Harmonic Assessment in Jordanian Low-Voltage Electrical Power Grid

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Abstract: With the proliferation of nonlinear loads in the power system, harmonic pollution becomes a serious problem that affects the power quality in both transmission and distribution systems. 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, this will make the harmonic assessment in the power system is easier and help proposing harmonic mitigation solutions. 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) and the most dominant harmonic in each load category.

Key-Words: Power quality, harmonics, distortion, harmonic assessment, dominant harmonic, 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 [2-4]. 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]-[4]. (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) [7]-[8]. (IV) Harmonics mitigation methods, which can be passive filters [9], active power filters[10], and hybrid filters [11].

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), and the most dominant harmonic.

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].

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

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

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 two 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

   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 *1-2* 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. On the other hand, Tables 3-4 show the THD for the Current waveforms. Each value represents the weighted average value for different measurements.

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 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

Tables 5-6 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. Tables 7-8 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 currents. Also, it easily can be noticed the similarity in the dominant harmonics for each load category for the two cities. This will help in designing the power filters (passive or active) that will be used to mitigate the harmonic pollution in the power system.

Table 4 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 5 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 6 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 7 Most Dominant Harmonic in the Current Waveform, Three Phase plus Neutral/ City #1

Current Dominant Harmonic	Phas e 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 8 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

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. 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 and dominant harmonic between loads with same load category. This paper is part of research to measure the harmonic level in four cities. The picture will completer at the end of this research.

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