Harmonic Analysis in the Arab American University Power System: Reasons, Nature, and Recommendations

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***Abstract*— This study investigates harmonic distortions in the Arab American University (AAUP) grid, which receives electricity from Tubas District Electricity Company (TDECO) through 11 transformers. The project collected data using power quality analyzers on four transformers, focusing on two key indicators: total harmonic distortion and total demand distortion. Results indicate that total demand distortion is a more reliable indicator and, so far, all transformers remain within IEEE limits. Future work aims to expand the analysis seasonally and encourages others to assess remaining transformers.**

***Keywords*— Harmonics, AAUP, Total harmonic distortion.**

I. INTRODUCTION

The power supply in Palestine faces significant challenges due to its reliance on Israeli-generated power, which is often insufficient and inconsistent. This dependency poses a threat to vital services such as healthcare, sanitation, the economy, manufacturing, and agriculture. To address the persistent power shortages, the Palestinian government and private companies have embraced renewable energy sources, with solar energy being a popular choice due to its independence from external control. Photovoltaic panels are used to harness solar radiation, producing DC power. However, the DC power isn't suitable for most daily applications, leading to the use of inverters for conversion to AC power. Unfortunately, inverters, employing semiconductor devices and Pulse Width Modulation (PWM) switching, inherently generate harmonics and noise during the conversion process. These harmonic distortions have the potential to be reintroduced into the power supply system at the Point of Common Coupling (PCC), which can lead to disruptions in both current and voltage waveforms, where this harmonic distortion raises concerns about its impact on electric machines, transformers, electronic equipment, and metering and relaying devices, as well as the risk of harmonic resonance, especially considering the presence of capacitor banks in power networks [1]–[6].

The ideal electric signal for end-users should consistently exhibit a pure sinusoidal waveform. However, achieving the perfect sinusoidal waveform can be challenging for various reasons, resulting in observable distortions, where this phenomenon, known as harmonic distortion, is not a recent development and has been a longstanding concern among electrical engineers. Its prevalence has increased over the decades, particularly following the industrial revolution, which introduced electronic devices like transistors, diodes, and various switching devices that inherently generate harmonics during their regular operation [7], [8].

Harmonic distortion primarily arises from non-linear loads, with power electronic equipment being a common source, frequently employed in power systems. The focus of the presented project centers on the analysis of the AAUP grid, which plays a crucial role in meeting the educational requirements of more than 11,300 students across 14 different faculties. The AAUP grid receives its power supply from (TDECO) through 11 transformers, with ratings of either 630 kVA or 1000 kVA, facilitating the conversion of voltage from a medium voltage level (33 kV) to a low voltage level (0.4 kV). Complementing these transformers, photovoltaic systems are integrated to cater to the energy demands of the university's various faculties. Currently, these photovoltaic systems are installed on the rooftops of three faculties: the Faculty of Engineering and Information Technology, the Faculty of Allied Medical Sciences, and the Faculty of Law. Furthermore, there are plans to expand the proposed system by installing additional PV systems on the rooftops of other faculties in the near future [9]–[18].

AAUP is dedicated to providing its students with high-quality education, employing advanced teaching techniques to prepare them for success in the competitive job market. To support these techniques, the university offers a range of well-equipped laboratories featuring essential apparatus, including computers, power electronic devices, and other non-linear equipment, which can introduce current harmonics into the power system. Consequently, deviations in current and voltage waveforms occur, leading to the injection of these current harmonics back into the supply system at the PCC, which in turn, exerts a significant influence on the functioning of diverse power system components, including capacitors, transformers, motors, and metering equipment. Such influence manifests in the form of elevated losses, overheating, overloading, and interference with telecommunication lines. It is of utmost importance to emphasize that if the degree of harmonic distortion emanating from the AAUP grid exceeds predetermined thresholds, it presents a substantial risk to sensitive loads. In such scenarios, it becomes imperative to implement strategies aimed at preserving the integrity of the power system equipment by ensuring that current and voltage waveform distortions remain within acceptable limits [17].

