Harmonic Assessment in Jordanian Power Grid Based on Load Type Classification

EYAD ALMAITA
Electrical Power and Mechatronics Engineering Department
Tafila Technical University
Tafila, Jordan
eyad.k.almaita@gmail.com

Abstract: The demand of efficient power converters lead to the proliferation of nonlinear loads in the power system. These nonlinear loads cause a serious problems that affect the power quality in both transmission and distribution systems. One of the major Power quality problems is Harmonic pollution. Understanding and quantifying the harmonics level in electrical power grid are crucial before proposing any successful method for mitigating harmonics problems in the grid. In this paper, the harmonics level in Jordan Low-Voltage Electrical Power Grid (JLVEPG) is investigated. The loads are divided into five categories: : (i) industrial loads, (ii) commercial loads, (iii) hospital loads, (iv) residential loads, and (v) office loads. Assuming each category will inject similar harmonics in the grid, which will facilitate harmonic assessment in the power system. Also, this categorization of the loads will make proposing harmonic mitigation solutions much easier. A field measurement for the major electrical units (Voltages, currents, and power) in JLVEPG is carried out for different locations in multiple cities. These measurements are followed by data analysis techniques in order to identify the total harmonic distortion (THD), the most dominant harmonic in each load category, and the harmonic power as a ratio to the active power.

Key-Words: Power quality, harmonics, distortion, harmonic assessment, Jordan, THD

1 Introduction

Recently, the power quality term has received more attention from both electric utility and electrical power customers. Several factors have brought power quality problems to the attention of utilities and customers; the more sensitive load equipment to power variation, the increasing harmonics level in power system, the increasing awareness of customers about power quality issues, and the network interconnection that magnify the impact of the failure of any network components. A suitable definition of power quality problem could be any deviation of voltage, current, and/or frequency that cause failure or misoperation of electrical equipment [1]. Harmonic pollution has become a serious problem that affects the quality of power in both transmission and distribution of power systems because the proliferation of nonlinear loads. The problems caused by harmonics include malfunctioning of fuses or circuit breaker relays, heating of conductors and motors, insulation degradation, and communication interference [2-5]. Because of these problems, harmonics mitigation in power system has become one of the most challenging problems in power system.

The research in harmonic distortion in power system can be divided into three parts: (I) Harmonics definition and the problem associated with harmonics and it is effect on power system and other sensitive loads [2-5]. (II) Harmonic assessment in the power system networks using measurements tools [5]-[6]. (III) Harmonic estimation using time domain techniques (Low pass, high pass and bass band filters) , frequency domain techniques (FFT and wavelet), and artificial intelligent techniques (Neural networks and fuzzy logic) [9-13]. (IV) Harmonics mitigation methods, which can be passive filters [14]-[15], active power filters [16][20], and hybrid filters [21].

Harmonic assessment is considered the first step needed to be done to improve the power quality in Jordan distribution grid. Once this step is done then a methodology to mitigate the harmonic distortion in the power system can be selected. Till now, the harmonics level in the Jordanian electrical grid has not been studied or assessed. This assessment is extremely important to be done nowadays in Jordan because it will help reducing the energy bill for Jordan. Also, it will help to develop the proper regulations, which will govern the permissible amount of harmonics that can be injected to the grid by a given costumer.

This paper will study and assess the harmonic level in Jordan Low-Voltage Electrical Power Grid

(JLVEPG). This assessment will be done through site measurements for the major electrical units (Voltages, currents, and power) in JLVEPG for different locations in multiple cities. These measurements will be followed by data analysis techniques in order to identify the total harmonic distortion (THD), the most dominant harmonic in each load category, and the harmonic power as a ratio to the active power.

2 Problem Formulation

The harmonic assessment in power system can be simplified by classifying the harmonic sources into finite classes. This classification is based on the load category, assuming each load category will mostly have the same types of loads, and these loads will inject approximately the same harmonic pollution type into the grid.

