

## LABORATORY POWER QUALITY STUDY OF AIR CONDITION SYSTEMS INDIVIDUALLY AND SIMULTANEOUSLY WITH COMPACT FLUORESCENT LAMPS (CFL)

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### ABSTRACT:

Khuzestan is one of the warmest provinces of Iran in which the air condition systems, i.e. window coolers and split coolers, are used over than nine month in year by the consumers. The lighting consumption is the second category of dominated consumption in Khuzestan. In recent years the CFL<sup>1</sup>, known as nonlinear loads, are widely used by the consumers. Therefore, the study of power quality indices of this equipment is useful. In order to study the power quality of air condition systems, ten kinds of widely used window and split coolers in warm climate areas are considered in laboratory and the measured current harmonics of them are compared with the corresponding standard. Furthermore the power quality of different kinds of CFL in short term (ten minute) is measured and their current harmonics are compared with the corresponding standard of lighting equipment. Then the power quality indices of simultaneously using of CFL and air condition systems, both window and split coolers, are studied.

The results show that the THDi<sup>2</sup> of air condition systems are low and its highest value is 26.4%. It should be mentioned that THDi of split coolers is more than window coolers.

When the CFL are considered with the air condition systems, the amount of the current harmonic of this combination may violate the standard limit. In this respect, if the portion of CFL in combination with split coolers and window coolers reach to 9.7% and 15.6% respectively, the amount of the current harmonic violate the standard limit.

### 1. INTRODUCTION

Khuzestan province is located in the warm moist air from the south west of Iran. The electrical consumption is determined with two kind of climate regimes consist of warm and cold weather conditions. The studies show the ambient air temperature plays main role in variation of electrical demand in compare with other climate indices such as humidity wind speed, barometric pressure and etc. As shown in table1 in the first half of the year more than 73% of the number of hours, the temperature is over 30°C and 94% over a period of hours, the air temperature is higher than 20°C. If the desired air temperature ranges from 20°C to 30°C, consumers should use the air condition systems at least 73% and maximum 94% of the time in the first half of year (warm period).

Table 1- Yearly Khuzestan temperature classification from 2004 to 2012

Temperature Classification °c	Time of the first half %	Time of the second half %
0-10	0	15.7
11-20	5.1	49.3
21-30	21.6	26.2
31-40	50.4	8.8
41-50	22.9	0

Air condition systems are the major part of electrical consumption in tropical areas like Khuzestan province. This load is almost constant and continuous but changes based on ambient temperature and relative humidity variations. In recent years the air condition systems specially split type widely used by the consumers so consideration of their features and effects on distribution network in compare with other types is inevitable.

The lighting equipment is also a part of electrical consumption. The CFL, known as nonlinear loads, are widely used by the consumers. Therefore study of power quality of these equipment especially current harmonic indices and power factor is necessary.

Order to evaluate power quality of air condition systems, ten kinds of widely used window and split air conditions in warm areas are considered in laboratory and the current harmonics measured and compared with the corresponding allowable limit. Laboratory study of power quality of cooling systems Pre-discussed samples has been evaluated in laboratory using a power quality analyzer model 3196 HIOKI in a short term of time (10 minutes) and recorded power quality indices. Then these values compared with standard ranges. Permissible harmonic current limit based on NO.6375-2 institute of standard and industrial research of Iran for odd and even orders are presented in table 2.

Table2- Permissible harmonic current limit in cooling equipment

Order of harmonic (h)	Max. of permissible harmonic current(A)	Order of harmonic (h)	Max. of permissible harmonic current(A)
2	1.08	3	2.3
4	0.43	5	1.14
6	0.3	7	0.77
8 ≤ h ≤ 40	0.23 * 8/h	9	0.4
		11	0.33
		13	0.21
		15 ≤ h ≤ 39	0.15 * 15/h

In this paper 8 number of split air condition systems and 2 number of window types with shown rated specifications in table 3 were investigated. The measurements were carried out at ambient temperature between 46°C to 50°C on August 2011 in Ahwaz.

