Proceedings of the 2008 IEEE
International Conference on Robotics and Biomimetics
Bangkok, Thailand, February 21 - 26, 2009

Automatic Fluorescent Lamp Detection Technique for Electronic Ballasts

Piyasawat Navaratana, Sumate Naetiladdanon and Anawach Sangsawang

Department of Electrical Engineering

King Mongkut's University of Technology Thonburi

Toongkru, Bangkok 10140, THAILAND

{piyasawat.nav, sumate.nae & anawach.san}@kmutt.ac.th

Abstract **- Due to the variation of fluorescent lamp power rating and types, the specified ballast could be used to meet the appropriate operating power. Generally, electronic ballast drives fluorescent lamp with fixed operating frequency. Such method can be used for only the designed lamp type and power rating. An operation of this type of ballast with mismatch lamp will cause damage on the lamp and/or ballast. This paper presents an Automatic Fluorescent Lamp Detection for Electronic Ballasts. This proposed method enables the ballast to determine the connected lamp's power rating and drive the lamp with proper operating frequency. The experimental results show 100% accuracy on the 3 power rated T8 lamps which are 18 watt, 32 watt and 36 watt.**

Index Terms - Fluorescent lamp, Power Rated, Electronic ballast, Current control.

I. INTRODUCTION

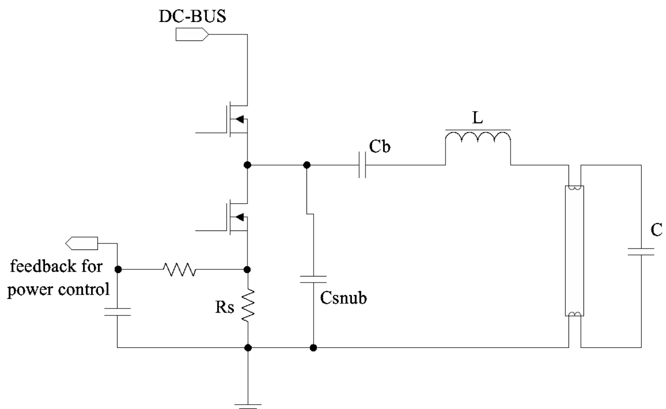
Plenty of organizations have many types of lamps installed, the fluorescent lamps usually be the highest in quantities due to its power efficiency. With fluorescent lamps, there are many types and power rated. With the large number of fluorescent types used, the more stocked lamps and ballasts are required. For example ballast for 18W, 32W and 36W T8 lamp should be stocked separately. And with the same physical size of 32W and 36W lamps, they can't be replaced by each other. Therefore, both lamps should be also stock separately. Using the mismatch ballast and lamp can cause damage on lamp and/or ballast. To solve this problem, automatic lamp detecting method is presented. After lamp power rated is detected, ballast will run at the proper frequency.

Unfortunately, there are not many literature techniques mention about lamp detecting methods. One of them, claimed to be the best method, using voltage across the lamp[1]. This method can differentiate lamp power using the lamp voltage. At ignition state, the lamp voltage is collected and used to classify the lamp. However, by the classical method that quickly decrease the driving frequency until the lamp voltage suddenly drop (current can be starting to flow through the lamp), the frequency at this after ignite stage can be varied. It's up to the lamp temperature, age and manufacturer. Therefore, the voltage across the lamp is varied too. Most of all, from Table 1 some type of lamp has the same voltage range (mark with dark gray). And by varying the frequency to supply the lamp power from 100% to 2%, the lamp voltage of some different rate is also overlapped. For example, 32WT8 and 58WT8 voltage is overlapped between 117V to 127V. This can outcome the incorrect lamp recognition.

