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# Power Quality Audit of a School of Engineering Building - Case Study

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## ABSTRACT

This paper presents a case study of power quality audit analysis for the School of Engineering building at The University of Jordan. The measurements of voltage, current, and power for seven days using Fluke power analyzer meter are presented in this study. Analysis of measured data shows that the system has two main problems. The first problem is current unbalance which causes a large residual current in the neutral. The second problem is the presence harmonic currents; especially the third harmonic current due to single-phase loading and fluorescent lighting system.

**Key words:** Power quality, harmonics, monitoring, harmonic analyzer, distortion.

## 1. INTRODUCTION

Recently, there has been a rapid growth in using power electronic devices and nonlinear loads which draw distorted currents. This growth increases the necessity to monitor and analyze the variations of power quality (PQ) variables and indices, mainly; voltage, current, and frequency. IEEE Standard 1159 defines PQ as: "*The concept of powering and grounding sensitive equipment in a manner that is suitable for the operation of that equipment*" [1], [2]. According to IEEE Std 1159-2009, PQ phenomena can be categorized into seven PQ problems namely; transients, short- and long-duration voltage variation, imbalance, waveform distortion, voltage fluctuation, and power frequency variations [1]. The main types of PQ disturbances, their descriptions, and their major causes are presented in Table 1 [3].

Switched power converters, industrial equipment, fluorescent lighting, computerized equipment, and other electronic devices are the main nonlinear loads that generate distorted currents [4]. The current harmonics produced by these non-linear loads causes significant problems in the power systems such as overloading the neutral conductors, overheating transformer windings, and capacitor failure [4]. These problems affect the performance and reliability of the distribution system. Therefore, monitoring distribution systems that are equipped with nonlinear loads is vital to detect and mitigate PQ problems to supply the customer with smooth and clean voltage and current waveforms.

**Table 1:** Summary of PQ disturbances, descriptions and causes

| Disturbance Type | Description | Causes |
|---|---|---|
| **Impulse** | Narrow pulse with fast rise and exponential or damped oscillatory decay; 50 V to 6 kV amplitude, 0.5 ms to 2 ms duration. | Load switching Fuse clearing Utility Switching Arcing contacts Lightning |
| **EMI** | Repetitive low-energy disturbances in the 10 kHz to 1 GHz band, with 100 V to 100 V amplitude. | Normal equipment operation (switching power supplies, motor speed controllers, etc.) Carrier power line communication Wireless broadcasting |
| **Sag** | Low voltage (typ. less than 80%), for more than one period | Starting heavy load Utility switching Ground fault |
| **Swell** | High voltage (typ. more than 110%), for more than one period | Load reduction Utility switching |
| **Flicker** | Small repetitive fluctuations in the voltage level | Pulsating Load |
| **Notch** | Repetitive dips in the line voltage, with short durations | Current commutation in controlled or uncontrolled three-phase |
| **Waveform Distortion** | Deviation from ideal sine wave due to the presence of harmonics or inter-harmonics | Rectifiers, phase-angle controllers, other nonlinear and/or intermittent loads |
| **Frequency Variation** | Deviation of the frequency form the nominal value | Poorly regulated utility equipment Emergency power generator |
| **Outage** | Zero-voltage condition of a single phase or several phases in a multiphase system, for more than a half period | Load equipment failure Ground fault Utility equipment failure Accidents Lightning Acts of nature |

Accordingly, measuring and analyzing PQ problems, particularly harmonic current measurements in power distribution networks, industrial facilities, and residential and commercial buildings, have received the attention of researchers in recent years. Surveys of studying and analyzing PQ problems in power distribution networks and industrial plants were presented in numerous research works [5]-[11]. Recording and displaying harmonics by measuring current and voltage harmonics for seven days at the sending end of five feeders of a distribution substation and at the main buses of industrial, commercial and residential facilities were presented in [12]-[14]. The impacts of harmonic current characteristics of single-phase power electronics loads and of large numbers of distributed single-phase computer loads were presented in [15], [16]. The measurements of the harmonics characteristics of different types of compact fluorescent lamps (CFLs) were presented in [17]. Advances in power quality monitoring equipment and software tools for analyzing power quality measurement results were described in [18].

