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SOAH DOCKET NO. 479-20-1118
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COMPLAINT OF PETTY GROUP, LLP	§	BEFORE THE STATE OFFICE
AGAINST RIO GRANDE ELECTRIC	§	
COOPERATIVE, INC.	§	OF
	§	
	§	ADMINISTRATIVE HEARINGS

DIRECT TESTIMONY AND EXHIBITS

OF

AMBER CONRAD

ON BEHALF OF

RIO GRANDE ELECTRIC COOPERATIVE, INC.

May 11, 2020

114

SOAH DOCKET NO. 473-20-1118
PUC DOCKET NO. 49795

DIRECT TESTIMONY AND EXHIBITS OF

AMBER CONRAD

Exhibit A	Résumé of Amber Conrad
Exhibit B	RGEC Timeline of Events
Exhibit C	Power Monitors, Inc. (PMI) White Paper(s)
Exhibit D	Petty Electrician Shared Data

DIRECT TESTIMONY AND EXHIBITS OF AMBER CONRAD

ON BEHALF OF

RIO GRANDE ELECTRIC COOPERATIVE, INC.

I. PROFESSIONAL TRAINING AND EXPERIENCE

Q. PLEASE STATE YOUR NAME AND BUSINESS ADDRESS.

A. My name is Amber Conrad. I am employed by Rio Grande Electric Cooperative, Inc. ("RGEC" or "Rio Grande") My business address is 778 E US Hwy 90, Brackettville, TX 78832.

Q. WHAT IS YOUR PRESENT POSITION?

A. I am a Project Manager for RGEC.

Q. PLEASE STATE YOUR EDUCATIONAL BACKGROUND AND PROFESSIONAL EXPERIENCE.

A. I have an Associates of Applied Science in Computer Drafting and Design from ITT Technical Institute San Antonio Texas. I also have a Bachelor's of Science in Project Management from ITT Technical Institute San Antonio Texas. I am currently a full time student enrolled with DeVry Universities Keller Graduate School of Management working on a Master's in Business Administration with a concentration in Project Management. My professional experience is outlined in **Exhibit A**. I have also participated in numerous webinars by various associations on topics related to the utility industry and completed training from PMI on harmonics and metering.

II. INTRODUCTION

Q. WHAT WAS YOUR ASSIGNMENT IN THIS PROCEEDING?

A. Having 4+ years of Cooperative experience at the time, I was appointed project manager of RGEC's harmonic investigative efforts. I took on the project management role of the project life cycle oversight. This oversight included meeting coordination, scheduled outage coordination, data compilation, and was RGEC's main contact when it came to external communications with RGEC consultants and RGEC members. In addition to providing project management support, I attended and participated in harmonic and power quality related workshops and technical trainings.

Q. WHAT IS THE SCOPE OF YOUR TESTIMONY?

A. My testimony will address RGEC's timeline of events that documents the investigative efforts of the internal task force.

Q. HOW DID RGEC TRACK INVESTIGATIVE EFFORTS OF ITS INTERNAL TASK FORCE?

A. Because RGEC was dedicating such a substantial amount of resources to the harmonics investigative efforts, general ledgers (GL) were utilized for tracking purposes.

Q. HOW MANY HOURS ARE CODED TO DATE TO THE GENERAL LEDGERS UTILIZED TO TRACK THE RGEC TASK FORCE'S HARMONIC INVESTIGATIVE EFFORTS?

A. As of 4/22/2019, a total of 2,513.05 hours have been coded to RGEC's 558.2 (Miscellaneous District Office Expenses – Carrizo) and 586.2 (Meter Expenses – Carrizo).