1 Compact fluorescent lamps

2 Total current Harmonic Distortion

**Table3- Rated specifications of the tested air condition system.**

Model	Type	Cooling Capacity (BTU)	Load Current (A)	Active Power (KW)
A	SPLIT	12000	5.4	1.21
B	SPLIT	12500	6.2	1.24
C	SPLIT	18000	8.3	1.8
D	SPLIT	18000	11.8	2.6
E	SPLIT	30000	14.2	3.07
F	SPLIT	30000	15.8	2.92
G	SPLIT	36000	17.1	3.54
H	SPLIT	38000	19	4.2
I	WINDOW	18000	9.3	2.21
J	WINDOW	19800	10.2	2.26

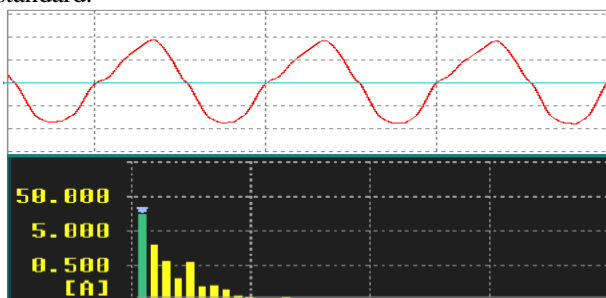
**1.1. SPLIT AIRCONDITION SYSTEMS**

In this case a split air condition system with 30000 Btu cooling capacity (E Model) has been tested and power quality parameters are shown in table 4.

**Table 4- Measured parameters for split model**

Voltage (V)	Current(A)	Active Power (KW)	Current THD %	Voltage THD %	PF
228	14.2	3.07	14.2	1.74	0.94

The active power and load current are 3.07(kW) and 14.2(A) respectively. These values are affected by weather conditions in Ahvaz and so are higher than rated values. The THDi and THDv<sup>3</sup> are 14.3% and 1.74% respectively. The current waveform and harmonic spectra are presented in figure 1. The distortion in current waveform is very low but it's somewhat asymmetrical also even harmonics appear in spectra. The current harmonics in different orders are compared with corresponding standard limits and results are given in table 6. The amounts of all odd and even order harmonics except second component are less than specified limits in standard.



**Figure (1) - current waveform and its harmonic spectra for split model**

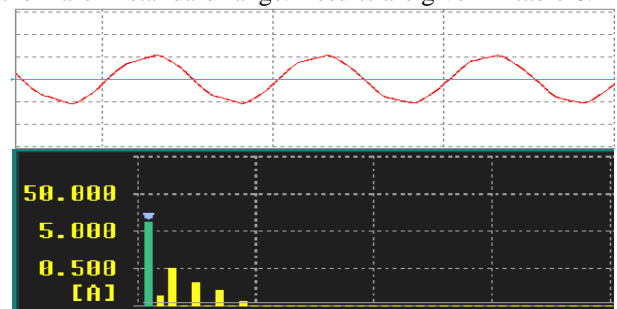
**1.2. WINDOW AIR CONDITION SYSTEMS**

In this case a window air condition system with 18000 Btu cooling capacity (I Model) has been tested and recorded power quality parameters are shown in table 5. The active power and load current are 2.08 (kW) and 9.2(A) respectively and are almost equal to rated value. The THDi is 5.23% and is much less than THDi in split type (E model). The THDv is 1.06%. The current waveform and harmonic spectra are depicted in figure 2.

**Table 5-Measured power quality parameters for I model**

Voltage (V)	Current (A)	Active Power (KW)	Current THD %	Voltage THD %	PF
228	9.2	2.08	5.23	1.06	0.98

The distortion in current waveform is very low and except second order there isn't any even order harmonic in its spectra. The current harmonic in different orders is compared with corresponding standard limit and all of them are in standard range. Results are given in table 6.