In this paper, analysis of a PQ audit study, that has been conducted using a PQ analyzer at the School of Engineering building at the University of Jordan, is presented. This study aims to evaluate the level of harmonic distortion in educational institutions. The paper is organized as follows. Section 2 presents the experimental setup for the measurement system. Analysis of the measured data and observations of the harmonic currents and power measurements are presented in Section 3. The conclusion is presented in Section 4.

## 2. EXPERIMENTAL SETUP

### 2.1 Point of Common Coupling (PCC)

In this study, PQ auditing is conducted in the building of the School of Engineering at The University of Jordan. Figure 1 shows the schematic representation of load distribution and point of common coupling (PCC) for the School of Engineering building. The main loads in the building are summarized in Table 2, it can be noticed that the main loads are single phase devices, lighting, personal computers, and devices that are used in the laboratories. These types of loads are sources of third, fifth, and seventh harmonics as they are supplied from switching mode power supplies.

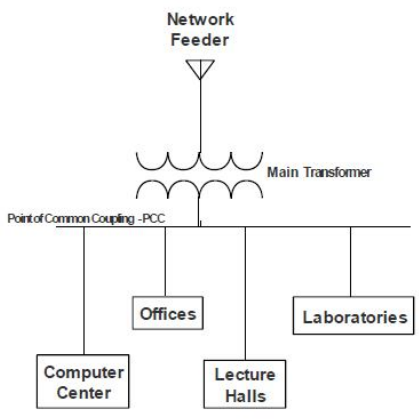



**Figure 1:** Load distribution at the School of Engineering building

**Table 2:** Types of equipment in the School of Engineering building

| Load | Main Equipment |
|---|---|
| **Computer Center** | More than 100 PCs |
| **Offices** | 1 PC (each)<br>Fluorescent Light |
| **Lecture Halls** | Fluorescent Lights |
| **Laboratories** | Three Phase Machines<br>Single Phase Machines<br>Measurement Devices<br>Fluorescent Lights |

### 2.2 Fluke Power Analyzer

In this study the Fluke (435-II) three phase power quality analyzer has been used to measure several variables including, voltage, current, power, energy, harmonics, unbalance, etc. [19]. The power analyzer has been connected to the main electrical panel that feeds the School of Engineering building as illustrated in Figure 2.

## 3. MEASURED DATA AND RESULTS

To investigate the effect of load types in the School of Engineering building, the power analyzer has been connected to the main feeder for a week of five working days (Sunday to Thursday) and a weekend (Friday and Saturday). The data were recorded for twenty-four hours per day with a sampling time of one sample per minute.

**Figure 2:** Connection of the PQ analyzer at the PCC of the panel

### 3.1 Power Measurements

The daily variation of the phase-A current in (RMS) value is shown in Figure 3. It is clear that the day can be classified into two periods; the first period is the working hours period which starts at (7:00 EEST) until (18:30 EEST) and the second period is the off-hours which starts at (18:31 EEST) until (6:59 EEST). Similarly, the variations of phase-B, phase-C, and neutral currents follow the same trends of phase-A. The average values for 15-minute duration of the phase currents that were recorded during working hours are given in Table 3.