This paper classify the loads into five distinct load categories: (i) industrial loads, (ii) commercial loads, (iii) hospital loads, (iv) residential loads, and (v) office loads.

The total harmonic distortion and the dominant harmonic will be measured and used as indications for the harmonic pollution in power system.

2.1 Definitions of measured parameters:

- **Fundamental frequency:** Refers to the power source frequency which is usually 50 Hz or 60 Hz.
- **Dominant Harmonic:** Refers to the harmonic order with greatest magnitude [14].
- **Total Harmonic Distortion (THD):** The ratio of the root-square for the sum of the square values of all the harmonics to the root-mean-square (rms) value of the fundamental component [12, 13].

$$\boldsymbol{THD_V = \frac{\sqrt{\sum_{n=2}^{\infty} V_n^2}}{V_1}}$$

$$\boldsymbol{THD_I = \frac{\sqrt{\sum_{n=2}^{\infty} I_n^2}}{I_1}}$$

Where :

THD_V= the voltage total harmonic distortion

THD_I= the current total harmonic distortion

V_1= the voltage fundamental component.

I_1= the current fundamental component.

V_n= the n^{th} voltage harmonic.

I_n= the n^{th} current harmonic.

2.1.1 Data collection and analysis scheme

The methodology of this paper includes:

1. Data aggregation through site measurements for the major electrical quantities such as voltages, currents, active power, and reactive power.

The data aggregation will be done as follows:

A. At first three cities will be chosen that consume the major portion of electrical power in Jordan , the proposed cities are:
   - City#1: represents the city with the highest number of population
   - City#2: represents the city with industrial base.
   - City#3: represents a city that contains an installed solar power project.

B. Different locations at each city will be chosen in order to measure the major electrical quantities (mentioned above), these locations will includes industrial facilities, malls, residential buildings, and governmental buildings, etc.

C. The measurements will be carried out by a Three-Phase Power recorder through different times, days, months, and years.

2. Data analysis through state of the art data mining techniques, which include time domain, frequency domain, and statistical techniques. The data analysis will show the following:
   A. The total harmonic distortion in the electrical grid, this can be identified using frequency domain analysis such as fast Fourier transform.
   B. The most dominant harmonic in the electrical grid, this can be identified using frequency domain analysis such as fast Fourier transform.
   C. Determine the amount of harmonics injected by each type of facilities (industrial, commercial, residential, and governmental), this can be identified by relates the data collected from each facility with the total harmonic distortion level at that one.
   D. Statistical analysis will be carried out to evaluate the growth rate of the total harmonic distortion in the grid.

3 Results

- All the measurements in this research is carried out by Fluke 435-II/437-II Three Phase Energy and Power Quality Analyzer.
- All the harmonic analysis is based on FFT algorithm. The FFT algorithm in accordance with IEC 61000-4-7 is used to calculate the fundamental and harmonic components of each input signal over a 10 cycle (50 Hz) time window.

Tables *1-3* show the THD for the voltage waveforms for the two cities. The THD for different load types was calculated for three phase voltages and the neutral to ground voltage. Each value represents the average value for different measurements. It can be seen that there is abig similarity in the THD level fror most of the load types between the city#1 and city#2. But as it can been seen city#3 has similar values only for the hospital and residential loads. On the other hand, Tables 4-6 show the THD for the Current waveforms. Each value represents the weighted average value for different measurements. The first notes in these tables are the high values for the THDs in the neutral current, which may explain the high distortion in the neutral to ground voltages. Also there is a similarity in the THD values of the phase’s currents. For example, most of the THD values of the phase’s currents for the residential loads concentrate around the 4-5% level. On the other hand, there is a big difference in the THD values for the industrial loads, which reflect the differences in these industries.