TABLE I
TYPE OF LAMP AND ITS CHARACTERISTICS AT FULL AND MINIMUM POWER[6]

Lamp type	Ratting //Run (W)	100% V	100% I	2% V	2% I	Rs (cal.)	Vh (cal.)
	96//94	198	0.475	166	0.011314	68.66	165.39
	40//38	99	0.384	95	0.007961	9.41	95.38
	34//32	71	0.453	100	0.006374	-66.56	100.83
T12	20//19	78	0.244	71	0.005374	29.60	70.55
	70//68	129	0.528	141	0.009617	-24.53	141.66
	58//56	113	0.495	127	0.008800	-29.09	127.54
	40//38	100	0.381	117	0.006514	-45.30	116.97
	36//34	100	0.341	117	0.005828	-50.63	116.97
	32//30	117	0.257	131	0.004587	-56.00	131.07
	18//16	69	0.231	67	0.004764	9.38	67.13
T8	17//16	81	0.197	78	0.004371	18.38	77.70
	54	152	0.355	205	0.005267	-151.55	205.86
	39	134	0.290	145	0.005381	-37.23	145.16
	35	219	0.160	301	0.002329	-516.83	301.72
	28	191	0.147	212	0.002640	-147.29	212.52
	24	88	0.272	99	0.004849	-39.77	99.19
	21	141	0.148	177	0.002376	-241.97	177.35
T5	14	98	0.143	106	0.002640	-60.25	106.23
	55	134	0.417	205	0.008193	-173.04	206.48
	40//38	170	0.224	198	0.005758	-129.65	198.74
	36//34	113	0.301	134	0.007592	-72.42	134.90
	24//23	75	0.307	99	0.006970	-80.17	99.55
PL-L	18//17	62	0.273	88	0.005770	-97.83	88.95
	42	177	0.238	212	0.005940	-152.63	213.04
	32	120	0.266	173	0.005541	-203.45	174.37
	26//24	99	0.242	166	0.004333	-282.13	167.39
TC-T	18//17	71	0.240	141	0.003606	-298.60	142.50
	26//24	106	0.226	134	0.005359	-128.03	135.04
	18//17	99	0.172	127	0.004007	-168.64	127.95
	13	99	0.131	127	0.003064	-220.53	127.95
TC-DEL	10	57	0.177	85	0.003536	-163.27	85.43
	11	75	0.147	99	0.003334	-167.63	99.55
	9//8	48	0.166	85	0.002828	-224.82	85.49
	7//6	37	0.163	71	0.002546	-211.30	71.25
TC-EL	5	27	0.186	42	0.003536	-85.22	42.73

978-1-4244-2679-9/08/$25.00 ©2008 IEEE



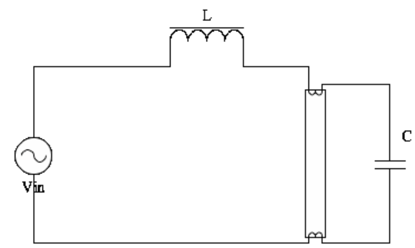


Fig. 1 a) Half bridge driver with resonance circuits b) Simplified inverter and resonant circuits

To make it possible to implement, the constrain must be set. By regulating the lamp power after the ignition stage, the frequency is fixed. So the frequency variation is eliminated. The second problem is the lamp voltage overlapped between some different power rate lamp. Looking at the calculated Vh and Rs in Table 1, this represent the V-I characteristic of fluorescent lamp. This value is coming from the lamp dynamic model described in [2]. Its can also used to calculates the running frequency of lamp running with the ballast resonant circuit. Focus on the pair of overlapped voltage lamp, the Rd and/or Vh is differed. Therefore, detecting lamp characteristic is the better way. The frequency used to run the lamp at steady power is the easy way to determine the lamp characteristic. This idea is simulated using 2 stages general used circuit as shown in Figure 1a. The simplified inverter and resonant circuits[3] (Figure 1b.) is used to plot out the running frequency related to the running lamp power as shown in Figure 2.

