Study of Power Quality Problems in Yemeni Educational Buildings

Ahmed M. A. Dubais[1,*], Abdulaziz M. S. Al-Dobhani [1,*]

Abstract

Power Quality (PQ) has become a big issue since the late 1980s. Equipments which are in use nowadays, require good power quality. However, the pure sinusoidal voltage or current waveform is distorted by the nonlinear properties of the equipments. The main purpose of this paper is to investigate the most common problems in power quality in educational buildings and propose a solution for the main dominate one. The Point of Common Coupling (PCC) was elected to be an incomer breaker. The study includes monitoring and measuring the power waveform for one week. The result are analyzed and compared with International Standards. Interruptions are the main problem while swells, dips and transients problems are caused as a result of the interruptions problems.

Keywords: PQ, PCC, Energy storage system, Backup generator, Interruption.

1. Introduction

According to IEEE standard, power quality is defined as, "the concept of powering and grounding sensitive equipment in a matter that is suitable to the operation of that equipment." [1]. Power utility systems have to provide customers with an uninterrupted smooth sinusoidal voltage with constant magnitude and frequency[2].

Equipments usually cause problems for the voltage supply like waveform distortions, because of its non-linear properties. This distortion produces many power quality problems which deviate from the standard limit [3]. Some of the most common power problems are voltage dips, voltage sag/brownouts, interruptions, voltage swell, harmonic, voltage fluctuation/flicker, and voltage unbalance [4]. The poor power can damage, premature aging, or hang up the electrical equipment. Poor Power Quality means high consumption in electricity and can lead to equipment failure. For example, if the supply voltage (rms 220V) increases above its nominal value by 10%, the power consumption will increase as well. This

[1] Department of Electronic Engineering, Faculty of Engineering, University of Science and Technology, Sana'a, Yemen

[*] Correspondence Authors: (a.aldubais@ust.edu), (aldobhany500@yahoo.com)

means, the problems of power quality have bad effects on the equipments and the power utility. International standards organizations are created limits of power quality problems. Equipments and power utility should follow these standards limits in order to operate safely.
As consequences of these problems, specifications of power quality have been developed.. Monitoring the quality of electric power has become an important procedure for detecting these problems.
There are many approaches to minimize power quality problems which lead to improve the system performance in the utility and costumer side. An integrated approach is proposed by Douglas and John to solve power quality problems. The proposed approach is illustrated in Table (1) [5]. A case study is proposed by El- Mofty and et al to treat the power quality problems individually where voltage dips are treated by installing power conditioners while voltage swells are mitigated by adjusting the tap changer of the transformer [6]. Salam et al indicated that, UPS is a good solution for power variation and tuned filter can mitigate harmonics. Single tuned harmonic filter is installed to mitigate harmonic distortion and power factor correction [7]. Sharanya et al proposed a (DVR) dynamic voltage restorer which is a custom power device for compensation of voltage sags and swells [8].

Tabel 1: Integrated approach to solve PQ problems[5]

Disturbance	Possible Cause	Utility-Side Solution	Customer-Side Solution
Voltage sag	Lightning strike Tree or animal contact	Dynamic voltage restorer, Static conditioner	Line conditioner, UPS
Overvoltage	Fault on another phase Load rejection	Dynamic voltage restorer, Fault Current, Limiter ,High energy, Surge arrester	Line conditioner Voltage regulator, UPS
Interruption	Blown fuse Breaker operation	Solid state circuit breaker Static condenser	UPS Motor gen set
Transient	Lightning strike Utility switching	High energy surge arrester	Line conditioner surge suppressor
Harmonic distortion	Nonlinear loads Ferroresonance	Filter, Static condenser Dynamic Voltage, Restorer	Line conditioner Filter
Electrical noise	Improper customer wiring or grounding	-	Grounding, Shielding Line conditioner, Filter

This paper is organized as follows: section (2) presents the most common problems of power quality. Section (3) is about the place of the study. In section (4), the data is analyzed and discussed. Finally, the conclusion of this work is given in section (5).