Q. WOULD YOU PLEASE SUMMARIZE THE FACTS AND CONCLUSIONS THAT RESULTED FROM YOUR REVIEW AND ANALYSIS?

A. Yes. RGEC assembled an internal task force to investigate, identify and ensure member compliance with IEEE 519.

- A timeline outlining the actions taken by RGEC throughout the course of harmonic improvements on the Brundage Substation Feeder (1) is provide as **Exhibit B.**
- RGEC continually monitored the electric service to Petty Ranch. The data collection dates are outlined in **Exhibit B** (Preliminary Order Issue 6).
- I understand that Petty made the conclusion that RGEC was the source of excessive harmonics. After reviewing the testimony of Nathaniel Morgan, I learned that he engaged several contacts within the electrical industry and told them of the issues experienced at Petty Ranch in which, none of these contacts listed harmonics as a concern. Upon Nathan's borrowing of a recording instrument, it was connected to the low voltage side of the Petty Ranch service. The attached **Exhibit D** contains the current harmonic content captured by the borrowed instrument, data that was shared with RGEC's Area Operations Manager Mark Byrom. Petty later hired Grubb Engineering (Preliminary Order Issue 7).
- RGEC's analysis of the PMI recorded data from the Petty Ranch led to RGEC task force to determine that pulsing current was trending with Petty's current THD. Subsequently leading the RGEC task force to believe that something at the Petty Ranch was producing current harmonics as mentioned in **Exhibit B.** Therefore, member compliance with IEEE519 per RGEC's Tariff 323.3 is an RGEC requirement (Preliminary Order Issue 8).

III. HARMONICS

Q. DO YOU KNOW WHAT CAUSES HARMONICS?

A. I am not an expert on harmonics but during my research of harmonic contributors, reading through numerous Power Monitoring, Inc. (PMI) White Paper(s)[1], and consulting with

1 Please see Exhibit C.

subject matter experts it is my understanding that non-linear loads could present high harmonics. Non-linear loads can include variable frequency drives (VFD's), light dimmers, battery chargers, and LED lights.

Q. CAN HARMONICS BE CORRECTED SOLELY BY THE UTILITY?

A. According to subject matter experts on my task force, harmonics cannot be corrected solely by the utility. The current thresholds established by the IEEE 519 standard are limits that those customers connected to the grid must comply with for the loads they are connecting to the utility voltage. Increases in current distortion leads to increased voltage distortion. Because of this, the underlying premise behind the IEEE519 standard is that if all customers connected to the grid are compliant where current TDD limits are concerned, then the utility can meet their respective IEEE519 voltage limits. That has been my primary role in leading the task force of subject matter experts to ensure member compliance.

Q. IF RGEC MEMBERS CONNECTED TO THE GRID ARE NOT IEEE 519 COMPLIANT, COULD RGEC MEET ITS IEEE 519 VOLTAGE REQUIREMENTS?

A. No. The IEEE 519 standard current thresholds are limits that those customers connected to the grid must comply with for the loads they are connecting to the utility voltage.

Q. ARE YOU FAMILIAR WITH HOW LONG IT WOULD TAKE A UTILITY TO CORRECT VOLTAGE HARMONIC DISTORTIONS ON THE UTILITIES GRID?

A. No. However, in working closely with RGEC's due to the complex nature of harmonics, it is impossible to define a set timeline for corrective actions. As the utility and in the spirit of IEEE 519, RGEC is to work cooperatively with its members. However, in order to work cooperatively with its members, the non-compliant members must first be identified. This identification process for RGEC involved RGEC's development of engineering consultant requests (ECR's) to formalize consultant engagement, outline consultant requirements, and expectations. This process also involved consultant testing of multiple sites connected to the Brundage Substation Feeder (1). In addition to external consultant data acquisition, RGEC performed its own internal testing under differing operating conditions that entailed scheduled outages at multiple sites. However, in order to execute such outages, advanced coordination was warranted, as electric disruptions impact pipeline transportation and pipeline support related activities. Then, following identification of non-compliant member(s), member notice, comes a corrective action period in which harmonic filter applications may be explored. Harmonic filters are customized specific to the load and the current producing content of such load. Therefore, extensive lead times are typical. Following filter/harmonic mitigating equipment installation, the utility must then undergo a testing and re-commissioning process at each identified site to ensure IEEE 519 compliance. Normal operating load must be performed at the site for adequate testing. If a failure outcome is reached, filter tuning may be required where manufacturer re-engagement is necessary. For these reasons, it is impossible for the utility to: (1) immediately resolve harmonic issues, and (2) to gauge a timeline for when harmonics issues will be resolved, due to the ever-changing variables and challenges related to each specific offending sit (Preliminary Order Issue 9).