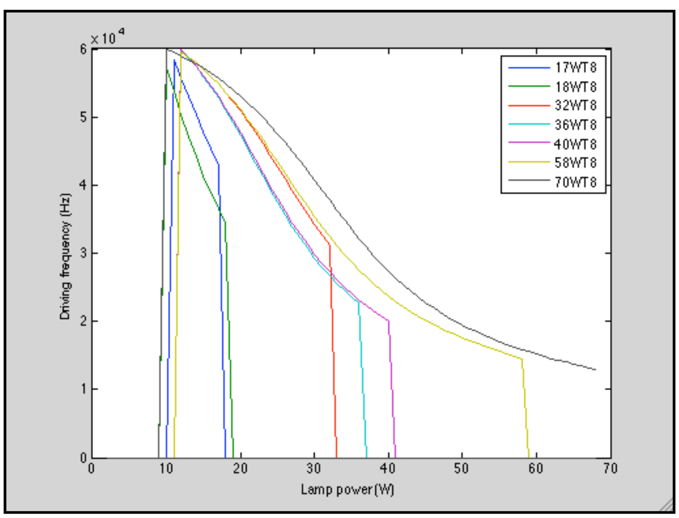


Fig.2 Frequency VS Lamp Power of T8

From Figure 2, the frequency is slightly difference between 36WT8 and 40WT8 and between 32WT8 and 58WT8. This graph show that the lamp detecting method can be implement using frequency at the steady lamp power.

This paper presents an automatic lamp detection using lamp power regulation and frequency detection. The lamp detecting algorithm divides into 3 steps which are the after ignition power regulation, possible step up power command and final decision. Using a microcontroller with PWM output, this algorithm is applied together with 2 stages general used circuit. The lamp power is regulated by using voltage across the resister(Rs) of low side driver MOSFET, assumed that power loss is constant related to the input power.

II. LAMP DETECTION ALGORITHM

A. *Lamp power regulation*

The average voltage across the Rs of low side driver MOSFET represent the current through the half-bridge driver (Figure 1a). This current is provide by DC-BUS which voltage is regulated by the high power factor boost converter.

$$P_{inv} = V_{DC}.I_{inv} \quad (1)$$

with constant V: $$P_{inv} \alpha I_{inv} \quad (2)$$

$$P_{inv} = P_{lamp} + P_{loss} \quad (3)$$

assume that P_{loss} is constant related to P_{inv} :

$$P_{inv} \alpha P_{lamp} \quad (4)$$

from (1): $$P_{lamp} \alpha I_{inv} \quad (5)$$

V_{DC} =DC voltage supplied by the boost converter

I_{inv} =Current through the inverter

P_{inv} = Power supplied by VDC through the inverter

P_{lamp} =Power using by the lamp

P_{loss} =Power loss by lamp filament and electrical componant

From equation (5), controls V_{RS} relatively controls P_{lamp}.

After preheat the filament, driving at high frequency, microcontroller quickly decrease the driving frequency until the voltage across the lamp suddenly dropped down. This is occur by the lamp suddenly change its impedance due to the complete ignition. The power command is then applied. This applied command is the lowest power rate of lamps to be detected. For example, use 16W power command for the group of T8. At the steady state (Pout=Pcommand), running frequency is collected. Because the frequency is commanded by microcontroller during power regulating loop, it already knows the running frequency itself. None of external frequency measurement is need. This frequency is used to classify the 18W(lowest) from the group. If frequency is in the range then it is the final decision and will step to the running procedure. To ensure that the lamp is recognized correctly, the possibility weight is introduced.

By the variation of lamps manufaturer, age and temperature, running frequency is not constant. From the experiment by regulating the lamp power, the results show the variation of running frequency. Table 2 and 3 present the average and standard deviation of running frequency at 16 to 68W of power regulation. The standard deviation is around 1-3% of average frequency. By simplifying the gaussian distribution, the trapezoid one is used. It is easier to implemented with the low-end 8 bits microcontroller. This trapezoid is what we call "possibility weight (*WP*)". Possibility weight of 18WT8 running at 16W (*WP18at16*)=1 means it is 100% possible that the lamp is 18W rate when considering at 16W power regulation.