Table 1 THD for the voltage waveform, three phase plus neutral/ City #1

load Type	**THD V AN Avg**	**THD V BN Avg**	**THD V CN Avg**	**THD V NG Avg**
Comm.	1.254	1.375	1.375	14.340
Office	1.310	1.311	1.290	134.198
Hosp.	1.691	1.619	1.642	238.459
Indus.	1.163	1.155	1.221	82.755
Resid.	1.340	1.336	1.327	84.723

Table 2 THD for the voltage waveform, three phase plus neutral/ City #2

load Type	**THD V AN Avg**	**THD V BN Avg**	**THD V CN Avg**	**THD V NG Avg**
Comm.	1.812	1.993	2.167	151.103
Office	1.195	1.189	1.148	150.286
Hosp.	1.079	1.104	1.031	78.695
Indus.	1.883	1.917	1.919	60.705
Resid.	0.980	0.951	0.882	142.095

Table 3 THD for the voltage waveform, three phase plus neutral/ City #3

load Type	**THD V AN Avg**	**THD V BN Avg**	**THD V CN Avg**	**THD V NG Avg**
Comm.	39.771	39.764	39.984	50.610
Office	50.604	50.571	50.586	184.746
Hosp.	1.054	1.134	1.163	76.791
Indus.	4.272	4.152	4.413	115.475
Resid.	1.703	1.618	1.536	151.204

Table 4 THD for the Current waveform, three phase plus neutral/ City #1

load Type	**THD A A Avg**	**THD A B Avg**	**THD A C Avg**	**THD A N Avg**
Comm.	5.074	5.306	8.994	147.114
Office	9.906	9.924	8.763	107.006
Hosp.	8.432	7.822	7.469	11.674
Indus.	5.795	5.605	8.209	26.626
Resid.	4.452	4.975	5.100	48.693

Table 5 THD for the Current waveform, three phase plus neutral/ City #2

load Type	THD A A Avg	THD A B Avg	THD A C Avg	THD A N Avg
Comm.	10.355	12.559	13.366	158.169
Office	4.638	6.504	4.866	72.527
Hosp.	4.548	4.318	2.780	51.951
Indus.	5.615	5.707	5.751	91.364
Resid.	9.545	10.318	12.752	63.303

Table 6 THD for the Current waveform, three phase plus neutral/ City #3

load Type	THD A A Avg	THD A B Avg	THD A C Avg	THD A N Avg
Comm.	4.768	3.671	4.790	102.094
Office	0.602	0.675	0.506	2.507
Hosp.	5.041	5.064	4.185	101.302
Indus.	31.613	30.869	31.623	32.997
Resid.	4.021	3.272	6.486	41.724

Tables 7-9 show the Most Dominant Harmonic in the Voltage Waveforms for different cities. It can be noticed that the fifth harmonic is dominant in the phase voltages, while the dc value is the dominant in the neutral-ground voltage. Tables 10-12 show the Most Dominant Harmonic in the current waveforms for different cities. It can be noticed that the third harmonic is dominant in the phase's currents, while the third harmonic is the dominant in the neutral current. Also, it easily can be noticed the similarity in the dominant harmonics for each load category for the three cities. This will help designing the power filters (passive or active) that will be used to mitigate the harmonic pollution in the power system.

Table 7 Most Dominant Harmonic in the Voltage Waveform, Three Phase plus Neutral/ City #1

Voltage Dominant Harmonic	Phase A	Phase B	Phase C	N
Comm.	5	5	5	0
Office	5	5	5	3
Hosp.	7	7	7	0
Indus.	7	7	7	0
Resid.	5	5	5	0

Table 8 Most Dominant Harmonic in the Voltage Waveform, Three Phase plus Neutral/ City #2

Voltage Dominant Harmonic	Phase A	Phase B	Phase C	N
Comm.	3	3	3	3
Office	5	5	5	0
Hosp.	5	5	5	3
Indus.	5	5	5	0
Resid.	5	5	7	0

Table 1 Most Dominant Harmonic in the Voltage Waveform, Three Phase plus Neutral/ City #3

Voltage Dominant Harmonic	Phase A	Phase B	Phase C	Neutral
Comm.	0	0	0	0
Office	0	0	0	7
Hosp.	5	5	5	9
Indus.	5	5	5	0
Resid.	5	5	5	9