The objectives of the proposed work are summarized as follows:

- Identify Harmonic Distortion Sources and Assess Their Impact on Power System Components.
- Examine the Theoretical Foundations of Harmonic Distortion Analysis, Including Fourier Transform Techniques.
- Conduct Harmonic Distortion Measurements in Selected Arab American University Buildings Using Suitable Power Analyzer Devices Over Defined Time Intervals.
- Analyze the Captured Harmonic Data Utilizing Appropriate Analysis Methods, Leveraging Excel Sheets and MATLAB Software.
- Assess the Extent of Harmonic Distortion Generated by AAUP Loads and Measure It Against Internationally Recognized Standards.
- Determine Whether Remedial Actions Are Necessary for AAUP to Address the Harmonic Distortion Issue.

II. METHODOLOGY

The investigation of harmonic distortion within a power system involves two main approaches: harmonic measurement and computer simulation. These methods help establish a comprehensive understanding of the system's harmonic levels. To collect harmonic measurement data, power quality analyzers are employed. In the proposed study, two types of power quality analyzers were utilized, which are: the EXTECH model PQ3350 and the FLUKE model 438-II.

The process for using the measuring device in the investigated study involved several steps, and it was applied to various buildings over successive time intervals:

1. Start by turning on the device, which can be done by pressing the power button. Select the appropriate mode, in this case, 3P4W, by pressing the "1ϕ3ϕ" button.
2. Connect the four test leads to the voltage terminals, specifically V1, V2, V3, and the neutral (VN) of the system.
3. For the current measurements, attach the test leads to L1, L2, and L3, corresponding to the 3P4W system.
4. Additionally, connect the three current probes to the power analyzer input terminals, denoted as I1, I2, and I3.
5. To measure current, clamp the probes onto the respective L1, L2, and L3 conductors, ensuring that the current flows from the front of the current probe to the back.
6. Select the harmonic mode on the device, enabling it to capture harmonic data.
7. At the end of the designated measuring interval, establish a connection between the power quality analyzer device and a computer using a USB cable. Proceed to download the recorded data, which is typically stored in the form of an Excel sheet for further analysis and interpretation.

The presented study is guided by the IEEE 519-1992 standard, which provides limits for allowable harmonic distortion impacting the current and voltage waveforms in power systems. Adhering to this recommended standard requires conducting measurements at the PCC between power suppliers and end-users. The PCC is strategically located within the power system to be in proximity to the user's side, allowing the supplier to serve multiple users efficiently. For industrial users, such as manufacturing plants, served through dedicated transformers, the PCC is positioned at the high-voltage side of the transformer. Conversely, in the case of commercial users, such as office parks and shopping malls, who receive their power supply through shared service transformers, the PCC is typically located on the low-voltage side of the transformer.

Given that non-linear loads used by end-users are responsible for distorting the current wave consumed from the source, which is in turn, distorts the voltage waveform generated by the power source and subsequently supplied to other users, there is a need for coordination between suppliers and users to mitigate these distortions and their adverse effects on the electrical network, as elaborated in chapter 2. Therefore, established standards and limits for distortion in both user-consumed current and source-generated voltage are crucial considerations when analyzing collected data. These limits serve as guidance in the design of power systems accommodating non-linear loads.

In accordance with IEEE 519-1992, at the PPC, it is imperative for system owners or operators to control and limit line-to-neutral voltage harmonics within specific bounds, as delineated in Table 1 of the standard. These limits are applicable to voltage harmonics characterized by frequencies that are integer multiples of the power frequency (usually 50 or 60 Hz) and should be quantified as percentages relative to the rated power frequency voltage measured at the PCC. Adhering to these limits helps ensure that power quality is maintained and that harmonic distortions remain within acceptable levels in the electrical distribution network.

For systems rated from 120 V through 69 kV, the IEEE 519-1992 standard prescribes recommended current distortion limits. These limits are applicable to users connected to systems where the rated voltage at the PCC falls within the range of 120 V to 69 kV.

Users at the PCC should restrict their harmonic currents in accordance with the values specified in Table II. It's important to note that these values are expressed as percentages of the maximum demand current (IL).