TABLE II
AVERAGE RUNNING FREQUENCY OF BALLAST(KHZ)

Run(W) Lamp	16	30	34	38	56	68
T870W	56.97	41.46	35.83	30.60	<25kHz	<25kHz
T858W	56.47	36.31	30.77	26.35	<25kHz	
T840W	55.12	30.77	25.91	<25kHz		
T836W	54.99	30.19	25.36			
T832W	56.48	35.08				
T818W	39.81					
T817W	46.26					

TABLE III
STANDARD DEVIATION OF RUNNING FREQUENCY OF BALLAST(KHZ)

Run(W) Lamp	16	30	34	38	56	68
T870W	2.85	1.66	0.72	1.01		
T858W	2.43	1.27	0.62	0.79		
T840W	1.20	0.92	0.57			
T836W	2.42	1.72	0.61			
T832W	1.24	0.70				
T818W	2.07					
T817W	1.41					

Fig. 4 show the trapezoidal distribution using in this algorithm. From the Figure, the possibility weight is calculated by:

$$W_P = \begin{cases} 1; \bar{X} - 0.5SD, f, \bar{X} + 0.5SD \\ \dfrac{1}{SD} f - \dfrac{\bar{X} - 1.5SD}{SD}; \bar{X} - 1.5SD, f, \bar{X} - 0.5SD \\ \dfrac{-1}{SD} f + \dfrac{\bar{X} + 1.5SD}{SD}; \bar{X} + 0.5SD, f, \bar{X} + 1.5SD \end{cases} \quad (6)$$

Where $\bar{X} = \frac{1}{n}\sum_{i=1}^{n} f_i$, $SD = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(f_i - \bar{X})^2}$ (7)

n=number of samples, f_i = frequency of sample i

The value of $\bar{X}$ and SD can be calculated by 2 methods. 1. from the real samples and 2. using frequency calculated by simplified inverter circuit and dynamic lamp model as mean and use 2-3% of calculated frequency as SD. Note that using the real samples will be better in performance depended on the number of samples used. If collecting the large number of sample is a difficult task, using the calculated one is fine (see the experimental results).

B. *Possible step up power command*

At this step, the power command is stepped up to the next power rated in the group if maximum W_P is not on the lamp that rated this power. For example, if maximum possibility weight is on 32WT8 running at 16W ($W_{P32at16}$)=1, it is the most possible that the lamp is 32W rate when considering at 16W power regulation. Nevertheless, the 32W lamp should run at 30W not 18W, the power command stepped up to the next level. After power command is stepped up, ballast will then regulates the output power to this new setting command. After controller reaches the steady state. The running frequency is collected. As the previous stage, the next power rated lamp is classified. The possibility weight is calculated using equation 6 also.

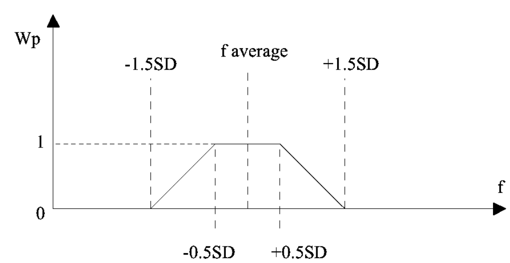


Fig. 4 possibility weight (W_P) VS running frequency

If lamp can not be classified in this stage, step up the power command and reclassify for the next power rated. Until the lamp is classified or reach the highest power command.

C. *Final decision*

In this stage, the possibility of all lamp rated is summed. The highest summing weight determines the most possible lamp rated. If W_{P_TOTAL} is equal, the lower one is used. And if none of W_{P_TOTAL} is equal or above 1, lamp is not classified and will be shut down.

III. HARDWARE CONFIGURATION

First of all, the resonance circuit is designed using the simple resonant circuit design method[2]. Given DC supply is V_{DD} then:

$$V_{Lamp} = \frac{\sqrt{2}}{\pi} V_{DD} = 0.4502 V_{DD} \quad (8)$$

To calculate resonance inductor (L), the type of lamp and range of power rated should be defined.

In this paper we mention about T8 that is widely used. The power rated are 17W, 18W, 32W, 36W, 40W, 58 W and 70W. Using equation (9) [3], resonant L is calculated.

$$L = \frac{V_{DC}^2 \eta}{4 f_{run} \sqrt{2}\pi^2 P_{run}} \tag{9}$$

assume that efficiency (η) is 0.95 and V_{DC} is 400V, L is calculated using f_{run} = 25kHz and 55kHz (microcontroller we use can generated PWM output with frequency not more than 100kHz. And Frequency below 20kHz the lighting efficiency is significantly drop[4].)