Table 10 Most Dominant Harmonic in the Current Waveform, Three Phase plus Neutral/ City #1

Current Dominant Harmonic	**Phase A**	**Phase B**	**Phase C**	**N**
Comm.	3	3	3	3
Office	3	3	3	3
Hosp.	3	3	3	0
Indus.	7	7	3	3
Resid.	3	3	3	3

Table 11 Most Dominant Harmonic in the Current Waveform, Three Phase plus Neutral/ City #2

Current Dominant Harmonic	**Phase A**	**Phase B**	**Phase C**	**N**
Comm.	3	3	3	3
Office	3	3	3	3
Hosp.	3	3	5	3
Indus.	5	5	5	3
Resid.	3	3	3	3

Table 12 Most Dominant Harmonic in the Current Waveform, Three Phase plus Neutral/ City #3

Current Dominant Harmonic	**Phase A**	**Phase B**	**Phase C**	**N**
Comm.	3	3	3	3
Office	0	0	0	0
Hosp.	3	3	3	3
Indus.	5	5	5	3
Resid.	5	5	3	3

Fig. 1-3 show Active Power consumed Due to the harmonics relative to the Active power consumed by the fundamental component. The figures show this ratio for each of the load types and for each city. It can be seen that there is a similarity in the pattern and the percentage between each of load type for the three cities. All these consumed harmonic powers are considered as waste and it is harmful to the electrical power system.

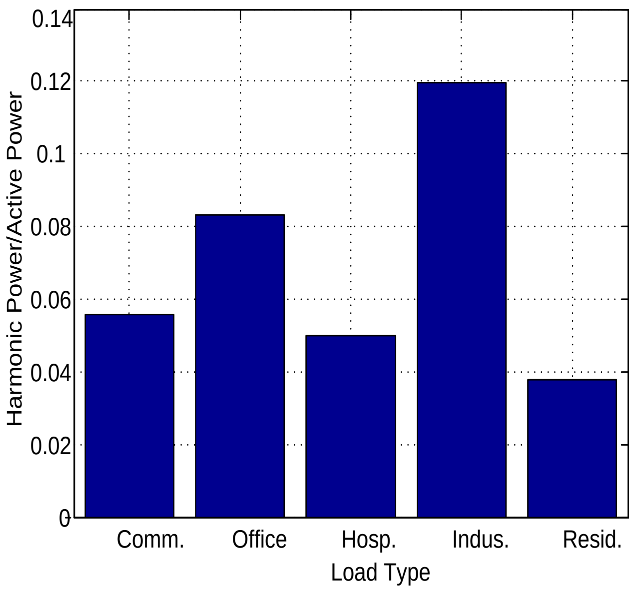

Fig. 1 Active Power consumed Due to the harmonics Relative the Active power consumed by the fundamental component /City#1

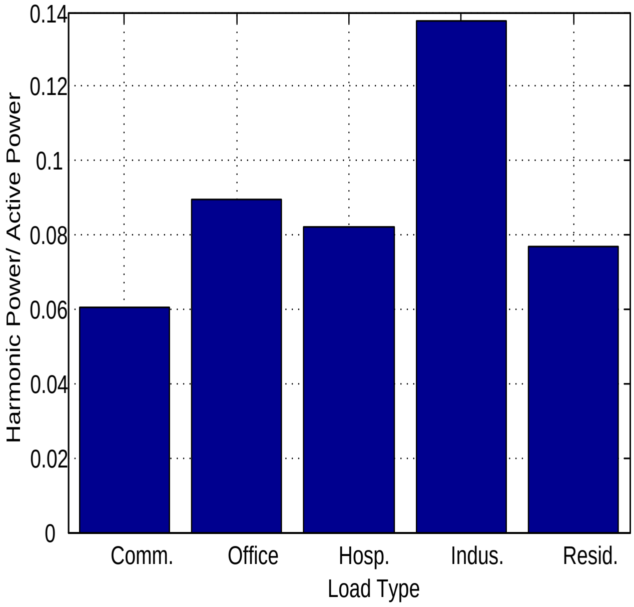

Fig. 2 Active Power consumed Due to the harmonics Relative the Active power consumed by the fundamental component /City#2

