

Novel Dummy Load for 40W Fluorescent Lamps

Bo-Hwan Choi^{*}, Hyun-Jae Kim^{**}, In-Yong Yeo^{*}, Bong-Cheol Kim^{***}, and Chun-Taek Rim[†]

^{†*}Department of Nuclear and Quantum Engineering, KAIST, Daejeon, Korea

^{**}Department of Electrical Engineering, KAIST, Daejeon, Korea

^{***}Optomind Inc., Suwon, Korea

Abstract

A new fluorescent dummy load to replace one of the fluorescent lamps in a dual lamp type rapid-start ballast for halving the lamp power is proposed. Using a circuit composed of a fundamental compensation circuit and a harmonic filter circuit, a new fluorescent dummy load having superior characteristics than a conventional dummy load is developed. The design principle and architecture of the proposed fluorescent dummy load is explained and verified by experiments.

Key words: Fluorescent lamp, Dummy load, Rapid-start ballast

I. INTRODUCTION

The global movement to replace fluorescent lamps with LED devices for saving energy is an important issue in recent lighting markets [1]-[7]. In particular, the LED drivers compatible with existing rapid-start ballasts have a major market in Japan, where urgent countermeasures to solve the electrical power shortage [8]-[10] are becoming crucial after the Tohoku earthquake. To meet the market demand, a passive type LED driver has been developed [11]-[15], which will be briefly introduced in this paper.

An immediate, economic, and practical solution to reduce lighting power is to remove one of the fluorescent lamps from a dual fluorescent lamps fixture. However, in a dual lamp type rapid-start ballast where two fluorescent lamps are serially connected, a fluorescent lamp will not light if one of them is simply pulled out.

A solution to this problem is a conventional dummy load that can be used as a substitute for the removed fluorescent [16], where the dummy load is made of a capacitors and a resistor. However, a dummy load has many problems: a large power loss in the rapid-start ballast, a reduced lifetime of the fluorescent lamp due to overcurrent, and a large total harmonic distortion (THD) which can cause malfunctions in power electronic devices [17]-[19]. Hence the conventional dummy loads used in rapid-start ballasts cannot meet THD regulations

and they undergo the danger of fire due to overheating.

In this paper, a new dummy load that overcomes these problems, where a few sets of LC series filters provide the same lamp current and diminish source side harmonic current, is proposed. The superiority of the proposed dummy load is verified by a comparison with a conventional dummy load.

II. PREVIOUS WORKS ON PASSIVE LED DRIVERS

In this section, the passive type LED drivers compatible with rapid-start ballasts, developed for the purpose of reducing power [11]-[14], are briefly introduced. The cause of fires in an LED driver with an SMPS is the large DC input capacitor of the SMPS, which can destroy the capacitor in a rapid-start ballast due to the excessive initial resonant voltage [11]-[14]. Furthermore, a SMPS usually suffers from harmonic distortions, EMI, a relatively short life time, and complexity caused by control integrated circuit [15].

Two types of LED drivers to solve these problems have been developed. The first type, shown in Fig. 1(a), is a 20W passive LED driver compatible with rapid-start ballasts, which gives luminance similar to that of a traditional 40W fluorescent lamp [11]-[13]. This type is made of a compensation circuit composed of passive elements. The compensation circuit was designed to meet requirements such as the output power, the input power factor, and the total harmonic distortion.

The compensation capacitor C_c makes the input power factor of a rapid-start ballast close to unity. The compensation inductors L_{c1} , L_{c2} , L_{c3} , and L_{c4} are used to maintain the same resonant frequency as the original rapid-start ballast for conventional fluorescent lamps. To connect the LED lamp freely regardless of the polarity of the rapid-start ballast, four

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[†]Corresponding Author: ctrim@kaist.ac.kr