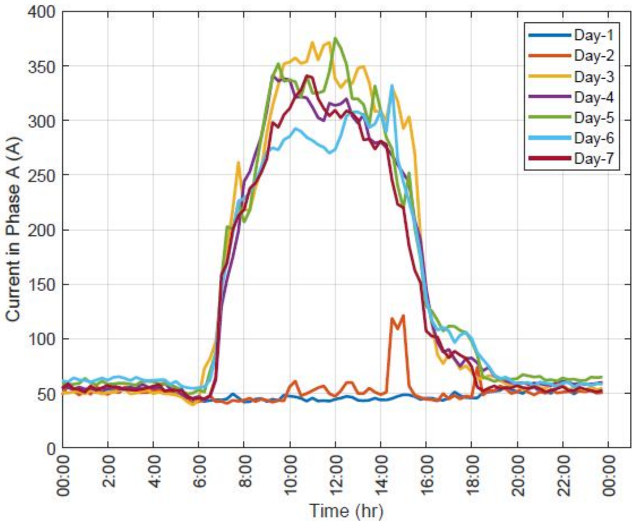



**Figure 3:** A 15 minute daily phase-A current variation

**Table 3:** A 15-minute average values of phase currents during working hours

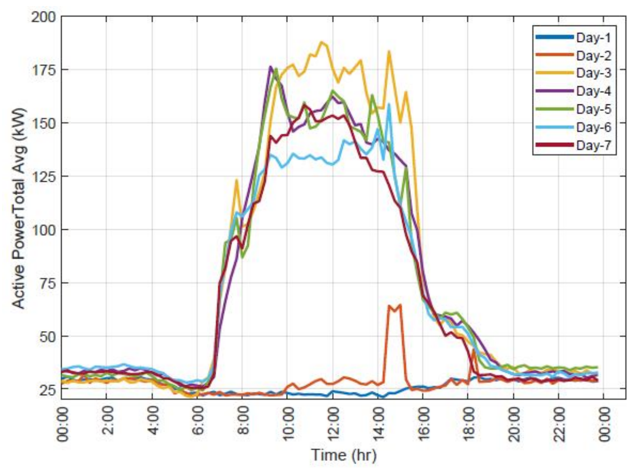
| Working hours (7:00 EEST - 18:30 EEST) | | | | | |
|---|---|---|---|---|---|
| **Days** | **Phase A** | **Phase B** | **Phase C** | **Neutral N** | **Unbalance (%)** |
| **Day 1 Friday** | 45.39 | 32.47 | 32.49 | 23.27 | 23.4 |
| **Day 2 Saturday** | 53.47 | 39.26 | 40.24 | 23.19 | 20.64 |
| **Day 3 Sunday** | 255.47 | 198.4 | 149.01 | 120.8 | 27.12 |
| **Day 4 Monday** | 236.61 | 182.23 | 120.8 | 112.21 | 31.54 |
| **Day 5 Tuesday** | 249 | 173.51 | 130.13 | 127.48 | 35.17 |
| **Day 6 Wednesday** | 229.19 | 157.2 | 115.81 | 115.99 | 36.91 |
| **Day 7 Thursday** | 225.99 | 165.76 | 120.8 | 111.43 | 32.27 |

Likewise, Table 4 shows the 15-minute average values of phases currents that were recorded during the Off-hours period. All power and harmonics measurements are analyzed for the working hours and non-holiday days (Sunday-Thursday). Examining Tables 3 and 4, it can be noticed that the phase currents are highly unbalanced and the neutral current and the percentage unbalance is relatively high. The current in Phase-A is around (1.25 - 1.45) times the current in Phase-B, and is around (1.5-1.9) times the current in Phase-C. Moreover, the results show that the neutral line carries current as high as Phase-C. This unbalance; as a result; increases the losses in the system.

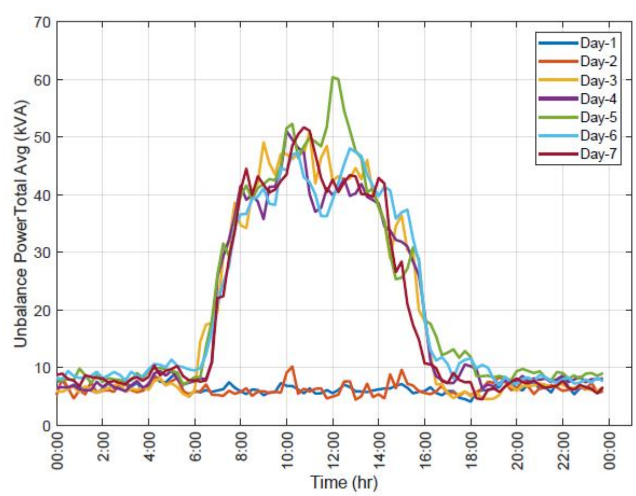
The Fluke Power Analyzer uses the IEEE-1459 standard for power measurements and energy loss calculations [18]. In this study, the waveform of the total active, and unbalanced power have been obtained as shown in Figure 4. A statistical analysis of the variation of the real, reactive and apparent power during the working hours is displayed in Figure 5(a). The power consumption during the five working days is almost the same.