**Figure (2) - The current waveform and harmonic spectra for I model**

**Table 6- Comparison of current harmonics with standard for E and I models**

H	Max. Of permissible harmonic current (A)	Measured harmonic current (A)		H	Max. Of permissible harmonic current (A)	Measured harmonic current (A)	
		E	I			E	I
3	2.3	0.73	0.392	2	1.08	1.87	0.035
5	1.14	0.68	0.229	4	0.43	0.193	0.012
7	0.77	0.16	0.133	6	0.3	0.094	0.011
9	0.4	0.07	0.06	8	0.23	0.118	0.006
11	0.33	0.03	0.033	10	0.184	0.054	0.005

As shown the amounts of 2th and 3th current harmonic components are  $H_{i2}=0.035$  A and  $H_{i3}=0.392$ A respectively where are less than corresponding values in split type.

**1.3. COMPARISON OF MEASURED VALUES FOR AIR CONDITION SYSTEMS**

The results of laboratory measurements for samples (as described in 2 sections) are presented briefly in table 7. These results were investigated and compared to each other's based on total current and THDi and amounts of odd and even order harmonics.

**Table 7- comparison of measured results for different air condition systems**

Model	$H_{i2}$ (A)	$H_{i3}$ (A)	$H_{i5}$ (A)	$H_{i7}$ (A)	PF	THDi(%)	THDv(%)
A	0.71	0.67	0.29	0.1	0.97	21.6	3.6
B	1.03	0.51	0.12	0.11	0.95	19.7	2.45
C	1.88	1.64	0.25	0.18	0.94	26.4	2.34
D	1.79	0.45	0.22	0.15	0.93	21.2	2.12
E	1.87	0.73	0.68	0.16	0.94	14.3	1.74
F	0.16	1.12	0.13	0.27	0.96	7.24	1.81
G	2.08	0.76	0.63	0.19	0.97	13.7	1.84
H	0.22	1.1	0.55	0.18	0.93	7.65	2.56
I	0.03	0.39	0.22	0.13	0.98	5.23	1.06
J	0.03	1.14	0.32	0.24	0.93	11.4	1.9

**1.3.1.CURRENT HARMONIC DISTORTION**

Study of laboratory measurements is showed distortion in

3 Total voltage harmonic distortion

the current waveform is low and its waveform is close to pure sinusoidal wave. The THDi are 26.4% and 5.23 in worst and best cases respectively that show cooling system are linear loads. Figure 3 is depicted THDi for selected air condition systems.

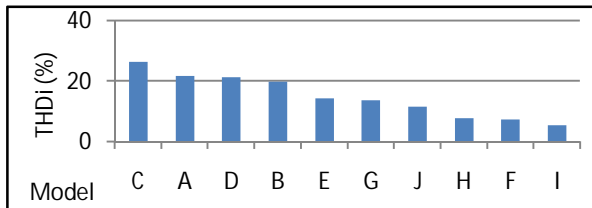


Figure 3- percentage of the THDi for tested air condition systems

THDi in split air conditions generally is more than window types and maximum of THDi belong to C model of split air condition with 18000 Btu cooling capacity and its minimum occur for I model of window types with 18000 Btu cooling capacity.

### 1.3.2. ODD AND EVEN ORDER HARMONICS

The harmonic spectra of cooling systems are limited such that the harmonic components of these systems are significant only to the eleventh order. In often of split air condition system even harmonics are created due to the asymmetry in current waveform and the highest amount of these harmonics belongs to second component. Figure 4 shows this component for tested cooling systems. The second current harmonic is more than standard limit for all kinds of split type but it's negligible for window air conditions. The amounts of odd harmonics are negligible and limited only to the eleventh order. In addition maximum of these harmonics is third component and figure 5 shows the amount of this component for different cooling systems.