Tel: +82-42-350-3883, Fax: +82-42-350-5867, KAIST

^{*}Department of Nuclear and Quantum Engineering, KAIST, Korea

^{**}Department of Electrical Engineering, KAIST, Korea

^{***}Optomind Inc., Korea

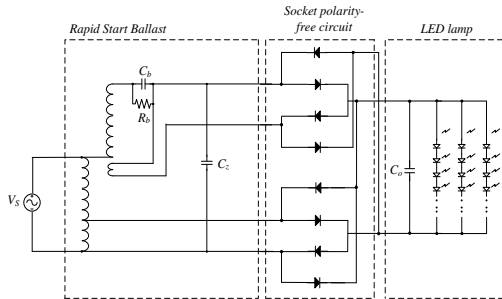
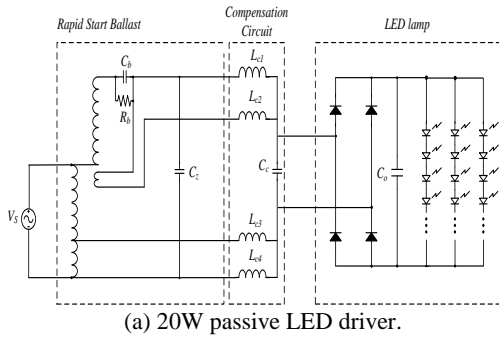


Fig. 1. Two types of LED drivers proposed in [12]-[13].

inductors were used. This LED driver used a small DC capacitor to prevent the fires found in conventional rapid-start ballasts.

The second type is a 40W LED driver using a socket polarity-free circuit, as shown in Fig. 1(b). It gives the same output power as a traditional 40W fluorescent lamp (patent pending). The socket polarity-free circuit consists of two pairs of common anode and common cathode diode modules, allowing for the maximum output voltage at the either end of an LED array. This type of driver also used a small DC capacitor to avoid fires in the same manner as the 20W passive LED driver.

These two LED drivers have advantages such as high robustness, low harmonic distortion, long lifetime, and safety when compared with conventional SMPS LED drivers. Thus the developed LED drivers are under tests for practical use and may reduce power consumption.

III. THE PROPOSED DUMMY LOAD

In an effort to reduce power consumption in lighting since the Fukushima nuclear accident in Japan, a dummy load to replace one fluorescent lamp in a dual lamp has drawn a great deal of attention.

When replacing the conventional two fluorescent lamps with a fluorescent lamp and a dummy load in a dual fluorescent lamp fixture, the following three requirements should be met.

The first requirement is to maintain the same operating

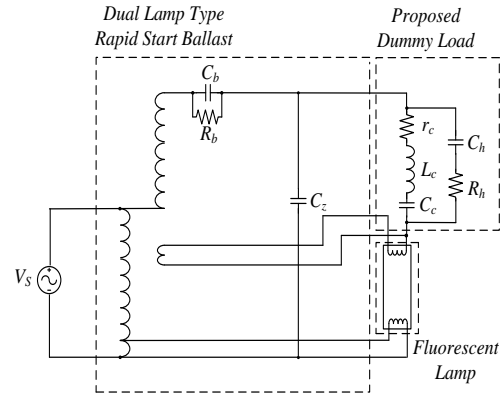
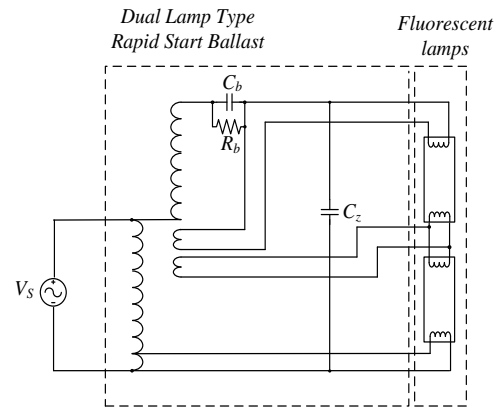
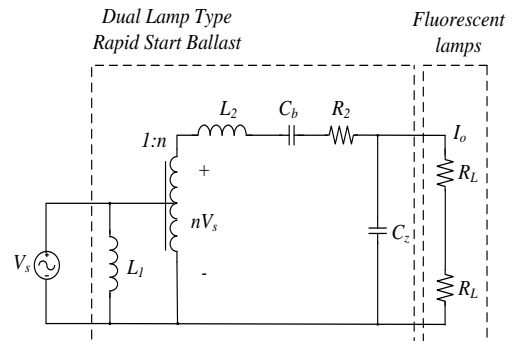


Fig. 2. The dual fluorescent lamp fixture with the proposed dummy load.