**Table 4:** A 15-minute average values of phase currents during off-hours

| Off-Hours (18:31 EEST - 6:59 EEST) | | | | |
|---|---|---|---|---|
| **Variable** | **Current Phase A** | **Current Phase B** | **Current Phase C** | **Current Neutral N** |
| **Day 1 Friday** | 57.78 | 40.3 | 35.94 | 23.21 |
| **Day 2 Saturday** | 50.79 | 39.33 | 35.68 | 22.99 |
| **Day 3 Sunday** | 55.15 | 46.39 | 38.74 | 25.84 |
| **Day 4 Monday** | 56.83 | 51.23 | 40.34 | 28.36 |
| **Day 5 Tuesday** | 61.11 | 47.39 | 37.74 | 33.18 |
| **Day 6 Wednesday** | 61.67 | 49.89 | 39.69 | 34.97 |
| **Day 7 Thursday** | 53.81 | 47.32 | 37.1 | 26.32 |




(a)



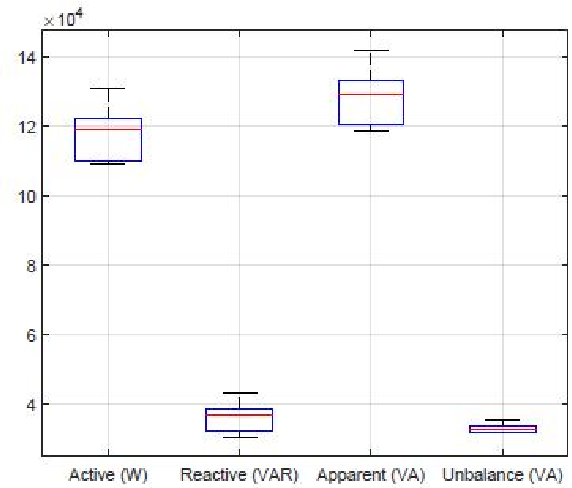

(b)

**Figure 4:** Daily variation of (a) total active power, (b) unbalance power

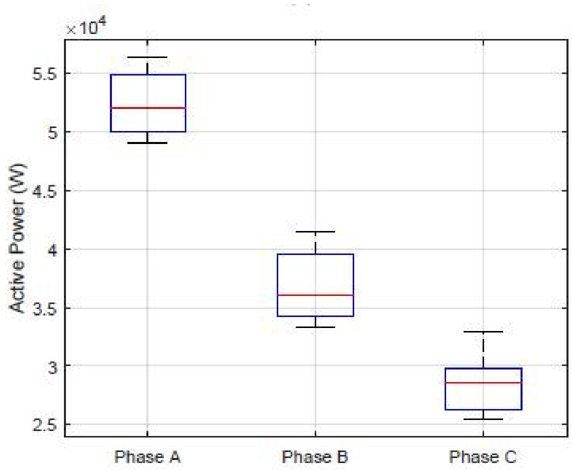
The average power consumption over the five days is around 117.7 kW of active power, 128.02 kVA of apparent power, 36.11 kVAR of reactive power, and 32.94 kVA of unbalance power which corresponds to 25% of the total average apparent power. A statistical variation of the total real, reactive and apparent power is presented in Figure 5(a). Similarly, the variation of the real power per phase is illustrated in statistical box-plot as shown in Figure 5(b). It is evident that most of the power consumption is drawn from phase-A. the variation of the average active power per phase is depicted in Figure 5(b).

