Harmonics Assessment at Mutah University Campus Buildings

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***Abstract*—Driven by continuous increase and high penetrations of non-linear loads, power electronics based loads and sources at LV and MV electrical networks, power quality become an important issue not only for customers but also for the utilities. Mutah University is a rich campus of these loads such as: personal computers, printers, fluorescent lamps and other sources might causes harmonics problem, therefore, it is imperative to examine and quantify power quality profiles and harmonics pollution in the campus. The paper investigates the harmonics profiles within Mutah university campus through extensive field measurements and comprehensive analyses.**

***Index Terms*—. Power Quality, Harmonics, Nonlinear Loads Fourier Analysis, measurement**

I. Introduction

In recent years, there has been an increased concern and emphasis on the quality of power delivered to factories, commercial establishments, and residences. This is due continuous increase and high penetrations of non-linear loads and power electronics based loads such as: Adjustable-speed drives, switching power supplies, arc furnaces, electronic fluorescent lamp ballasts and other harmonic-generating equipment. Further, utility switching and fault clearing produce disturbances that affect the quality of delivered power [1] [2]. One of most common power quality disturbances is the wave distortion (known as Harmonics). Harmonics are sinusoidal waveforms with a frequency equal to an integer multiple of the fundamental frequency, assumed frequently to be the same as the power system frequency (50 or 60 Hz).

Harmonic disturbances come generally from equipment with a non-linear voltage/current characteristic. Examples of sources of waveform distortion are the saturation of a transformer core, staticpower converters and other non linear and time-varying loads (such as arc furnaces).

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Nowadays a large part of industrial, commercial and domestic loads is non-linear, making the distortion level on the low-voltage (but not only) supply network a serious concern [9].

High harmonic distortion can negatively impact a facility's electric distribution system, and can generate excessive heat in motors, causing early failures. Heat also builds up in wire insulation causing breakdown and failure. Increased operating temperatures can affect other equipment as well, resulting in malfunctions and early failure. In addition, harmonics on the power line can prompt computers to restart and adversely affect other sensitive analog circuits

The international research in power system quality area has been since 1980's. Since then, researchers have investigated the increased use of nonlinear devices on the electrical networks and power quality profile. The research in power quality topics varies from harmonics identification and impact on electrical networks [21][22], harmonic estimation and assessment [23]-[32], harmonics mitigation methods and techniques [33]-[40] and power quality standards[24]-[43].Several international journals and conferences papers have dealt with the impact of power quality related problems on Distribution electrical network system [44][45], power quality assessment within the residential and commercial area with various tasks, such as; the impact of residential appliances on the power quality profiles was analyzed in [46], the impact of adjustable speed driven air conditioning units was studied in [47], and reference [48] discussed the impact of large motor starting and Loading on the power quality and harmonics distortion.

This paper aims to deeply identify and quantify the harmonics problems may arise within Mutah University Campus. The study was conducted at one campus building, engineering building.

II. Harmonic Analysis and Decomposition of Distorted Waveform

Each distorted signal/waveform can be composed from harmonic components, so also can any periodic waveform be decomposed into harmonic components

Any periodic waveform can be deconstructed into a sinusoid at the fundamental frequency with
a number of sinusoids at harmonic frequencies. Depending on the kind of waveform, these coefficients may or may not exist. A d.c. component may complete these purely sinusoidal terms. This concept can be explained by the following equation [7]-[9]:

$$f\ (t) = \frac{a_o}{2} + \sum_{n=1,2,3...}^{\infty} (a_n \cos n\omega t + b_n \sin n\omega t) \qquad (1)$$

Where

f(t) is a generic periodic waveform;
a_o :is the d.c. component
an, bn : are the coefficient of the series
n is an integer number between 1 and infinity; and T = 2π is the period.

The coefficients of the series can be calculated as follows:

$$a_o = \frac{1}{(T)} \int_0^T \sqrt{2} V_p \sin \omega t \, d(\omega t)$$

$$a_n = \frac{1}{(T/2)} \int_0^T v_s \cos n\omega t \, d(\omega t) = \frac{1}{(\pi)} \int_0^{2\pi} V_p \sin \omega t \cos n\omega t \, d(\omega t)$$

$$b_n = \frac{1}{(T/2)} \int_0^T v_s \sin n\omega t \, d(\omega t) = \frac{1}{(\pi)} \int_0^{2\pi} V_p \sin \omega t \sin n\omega t \, d(\omega t)$$

Harmonic pollution on a power line can be quantified by a measure known as total harmonic distortion or THD [1]. Total harmonic distortion factor is the ratio of the r.m.s. values of harmonic components to the r.m.s. value of fundamental component.