(a) The dual fluorescent lamp fixture with conventional two fluorescent lamps.



(b) The simple equivalent circuit of (a).

Fig. 3. The dual fluorescent lamp fixture and its simple equivalent circuit.

conditions, which are the output power, voltage, and current of the remaining fluorescent lamp. The second is to guarantee the input power factor which should be above 0.9. The last is to keep the THD of the source current under the THD regulation.

A dummy load which meets these design requirements is

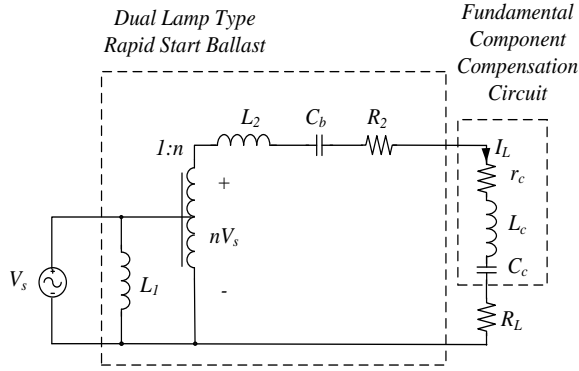


Fig. 4. The equivalent circuit of the dual fluorescent lamp fixture with the fundamental component compensation circuit.

proposed in this paper, as shown in Fig. 2. The design procedures for the proposed dummy load are explained in this section.

A. Design of the Dummy Load

To meet the design requirements, the proposed dummy load is designed to be composed of a fundamental component compensation circuit and a harmonic component filter circuit.

The dual fluorescent lamp fixture, which contains two lamps in series with a rapid-start ballast, is shown in Fig. 3(a). For the sake of simplicity, Fig. 3(a) is represented as a simple equivalent circuit, as shown in Fig. 3(b) [12], [13]. Here, L_1 is the equivalent inductance from the primary side including the magnetizing inductance of the transformer, and L_2 is the equivalent inductance from the secondary side including the leakage inductances of the transformer. n is the turn ratio of the transformer. R_L is the equivalent resistor for a fluorescent lamp. R_2 is the equivalent parasitic serial resistor inside the rapid-start ballast. The capacitor C_z is relatively small at the fundamental frequency, and the resistor R_b is large enough so that they can be negligible in the simple equivalent circuit. r_c is the equivalent parasitic resistor of the inductor in the dummy load.

Basically, passive elements which have little power dissipation are used for the proposed dummy load, and the fundamental component compensation circuit consists of an inductor L_c and a capacitor C_c .

Fig. 4 illustrates an equivalent circuit of the dual fluorescent lamp fixture where a fluorescent lamp is replaced with the fundamental component compensation circuit.

If the load current I_L in Fig. 4 has same value as I_o in Fig. 3(b) at the fundamental frequency, the operating conditions of each fluorescent lamp in Fig. 3(b) and the remaining

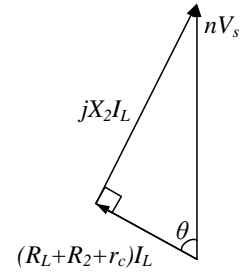


Fig. 5. The vector diagram of Fig. 4.