TABLE IV
RESONANCE INDUCTOR CALCULATED RESULTS FOR T8

Power rated(W)	L for f=25kHz(H)	L for f=55kHz(H)
17	6.80E-03	3.09E-03
18	6.80E-03	3.09E-03
32	3.63E-03	1.65E-03
36	3.20E-03	1.45E-03
40	2.86E-03	1.30E-03
58	1.94E-03	8.83E-04
70	1.60E-03	7.27E-04

From Table 4, if we choose L=1.6mH this ballast will run with the lamp rated from 36W to 70W. If we choose 3.2mH, it will run with the lamp rated from 17W to 36W. If we choose 1.6mH, it will run with the lamp rated from 32W to 70W. The 32mH is selected because those rates are widely used in the market.

After that, with appropriate preheat current and preheat voltage, resonance C is calculated [3]:

$$C = \frac{I_{ph}^2 L}{\left(V_{ph} + V_{DC}/\pi\right)^2 - \left(V_{DC}/\pi\right)^2} \tag{10}$$

that given C=4.26nF. Thus, 4.7nF is used.

IV. Simulation Results

For working with T8 fluorescent lamp, the first control loop will start with 17W. Then the next power rates are applied until maximum W_P is on the lamp at its rate. Then W_P in every step will be summed by its relative power rated and classified by the maximum summing weight. Finally, if summation of W_P is not equal or above 1, lamp will not be classified.

To simulate the result, the fluorescent lamp dynamic model [2] is used

$$R_{lamp} = \frac{V_o R_s}{V_o - V_H} \tag{11}$$

The V_S and R_S can be found by measuring the lamp Voltage and Current. The results are in Table 1.

$$R_S = \frac{V_{fullpower} - V_{\min power}}{I_{fullpower} - I_{\min power}}$$

$$V_H = V_{\min power} - I_{\min power} R_S \tag{12}$$

Using these model, running frequency of designed ballast is calculated:

TABLE V
CALCULATED RUNNING FREQUENCY OF BALLAST WITH DESIGNED CIRCUIT

Run(W) / Lamp	16	30	34	38	56	68
T870W	57.3kHz	39.6kHz	34kHz	29.1kHz	<20kHz	<20kHz
T858W	56.2kHz	34.1kHz	29.1kHz	25.3kHz	<20kHz	<20kHz
T840W	53.7kHz	29.5kHz	25.4kHz	22.3kHz	<20kHz	<20kHz
T836W	54.2kHz	30.2kHz	26kHz	22.7kHz	<20kHz	<20kHz
T832W	57.5kHz	35.4kHz	29.5kHz	25kHz	<20kHz	<20kHz
T818W	40kHz	20.4kHz	<20kHz	<20kHz	<20kHz	<20kHz
T817W	46.7kHz	23.9kHz	20.8kHz	<20kHz	<20kHz	<20kHz