2. Power Quality Problems

The most common power quality problems, their causes, the effects and the techniques to mitigate/reduce them are described in the following paragraphs:

Transients: transients are extreme voltages suddenly increased with very short time usually less than 50msec. The transient is produced by a very rapid change in the steady-state condition of voltage, current, or both [9]. There are two types of transient. The first one is called impulsive transient and the second one is called oscillatory transient. Lightning strikes or loose connection in the distribution system can cause transient disturbance. On the other hand, the change in voltage or current in a very fast time can cause a serious damage to sensitive electronic equipments. The common solutions for them are by using transient voltage surge suppression (TVSS) or installing line reactors that can damp the oscillatory transient [10].

Short-Duration Voltage Variations: fault conditions, discontinuous loose connections in cable wiring or inserting large load to the power utility are the main sources of short duration variations [11]. Short duration variations are rapidly changed in voltage magnitude for less than one minute as shown in Table (2) [12].

Tabel 2: Short duration classification

Short duration variations types		**Typical duration**	**Typical voltage Magnitude**
Instantaneous	Interruption	<600ms	-
	Sag	10-600 ms	0.1-0.9pu
	Swell	10-600 ms	1.1-1.8pu
Momentary	Interruption	10ms-3s	<0.1pu
	Sag	600ms-3s	0.1-0.9pu
	Swell	600ms-3s	1.1-1.4pu
Temporary	Interruption	>3s-1min	<0.1pu
	Sag	>3s-1min	0.1-0.9pu
	Swell	>3s-1min	1.1-1.2pu

Equipment malfunctions, loose connections, faults and shutting down are consequences of power interruption [11]. Sags are usually associated with faults in the system such as switching on heavy loads. Switching off a capacitor bank, or dismantle wiring leads to sag voltage [4]. The voltage swell usually occurs when switching capacitors on, shutting loads off, or single phase fault in three phase system [13]. The most common used solutions for these problems are by using Uninterruptable Power Supply (UPS) or energy storage [10].

Long Duration Voltage Variations: the long duration voltage variation occurs when the voltage amplitude is changed. It is classified by IEEE and International Electrotechnical

Commission (IEC) into three types [14] sustained interruption, undervoltage, and overvoltage. Load variations and switching operations on a system are the main reason of Long duration variations. Most of PQ analyser nowadays use iec61000-4 and en50160 standards [15, 16] for long duration variations. UPS is a good treatment for sustained interruption and undervoltage [14]. Relays, contactors, arcing horns, and Zener diodes are used to keep equipments within standard limits of overvoltage [16] [17].

Harmonic: harmonic distortion is a corruption of the fundamental sinusoidal waveform that combines with original waveform at frequencies with integer multiple of the fundamental frequency. Nonlinear loads, such as Adjustable Speed Driver (ASD), Compact Fluorescent Lamp (CLF), Switch Mode Power Supply (SMPS) as in computers, and static Uninterruptable Power Supply (UPS) systems are caused harmonics. IEC 555-2 sets 5% as the upper limit for Current Total Harmonic Distortion (THDI), and 8% as the upper limit for Voltage Total Harmonic Distortion (THDV) where equipments are connected to the utility [18, 19]. To eliminate harmonic distortion passive filter, active filter or both are used [20].

3. UST PQ Problems as a Case study

In this case study, power quality problems are monitored in the girls' campus of the University of Science and Technology-Yemen (UST). The building feeds from low voltage (LV) board and has a backup generator. The monitoring is done at PCC point for one week. Data is collected and is stored in external memory card by PQ analyzer. The monitoring time is chosen at rush work hours for a week continuously. Three-phase Power Quality and Energy Analyzer 435-II from Fluke Company which used to measure, record, and analyze the three phase power system is installed at PCC. Figure (1) shows the Fluke 435-II.