Q. HOW MANY SITES HAS RGEC MONITORED FOR HARMONICS ON THE BRUNDAGE SUBSTATION FEEDER (1)?

A. RGEC has monitored (25) different sites connected to the Brundage Substation Feeder (1).

Q. PLEASE DESCRIBE THE SERVICE LOAD TYPES RGEC MONITORED FOR HARMONICS.

A. RGEC's harmonic investigative efforts included industrial loads (oil and gas related), irrigation loads, and residential loads.

Q. ARE YOU FAMILIAR WITH HARMONIC FILTERS THAT CAN BE INSTALLED ON RESIDENTIAL LOADS?

A. Generally, RGEC would not be involved with equipment installed beyond our point of demarcation. However, as the task force has worked closely with consultants and our material alliance supplier, we have knowledge of filter manufacturers that have previously developed, and continue to develop, filters for residential customers.

Q. DID YOU EVER SEE DRYWALL CRACKS AT THE PETTY RANCH CASITAS?

A. No. A few RGEC representatives and I were at the Petty Ranch on March 6, 2019 for a site visit with Petty Representative Kyle Haley. Mr. Haley did not show up but we were able to access the casitas with the Petty contractors that were on site that day. I did not see any drywall cracks or damages at that time.

Q. DOES THIS CONCLUDE YOUR DIRECT TESTIMONY?

A. Yes, it does.

EXHIBIT A

Amber Conrad
36 Chandler Place | Brackettville, TX 78832
Phone: (830) 563-5724 | E-Mail: ambercastilla@yahoo.com

PROFESSIONAL PROFILE

- Project Manager with expertise in overseeing a diverse range of projects including industrial consumers as well as Government entities.
- Skilled at building and optimizing organizational processes, enhancing productivity, and maximizing financial control in the electrical distribution utility operations.
- Successful in developing and executing strategic plans, setting and administering budgets, and managing multiple ongoing projects from inception to successful completion.
- Develop key network relationships for enhancing contract performance and objectives.

SKILLS SUMMARY

- Project Planning/Execution
- Problem Solving
- Material Acquisition
- Financial Plan Development
- Cost and Budget Tracking
- Training and Leadership Development
- Strategic Planning and Leadership
- Decision Making
- Project Closeout/Reconciliation
- Change Management
- Revenue Goal/Growth Attainment
- Customer Satisfaction

EDUCATION

ITT Technical Institute-San Antonio, Texas
Associates of Applied Science in Computer Drafting and Design — June 2010

ITT Technical Institute-San Antonio, Texas
Bachelor of Science in Project Management — March 2012

Master of Business Administration (MBA) — Current
Keller Graduate School of Management – DeVry University

PROFESSIONAL EXPERIENCE

Rio Grande Electric Cooperative, Inc. — February 2017 - Present
Project Manager

Responsible for the management of a $22 million privatization contract to ensure contract compliance and successful operations. Facilitate the improvement of electrical distribution system by coordinating maintenance requirements and fulfilling renewals and replacements obligations. Orchestrate synergies to improve business processes and ensuring optimum performance is achieved. Deliver quality construction with integrity and professionalism to fulfill our obligation to meet the needs of those we serve while conducting financially successful projects.

Rio Grande Electric Cooperative, Inc. — June 2016 – February 2017
Interim Project Manager

Promoted by the CEO to develop and deploy a project management workflow to streamline strategic planning, setting and administering project budgets, and assist in the oversight of the project execution phase to meet short and long term contractual objectives. Participated in the operational restructuring to address business growth, reduce costs, and improve services.

Rio Grande Electric Cooperative, Inc. October 2014 – June 2016

Project Coordinator

Coordinated construction activities for Government electrical distribution projects as well as consumer engaged electrical requirements. Collaborated closely with clients, Project Manager, System Engineer, and Operations throughout the project lifecycle. Facilitated the project inception and design, materials acquisition, resource planning, and project closeout. Coordinated periodic meetings and site walk-throughs to discuss project progress, concerns, and safety compliance requirements.