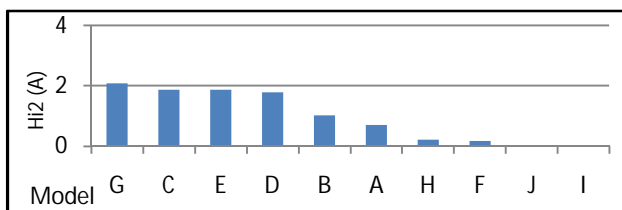


Figure 4-the amount of second current harmonic for tested air condition systems

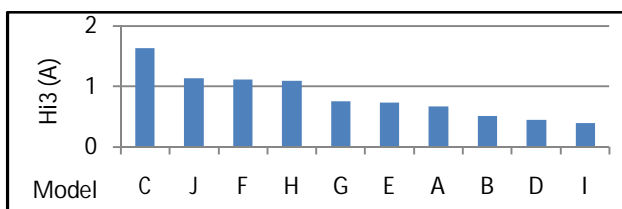


Figure 5-the amount of third current harmonic for tested air condition systems

## 2. EVALUATION OF CFL POWER QUALITY

In recent years the CFL are widely used by the consumers because of high lumen efficiency and longevity in compare with tungsten lamps. These lamps are made from 11 to 250 watt with various brands and shapes. In

this laboratory study 15 no. of 23 watt CFLs with same brand are considered in several cases and results show in table 8. Also current waveform and harmonic spectrum for a CFL are depicted in figure 6. As shown current distortion is high and waveform isn't sinusoidal THDi is 137% that is too higher than tungsten lamps and power factor is PF=0.543 which is very low and so using of capacitor for power factor improvement is necessary. In addition there aren't any even order harmonics in CFL spectrum due to symmetry in current waveform. Using of CFLs simultaneously causes the amounts of harmonics reduce somewhat e.g. for 15 No. of CFLs THDi is 132.7% which is 4.8% less than a CFL be used. The reason is the phase difference between different harmonic components in various CFLs so if this phase difference be 180 degree harmonic components and THD decrease significantly. To consider the power quality indices for a CFL, the harmonic content in different orders is compared with lighting equipment standard and results presented in table 9. As shown the amounts of the odd current harmonics violate the standard limit and maximum of these harmonics is third component with Hi3=85%.

Table 8- power quality indices for different number of CFLs

Number of 23 watt CFLs	Active Power (W)	current (A)	THDi (%)	THDV (%)	PF
1	22	0.17	137.5	0.81	0.543
5	109	0.86	143.1	0.8	0.536
10	218	1.69	139.7	0.95	0.546
15	342	2.58	132.7	1.15	0.564



Figure (6) - The current waveform and harmonic spectra for a CFL

Table 9- Comparison of current harmonics with standard for a CFL

Order of harmonic (h)	Maximum of permissible harmonic current (%)	Measured harmonic current (%)
2	2	0.2
3	30 $\lambda=16.5$	88.3
5	10	68.4
7	7	47.3
9	5	32.3
39 <h<sub>h&lt;11</h<sub>	3	26.4

## 3. INVESTIGATION OF POWER QUALITY IN CFL AND AIR CONDITION SYSTEMS COMBINATION

In the previous sections the power quality of air condition systems and CFLs were studied in the laboratory separately and the harmonic content of each them with the standard limits were compared and results discussed. In this section to consider CFLs affects on air condition systems, the combination of CFLs with a E model of split

air condition systems and a I model of window types have been evaluated in the same laboratory condition.

### 3.1. CFL AND SPLIT AIR CONDITION COMBINATION

In this case a E model of split air condition systems with 30000 Btu cooling capacity and different number of 23 watt CFLs, numbers of CFLs changes from 0 to 30 with 5 number steps, have been combined and power quality indices and harmonic components measured and results are presented in table 10. As explained in 2-1 sections current waveform distortion for split air condition model E is low and the amounts of odd harmonics in all of orders are less than the standard limits and for even harmonics only second harmonic violates the allowable range. However results show if numbers of CFLs increase THDi and harmonic components in different orders increase especially when number be over 15. These results for THDv are similar but with less intense. When numbers of CFLs exceed 15 no. the amount of harmonics from 5th to 11th orders violate standard ranges. For third order harmonic this take places for over 25 numbers of CFLs. Rated power of split air condition (2.08Kw) individually is most greater than Rated power of CFLs and so total power factor variations is negligible.