The total harmonic current distortion factor (THD_I) can be calculated by:

$$THD\%\big|_I = 100\% \times \sqrt{\sum_{h \neq 1} \left(\frac{I_h}{I_1} \right)^2} \qquad (2)$$

Where :

I1: fundamental rms current component
Ih: harmonics rms current component

The total harmonic voltage distortion factor (THD_V) can be calculated by :

$$THD\%\big|_V = 100\% \times \sqrt{\sum_{h \neq 1} \left(\frac{V_h}{V_1} \right)^2} \qquad (3)$$

Where:

V1: fundamental rms voltage component
Vh: harmonics rms voltage component

III. System Description

Figure 1 below shows the single line diagram (SLD) of electrical system and the main distribution board (MDB) at Building Engineering. The electrical network consists of 2.0 MVA step-down transformer 11/0.4 kV feed the building via cables connected to MDB. Then MDB distributes to the floors. The building consisted of three floors.The building consist of three floors: Floor distribution and load types at engineering building are: Lighting –CFL Lamps; Data show –Projector; Labtops, Personal computers/Printers/Scanners

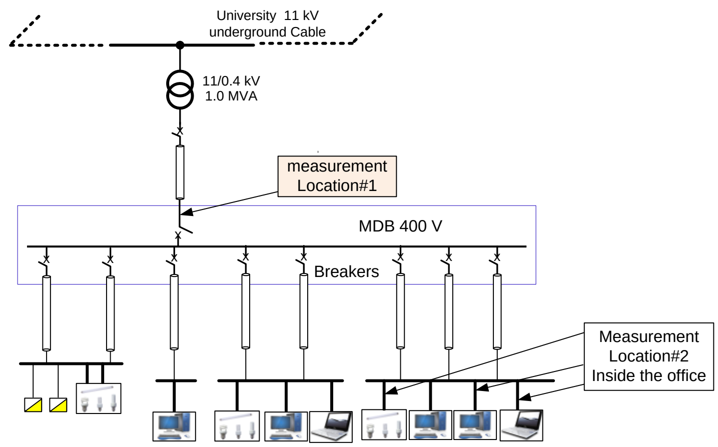

Figure 1 Schematic diagram and SLD of main distribution board at engineering building.

IV. Harmonics Measurement

Two type of power quality recorders have been used namely: Fluke 345 II and Fluke 43B in this work: Three devices of Fluke 345 II, for three phase measurement, and Two devices of Fluke 43B for single phase measurement.

1. Three Phase Measurement

The voltage, current, power factor, THD and harmonics contents were monitored, as the typical required measurements qualities for power quality investigation, at this site. Measurement duration was 10day 1h 40m; Start: 28/11/2016 11:40 End at: 08/12/2016 01:20. The measurement are conducted by Three Phase Power Quality Fluke 435-II_at distribution board (MDB) at the building, while Single Phase Power Quality Fluke 43B used to the single phase loads.

Figures 2 and 3 show snapshots for currents and voltages waveforms. As it is observed from these figures there is a high percent of distortion in the current signals.

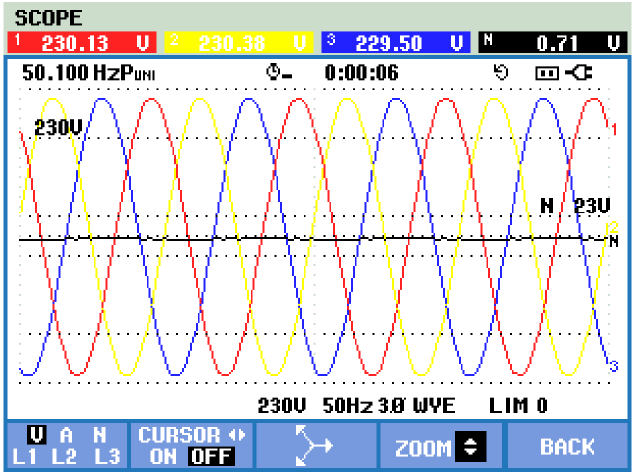

Figure 2: Three phase Voltage wave.

