Portland State University
Electrical & Computer Engineering
EE 347 Power Systems I

- Lab 3: Harmonic Analysis-

Introduction

This lab explores the phenomena of harmonics induced by nonlinear single- and three-phase loads. Students use a Tektronix PA4000 Power Analyzer to observe harmonics and study their characteristics. Students investigate the harmonic content of several types of nonlinear loads, calculate harmonic distortion, calculate several metrics of power factor and make observations of distorted waveforms within both hot and neutral lines. Students also consider the impacts that harmonics may have on the sizing of and voltage drop across conductors.

Prior to watching the demonstration video, please read the "Getting Started" and "Front Panel Operation" sections of the PA4000 Power Analyzer user's manual, which is posted within Canvas. Please read this document ahead of time so as to be better prepared to follow the laboratory procedures.

Objectives

Students learn:

- how harmonics arise from different loads and in different configurations
- to characterize harmonic currents as spectral components
- to quantify harmonic distortion and various measures of power factor
- the causes of harmonic currents in the neutral line of balanced three-phase loads.

Analyze and interpret data, and draw conclusions

Develop engineering documentation:

- One-line diagram
- Bill of materials
- Points list

Part 1: Circuit Build and Data Gathering

1.1 Single Phase Nonlinear Loads

Prepare the test bench for measurements.

1. Connect one metal junction load box to the 8821 power supply in a single phase configuration.
2. Connect Channel 1 of the PA4000 between the load and the supply using a "single-phase, two wire" configuration and the 1 A current channels.

Configure the PA4000 to measure V_{ϕ}, I_{Line}, P_L, Q_L, S_L, PF, THD_V , THD_I, and the current and voltage of the first 21 harmonics.

1. Input-Wiring-Configuration to "1 Phase 2 Wire."
2. Input-Shunts to 1 A.
3. Input-Scaling-Volts & -Amps to 1.0.

Refer to the PA4000 user's manual, posted within the ECE 347 D2L site.

Use the PA4000 to measure harmonics of single-phase loads. Begin by measuring the harmonic content of a linear load: an incandescent light bulb.

1. Plug a 60 W incandescent bulb into the non-dimmer receptacle of the junction box.
2. Follow the lock-out/tag-out start-up procedure.
3. Energize the circuit.

4. Use the PA4000 'wave' screen to observe the waveform of the current and voltage.
5. Use the 'bar' and 'results' screens to observe the spectral content of the current and voltage fundamental and harmonics, if present.
6. Record measurements.

Measure the harmonic content of a non-linear load: an incandescent light bulb controlled through a dimmer switch.

1. Plug the same incandescent bulb into the dimmer receptacle of the junction box.
2. Vary the dimmer pot through its full range, stopping at three points to take measurements.
3. Using the PA4000 'wave' screen, observe the effect of the dimmer switch on the waveform of the load current.
4. Note observations as a function of dimmer position.
5. Observe the spectral content of the current and voltage to the 21st harmonic.
6. Record measurements at two positions of the dimmer switch.

Measure the harmonic content of another non-linear load: a compact fluorescent light bulb (CFL).

1. Plug the same CFL bulb into the non-dimmer receptacle of the junction box.
2. Using the PA4000 'wave' screen, observe the waveform of the load current.
3. Observe the spectral content of the current and voltage out to the 21st harmonic.
4. Record measurements.
5. De-energize the circuit
6. Follow the lock-out/tag-out shut-down procedure.

1.2 Three Phase Non-linear Loads

Prepare the test bench for measurements.

1. Connect three metal junction load boxes to the 8821 power supply in a three phase Wye configuration.
2. Connect Channels 1 through 3 to monitor the loads using a "three-phase, four wire" configuration. Group B.
3. Connect Channel 4 to monitor the current in the neutral line as it returns to the power supply. Group A.
4. Use the 1 A current channels.

Configure the PA4000 to measure V_{ϕ}, I_{Line}, P_L, Q_L, PF, THD_V , THD_I, and the current and voltage of the first 21 harmonics.

1. Set Input-Wiring-Configuration to "3 Phase 4 Wire" for Group A
2. Set Input-Wiring-Configuration to "1 Phase 2 Wire" for Group B.
3. Configure Group A to measure all phase voltages and line currents, P_L Q_L, S_L PF, THD_V, THD_I, and the current and voltage of the first 21 harmonics.
4. Configure group B to monitor I_N and the current of the first 21 harmonics. Set Input-Shunts to 1 A.
5. Set Input-Scaling-Volts and -Amps to 1.0.

Measure the harmonic content of a linear load: incandescent light bulbs.

1. Plug 60 W incandescent bulbs into the non-dimmer receptacles of the junction boxes.
2. Follow the lock-out/tag-out start-up procedure.
3. Energize the circuit.
4. Observe the waveforms of the current and voltage in the hot and neutral lines.
5. Record measurements.

Measure the harmonic content of a non-linear load: CFLs

1. Plug CFLs into the non-dimmer receptacles.
2. Observe the waveform and spectral content of the currents and voltages.
3. Record measurements
4. De-energize the circuit
5. Follow the lock-out/tag-out shut-down procedure.

Part 2. Data Analysis and Interpretation, Drawing Conclusions

For the Single Phase circuits,

1. For the incandescent, dimmer (3 positions) and CFL cases, calculate power factors: true, distortion and displacement. Which power factor does the PA4000 display?
2. Verify the PA4000's calculations of harmonic distortion (THD_I, THD_V).
3. Summarize measurements and calculations using tables and/or plots.
4. Comment on and explain the leading or lagging nature of the three loads.
5. Consider the RMS current that would arise in the neutral if these loads were connected in a balanced three phase configuration. Calculate this current for each of the three cases.
6. What does the dimmer do and how does it do it?

For the Three phase circuits,

1. Compare the measurements of the RMS current in the neutral with the calculations made in Part 2 Task 5.
2. Consider the harmonic content of the neutral current for each of the load cases. Comment.
3. What is the frequency of the dominant current harmonic in the neutral line? Considering the frequency dependence of the reactance of the line, what implications does that frequency have regarding voltage drop within the neutral?
4. Calculate the current expected in the neutral line when loading is unbalanced; consider the case studied above with one and two incandescent bulbs plugged in. Compare calculations with measurements.

Part 3. Engineering Documentation Deliverables

Prepare a brief report discussing the data analysis, interpretations, and conclusions. The report shall also include the following deliverables.

For the three-phase harmonics demonstration, prepare the following documents

1. One-line diagram of the test bench.
2. BoM of equipment and supplies used in the demonstration.
3. Points lists for each of the equipment used in the demonstration.

An example points list is posted within Canvas.

The report shall be submitted via Canvas as a single pdf file.