Figure (1): Fluke Power Quality and Energy Analyzer 435-II

3.1 Case Study Description

Girls' campus has a backup generator beside the power that is fed by supplier. Monitoring of the installations and the equipments regularly has to be intensified. Planning, investment, and mitigating are required. In order to take the measurements of power quality problems for all loads in the girls' campus, the measurements of power quality disturbances are taken at PCC. However, Point of Connection (POC) is different from PCC. When a PQ Analyzer is installed near a load in order to take measurements, this place can be called A POC. Moreover, a PCC and a POC could or could not be as the same visual point, depending on the grid configuration as shown in Figure (2) [21].

Power quality problems are monitored for one week according to EN 50160 standard. Voltage, Current, Frequency, transient, short duration, current unbalances, power, power factor, and harmonics are the parameters which are concerned. The PQ problems are monitored during the period from 4/1/2015 to 11/1/2015. The Power Log software analyze the main PQ problems data considering EN 50160 standard limits.

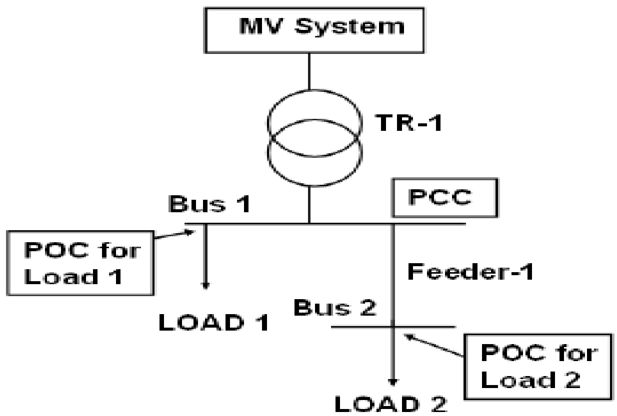

Figure (2): PCC and POC connections

3.2 Load Types in the Buildings

Girls' campus has seven floors and contains many different types of loads. Every floor has a number of academic offices, labs, and halls. The girls' campus also has one clinic, three restaurants and a theatre (200 seats). The campus has different loads like computers, photocopiers, heaters, electric water boilers, and scanners. It also has fans, refrigerators, fluorescent, and economical lamps. In general, girls' campus has more than 400 PCs, more than 80 dentist chairs, and 4 lifts. It also has more than 100 fans, 50 data shows, and 1000 fluorescent lamps.

4. Data Analysis

PQ problems are mostly generated whether internally such as harmonics or externally such as transients, interruptions, swells and dips. The nonlinear loads in commercial buildings generate internally PQ problems while the externally PQ problems like interruptions are often generated from the utility company or natural phenomenon.

Fluke 435-II PQ analyzer is used to monitor and record the normal and the non-normal Power values. The data are investigated and analyzed in order to determine if power quality is within the acceptable recommended levels or not.

4.1 Voltage Waveform Analysis

Figures (3, 4) and (5) show the voltage behaviour for the three phases. Many violent events are noticed and recorded in the three phases as seen from the data that are collected during one week. These violent events are distributed into four parameters types interruptions (happened 60 times), dips and swells (happened 148 times) and transients (happened 89 times).

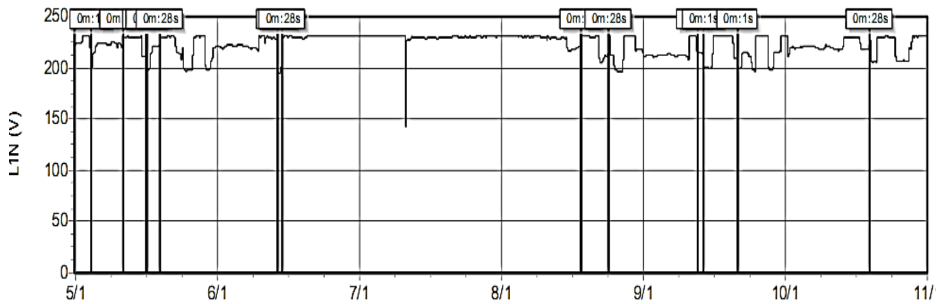

Figure (3): The line one voltage (5-1-2015 to 11-1-2015)