fluorescent lamp in Fig. 4 are equalized. The vector diagram of Fig. 4 is illustrated as shown in Fig. 5. The secondary side reactance of the rapid-start ballast in Fig. 4, X_2 , is defined as follows:

$$X_2 = \omega L_t - \frac{1}{\omega C_t} \quad (1)$$

$$L_t = L_2 + L_c \quad (2)$$

$$C_t = \left(\frac{1}{C_b} + \frac{1}{C_c} \right)^{-1} \quad (3)$$

Using the vector diagram of Fig. 5, the value of X_2 can be derived as follows:

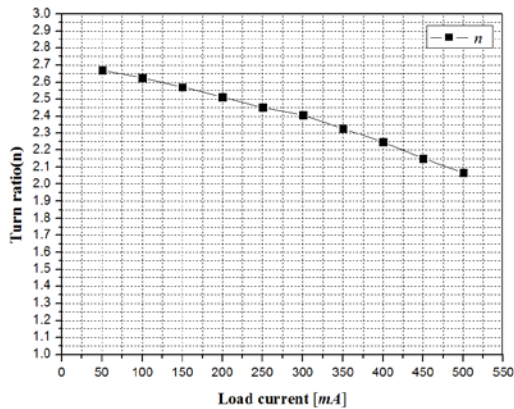
$$(nV_s)^2 = I_L^2 (R_L + R_2 + r_c)^2 + I_L^2 X_2^2 \quad (4)$$

$$X_2 = \sqrt{\frac{n^2 V_s^2}{I_L^2} - (R_L + R_2 + r_c)^2} \quad (5)$$

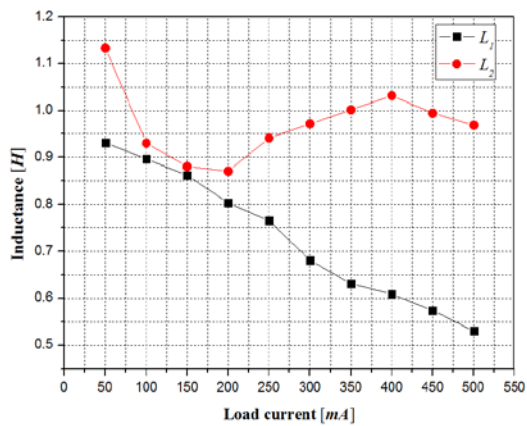
To find the values of L_c and C_c , the values of n , L_1 and L_2 should be defined. The turn ratio n and inductances L_1 and L_2 vary with the source voltage and load current due to the non-linearity of the rapid-start ballast [12], [13].

Fig. 6(a) and (b) represent the variations of n , L_1 and L_2 with a load current when the source voltage is $100V_{rms}$, which is the operating voltage of the rapid-start ballast.

The current of each fluorescent lamp is about 340mA in Fig. 3(b). Therefore, the values of n , L_1 , and L_2 are selected as 2.35, 0.65H, and 0.99H, respectively. Using (1)-(5) with above selected values of n , L_1 , and L_2 , several combinations of L_c and C_c can be obtained.



(a) The variation characteristics of n .



(b) The variation characteristics of L_1 and L_2 .

Fig. 6. The characteristics of the dual lamp type rapid-start ballast.

The input power factor, which is the second design requirement, can be obtained over 0.95 for all combinations through the following equation:

$$p.f. = \frac{I_L \cos \theta}{\sqrt{\left(\frac{V_s}{n\omega L_1} - I_L \sin \theta\right)^2 + (I_L \cos \theta)^2}} \quad (6)$$

where $\cos \theta$ and $\sin \theta$ are defined as follows:

$$\cos \theta = \frac{I_L (R_L + R_2 + r_c)}{nV_s} \quad (7)$$

$$\sin \theta = \frac{I_L X_2}{nV_s} \quad (8)$$

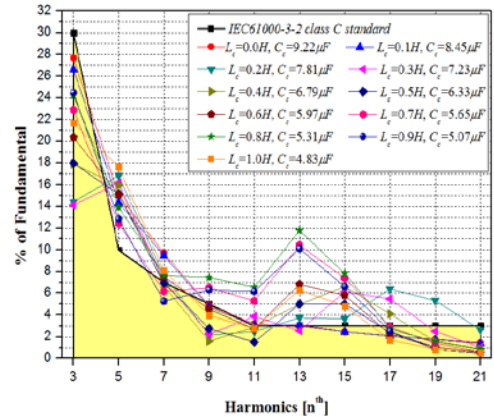


Fig. 7. The measured source side harmonic currents with combinations of L_c and C_c .