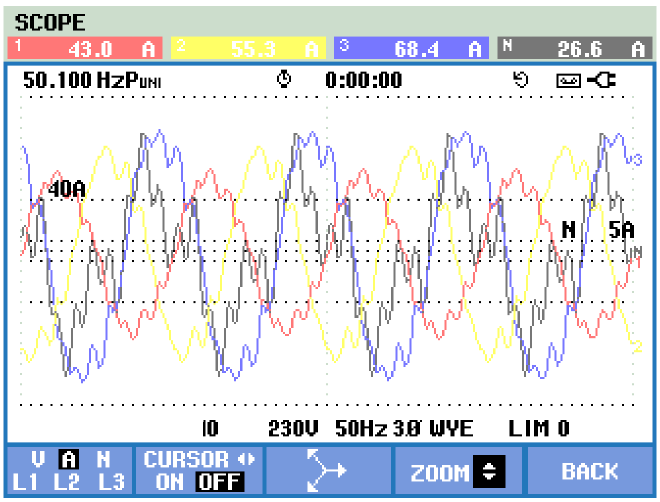

Figure 3: Three phase current wave.

The pattern of current (THD) during the test period is depicted in Figures 4-7 below. As seen from these plots that the current THD pattern shows different profile for each phase. The range of measured THD for phase (A) is between 7.5% and 20 %, while for Phase(B) it changes between 10% and 57.0%, while for phase(C) the range from 11% to 41%. This divergence is due to single load operation and unbalance load switching. For deep look to the individual harmonics, the highest harmonics orders appear in phase (A) are 3rd and 11th, while 3rd and 5th are the highest for phase(B) and phase (C).

As displayed in Figure 7, the THD in Neutral current is high, reaches as high as 320% with 3rd and 9th harmonic order are the dominant orders (which are known as triplen harmonics). This appearance of these harmonics orders is attributed to high unbalance phase current which flow in the neutral (and appear as zero sequence current).

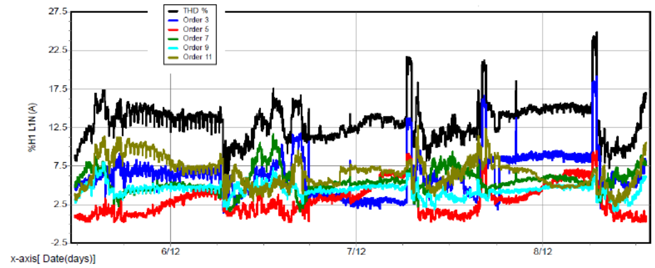

Figure 4 Harmonics contents and THD profile for Phase (A) current.

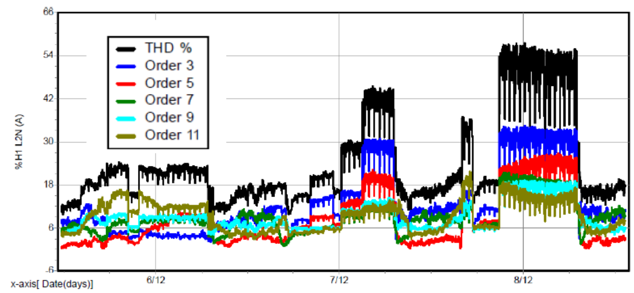

Figure 5 Harmonics contents and THD profile for Phase (B) current.

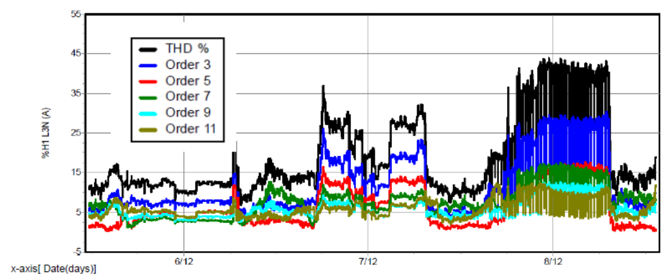

Figure 6 Harmonics contents and THD profile for Phase (C) current.