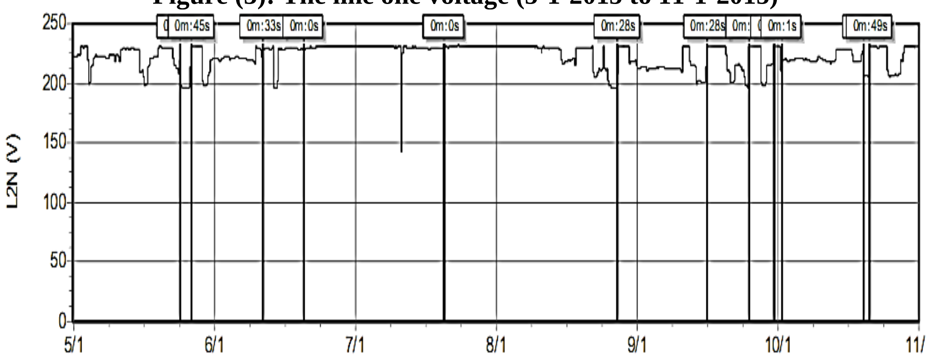

Figure (4): The line two voltage (5-1-2015 to 11-1-2015)

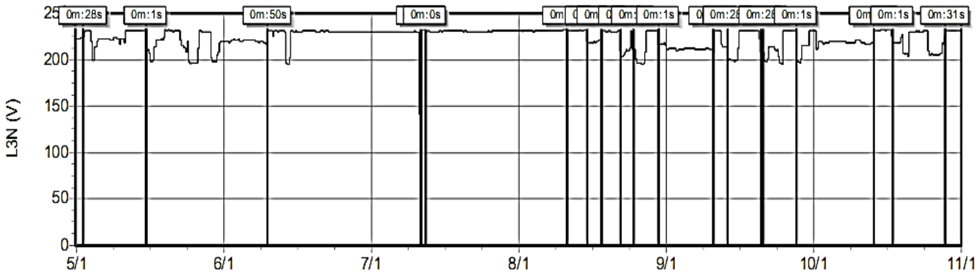

Figure (5): The line three voltage in girls campus (5-1-2015 to 11-1-2015)

PQ analyzer discovers the problems and records these problems with their happening time accurately. For example, on 4/1/2015 at 01:03:44:131 millisecond PM, an interruption event is occurred while transient event is occurred on the same date at 1:04:12:680 millisecond PM in line one and three. The dip event is also occurred on 1/4/2015 at 1:04:13:49 millisecond PM and recorded 197v value in line 2. The interruption event is occurred on 5/1/2015 at 7:57:57:84 millisecond AM. After that, transient, dip, and swell are occurred respectively.

The loads or the external sources are the main factor that cause the violent events. For example, the interruption is externally event. The utility company is the main responsible of the interruptions for several times in a day in Yemen. The switching between the voltage supplier and the backup generator is also the reason of the interruptions. The interruption occurs during the switching from backup generator to voltage lines (when the voltage comes back). During a week of the study, 60 interruptions are recorded for 95% of the observation. These interruptions are above the accepted level and should be treated.

The dips and swells occurred 148 times and can be ranked upon its magnitude and duration as shown in Tables (3) and (4) respectively. The voltage that is supplied from utility company has a magnitude equals to 220V_{ph} (rms) and it is not the same as backup generator (rms 230 V_{ph}). The backup generator voltage deviates from the nominal voltage (220V_{ph}) with 4.35%. This deviation causes the PQ analyzer to indicate there is a problem occurred during the measuring operation.

Tabel 3: Dips events

Residual voltage (%U)	Duration (ms)						
	t<10	10<t<=200	200<t<=500	500<t<=1000	1000<t<=5000	5000<t<=60000	t<60000
90>U>=80	1	24	5	1	2	0	4
80>U>=70	0	0	0	1	0	0	1
70>U>=40	0	0	0	0	0	0	0
40>U>=5	0	0	0	0	0	0	0
U<5	0	1	0	7	40	53	19

It is clear from the data in the Table (3) that most of dip events occur during the switching from voltage supplier line to backup generator and vice versa. For example, an interruption occurred on 4/1/2015 at 1:03:44:171 millisecond PM for duration 28 seconds. As a result of that, a dip is also occurred on the same date at 1:04:13:49 millisecond PM when the system is restarted as shown in Figure (6).