The largest loads are fed from Phase A and the neutral current approaches 118 A during working hours. The high current in neutral might be due to two main reasons; the first one is the non-uniform load distribution among the three phases in the School of Engineering building as indicated in Table 3, and the second reason is the 3rd current harmonics which has zero sequence component that flows in the neutral line.

Table 5 shows the average values of the true power factor (PF) and displacement power factor.




(a)



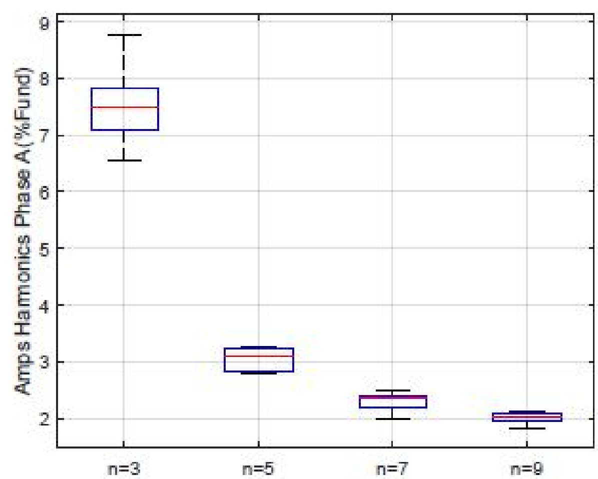

(b)

**Figure 5:** Statistical analysis of variation of (a) real, reactive and apparent power, (b) active power per phase.

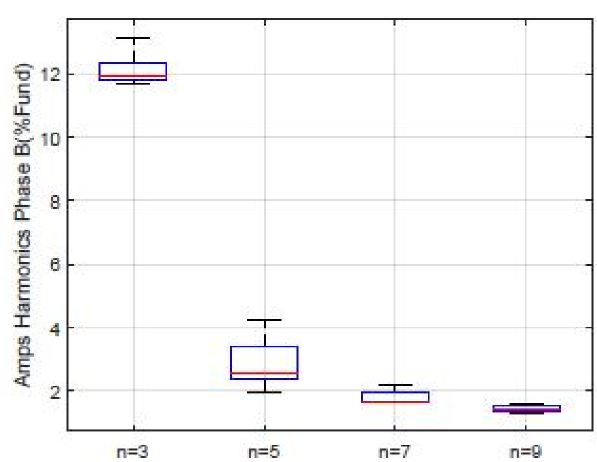
**Table 5:** The average load power factor at the PCC

| Working hours (7:00 EEST - 18:30 EEST) | | | |
|---|---|---|---|
| **Power Factor/Phase** | **Phase A** | **Phase B** | **Phase C** |
| **True PF** | 0.96 | 0.93 | 0.97 |
| **Displacement PF** $\cos(\phi)$ | 0.96 | 0.93 | 0.98 |

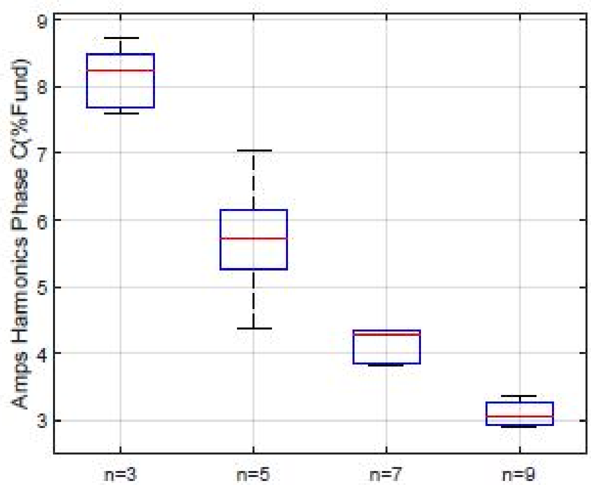
The variations of the odd harmonic of the phase currents for five days is shown in Figure 6. Similarly, Figure 7 displays the corresponding percentage values of the odd harmonic currents relative to the fundamental current. It can be seen that the percentage third current harmonic extends between (7%-13%), whereas the values of the percentage fifth, seventh, and ninth harmonic currents extend between (1.5%-5%). The variations of the phase voltages and currents THD indices for five days are illustrated in Figure 8. A snapshot of the distorted current waveforms of the three phases is depicted in Figure 9. It can be observed that both phases B and C are more distorted than phase-A. The average values of the total harmonic distortion (THD) indices of the phase currents and neutral that were measured during the working hours are presented in Table 6. It can also be noted that the neutral current is rich of 3rd harmonic.