TABLE I. VOLTAGE DISTORTION LIMITS BASSED ON IEEE STANDARD.

Bus voltage V at PCC	Individual harmonic (%)	Total harmonic distortion THD (%)
$V \leq 1.0$ kV	5.0	8.0
1 kV < $V \leq 69$ kV	3.0	5.0
69 kV < $V \leq 161$ kV	1.5	2.5
161 kV < V	1.0	1.5

The current value mentioned in the standard is established at the PCC and should represent the summation of currents corresponding to the maximum demand observed during each of the twelve preceding months, divided by 12. It is important to emphasize that Table II, which specifies current distortion limits, pertains specifically to harmonic currents with frequencies that are integer multiples of the power frequency.

The Arab American University power system is supplied by TDECO at a medium voltage level of 33 kV. The university has fourteen faculties, five gates, a stadium, markets, and stores, all of which receive their power supply from eleven active transformers with ratings of either 630 kVA or 1000 kVA. These transformers convert the voltage from the medium voltage level (33 kV) to the low voltage level (0.4 kV) suitable for consumption. Photovoltaic systems have been installed to meet the energy needs of the faculties. Currently, only three faculties (Engineering and Information Technology, Allied Medical Science, and Law) have PV panels mounted on their rooftops, but plans are underway to install more PV cells on the roofs of other faculties in the near future.

TABLE II. LIMITS ON CURRENT DISTORTION FOR SYSTEMS WITH RATINGS FROM 120 V TO 69 KV.

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order (odd harmonics)						
I_{SC}/I_L	$3 \leq h < 11$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h \leq 50$	TDD
$< 20^c$	4.0	2.0	1.5	0.6	0.3	5.0
20 - 50	7.0	3.5	2.5	1.0	0.5	8.0
50 - 100	10.0	4.5	4.0	1.5	0.7	12.0
100 - 1000	12.0	5.5	5.0	2.0	1.0	15.0
> 1000	15.0	7.0	6.0	2.5	1.4	20.0

The measurements were conducted using an EXTECH power quality analyzer, which was installed on the main feeders situated within an electrical room in the B2 basement. The data collection period spanned from January 19, 2023, to January 25, 2023. A summary of the measurements obtained from the power quality analyzer is presented in the Table III.

The load currents are determined based on the electric bill for the Allied Medical Science transformer, and a summary of this calculation is provided in Table IV.

TABLE III. SUMMARIZED HARMONIC MEASUREMENTS OF ALLIED MEDICAL SCIENCE B.

Criteria	THD	TDD
Minimum	10.3%	0%
Maximum	617.70%	37.87%
Average	51.24%	11.81%

TABLE IV. ELECTRICAL ENERGY CONSUMPTION BILL FOR ALLIED MEDICAL SCIENCE FACULTY.

Date	Energy consumed (kwh)
1/2022	35925
2/2022	30094
3/2022	28585
4/2022	18374
5/2022	25741
6/2022	36267
7/2022	28016
8/2022	40542
9/2022	34512
10/2022	30415
11/2022	26140
12/2022	27504

The following table lists the monthly power factor measured for all Transformers:

TABLE V. POWER FACTOR FOR UNIVERSITY TRANSFORMERS.

Transformer	Power Factor
Allied medical science	0.94
Sport hall	0.97
Electric poles	0.96
LAW	0.94

The table below displays individual harmonic currents along with their associated limits, as referenced in Table III. Each of the individual harmonic current values is calculated as the average of measurements taken during the specified data collection period using the quality analyzer. Values highlighted in red within the table denote cases where the TDD values have surpassed their specified limits:

TABLE VI. INDIVIDUAL HARMONIC CURRENTS OF ALLIED MEDICAL SCIENCE COMPARED TO IEEE LIMITS.

Harmonic order	Actual value (A)	Limit value (A)
3	10.13	12
5	36.22	12
6	26.51	12
9	3.15	12
11	5.02	5.5
13	8.82	5.5
15	2.93	5.5
17	4.9	5
19	4.2	5

III. RESULTS

Following data analysis, it has been determined that the Total Demand Distortion (TDD) for the Allied Medical Sciences faculty is 11.8, where this value falls below the IEEE-established limit of 15. A closer inspection of the individual harmonics, however, reveals that the 5th, 7th, and 13th harmonic orders have surpassed the limits set by the IEEE.