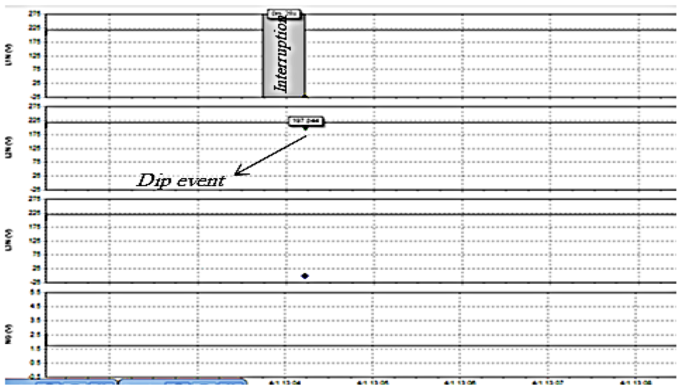

Figure (6): Sample of dip event

Little dip events happened as a result of external sources by the voltage supplier or by heavy loads that injected to the network such as PCs.

The swell events are usually happened during the switching from the voltage supplier line (rms $220V_{ph}$) to backup generator (rms $230V_{ph}$). Table (4) shows the number of swells events with different durations and different magnitudes.

Tabel 4: Swells events

Residual voltage (%U)	Duration (ms)				
	t<10	10<t<=200	10<t<=200	10<t<=200	10<t<=200
U>=120	0	0	2	0	0
120>U>=10	4	26	17	0	0

The international standard says that the swell occurs when the voltage amplitude is increased to be within 1.1pu and 1.8pu. By applying the limit standard, the acceptable limit for the backup generator is less than or equal to 253v while the reference voltage of the PQ analyzer is 220v (the acceptable limit is less than or equal 242v). When the backup generator feeds the network and the voltage increases to 250v as an example, the device will indicate that a swell event is occurred as mentioned previously. Figure (7) shows an example of swell events.

As mentioned previously, interruptions cause violent events which can make the analysis inaccurate. To analyze the data more easily, the violent events that happened during the interruption should be ignored.

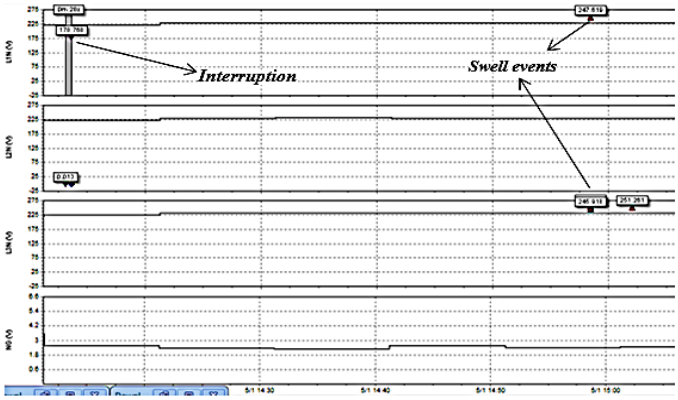

Figure (7): An example of swell events

After avoiding the voltage unbalances events during the interruption events, the maximum value of voltage unbalance is about 1.21% which occurred on 11/1/2015 at 8:01:16:883 millisecond AM as shown in Figure (8). As a result, the voltage unbalance is less than acceptable limit (2%) according to EN50160.

