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Influence of Harmonics in Laboratory due to Nonlinear Loads

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ABSTRACT

This research was focused on the customer's side of the meter which is the effect of harmonics on a laboratory in Electrical System Engineering School at K.Wai Perlis. Harmonic currents in equipments can cause them to experience overheating and increased losses, while harmonic voltage produces magnetic fields rotating at a speed corresponding to the harmonic frequency. This also results in equipments heating, mechanical vibrations and noise, reduced efficiency, reduced life, and voltage stress on insulation of equipment windings. The loads in this research are computers, Compact Fluorescent Lamps CFLs), Air Conditions and printers,which all of the loads are harmonic significant The instrument to measure and monitoring is Fluke 435 Power Quality Analyzer. With the operation of varying nonlinear loads, the injected harmonic current magnitudes and phase angles vary in a random way. This research offers the advantage of providing the utility a wealth of information on the effects of harmonics in their equipments. This will subsequently make them aware of the causes of increased cost and reduced efficiency that may be experienced by using these equipments. This paper describes the investigation cost of harmonic effect as THD, and harmonic energy losses cost.

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1. INTRODUCTION

Because electrical devices that act as nonlinear loads draw current non linearity, they are responsible for injecting harmonic currents into the electricity network. Harmonics is a more important issue for the industry, commerce and the home consumer now than it was a few decades ago. The equipments in laboratory are Compact Fluorescent Lamps (CFLs), Personal Computers, Laptops, Printers and Air Conditions where all of them can be similarly as harmonic significant. There are many causes of harmonics in a power system. In distribution system, transformers are capable of producing harmonics due to magnetic core saturation [1-4]. The effects of harmonics on equipment are: additional heating and higher dielectric stress on the capacitors, interruption capability of circuit breakers, the skin effect of the conductors, reduce lamp life, measurement errors in instrument like wattmeter, voltmeter etc, overheating, pulsating torque and noise on rotating machines, etc [5]. The cost to end users comes when the harmonic currents is added to the normal load and increase losses and loading on their distribution systems. The increased losses reduce the capacity of the system, including conductors, transformers. The increased loading generates heat and accelerates the aging of power equipment, like transformers [5-6].

Harmonic distortion is not new and it constitutes at present one of the main concerns for engineers in the several stages of energy utilization within the power industry. In the past, harmonics represented less of a problem due to the conservative design of power equipment and to the common use of delta-grounded wye connections in distribution transformer. But, the increasing use of nonlinear loads in industry is keeping harmonic distortion in distribution networks on the rise. Before analyzing the harmonic effect, we define the characteristic and model of equipment as below:

1.1. Characteristics and Modelling of Equipment

One important step in harmonic analysis is to characterize and to model harmonic source and all components in system. As we know, the equipments in Power System Analysis & Control laboratory UniMAP are Compact Fluorescent Lamps (CFLs), Computers, Air Conditions and printers, where all of them can be similarly as industry medium scale. Each equipment can be modeled as follow:

1.2. Personal Computer

Personal computer has significantly contributed to harmonics problem by lowering voltage distribution system. The current THD for personal computer exceed 100%, as the result of high level individual distortions introduced by the third and fifth harmonics. The total current drawn by personal computer and its monitor is less than 2 A, but a typical high-rise building can contain several hundred computers and monitors. The net effect of this on the total current harmonic distortion of a facility is not difficult to visualize.

1.3. Compact Fluorescent Lamp

The fluorescent lamp was the first major advance to be a commercial success in small-scale lighting since the tungsten incandescent bulb. Fluorescent lamps are about 2 to 4 times as efficient as incandescent lamps at producing light at the wavelengths that are useful to useful to humans [3]. Due to heavy use of non-linearity gas discharge lamp, the fluorescent lamps that employ magnetic or electronics ballast which are considered as a significant contributor to harmonic

2. AIR CONDITIONING

Air conditioner manufacturers have responded by exploring a variety of technological innovations to increase the energy efficiency of their products. One example of innovation is the variable speed air conditioner, with increased efficiency gained by application of power electronics technology [7-8].The majority of air conditioners contain a compressor driven by a single-speed induction motor, and exhibit fixed efficiency and cooling capacity. Studies indicate that variable-speed air conditioners require 40% less energy than single-speed air conditioners, and are capable of servicing a given cooling load at substantially reduced energy costs [9-10].

