF is 0.953.

Table I.B shows the test results without harmonics for WOLED. Similar results were obtained that the value of active power, reactive power, and apparent power on each phase is almost the same that shows the balance connection. Reactive power and phase angle has negative value indicates the system is capacitive. Average value of DPF is 0.972.

Comparison of the phase angle between Table I.A and Table I.B shows that fluorescent have greater phase angle. According to (2) the greater phase angle it has the smaller DPF, in this case the value of DPF same with PF value because the harmonic components is not taken into account. It conclude that WOLED has greater DPF than fluorescent, but we can't say that WOLED has better energy efficiency than fluorescent before included harmonics analysis because harmonics has a big influence in power factor. Current and voltage phasor diagram of this test is shown in Fig. 7, it seen that current is lead the voltage and has negative phase angle.

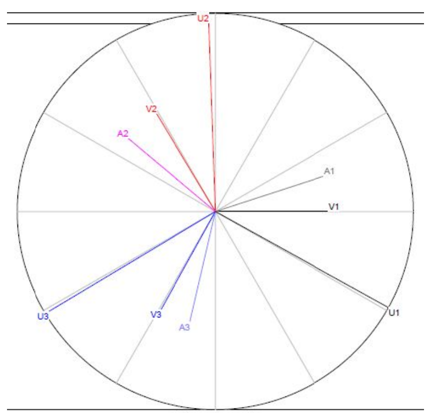
TABLE I
Test Result Without Harmonics

Parameter	Phase 1	Phase 2	Phase 3	All
Watt	27.55	26.745	26.455	80.575
var	-8.845	-9.02	-7.735	-25.285
VA	37.7	37.87	36.955	111.81
Phase Angle(°) A-V	-18	-19	-16	
DPF	0.952	0.947	0.959	0.953

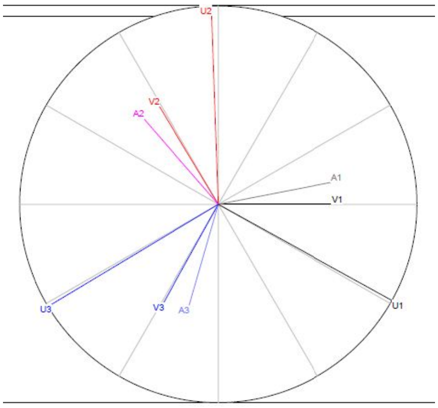
(a) Fluorescent

Parameter	Phase 1	Phase 2	Phase 3	All
Watt	10.87	10.065	10.07	30.955
var	-1.7	-3.62	-1.57	-6.86
VA	11.465	11.16	10.66	33.215
Phase Angle(°) A-V	-9	-20	-9	
DPF	0,988	0.941	0.988	0.972

(b) WOLED



(a)Fluorescent



(b) WOLED

Fig. 7 Three Phase Phasor Diagram: (a) Fluorescent, (b) WOLED

B. With Harmonics

The results of experiments which include harmonic can be seen in Table II. The value of reactive power increases while the value of active power and apparent power is almost constant, it's indicating the existence of harmonics can increase the reactive power which means losses is increase too. The values of DPF and phase angle are having very small change that can be considered to be constant. Because the harmonics include into account, the value of the power factor used is TPF. TPF value is less than DPF because of harmonics effect. The average value of fluorescent's TPF can be seen in Table I.A that is 0.717, while the average value of WOLED's TPF is 0.933, see Table I.B. It is clear that in terms of TPF, WOLED still have a greater value. Thus, we conclude that WOLED has better efficiency of power consumption than fluorescent. TPF value charts can be seen in Fig. 8.

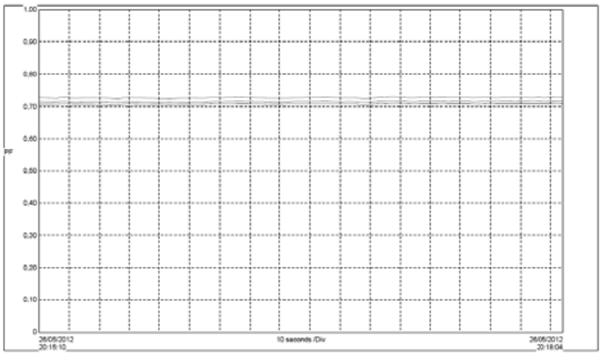
TABLE II
TEST RESULT WITH HARMONICS

Parameter	Phase 1	Phase 2	Phase 3	All
Watt	27.71	26.75	26.505	80.98
var	-25.98	-26.445	-25.805	78.575
VA	37.98	37.615	36.99	112.86
Phase Angle(°) A-V	-18	-19	-17	
DPF	0.951	0.947	0.958	0.952
TPF	0.73	0.711	0.716	0.717

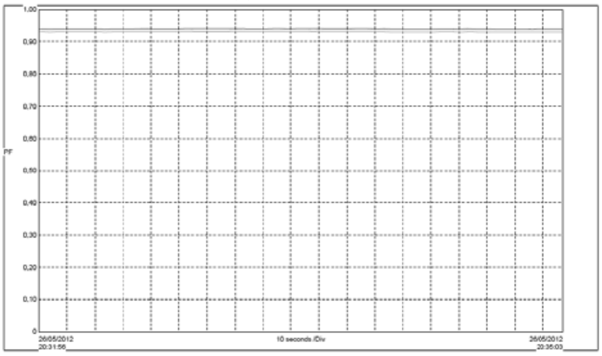
(a) Fluorescent

Parameter	Phase 1	Phase 2	Phase 3	All
Watt	10.9	10.055	10.04	31.065
var	-3.65	-4.79	-3.435	-11.81
VA	11.495	11.135	10.61	33.285
Phase Angle(°) A-V	-9	-20	-9	
DPF	0.988	0.942	0.989	0.973
TPF	0.948	0.903	0.946	0.933

(b) WOLED



(a) Fluorescent



(b) WOLED

Fig. 8 Power Factor (PF) : (a) Fluorescent, (b) WOLED

V. CONCLUSION

This experiment obtains power factor of fluorescent lamp and WOLED and analyzes them. Based on the obtained results, we are able to say that WOLED has greater both DPF and TPF than fluorescent lamp. Thus, we conclude that WOLED lamp is more energy efficient than fluorescent lamp.

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