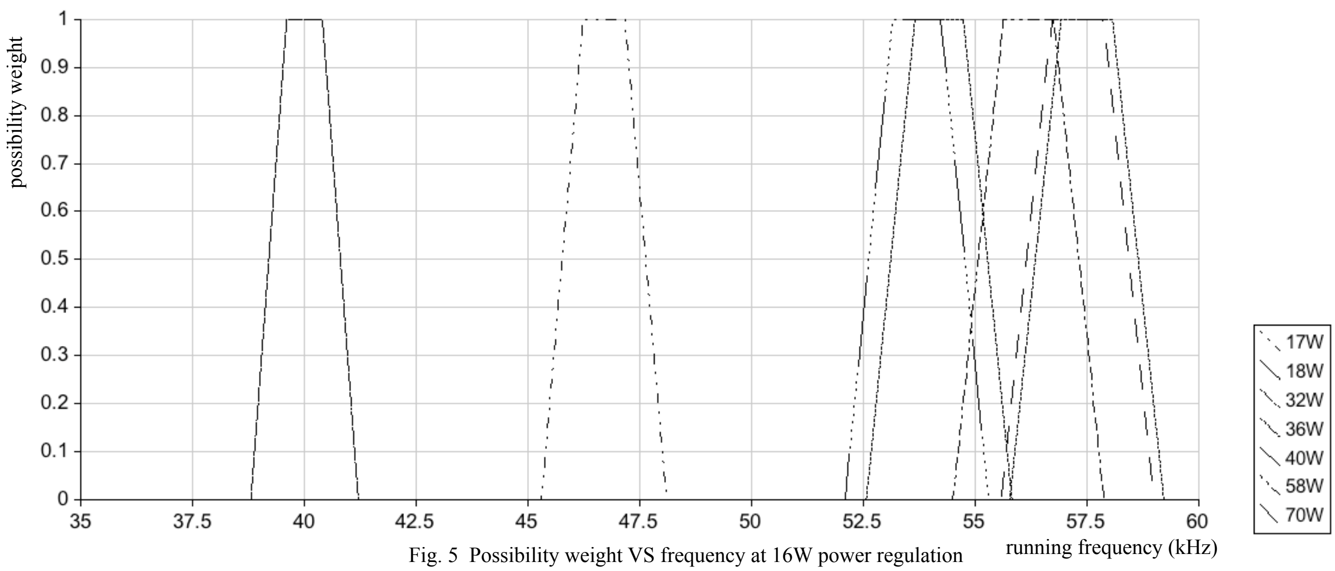


Fig. 5 Possibility weight VS frequency at 16W power regulation

Table 4 show that the designed ballast can run with T8-17W, 18W, 32W and 36W with full power. This ballast can also run with T8-40W, 58W and 70W but not the full power. The dark-gray highlight means “over rated running and can damage the lamp”. The gray means “frequency is lower than 25kHz”. By selecting SD 2%, from equation (6) with power command =16W:

$$W_{P17at16} = \begin{cases} 1; 46.23kHz, f, 47.17kHz \\ 1.07f - 48.5; 45.3kHz, f, 46.23kHz \\ -1.07f + 51.5; 47.71kHz, f, 48.1kHz \end{cases} \quad (13)$$

$\overline{X}$ =46.7kHz, SD=0.934kHz

$W_{P17at16}$ is possibility that the lamp is 17WT8 by determining at 16W power regulation.

$$W_{P36at16} = \begin{cases} 1; 53.66kHz, f, 54.74kHz \\ 0.92f - 48.5k; 48.5kHz, f, 53.66kHz \\ -0.92f + 51.5k; 54.74kHz, f, 55.83kHz \end{cases}$$

(14)

$\overline{X}$ =54.2kHz, SD=1.084kHz

$W_{P36at16}$ is possibility that the lamp is 36WT8 by determining at 16W power regulation.

Use the same equation by varying the power command and lamp type, the W_P related to them are calculated and used in this software. This calculation is plotted in Figure 5.

V. EXPERIMENTAL RESULTS

The experiments are divide into 2 part that are A. closed loop power control at 16W, 30W, 34W and 38W to find W_P of tested lamp and B. implement the automatic lamp detection to find out the classification rate. this experiment is set up by using designed ballast with 15 fluorescent lamps of each type. In each type, the lamp has 3 group of age include 5 out of the box lamps (new), 5 of 100 hours lamps and 5 of over 1000 hours lamps.

Note: Some of lamp is hardly to find (17W, 40W), less than 15 lamps is used and none of them are new.

A. Closed loop power control to find W_P

By picking up a 36W lamp, running at 16W regulated, the frequency is 55.8kHz. Using equation (6) given $W_{P17at16}$ = 0, $W_{P18at16}$ =0, $W_{P32at16}$ =0.32, $W_{P36at16}$ =0.32 and $W_{P40at16}$ =0. The $W_{P17at16}$ and $W_{P18at16}$ are not the highest one, power command is stepped up to 30W.

By running at 30W regulated, the frequency is 29.9kHz given $W_{P32at30}$ =0, $W_{P36at30}$ =1 and $W_{P40at30}$ =0.96. Also, the $W_{P32at30}$ is not the highest one, power command is stepped up to 34W.

By running at 34W the frequency is 25.8kHz given $W_{P36at34}$ =1 and $W_{P40at34}$ =0.87. the $W_{P36at34}$ is the highes, go to the final dicision.