2.1. Harmonic Indices

The most common harmonic index, which related to the voltage waveform, is the THD, as the root mean square (rms) of the harmonics expressed as a percentage of the fundamental component. It can for voltage and current as follow:

$$THD = \frac{\sqrt{\sum_{h=2}^{\infty} V_h^2}}{V_1} \quad (1)$$

And the power losses due to harmonic:

Active Power:

$$P = \frac{1}{T}\int_0^T p(t)dt = \sum_{h=1}^{\infty} V_h I_h \cos(\theta_h - \delta_h) = \sum_{h=1}^{\infty} p_h \quad (2)$$

Reactive Power:

$$Q = \frac{1}{T}\int_0^T q(t)dt = \sum_{h=1}^{\infty} V_h I_h \sin(\theta_h - \delta_h) = \sum_{h=1}^{\infty} Q_h \quad (3)$$

Apparent Power:

$$S^2 = P^2 + \sum_{h=1}^{n} V_h I_h \sin(\varphi_h) + D^2 \quad (4)$$

And for three phase systems, the per phase (*k*) vector apparent power S_v :[3]

$$S_v = \sqrt{\left(\sum_k P_k\right)^2 + \left(\sum_k Q_k\right)^2 + \left(\sum_k D_k\right)^2} \qquad (5)$$

2.3. Standardization of harmonic levels

The rms value of a voltage waveform, considering the distortion produced by harmonic current, IEEE-519 defines the limits as a function of the ratio between the short circuit current at the PCC (I_{sc}) and the average current corresponding to the maximum demand during a period of 12 months (I_L) [11].

3. RESEARCH METHOD

The research was measured with Fluke Power Quality Analyzer as Figure 1, and the connection circuit instrument and switching board as Figure 2. Power Quality Analyzer has been used to record the harmonic data. Data that has been collected are frequency, voltage, harmonic distortion, voltage harmonic and current harmonic. All those data have been transferred to computer by using Universal Serial Bus (USB) and View software.


Figure 1 Power Quality Analyzer


Figure 2 The clamp connection for each phase

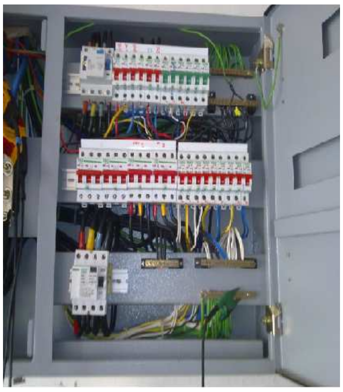
Figure 3. The connection for ground (earthing)


Figure.4: Overall View of Power System Analysis and Control Laboratory

This part will present the result of the harmonic from five days data analysis taken from distribution board at laboratory. Data from five days of measuring are used to see the differential harmonic distortion due to non linear load equipment during laboratory operation. The loads for red phase are 1 unit of 2HP and 1 unit of 1HP air conditioning, 14 unit of 36 W fluorescent and 12 unit of computer. For yellow phase, 1 unit 2HP air conditioning, 13 unit of 36 W fluorescent lamp and 11 unit computer and for blue phase, 1 unit of 2HP air conditioning, 13 units of 36W fluorescent lamp and 12 unit of computers.

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4. RESULTS AND ANALYSIS

From measurement the data are as Table 1 till Table 8 and from Figure 5 and Figure 6. From the data and results, we find that the system has unbalanced nonlinear loads, where in fundamental condition line 1, line 2 and line 3 have 2.597 A, 5.458 A, and 5.914 A. And voltage at line 1, line 2, and line 3 are: 243.8V, 241.0V and 242.8V.