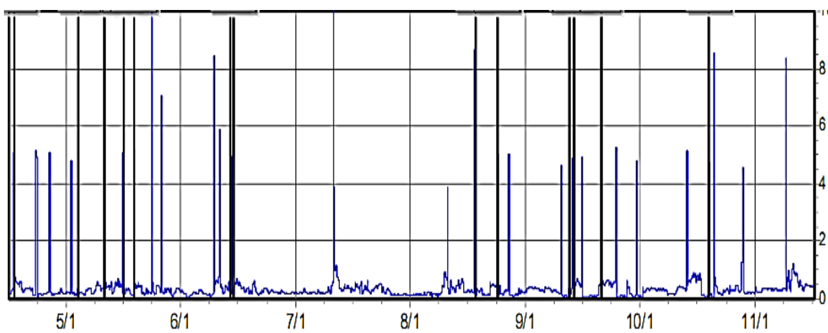

Figure (8): Voltage unbalances (5-1-2015 to 11-1-2015)

All the transient events happen when the voltage is come back after the interruptions as shown in Figure (9). The large loads such as PCs, motors and CLFs draw high current which lead to generate transient events.

Date	Function	Duration	L1N(V) / L1(A) Min	L1N(V) / L1(A) Avg	L1N(V) / L1(A) Max	L2N(V) / L2(A) Min	L2N(V) / L2(A) Avg	L2N(V) / L2(A) Max	L3N(V) / L3(A) Min	L3N(V) / L3(A) Avg
1/4/2015 01:03:44 ١٧١ مmsec	Interruption	0m.28s.508ms.	0							
1/4/2015 01:04:12 ٦٨٠ مmsec	Transient			Transient No. 1						
1/4/2015 01:04:12 ٧٢٥ مmsec	Transient									Transient No. 2
1/4/2015 04:55:11 ١٦٦ مmsec	Interruption	0m.1s.243ms.							0	
1/4/2015 04:55:12 ٤١٠ مmsec	Transient			Transient No. 3						
1/4/2015 05:42:19 ٧٦٧ مmsec	Interruption	0m.28s.693ms.							0	
1/4/2015 05:42:48 ٤٦٠ مmsec	Transient									Transient No. 4
1/4/2015 05:45:31 ١٤٨ مmsec	Interruption	0m.1s.230ms.				0				
1/4/2015 05:45:32 ٣٧٨ مmsec	Transient						Transient No. 5			
1/4/2015 05:45:32 ٣٨٤ مmsec	Transient			Transient No. 6						
1/4/2015 05:58:38 ٤٧٧ مmsec	Interruption	0m.28s.414ms.							0	
1/4/2015 05:59:06 ٨٩١ مmsec	Transient									Transient No. 7
1/4/2015 06:09:13 ٣٤٢ مmsec	Interruption	0m.1s.200ms.							0	
1/4/2015 06:09:14 ٥٤٥ مmsec	Transient						Transient No. 8			
1/4/2015 08:40:15 ٢١٠ مmsec	Interruption	0m.28s.526ms.							0	
1/4/2015 08:40:43 ٧٣٦ مmsec	Transient									Transient No. 9
1/4/2015 08:40:43 ٧٦٧ مmsec	Transient									Transient No. 10
1/4/2015 10:55:29 ٢٨٦ مmsec	Interruption	0m.1s.75ms.				0				
1/4/2015 10:55:30 ٣٦١ مmsec	Transient			Transient No. 11						
1/5/2015 01:01:31 ٣٠٤ صmsec	Interruption	0m.28s.554ms.							0	
1/5/2015 01:01:59 ٨٥٨ صmsec	Transient									Transient No. 12
1/5/2015 01:01:59 ٨٨٨ صmsec	Transient									Transient No. 13
1/5/2015 02:27:31 ٨٢٨ صmsec	Interruption	0m.1s.206ms.	0							
1/5/2015 02:27:33 ٣٤ صmsec	Transient									Transient No. 14
1/5/2015 02:27:33 ٨١ صmsec	Transient			Transient No. 15						
1/5/2015 07:57:57 ١٦٤ صmsec	Interruption	0m.29s.241ms.	0							
1/5/2015 07:58:26 ٤٠٥ صmsec	Transient			Transient No. 16						

Figure (9): Transient events

After the analysis of the data, the PQ problems in girls' campus are classified into Interruptions, Swells and dips and Transients

The voltage interruptions are the main source problem for most other PQ problems like dips, swells, and transients in this case study. Interruptions have to be solved since they are the source for other problems.