In the final decision step, lamp will be classified into 36WT8 because the summation of W_{P36}=2.32 which is the highest as seen in Table 6.

TABLE VI
POSSIBILITY WEIGHTS OF TESTED 36W T8

Run Rate(W)	16	30	34	38	56	68	Sum
70	0.45	0.00	0.00				0.45
58	1.00	0.00	0.00				1.00
40	0.00	0.96	0.87				1.83
36	0.32	1.00	**1.00**				**2.32**
32	0.32	0.00					0.32
18	0.00						0.00
17	0.00						0.00

Again pick up a 32W lamp, the result is in Table 7. In step 2 of algorithm, ballast will step to final decision due to $W_{P32at30}$ is maximum ($W_{P32at30}$ =1). In the final decision, lamp will be classified as 32WT8 because the summation of W_{P32}=2 which is the highest as shown in Table 7.

TABLE VII
POSSIBILITY WEIGHTS OF TESTED 32W T8

Run Rate(W)	16	30	34	38	56	68	Sum
70	0.94	0.00					0.94
58	1.00	0.44					1.44
40	0.00	0.00					0.00
36	0.00	0.00					0.00
32	1.00	**1.00**					**2.00**
18	0.00						0.00
17	0.00						0.00

B. Implementation of automatic lamp detection

By testing with 3 type of lamps include 18W, 32W and 36W T8. The result show the 100% classification rate. This experiment is done by measuring the lamp output power after 30 seconds after switched on.

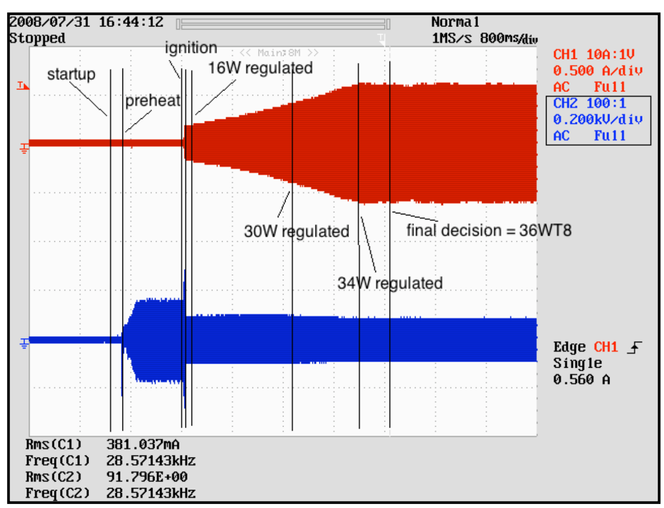


Fig. 6 Automatic lamp detection with 36WT8 (lamp current and voltage)

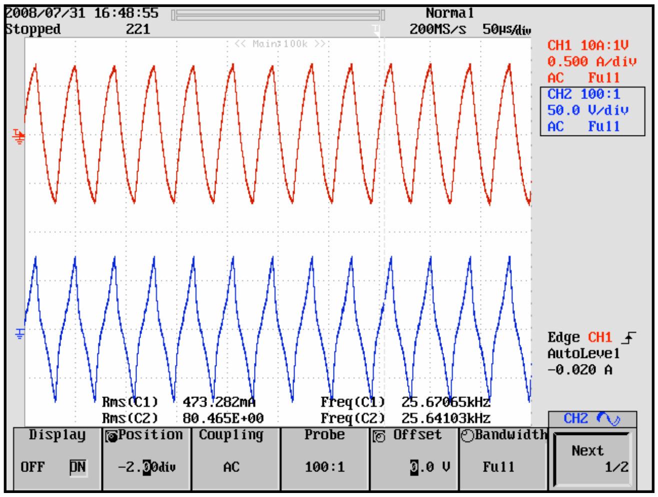


Fig. 7 Lamp current and voltage (zoom) of running 36WT8

3 seconds after ignited, 36W lamp is detected. This make the lamp not flash to the maximum power but slowly increase its power to the maximum. Figure 7 show running frequency is 25.6 kHz.