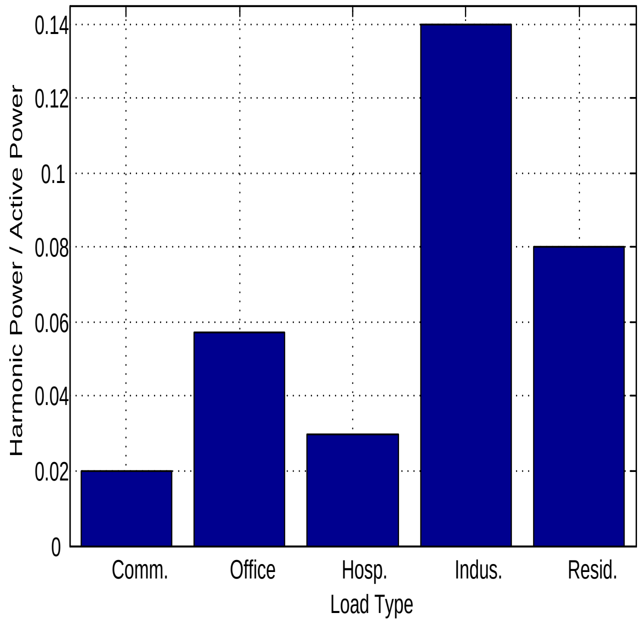

Fig. 3 Active Power consumed Due to the harmonics Relative the Active power consumed by the fundamental component /City#3

4 Conclusion

In this Paper, the harmonics level JLVEPG was investigated. Field measurements for the major electrical units in JLVEPG are carried out for different locations in multiple cities. These measurements are followed by extensive data analysis techniques in order to identify the total harmonic distortion (THD), the most dominant harmonic in each load category, and the harmonic power as a ratio to the active power. The electrical loads were categorized into five sectors which are: commercial, governmental, hospital, industrial, and residential. The harmonics pollution levels in many of these sectors are exceeding the national and international standard. Also The results show similarity in the THD level, dominant harmonic, and the harmonic power to the active power ration between loads with same load category. This paper is part of research to measure the harmonic level in four cities. The picture will be complete at the end of this research.

Acknowledgment

This research was supported by Scientific Research Support Fund (SRSF) in Jordan.

References:

1. Almaita, E. and Asumadu, J., “Radial Basis Function Neural Networks (RBFNN) and p-q Power Theory based Harmonic Identification in Converter,” *JOURNAL OF POWER ELECTRONICS, vol. 11, pp. 922-930, Nov, 2011*
2. Almaita, E.; Asumadu, J.A.; , "On-line harmonic estimation in power system based on sequential training radial basis function neural network," *Industrial Technology (ICIT), 2011 IEEE International Conference on* , vol., no., pp.139-144, 14-16 March 2011
3. Almaita, E.; Asumadu, J.A.; , "Dynamic harmonic identification in converter waveforms using radial basis function neural networks (RBFNN) and p-q power theory," *Industrial Technology (ICIT), 2011 IEEE International Conference on* , vol., no., pp.133-138, 14-16 March 2011.
4. Tang, Junchaojie, et al. "DC-Side Harmonic Mitigation in Single-Phase Bridge Inverter." *Industrial Informatics-Computing Technology, Intelligent Technology, Industrial Information Integration (ICIICII), 2015 International Conference on*. IEEE, 2015.
5. Sumaryadi, H. Gumilang and, and A. Suslilo, "Effect of power system harmonic on degradation process of transformer insulation system," *in Properties and Applications of Dielectric Materials, ICPADM 2009. IEEE 9th International Conference on the*, pp. 261-264, 2009.
6. Dysko, Adam; Burt, G.M.; McDonald, James R.; Hunter, Ian B B, "Assessment of harmonic distortion levels in LV networks with increasing penetration levels of inverter connected embedded generation," *Electricity Distribution, 2005. CIRED 2005. 18th International Conference and Exhibition on* , vol., no., pp.1,5, 6-9 June 2005
7. Kocewiak, L.H.; Hjerrild, J.; Bak, C.L., "The impact of harmonics calculation methods on power quality assessment in wind farms," *Harmonics and Quality of Power (ICHQP), 2010 14th International Conference on* , vol., no., pp.1,9, 26-29 Sept. 2010