(a)




(b)




(c)

**Figure 6:** A five-day variation of odd harmonics (a) Phase-A, (b) Phase-B, (c) Phase-C

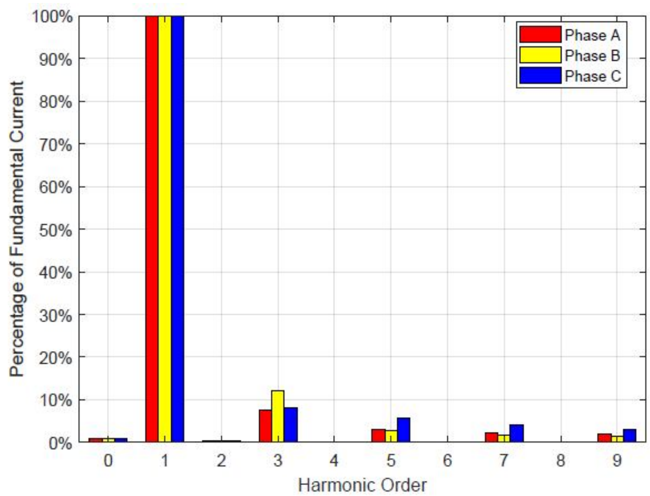
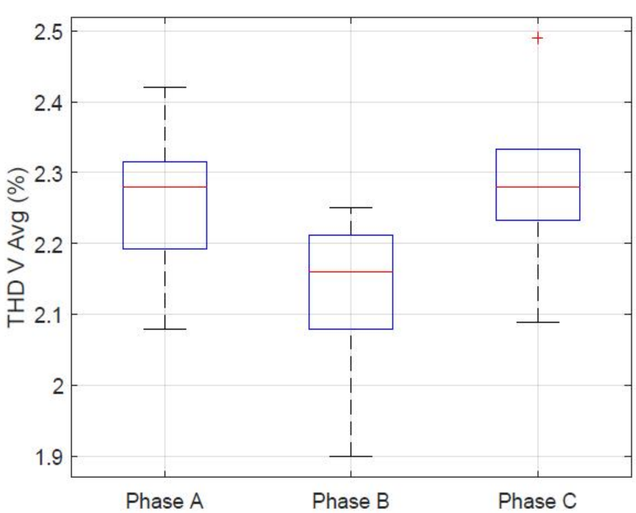
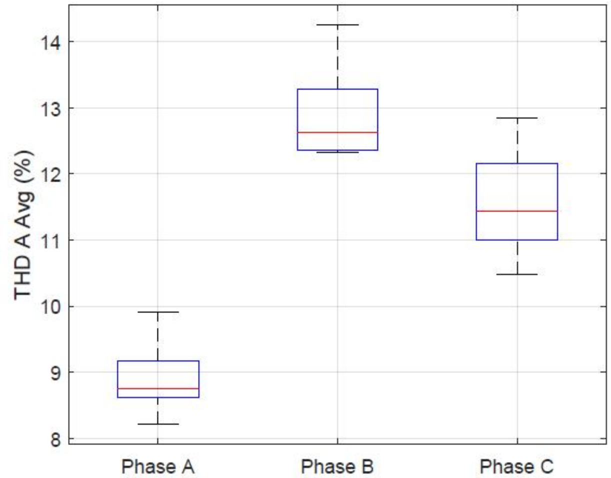