Furthermore, a graphical representation of the current waveform for the Allied Medical Sciences faculty has been generated using the Fourier series principle with MATLAB software, where this waveform is depicted in the figure below:

It is clear from the above figure that the current wave of Allied Medical Science faculty does not have a pure sinusoidal waveform and the waveform appear to be distorted.

THD and TDD values were compared between holidays and working days using data samples collected during the same time intervals to determine the distinctions.

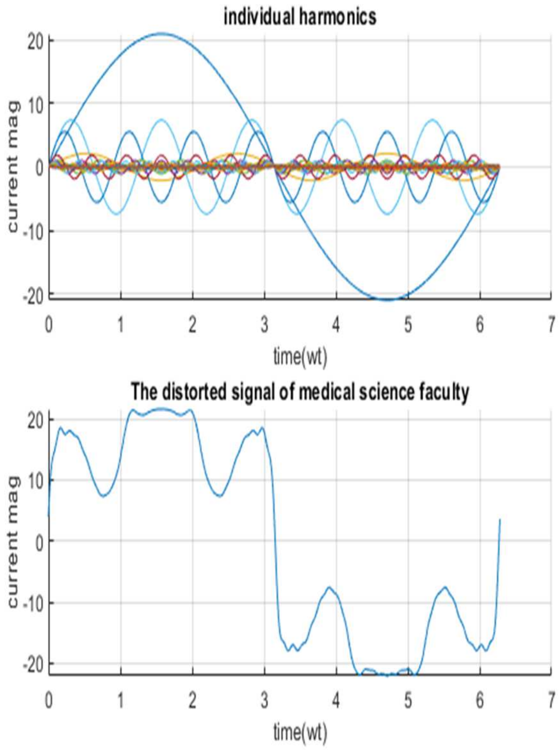

Fig. 1. Waveform of allied medical sciences building B.

The table below summarizes the data in the sample:

TABLE VII. COMPARISON OF TDD AND THD LEVELS BETWEEN HOLIDAYS AND WORK DAYS IN FACULTY OF MEDICAL SCIENCES.

Criteria	RMS current	THD	TDD
Holiday(19-21/Jan)	16.92A	53.21%	11.66%
College day (22-25/Jan)	18.31 A	48.98%	12.87%

Additionally, time-based trends for THD and TDD levels were graphically represented as follows:

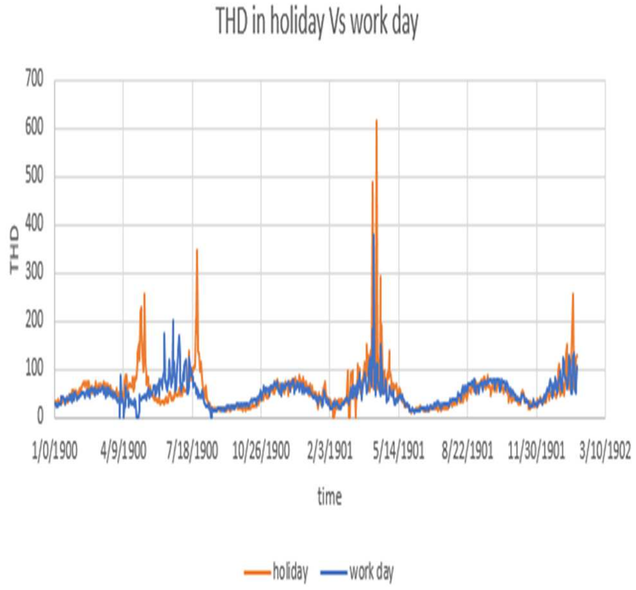

Fig. 2. Comparison of THD levels between holiday and work day in faculty of medical sciences.