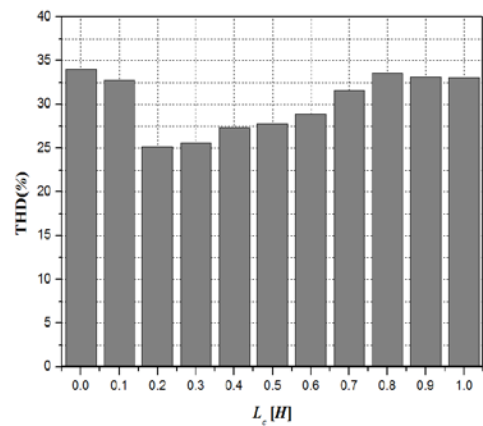


Fig. 8. The measured THD with combinations of L_c and C_c .

From the view point of manufacturing, a small inductor size is desirable. As a result, the value of inductor L_c is selected among 0.1~1.0H in the following design processes and experiments.

To find an optimal combination of L_c and C_c , the third design requirement, which is to keep the THD of the source current under the THD regulation, is considered. However, it is not entirely possible to characterize the source side harmonic currents because of the non-linearity in the rapid-start ballast [12], [13]. Hence it is necessary to measure the THD characteristics by experiments for the above L_c and C_c combinations. The measured source side harmonic currents, shown as a percentage of the fundamental current, are given in Fig. 7. The measured THD for the above combinations of L_c and C_c is illustrated in Fig. 8.

In Fig. 7, all of the above combinations of L_c and C_c exceeds the THD regulation which is the IEC61000-3-2 class C standard. Therefore, it is verified that a harmonic component filter circuit is essential to satisfy the THD regulation.

Prior to the harmonic component filter circuit design, the optimal values of L_c and C_c are determined to be $0.2H$ and $7.81\mu F$, respectively. This is done by considering the lowest THD among the above combinations of L_c and C_c , as shown in Fig. 8.

To design the harmonic component filter circuit, capacitor C_z in the rapid-start ballast, which was ignored at the fundamental frequency, should be considered. The harmonic component filter circuit consists of a capacitor C_h and a resistor R_h . Fig. 9 shows the equivalent circuit which includes C_z and the harmonic component filter circuit.

It is identified that the 5th source side harmonic current exceeds the THD regulation more than the other harmonic currents, as shown in Fig. 7. Hence it is essential to diminish the 5th source side harmonic current by using the harmonic component filter circuit. A method to reduce the 5th source side harmonic current is by increasing $|Z_T(j\omega)|$ at the 5th harmonic, which is the amplitude of impedance Z_T , as shown in Fig. 9.

$|Z_T(j\omega)|$ is expressed as follows:

$$|Z_T(j\omega)| = \sqrt{\frac{\gamma^2 + \delta^2}{\alpha^2 + \beta^2}} \quad (9)$$

$$\alpha = \omega^4 L_c C_z (R_h + R_L) - \omega^2 \left\{ R_h \left(1 + \frac{C_z}{C_c} \right) + r_c \left(1 + \frac{C_z}{C_h} \right) + R_L C_z \left(\frac{1}{C_c} + \frac{1}{C_h} \right) \right\} \quad (10)$$

$$\beta = -\omega^3 \left[L_c \left(1 + \frac{C_z}{C_h} \right) + C_z \{ R_h (R_L + r_c) + R_L r_c \} \right] + \omega \left(\frac{C_c + C_h + C_z}{C_c C_h} \right) \quad (11)$$

$$\gamma = -\omega^2 \left\{ \frac{L_c}{C_h} + R_h (R_L + r_c) + R_L r_c \right\} + \frac{1}{C_c C_h} \quad (12)$$

$$\delta = -\omega^3 L_c (R_h + R_L) + \omega \left(\frac{R_h + R_c}{C_c} + \frac{R_c + r_c}{C_h} \right) \quad (13)$$

The value of C_h , which results in the highest $|Z_T(j\omega)|$ at the 5th harmonic, is obtained as $2.6 \mu F$ by using (9), where $C_z = 180nF$.