4.2 Total Harmonic Distortion of the Voltage (THD_V)

Figures (10), (11) and (12) illustrate the Total Harmonic Distortions for voltage (THDV) for three phases. The THD_V reached to 8% on 10/1/2015 at 9:31:16 883 millisecond PM on line one while it reached to 7% on line two and 4% on line three. These values are still within acceptable limits (8%). Line one should be considered and observed because its value is in critical level.

As shown in the Figures below, the vertical lines mean interruptions periods and the PQ analyzer gives a value equal to 327.67%. This value is used when the measured value cannot be calculated. It also means that the PQ analyzer was not able to measure THDV because the waveform was too small or zero caused by interruption.

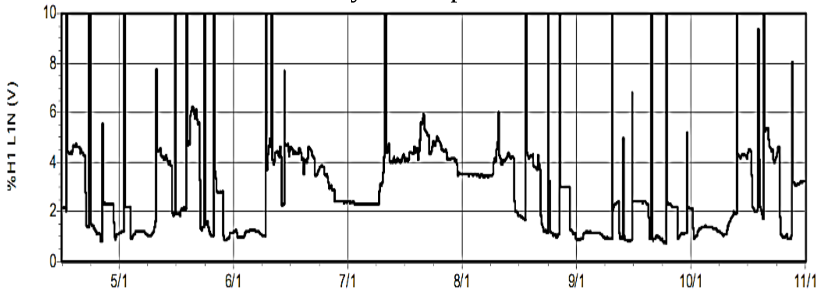

Figure (10): Line one THDV (5-1-2015 to 11-1-2015)

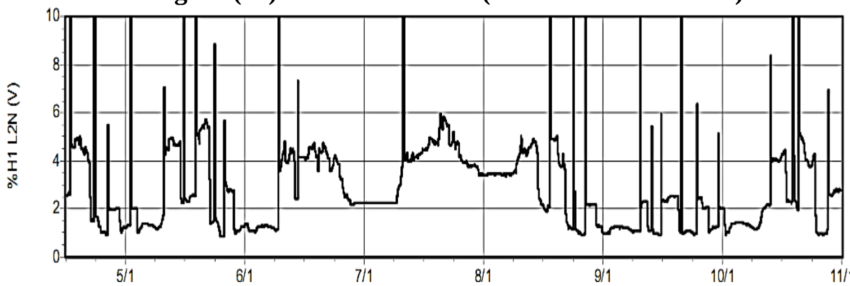

Figure (11): Line two THDV (5-1-2015 to 11-1-2015)

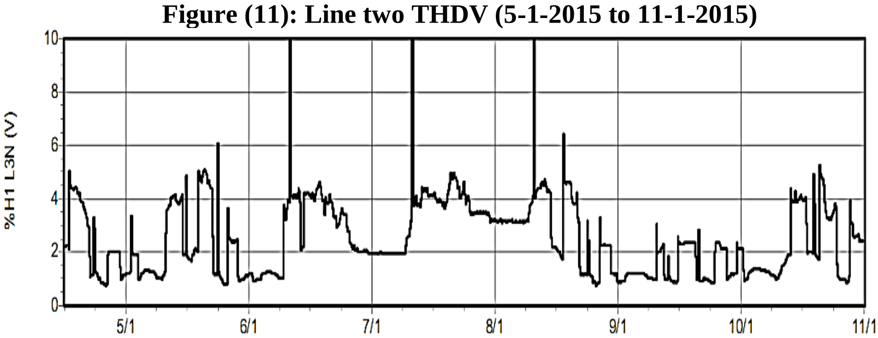

Figure (12):Line three THDV (5-1-2015 to 11-1-2015)

Harmonics in girls' campus does not categorize as problem since they are in acceptable standard limits.
It can be concluded that the voltage interruptions are the main source of the other problems in educational buildings in Yemen. As consequences of the voltage interruptions, many PQ problems such as voltage swells, voltage sags, and transients are occurred. Flywheel energy storage can be used to mitigate voltage interruption and other problems such as voltage sags.