**Table10- power quality indices for CFLs and split air condition system combinations**

Case	Active Power (KW)	current (A)	THDi (%)	Hi3 (A)	Hi5 (A)	Hi7 (A)
E model	3.07	14.2	14.3	0.73	0.68	0.16
E model with 1 CFL	3.22	15.2	14.51	0.89	0.80	0.4
E model with 5 CFLs	3.31	15.4	14.92	1.02	1.03	0.45
E model with 10 CFLs	3.4	15.9	15.99	1.19	1.20	0.66
E model with 15 CFLs	3.51	16.4	18.1	1.36	1.54	0.83
E model with 20 CFLs	3.65	17	20.67	1.87	1.86	1.04
E model with 25 CFLs	3.77	17.4	23.47	2.43	2.1	1.26
E model with 30 CFLs	3.88	18.1	25.79	2.68	2.47	1.47

### 3.2. CFL AND WINDOW AIR CONDITION COMBINATION

In this case a I model of window air condition with 18000 Btu cooling capacity and CFLs with similar conditions that mentioned in 4-1 section have been tested and results are presented in tables 11. As explained in 2-2 section for this model current waveform distortion is low and the amounts of odd and even harmonics in all of orders are less than the standard limits. However results show if the number of CFL increases THDi and harmonic components in different orders increase especially when number be over 15. These results for THDv are similar but with less intense. When numbers of CFLs exceed 15 the amounts of harmonics from 5th to 11th orders violate standard ranges and power factor reduced so that reaches to 0.94. For third order harmonic this take places for 30 numbers of CFL.

As shown when the CFLs are considered with both kinds of air condition systems (split or window) the amount of the current harmonic of this combination may violate the standard limit. In this respect, if the active power portion of CFL in combination with split and window air conditions reaches to 9.7% and 15.6% respectively, the amount of the current harmonic violate the standard limit.

**Table11- power quality indices for CFLs and window air condition system combinations**

Case	A. Power (KW)	current (A)	THDi (%)	Hi3 (A)	Hi5 (A)	Hi7 (A)
I model	2.08	9.2	5.23	0.39	0.22	0.13
I model with 1 CFL	1.88	8.24	9.03	0.59	0.39	0.19
I model with 5 CFLs	1.97	8.66	9.94	0.51	0.535	0.32
I model with 10 CFLs	2.08	9.2	16.14	0.91	0.87	0.52
I model with 15 CFLs	2.19	9.8	20.08	1.09	1.15	0.74
I model with 20 CFLs	2.32	10.4	26.3	1.72	1.43	0.98
I model with 25 CFLs	2.42	11.04	31.2	2.12	1.85	1.21
I model with 30 CFLs	2.56	11.82	35.9	2.61	2.21	1.47

### 4. CONCLUSIONS

In this paper the performances of power quality of air condition systems individually and simultaneously with CFL were evaluated and power quality indices are measured and investigated. Then the CFL with various portion of air condition active power and split or window air conditions were combined and results considered. The important conclusions are as below:

- Study of result of air condition system samples shows current waveform distortion is low and its waveform is close to sinusoidal wave. THDi's are 26.4% and 5.23% in worst and best cases. THDi in split air conditions generally better than window type.
- In often of split coolers even harmonics are created due to the asymmetry in current waveform and only the second current harmonic is more than standard limit. It's negligible for window air conditions.
- The Amount of odd harmonics in air condition systems is negligible and limited only to the eleventh order. The maximum of these harmonics is third component but it's in standard range.
- The Combination of CFLs with air condition systems (split or window) shows when number of CFLs be over 15 THDi and harmonic components inviolate standard limits.
- If the active power portion of CFL in combination with air conditions reaches to 9.7% and 15.6% respectively, the amount of the current harmonic violate the standard limit.

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