Table 1 Result for harmonic voltage line 1

Harmonic	Harmonic Voltage Line 1 (%)				
Order	1st day	2nd day	3rd day	4th day	5th day
3	0.259346	0.257815	0.386216	0.216686	0.176945
5	0.045294	0.044561	0.030818	0.029604	0.057175
7	0.027785	0.032775	0.021277	0.040036	0.129256
9	0.278764	0.280708	0.321241	0.253513	0.281794
11	0.062895	0.071102	0.013395	0.042864	0.143449
13	0.041695	0.040434	0.053287	0.063976	0.083596
15	0.143487	0.156794	0.139269	0.161859	0.119213

Table 2 Result for harmonic voltage line 2

Harmonic	Harmonic Voltage Line 2 (%)				
Order	1st day	2nd day	3rd day	4th day	5th day
3	0.350214	0.456995	0.910929	0.758731	0.316813
5	1.511814	1.668123	1.378935	1.504058	0.89779
7	1.403406	1.442292	1.267601	1.011369	0.955736
9	0.858103	0.853962	0.874624	0.673652	0.868251
11	1.04697	1.081997	0.909549	1.28417	2.401119
13	0.403564	0.429136	1.020803	0.623997	0.788961
15	0.372576	0.341534	0.403372	0.37066	0.333055

Table 3 Result for harmonic voltage line 3

Harmonic	Harmonic Voltage Line 3 (%)				
Order	1st day	2nd day	3rd day	4th day	5th day
3	0.612227	0.762614	1.327683	0.972964	0.602304
5	1.713508	1.838346	1.7763	1.534656	1.102821
7	1.421677	1.366219	1.25313	0.826752	1.204415
9	0.578123	0.530224	0.930943	0.830503	0.794858
11	0.848553	0.867062	0.688877	1.096931	2.55875
13	0.352649	0.362005	1.046268	0.626451	0.956049
15	0.442362	0.495194	0.447613	0.445369	0.223913

Table 4 Result for harmonic current line 1

Harmonic	Harmonic Current Line 1 (A)				
Order	1st day	2nd day	3rd day	4th day	5th day
3	0.611449	0.08405	0.095853	0.256878	0.117919
5	0.379416	0.104406	0.13057	0.193865	0.05384
7	0.100685	0.082026	0.095551	0.082238	0.054016
9	0.118543	0.02285	0.032936	0.045489	0.040652
11	0.118066	0.049151	0.050263	0.04871	0.056064
13	0.073995	0.031617	0.041883	0.025141	0.003083
15	0.029868	0.031443	0.027595	0.004826	0.006791

Table 5 Result for harmonic current line 2

Harmonic	Harmonic Current Line 2 (A)				
Order	1st day	2nd day	3rd day	4th day	5th day
3	3.479175	0.566103	0.25113	0.487873	0.414514
5	1.484662	0.295319	0.248295	0.210913	0.226809
7	0.074464	0.096627	0.183544	0.051003	0.193312
9	0.361177	0.191637	0.165767	0.149956	0.181092
11	0.455713	0.090183	0.129957	0.076265	0.172899
13	0.312872	0.076078	0.059378	0.045884	0.038584
15	0.098607	0.024859	0.02882	0.016513	0.004888

Table 6 Result for harmonic current line 3

Harmonic	Harmonic Current Line 3 (A)				
Order	1st day	2nd day	3rd day	4th day	5th day
3	2.487111	0.914975	1.024711	0.615736	0.416347
5	0.965387	0.396128	0.53632	0.372143	0.195058
7	0.196158	0.091483	0.1394	0.141315	0.075208
9	0.364565	0.16722	0.180557	0.132282	0.103074
11	0.205229	0.098968	0.114997	0.111799	0.112813
13	0.090999	0.040559	0.036394	0.064113	0.0368
15	0.077157	0.048074	0.083918	0.057694	0.006218

Table 7 Result for THD current

Line	THD current (%)				
	1st day	2nd day	3rd day	4th day	5th day
1	29.764	11.881	10.92	20.441	12.737
2	13.876	3.572	1.9066	2.871	11.909
3	0.077	20.984	19.201	16.151	43.286

Table 8 Result for harmonic power losses

Line	Harmonic power losses (kW)				
	1st day	2nd day	3rd day	4th day	5th day
1	0.0296167	0.005168	0.051276	0.024802	0.020088
2	0.0389521	0.320457	0.398447	1.518471	0.359977
3	0.6939993	0.14234	0.089534	0.976992	0.406569
Total	0.7625681	0.467965	0.539244	2.520265	0.786634