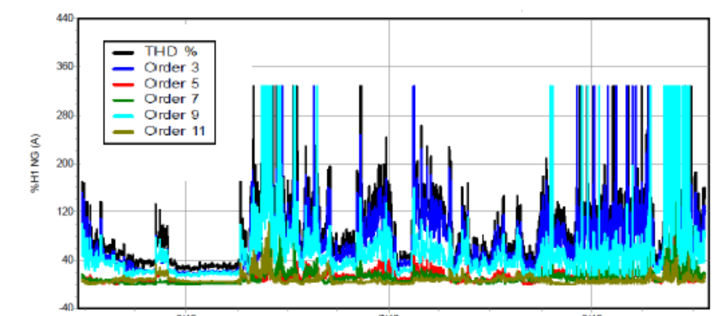

Figure 7 Harmonics contents and THD profile for Neutral current.

Figure 8 shows the minimum, maximum and average THD and harmonics for THD and Harmonics spectrum during the test period. It is clear that the 11th order is the dominant in the phase and the triplen order is the neutral.

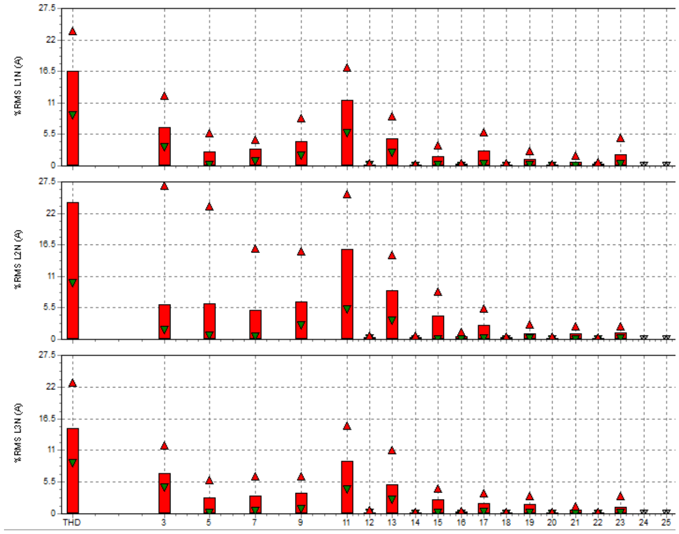

Figure 8 THD and Harmonic phase Current Spectrums %r

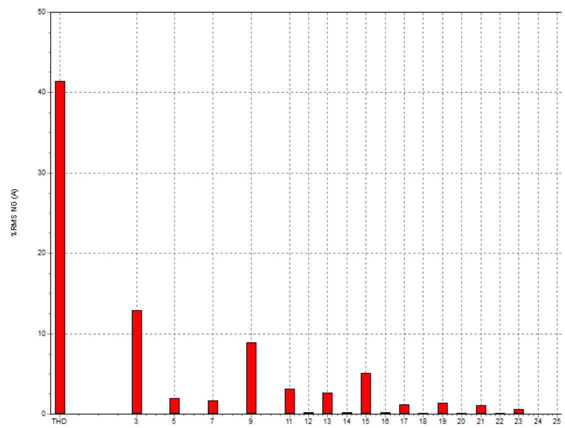

Figure 9 THD and Harmonic Neutral Current Spectrums

2. *Single Phase Measurement*

Since the majority of the loads at the engineering building are single phase loads, single phase measurements for three common load types has been conducted, namely: Personal Computer (PC- Desktop), laptops and lighting systems (Future monitoring and analysis will be conducted for other loads such as printer, scanners, heaters …etc). Single phase recorded Fluke 34B has been used for recording the current and voltage waveform and obtain harmonics spectrum of the loads.

Power Quality Measurement of Desktop (Personal Computer) (PC)

A four cycles window of the current and voltage waveforms and the harmonics spectrum, are shown in Figures 10 and 11, respectively. The plot shows that the current waveform is highly distorted this type of pattern due to switch mode power supply. The recorded current THD as high as 72.2% .The dominant harmonics currents levels relative to the fundamental are tabulated in Table 3.