Although the 5th source side harmonic current was reduced by the selected C_h , the other source side harmonic currents still exceed the THD regulation.

Therefore, R_h , which can decrease the other source side harmonic currents, should be added to the harmonic component filter circuit. 56.2Ω was selected for R_h by experiments because the effect of R_h on the source side harmonic currents is not entirely possible to analyze. A new $|Z_T(j\omega)|$ curve can be obtained, as shown in Fig. 10.

B. Experimental Verification

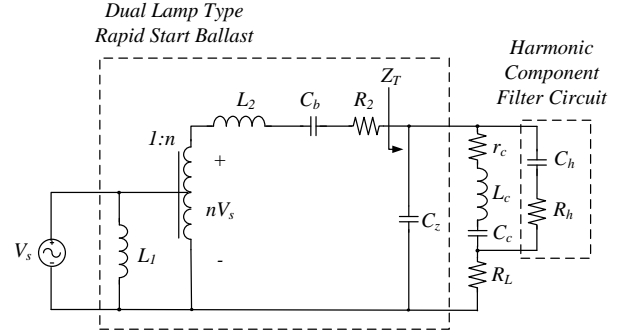


Fig. 9. The equivalent circuit of the dual fluorescent lamp fixture with the harmonic component filter circuit.

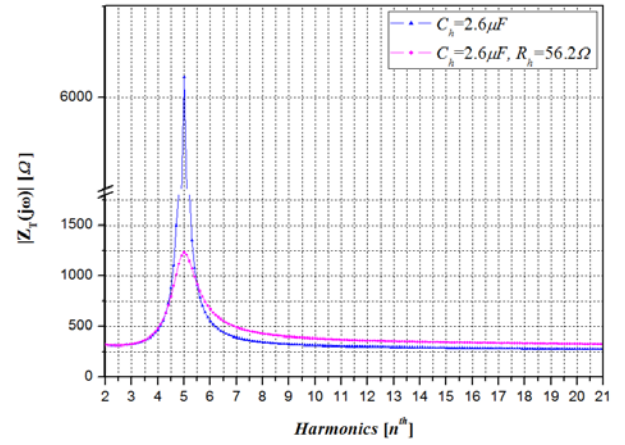


Fig. 10. The curves of $|Z_T(j\omega)|$.

By replacing the conventional two fluorescent lamps with a fluorescent lamp and the proposed dummy load in a dual fluorescent lamp fixture, the three design requirements can be satisfied through experiments.

First of all, the measured current, voltage, and power of the remaining fluorescent lamp were $325mA$, $110V_{rms}$, and $35.8W$, respectively, at a $100V_{rms}$ source voltage. These are almost identical to the operating conditions of a fluorescent lamp in the dual fluorescent lamp fixture, which are $343mA$, $104V_{rms}$, and $35.8W$ at the same source voltage.

Secondly, the measured input power factor of the dual fluorescent lamp fixture was measured at 0.99, when a fluorescent lamp had been replaced with the proposed dummy load.

Lastly, the THD of the source current was kept under the THD regulation, as shown in Fig. 11.