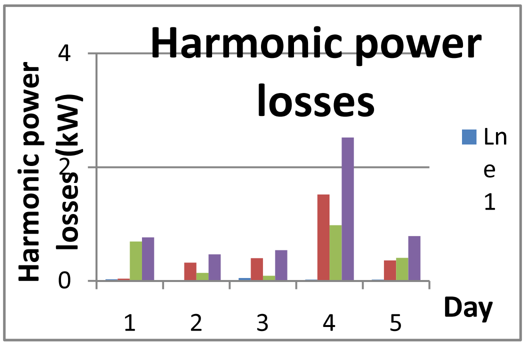

Figure 5 Total power loss during measurement

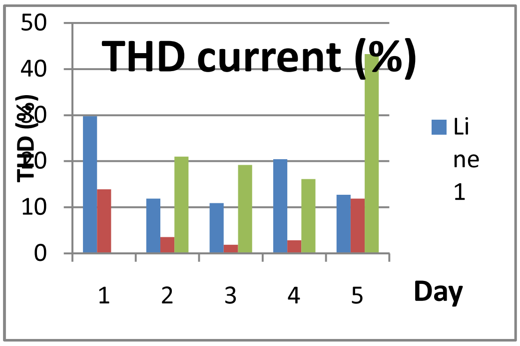

Figure 6 THD currentof five days measurement

Powers for each line in fundamental condition are: 630.3W, 1,314.2W, and 1,415.2W, while for RMS result are: 629.5W, 1,310W, and 1,433.9W. This due to the each harmonic powers maybe plus or minus sign. So, the power at fundamental is bigger than RMS result. The total power losses due to harmonic for channel line 1, line 2 and line 3 are: -0.368W, -3.209W and -1.46W. For Apparent power (VA) at channel line 1, line 2 and line 3 in fundamental condition are: 633.2VA, 1.,15.2VA and 1,436.1VA, while in RMS are: 790.6VA, 1,639.3VA, and 1,679.1VA. This is due to harmonic orders. For reactive power (VAR) at line 1, line 2 and line 3 in fundamental condition are: 60.5VAR, 52.15VAR and 45.18VAR, while in RMS are: 478.2VAR, 984.6VAR and 873.8VAR. This is due to harmonic too.

The voltage THD for line 1, line 2 and line 3 are: 1.92%, 1.81% and 1.96%. And from calculation are: 2.12%, 2.12% and 2.2%. The current THD for line 1, line 2 and line 3 are: 71.38%, 72.72% and 59.46%, while from calculation are: 72.5%, 74.8% and 60.2%.

In fundamental condition, the cosφ at line 1, line 2 and line 3 are: -0.995, -0.999 and 0.999, while in RMS, p.f. at line 1, line 2 and line 3 are: 0.796, 0.799 and 0.854. This is due to cos φ is ratio between load power and apparent power of fundamental component, while p.f. is ratio between load power and total apparent power (including harmonics).

Figure 5 above shows total of power loss during measurement in five days working time. From graph shows that day four produced more power loss which that day the harmonic is very high because the usage of non-linear loads during laboratory operation.

Total power loss after five days measuring harmonic:

$$P_{h\ total} = P_{h\ day2} + P_{h\ day3} + P_{h\ day4} + P_{h\ day5}$$

$$= 0.7625681 + 0.467965 + 0.539244 + 2.520265 + 0.786634 = 5.076689\ \ kW$$

Calculation for total cost of power loss per week working day:

$$\frac{Cost\ losse\ s}{month} = kWhxhxdayx\ {}^{RM}\!/_{kWh}$$

$$= 5.076689\ kWx8hx22\ dayxRM\ 0.37 / kWh\ = RM\ 330.59 / month$$

where 1month =22 work days

From graph figure 6 above shows the total harmonic distortion during measurement. Its show that line 3 produced more harmonic distortion from day by day which is the loads of line 3 is fluorescent lamp. During laboratory operation or not the fluorescent lamp need to be open during working hours.

5. CONCLUSION

Loads are unbalanced and nonlinear. THD for voltage in each channel are smaller than standardization level IEEE519, where 2.12%, 2.12% and 2.2%. are smaller than 5% in system <6.9KV. THD for current in each channel are smaller than standardization level IEEE519, where 71.38%, 72.72% and 59.46% are smaller than 115%. So, the system do not required filter.

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