**Figure 7:** Spectrum of percentage harmonic currents




(a)




(b)

**Figure 8:** Variation of total harmonic distortion indices (a) voltage THD, (b) Current THD

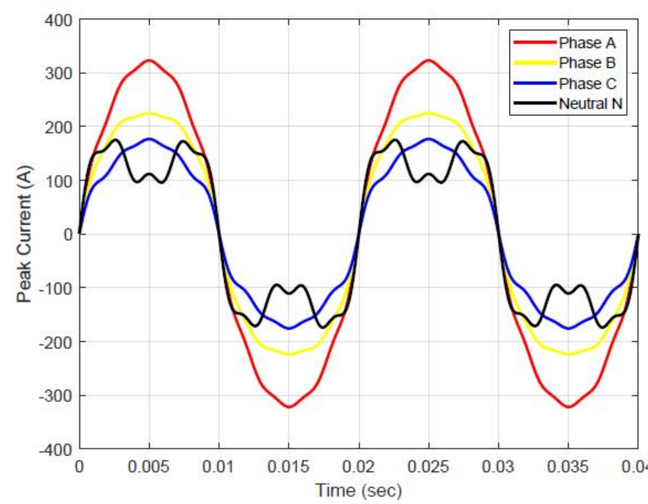



**Figure 9:** A snapshot of phase and neural current waveforms

**Table 6:** A five-day average percentage current THD indices

| **Working hours (7:00 EEST - 18:30 EEST)** | | | | |
|---|---|---|---|---|
| Day/THD | $THD_I$ (%) **Phase A** | $THD_I$ (%) **Phase B** | $THD_I$ (%) **Phase C** | $THD_I$ (%) **Neutral N** |
| **Day 3 Sunday** | 8.76 | 12.95 | 10.48 | 70.53 |
| **Day 4 Monday** | 9.91 | 14.26 | 11.92 | 66.66 |
| **Day 5 Tuesday** | 8.21 | 12.33 | 11.18 | 34.26.5 |
| **Day 6 Wednesd** | 8.93 | 12.36 | 11.43 | 36.38 |
| **Day 7 Thursday** | 8.75 | 12.62 | 12.85 | 48.89 |

## 4. CONCLUSION

In this paper, a power quality audit analysis for seven days at the School of Engineering building at the University of Jordan is presented. The Fluke analyzer (435-II) was used to measure and record the power quality indices and current waveforms. The measured data and waveforms show that the system has two main problems; the large current unbalance and high neutral current. The second problem is the harmonic distortion; mainly, the third harmonic current which was generated by single-phase loads and fluorescent lighting. In this study, it was also found that the values of the phase current and total harmonic distortion at the PCC are within the limits. The problem of current unbalance, however, can be solved by re-distributing the loads among the phases as evenly as possible.