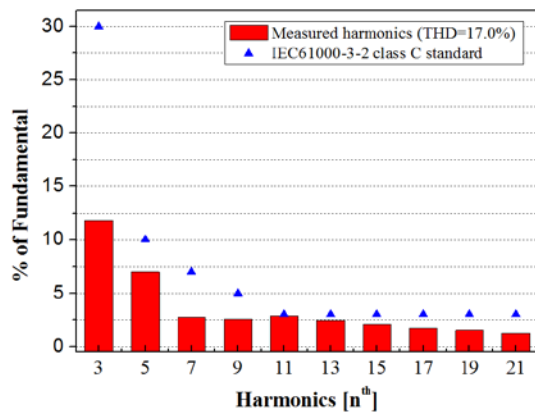


Fig. 11. The measured source side harmonic current of the dual fluorescent lamp fixture with the proposed dummy load.

TABLE I
EXPERIMENTAL CIRCUIT PARAMETERS

Parameter	Value
V_s	110V _{rms}
f_s	60Hz
L_c	0.2H
C_c	7.81 μ F
C_h	2.6 μ F
R_h	56.2 Ω

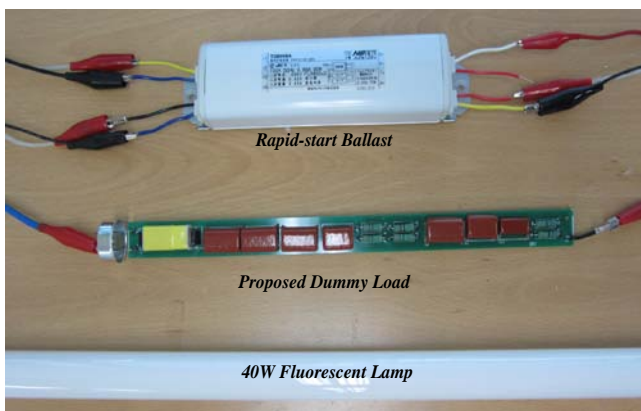


Fig. 12. A prototype of the proposed dummy load.

It is verified that the 5th source side harmonic current was reduced by adding C_h and that the other source side harmonic currents went down by the additional R_h . The experimental circuit parameters including the source voltage V_s , and the source frequency f_s are summarized in Table I. The prototype of the proposed dummy load, as shown in Fig. 12, shows a compact size which can be installed in a typical fluorescent tube, which is 1.70 X 47.5 cm².

TABLE II
MEASUREMENT RESULT OF OPERATING CONDITIONS

Parameter	Two fluorescent lamps	A fluorescent lamp with a conventional dummy load	A fluorescent lamp with the proposed dummy load
I_L	343mA	403mA	325mA
V_L	104V _{rms}	109V _{rms}	110V _{rms}
P_L	35.8W	44.0W	35.8W
P_b	17.1W	18.9W	5.36W
P_T	88.7W	62.9W	42.3W
$p.f.$	0.94	0.99	0.99

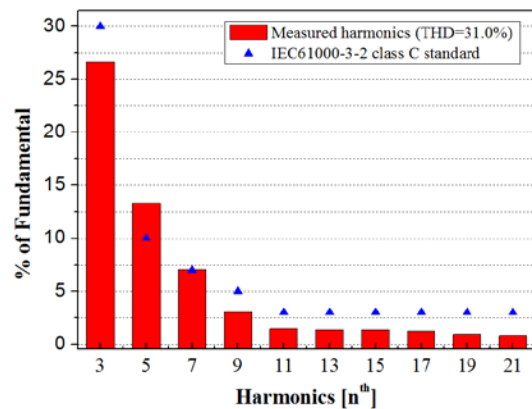


Fig. 13. The measured source side harmonic current of the dual fluorescent lamp fixture with the conventional dummy load.

IV. COMPARISON WITH A CONVENTIONAL DUMMY LOAD

Several experiments for the comparative analysis of the proposed dummy load and a conventional dummy load were performed. The conventional dummy load is composed of two large electrolytic capacitors back-to-back connected with diodes.

The current I_L , voltage V_L , and power P_L of the remaining fluorescent lamp, and the power of the rapid-start ballast P_b together with the input power P_T were measured by a WT1600 digital power meter, as summarized in Table II.