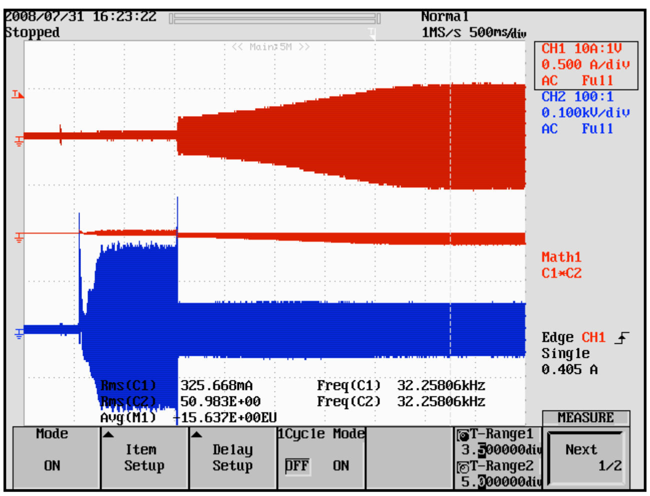


Fig. 8 Automatic lamp detection with 18WT8 (lamp current and voltage)

Figure 8 show that about 2 seconds after ignite, the lamp is classified as 18W. Therefore, the "Avg(M1)" show the regulated lamp power at running stage = 15.637W. The running lamp current, lamp voltage and frequency is shown in Figure 9.

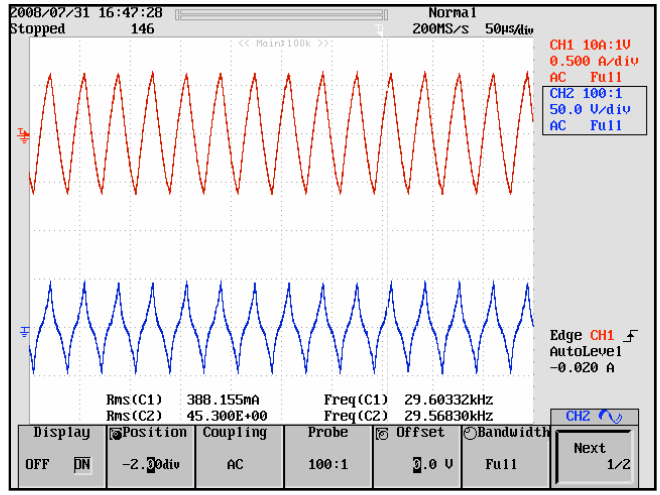


Fig. 9 Automatic lamp detection with 18WT8 (lamp current and voltage)

VI. CONCLUSIONS

By the method presented, it shows the trustability of detected results. This method combines with lamp power regulation and lamp power rate classification using its running frequency. It results in correct determination of lamp power rating on all of samples. To complete this algorithm, ballast take less than 5 seconds after ignition stage. The only thing to be concerned is the variation of resonance inductor value. It highly affects the operating frequency that is the most important role in this method.

REFERENCES

[1] L.M. Lee, S.Y.R. Hui and H.S.H. Chung, "An Automatic Lamp Detection Technique for Electronic Ballasts", *IEEE*, 2005, pp 575-581

[2] T.-F. Wu, J.-C. Hung and T.-H. Yu, "A PSpice Model for Fluorescent Lamps Operated at High Frequencies", *IEEE*, 1995, pp. 359-364

[3] Zhi Lie, Philip K. T. Mok, Wing-Hung Ki and Johnny K. 0. Sin, "A Simple Method to Design Resonance Circuits of Electronic Ballast for Fluorescent Lamps", *IEEE International Symposium on Circuits and Systems*, pp 1744-1747, 1997

[4] 1. John, E. Kaufman, Jack F. Christensen and Illuminating Engineering Society of North America, 1984, "IES Lighting Handbook", Illuminating Engineering Society

[5] Thomas J. Ribarich and John J. Ribarich (conslt.), "A New Procedure for High-Frequency Electrßonic Ballast Design", *IEEE Industry Applications Society Annual Meeting, New Orleans, Louisiana, October 5-9, 1997*

[6] International Rectifier Corporation, IR Ballast Designer version 4.1.7, lamp characteristics, 2006