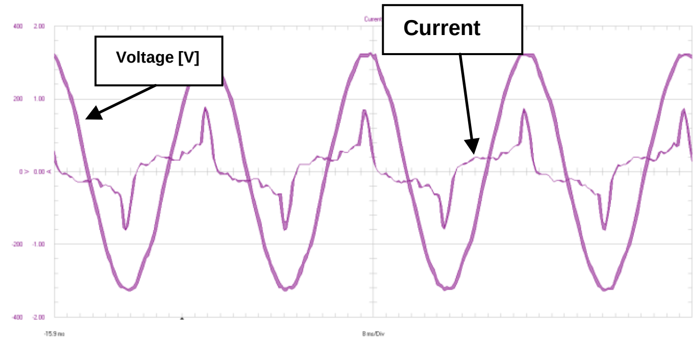

Figure 10 Current and voltage waveform of Personal Computer

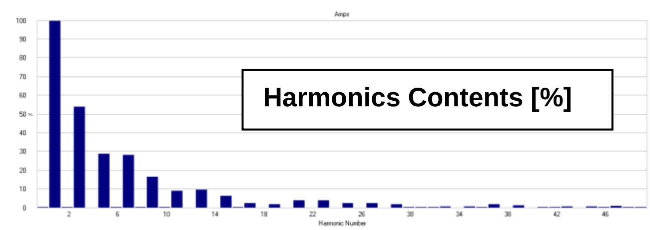

Figure 11 Harmonics current spectrum of Personal Computer

Harmonics Measurement of Fluorescent Lamps

Measurements were conducted for one set of Fluorescent Lamps consist of four tubes. Figure 12 below shows the two samples of current and voltage waveforms. Figure 13 shows the corresponding harmonics spectrum for the lower (current) waveforms.

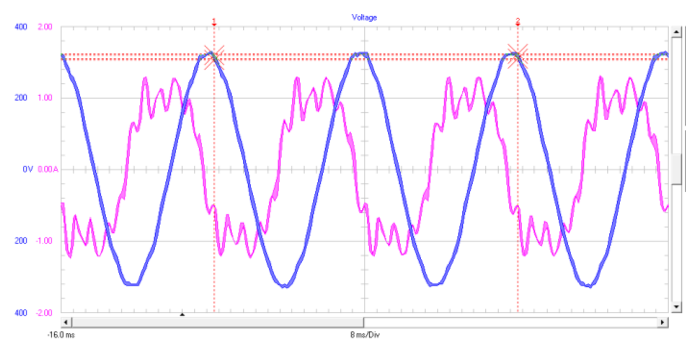

Figure 12 Two samples of current and voltage waveforms for Fluorescent Lamps.

Table 3 below summarizes the dominant harmonics currents levels relative to the fundamental of Fluorescent Lamps. Where the recorded THD for current and voltage are 25% and 2.5%, respectively

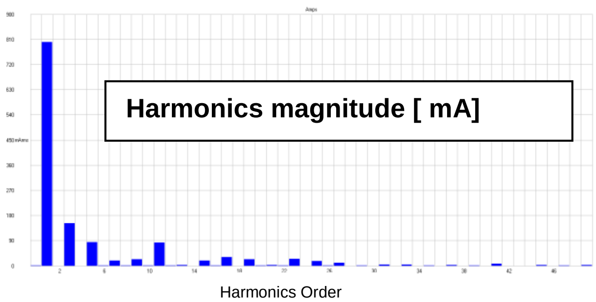

Figure 13 Harmonics current spectrum of Fluorescent Lamps.

Harmonics Measurement of Laptop

A measurement has been conducted for a laptop (Toshiba Model). Figure 14 below shows the current and voltage waveforms for four cycles. Figure 15 shows the corresponding harmonics spectrum for the current waveforms. As it is clear the current waveform of laptop is very rich of odd harmonics, where the recorded THD for current reaches as high as 137.8%. .