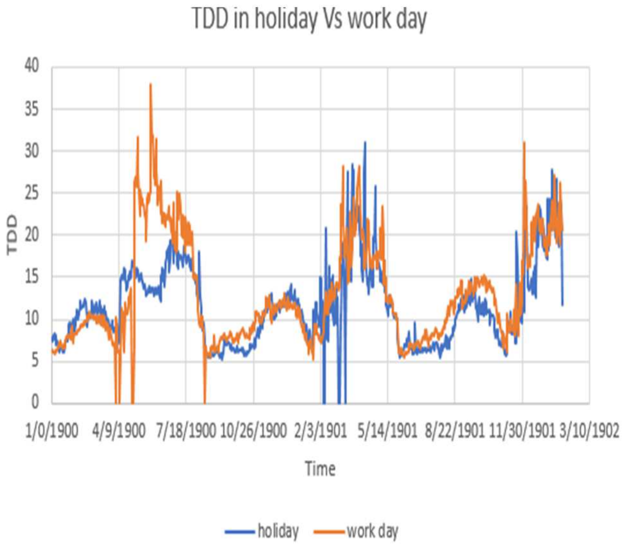

Fig. 3. Comparison of TDD levels between holiday and work day in faculty of medical sciences.

The previous figures clearly illustrate that during holidays when there is a lower demand for power and consequently fewer loads in operation, the total harmonic distortion (THD) tends to be higher, while the total demand distortion (TDD) is comparatively lower when compared to values observed on regular college days, where observation implies that the impact of harmonics, as indicated by the TDD value, is more pronounced during workdays when there is a higher electrical load and activity.

IV. DISCUSSION

- Dominance of Odd Orders: The study indicates that the first odd harmonic orders (1st to 13th) consistently exhibit higher levels compared to other harmonic orders. Specifically, the 5th, 7th, and 13th harmonic orders consistently exceed the IEEE limits, suggesting their significance in the distortion of the power system.

- Transformers Within IEEE Limits: It has been demonstrated that all analyzed transformers operate with harmonic levels that fall within the allowable IEEE limits. The conclusion was validated by comparing the resulting Total Demand Distortion (TDD) values with the IEEE limit.
- Complex Relationship with Workdays and Holidays: The comparison between workdays and holidays did not establish a clear and direct relationship with harmonic distortion levels. Additional measurements and in-depth case studies are recommended to gain a more comprehensive understanding of how harmonic distortion varies based on daily load patterns.

V. CONCLUSIONS AND RECOMMENDATIONS

The proposed study investigated harmonic distortion in the Arab American University power system and found that it is not a major concern. Harmonic distortion was not related to the amount of electrical load consumption, and the levels of harmonic distortion were within permissible limits. However, the levels of harmonic distortion were not constant and fluctuated over time. The international standards related to harmonic distortion indeed remain a subject of debate and varying interpretations within the industry. Moreover, it's generally not perceived that electricity distribution companies would impose financial penalties on institutions like the Arab American University of Palestine for exceeding allowable limits for harmonic distortion. These standards are often seen as guidelines to promote power quality and reliability rather than rigid regulations with punitive consequences. However, adherence to these standards is encouraged to maintain the overall stability and efficiency of power systems while minimizing potential disruptions.

The study can be applied in the coming years, but there are opportunities to improve and expand it further.

- Coordination between Suppliers and Users: Continued collaboration and coordination between power suppliers and users are essential to mitigate distortions and their impacts on the electrical network. Adherence to specified standards and limits for both user-consumed current and source-generated voltage should be a fundamental aspect of data analysis.
- Extended Measurement Period: Extending the measurement duration beyond a week to encompass an entire semester is advisable, where this longer timeframe would account for variations in load and ambient conditions, which change with each semester, consequently affecting harmonic distortion levels.
- Harmonic Analysis with ETAP: Consider conducting harmonic analysis using tools like ETAP to compare simulated data with the measured results. The comparative analysis can provide deeper insights into harmonic levels within the AAUP grid and aid in validation and fine-tuning of simulation models.
- Exploration of Harmonic Utilization: Explore the possibility of harnessing harmonics for beneficial purposes rather than solely aiming to reduce them.
- Comparing THD and TDD between day and night to understand the impact of inverters on harmonic levels.

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