8. Barros, J.; de Apraiz, M.; Diego, R.I., "On-line monitoring of electrical power quality for assessment of induction motor performance," *Electric Machines and Drives Conference, 2009. IEMDC '09. IEEE International* , vol., no., pp.1140,1145, 3-6 May 2009
9. Ahmed, E.E.; Xu, W., "Assessment of harmonic distortion level considering the interaction between distributed three-phase harmonic sources and power grid," *Generation, Transmission & Distribution, IET* , vol.1, no.3, pp.506,515, May 2007
10. H. Akagi, "New trends in active filters for power conditioning," *IEEE Trans. Ind. Appl.*, Vol. 32, pp. 1312-1322, Nov./Dec. 1996.
11. M. El-Habrouk, M. K. Darwish, and P. Mehta, "Active power filters: a review," *Electric Power Applications, IEE Proceedings* , Vol. 147, pp. 403-413, 2000.
12. T. C. Green and J. H. Marks, "Control techniques for active power filters," *Electric Power Applications, IEE Proceedings,* Vol. 152, pp. 369-381, 2005.
13. B. Singh, K. Al-Haddad, and A. Chandra, "A review of active filters for power quality improvement," *IEEE Trans. Ind. Electron.,* Vol. 46, pp. 960-971, Oct. 1999.
14. G. W. Chang, C.-I. Chen and Y.-F. Teng, "Radial-Basis-Function-Based Neural Network for Harmonic Detection," *IEEE Trans. Ind. Electron.,* Vol. 57, pp. 2171-2179, Jun. 2010.
15. Pandi, V.R.; Zeineldin, H.H.; Weidong Xiao, "Passive harmonic filter planning to overcome power quality issues in radial distribution systems," *Power and Energy Society General Meeting, 2012 IEEE* , vol., no., pp.1,6, 22-26 July 2012
16. Nassif, A.B.; Wilsun Xu, "Passive Harmonic Filters for Medium-Voltage Industrial Systems: Practical Considerations and Topology Analysis," *Power Symposium, 2007. NAPS '07. 39th North American* , vol., no., pp.301,307, Sept. 30 2007-Oct. 2 2007
17. Virmani, R.; Gaur, P.; Santosi, H.; Mittal, A.P.; Singh, B., "Performance comparison of UPQC and Active Power Filters for a non-linear load," *Power Electronics, Drives and Energy Systems (PEDES) & 2010 Power India, 2010 Joint International Conference on* , vol., no., pp.1,8, 20-23 Dec. 2010
18. Fang Zheng Peng, "Application issues of active power filters," *Industry Applications Magazine, IEEE* , vol.4, no.5, pp.21,30, Sep/Oct 1998 doi: 10.1109/2943.715502
19. Huang, S.J.; Wu, J. -C, "Design and operation of cascaded active power filters for the reduction of harmonic distortions in a power system," *Generation, Transmission and Distribution, IEE Proceedings-* , vol.146, no.2, pp.193,199, Mar 1999
20. Corasaniti, V.F.; Barbieri, M. B.; Arnera, P.L.; Valla, M.I., "Comparison of active filters topologies in medium voltage distribution power systems," *Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, 2008 IEEE* , vol., no., pp.1,8, 20-24 July 2008
21. Pereira, R.R.; da Silva, C.H.; da Silva, L.E.B.; Lambert-Torres, G.; Pinto, J. O P, "New Strategies for Application of Adaptive Filters in Active Power Filters," *Industry Applications, IEEE Transactions on* , vol.47, no.3, pp.1136,1141, May-June 2011