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## REFERENCES

1. IEEE, **IEEE recommended practice for monitoring electric power quality**, *IEEE Std 1159-2009 (Revision of IEEE Std 1159-1995)*, pp. c1–81, June 2009.
2. **The authoritative dictionary of IEEE standards terms**, seventh edition, *IEEE Std 100-2000*, pp. 1–1362, Dec 2000.
3. S. Khalid and B. Dwivedi, **Power quality issues, problems, standards & their effects in industry with corrective means**, *International Journal of Advances in Engineering & Technology*, vol. 1, no. 2, pp. 1–11, 2011.
4. R. Redl and A. S. Kislovski, **Telecom power supplies and power quality,** in *Telecommunications Energy Conference, 1995. INTELEC'95., 17th International*. IEEE, 1995, pp. 13–21.
5. L. M. Tolbert, H. D. Hollis, and P. Hale, **Survey of harmonics measurements in electrical distribution systems**, in *Industry Applications Conference, 1996. Thirty-First IAS Annual Meeting, IAS'96., Conference Record of the 1996 IEEE*, vol. 4. IEEE, 1996, pp. 2333–2339.
6. A. Asheibi, D. A. Stirling, and D. Sutanto, **Analyzing harmonic monitoring data using data mining**, 2006.
7. S. Sultan and M. Darwish, **Power quality evaluation in Libyan electrical distribution networks,** in *Renewable Energies and Vehicular Technology (REVET), 2012 First International Conference on*. IEEE, 2012, pp. 372–378. https://doi.org/10.1109/REVET.2012.6195299
8. K. R. Milani, B. Adham, M.R. Banaei, and F. M. Kazemi, F. M, **Measurement and analysis of base transceiver stations power quality parameters and assessment of its unfavorable effects on Iran distribution systems**. *CIRED-Open Access Proceedings Journal*, vol.1, pp. 761-765, 2017. https://doi.org/10.1049/oap-cired.2017.0652
9. R. R. Nasyrov, R. I. Aljendy, and T. Kherbek, **Study and analysis of power quality situation in electrical power network. case study: Lattakia- Syria,** in *Young Researchers in Electrical and Electronic Engineering (EIConRus), 2018 IEEE Conference of Russian*. IEEE, 2018, pp. 712– 718. https://doi.org/10.1109/EIConRus.2018.8317193
10. R. Lamedica, G. Esposito, E. Tironi, D. Zaninelli, and A. Prudenzi, **A survey on power quality cost in industrial customers**, in *Power Engineering Society Winter Meeting, 2001. IEEE*, vol. 2. IEEE, 2001, pp. 938–943.
11. M. Shwehdi, **Harmonics effect in industrial and university environ- ments**, in *Power Quality Harmonics Analysis and Real Measurements Data*. InTech, 2011. https://doi.org/10.5772/16395
12. A. E. Emanuel, J. A. Orr, D. Cyganski, and E. M. Gulachenski, **A survey of harmonic voltages and currents at distribution substations**, *IEEE Transactions on power delivery*, vol. 6, no. 4, pp. 1883–1890, 1991. https://doi.org/10.1109/61.97736
13. A. E. Emanuel, J. A. Orr, D. Cyganski, and E. M. Gulachenski, **A survey of harmonic voltages and currents at the customer's bus**, *IEEE Transactions on power delivery*, vol. 8, no. 1, pp. 411–421, 1993. https://doi.org/10.1109/61.180363
14. Elmer R. Magsino, **Energy Monitoring System Incorporating Energy Profiling and Predictive Household Movement for Energy Anomaly Detection**, *International Journal of Emerging Trends in Engineering Research*, vol. 7, no. 8, pp. 151-156, 2019. https://doi.org/10.30534/ijeter/2019/08782019
15. A. Mansoor, W. Grady, A. Chowdhury, and M. Samotyi, **An investigation of harmonics attenuation and diversity among distributed single-phase power electronic loads**, in *Transmission and Distribution Conference, 1994., Proceedings of the 1994 IEEE Power Engineering Society*. IEEE, 1994, pp. 110–116.
16. A. Mansoor, W. Grady, P. Staats, R. Thallam, M. Doyle, and M. Samotyj, **Predicting the net harmonic currents produced by large numbers of distributed single-phase computer loads**, *IEEE Transactions on Power Delivery*, vol. 10, no. 4, pp. 2001–2006, 1995.
17. R. Dwyer, A. K. Khan, M. Mcgranaghan, L. Tang, R. K. Mccluskey,
R. Sung, and T. Houy, **Evaluation of harmonic impacts from compact fluorescent lights on distribution systems**, *IEEE Transactions on Power Systems*, vol. 10, no. 4, 1995.
18. C. J. Melhorn and M. F. McGranaghan, **Interpretation and analysis of power quality measurements**, *IEEE Transactions on Industry Applications*, vol. 31, no. 6, pp. 1363–1370, 1995.
19. Fluke 434-II/435-II/437-II **Three Phase Energy and Power Quality Analyzer**, User's Manual.