5. Conclusion and Future Work

In this paper, the power quality problems in commercial buildings have been investigated. The study of power quality problems for educational buildings still lacking in Yemen up to my knowledge. The problems of the power quality have been investigated in girls' campus of the University Science and Technology in Sana'a. The study has focused on whether this building follows the international standards and the limits of the power quality. In this study, the main problem of the PQ is the sustain interruption. Therefore, it can be solved by using any energy storage system such as Flywheel energy storage.
It is recommended to extend this study to include other facilities such as factories and power utility.

6. References

[1]I. S. Association, "1159-2009. IEEE Recommended Practice for Monitoring Electric Power Quality Industrial and Commercial Applications," ed: New York: IEEE Press, 2009.
[2] S. A. Mohammed, A. G. Cerrada, M. Abdel-Moamen, and B. Hasanin, "Dynamic Voltage Restorer (DVR) System for Compensation of Voltage Sags, State-of-the-Art [
[3]M.-Y. Chan, K. K. Lee, and M. W. Fung, "A case study survey of harmonic currents generated from a computer centre in an office building," Architectural Science Review, vol. 50, no. 3, 2007.
[4]J. Seymour and T. Horsley, "The seven types of power problems," 2005.
[5]J. Douglas, "Power quality solutions," Power Engineering Review, IEEE, vol. 14, no. 3, 1994.
[6]A. El Mofty and K. Youssef, "Industrial power quality problems," in Electricity Distribution, 2001. Part 1: Contributions. CIRED. 16th International Conference and Exhibition on (IEE Conf. Publ No. 482), vol. 2, 2001.

[7]G. Salam and S. M. Nasri, "Survey of power quality problems in industrial zones in Egypt," in Electricity Distribution, 2005. CIRED 2005. 18th International Conference and Exhibition on, 2005.
[8]M. Sharanya, B. Basavaraja, and M. Sasikala, "An Overview of Dynamic Voltage Restorer for Voltage Profile Improvement," International Journal of Engineering and Advanced Technology (IJEAT) ISSN, 2012.
[9]A. Std, "C84. 1-1989,“," Electric Power Systems and Equipment–Voltage Ratings (60Hz), 1989.
[10] J. Seymour and T. Horsley, "The seven types of power problems," APC, USA, 2005.
[11] IEEE-Std-1159, "IEEE Recommended Practice for Monitoring Electric Power Quality," IEEE Std 1159-1995, 1995.
[12] E. Fuchs and M. A. Masoum, Power quality in power systems and electrical machines, Academic press, 2011.
[13] R. Sedaghati, N. M. Afroozi, Y. Nemati, A. Rohani, A. R. Toorani, N. Javidtash, et al., "A Survey of Voltage Sags and Voltage Swells Phenomena in Power Quality Problems," Meta, vol. 1, no. 2, 2013.
[14] A. Olatoke, "Investigations of power quality problems in modern buildings," Brunel University School of Engineering and Design PhD Theses, 2011.
[15] E. Compatibility, "Part 4: 30: Testing and measurement techniques–Power quality measurement methods," IEC 61000-4-30 Std2003.
[16] E. CENELEC, "50160, 1999–Voltage characteristics of electricity supplied by public distribution systems," European standard, 1999.
[17] R. C. Dugan, M. F. McGranaghan, and H. W. Beaty, "Electrical power systems quality," New York, NY: McGraw-Hill,| c1996, vol. 1, 1996.
[18] L. Cividino, "Power factor, harmonic distortion; causes, effects and considerations," in Telecommunications Energy Conference, 1992. INTELEC'92., 14th International, 1992.
[19] A. Ferreira-Filho, M. de Oliveira, and F. Bonincontro, "A contribution to establish proceedings for Quantification of Voltage Harmonic Distortion in Commercial Buildings," in IEEE Proceedings, 2002.
[20] H. Akagi, "Modern active filters and traditional passive filters," 2006.
[21] S. Bhattacharyya, "Power quality requirements and responsibilities at the point of connection," Technische Universiteit Eindhoven, 2011.