From the view point of energy savings, the input power P_T should be minimized. 25.8W can be saved by the conventional dummy load whereas 46.4W can be conserved by the proposed dummy load.

It was observed that this simple conventional dummy load caused a much larger load current, which results in overload in the remaining fluorescent lamp. This over power consumption causes a life-shortening problem for the fluorescent lamp.

Moreover, the THD regulation was not met by the conventional dummy load, as shown in Fig. 13, since there

is no harmonic filter circuit in it.

V. CONCLUSIONS

The proposed dummy load composed of a fundamental component compensation circuit and a harmonic component filter circuit showed very good performances when compared with a conventional dummy load.

It provides 20.6W increase in power savings when compared to the conventional dummy load while meeting the rated output current, power factor, and THD regulations faithfully.

Therefore, it can be concluded that the proposed dummy load is a practical and urgently needed countermeasure for the electrical power shortage in Japan.

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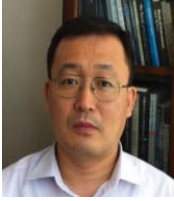
Bo-Hwan Choi received his B.S. from Sungkyunkwan University, Suwon, Korea, in 2011. He is currently pursuing an Integrated Master's Ph.D. in Nuclear and Quantum Engineering at KAIST (Korea Advanced Institute of Science and Technology), Daejeon, Korea. His research interests are in the field of power electronics related to nuclear power plants, and his current research interests include power conversion circuits and contactless power supplies.



Hyun-Jae Kim received his B.S. from Sungkyunkwan University, Suwon, Korea, in 2010, and his M.S. from KAIST (Korea Advanced Institute of Science and Technology), Daejeon, Korea, in 2012, both in Electrical Engineering. His current research interests are in the field of power electronics related to LED drivers and contactless power supplies.



In-Yong Yeo received his B.S. from Hanyang University, Seoul, Korea, in 2011, and he is currently pursuing his M.S. in Nuclear Quantum Engineering at KAIST (Korea Advanced Institute of Science and Technology), Daejeon, Korea. His research interests are in the field of power electronics related to nuclear power plants, and his current research interests include power conversion circuits and contactless power supplies.



Bong-Cheol Kim was born on Jeju Island, Korea, in 1962. He received his B.S. in Electrical and Electronic Engineering from Ajou University, Suwon, Korea, in 1985 and his M.S. in Electrical and Electronic Engineering from KAIST (Korea Advanced Institute of Science and Technology), Daejeon, Korea, in 1987. From 1987 to 1990,

he was with the Institute of Samsung Electronics, Kiheung, Korea. From 1991 to 2003, he organized and worked for PROWTech Inc. in the field of infrared and visible LEDs as a CTO of PROWTech Inc., Chungbuk, Korea. His research interests include opto-electronic components such as Laser Diode and LEDs, and also LED lighting solutions for general illumination. He is currently working on smart and robust LED driving technology development in the field of LED general lighting with KAIST as a president and CEO of Optomind Inc.



Chun-Taek Rim received his B.S. from KIT (Kumoh Institute of Technology), Gumi, Korea, in 1985, and his M.S. and Ph.D. from KAIST (Korea Advanced Institute of Science and Technology), Daejeon, Korea, in 1987 and 1990, respectively, all in Electrical Engineering. Since 2007, he has been an Associate Professor of Nuclear and Quantum

Engineering at KAIST. From 1990 to 1995, he was a Military Officer. From 1995 to 2003, he was a Senior Researcher at the Agency for Defense Development. From 2003 to 2007, he was a Senior Director at the Presidential Office. He has authored or coauthored 62 papers, written 4 books, and holds 63 patents. He is currently developing an inductive power transfer systems for on-line electrical vehicles, and leading the Mobile Power Electronics Lab, named Tesla Lab, at KAIST. His research interests include future green transportation such as electrified vehicles, ships and airplanes, and wireless power systems for robots, home appliances and bio-medical applications.