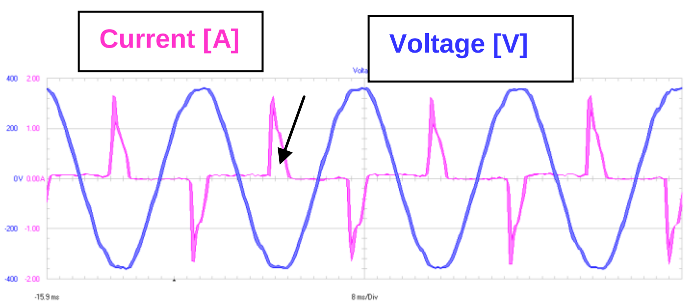

Figure 14 Current and voltage waveforms for Laptop

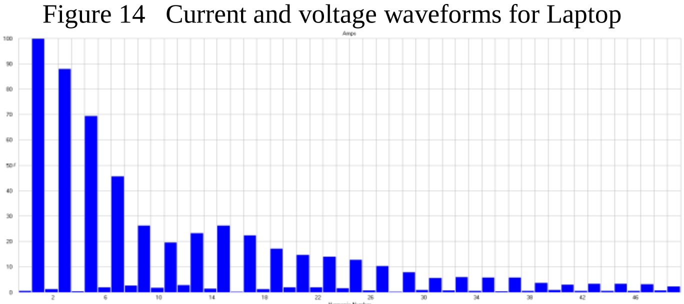

Figure 15 Harmonic Current Spectrums for Laptop

Table 5 summaries and compares the value of THD for three studied loads. Laptop is the highest, then Desktop and Fluorescent Lamps. Further comparison, Table 6 summarizes the breakdown of harmonics contents for the studied loads.

Table 5 THD comparison for the three Loads

	Desktop (PC)	**Fluorescent Lamps.**	**Laptop**
Current THD	72.2%	25%	137.8%

Table 6 Harmonics order comparison for the three Loads

Harmonies order	**Desktop (PC)**	**Fluorescent Lamps.**	**Laptop**
3rd	**55.0%**	**19.1%**	**88.0%**
5th	**28.6%**	**10.6%**	**69.4%**
7th	**28.1%**	**3.3%**	**47%**
9th	**17.6%**	**4.0%**	**27.3%**
11th	**9.0%**	**10.3**	**19.5%**
13th	**9.7%**	**3.3%**	**24.3%**
15th	**7.3%**	**4.9%**	**27.3%**
17th	**3.5%**	**3.9%**	**23.4%**

Table 7 shows the average harmonics percentage at the main connection points

Table 7 Harmonics order comparison for the three Loads

Harmonies order	**Phase A**	**Phase B**	**Phase C**	**Neutral**
3rd	**6.75%**	**6.25%**	**7.14%**	**31.6%**
5th	**2.42%**	**6.56%**	**2.829%**	**4.19%**
7th	**3.05%**	**5.27%**	**3.13%**	**3.52%**
9th	**4.24%**	**6.69%**	**9.17%**	**19.51%**
11th	**11.54%**	**16.23%**	**5.01%**	**6.52%**
13th	**4.82%**	**8.77%**	**5.01%**	**5.46%**
15th	**1.6%**	**4.21%**	**2.50%**	**8.49%**
17th	**2.7%**	**2.57%**	**1.83%**	**2.09%**

V. Discussion and Analysis

With deep look to the results in Table 6 and 7, it is understood that the contribution of harmonics contents, hence the THD, from each individual loads are varying and the net THD and harmonics contents at the main distribution Panel (MDP) are different. Generally speaking the harmonics contents at MPD is less than that in individual loads, 3^{rd} harmonics for the three loads are : 55%, 19.1%, 88.0% while the net 3^{rd} harmonics at MPD reach to 31.6% is can be attributed to harmonics cancelation may occur between the loads . Same trend appear in 5^{th} harmonics; for individual loads are 28.6%, 10.6%, 69.4% while at the MDP the maximum recorded 5^{th} is 6.56%, this results also due to harmonics cancelation.

Neutral current shows high THD value, it reaches as high as 320% with the 3^{rd} and 9^{th} harmonic order (which is known as triplen harmonics) are the dominant orders. Appearance of this harmonics orders is attributed to high unbalance current which flow in the neutral and appear as zero sequence current

VII. Acknowledgment

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VIII. CONCLUSIONS

In this work, harmonics assessments study at engineering building at Mutah University are carried out. Three phases as well as single phase measurement are conducted. The results show there is unbalance load at the building which is due to the dynamics switching of the loads. The recorded THD is out of intentional strands the contribution of this building, and other buildings in the campus on the main substation will be investigated in the near future.

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