Alpha Insulation and Waterproofing March 2010 – June 2010

Central Job Processing Technician

Under supervision, assisted in the development and maintenance of preliminary plans and the breakout of scopes of work consisting of waterproofing, caulking and moisture protection systems, insulation, and fireproofing for commercial and industrial construction projects. Communicated with the Quality Control supervisor to ensure that the appropriate information is given to the Project Manager, Architect, and Engineers throughout the design phase while practicing confidentiality with contracts. Collect data from various manufacturers and produce Material Safety Data Sheets (MSDS) to meet the Occupational Health and Safety Administration (OSHA) compliance.

EXHIBIT B

EXHIBIT C

EXHIBIT D

Amber Conrad
36 Chandler Place | Brackettville, TX 78832
Phone: (830) 563-5724 | E-Mail: ambercastilla@yahoo.com

PROFESSIONAL PROFILE

- Project Manager with expertise in overseeing a diverse range of projects including industrial consumers as well as Government entities.
- Skilled at building and optimizing organizational processes, enhancing productivity, and maximizing financial control in the electrical distribution utility operations.
- Successful in developing and executing strategic plans, setting and administering budgets, and managing multiple ongoing projects from inception to successful completion.
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Interim Project Manager

Promoted by the CEO to develop and deploy a project management workflow to streamline strategic planning, setting and administering project budgets, and assist in the oversight of the project

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WHITE PAPER:
UNDERSTANDING TOTAL HARMONIC DISTORTION

Contributed by Cowles Andrus September 2012

ABSTRACT

This paper discusses the causes of Total Harmonic Distortion, how it is calculated, measured, and how it can impact a power distribution system.

Total Harmonic Distortion (THD) can be a challenging concept because of the complexity of the power system and its many individual components. THD is better understood when a power system is defined by its simplest parts– the power source and load, as shown in Figure 1.

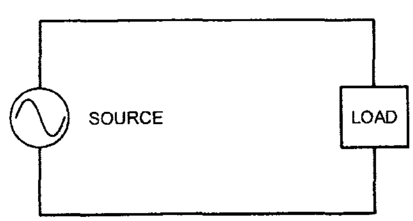

Figure 1. Most basic parts of a power system

Because the load affects the current draw on a system, the power quality of the system is often affected as well, depending on the type of load. Loads can be either linear or non-linear. A linear load draws current that is sinusoidal in nature and has smooth current and voltage transitions, so generally this does not distort the waveform as seen in Figure 2.

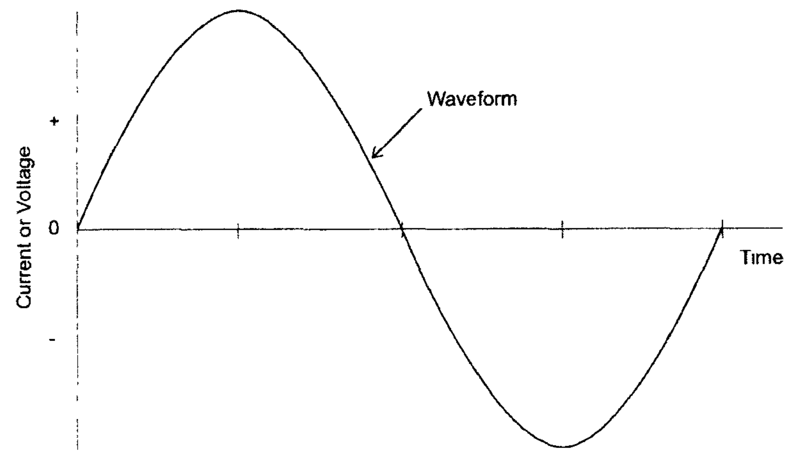

Figure 2. Ideal sine wave with a linear load provided to the source

Many home appliances such as electric hot water heaters, base board heat, irons, and incandescent lighting have mostly resistive loads, which are relatively linear. **Harmonic distortion is not usually caused by the power generation or distribution system itself and was not really an issue before 1960.** Around this point in time changes in technology began to contribute to changes in customer load. Non-linear components such as diodes and SCR (or thyristors) started to be incorporated into household devices and appliances.

Some devices that have been known to present **non-linear loads to the power grid include AC/DC converters, motor speed controls/light dimmers, adjustable frequency drives, copiers, battery chargers, UPS, and also items such as electric welders, electronic ballast, and arc furnace.** Higher energy efficiency lighting and government phasing out of incandescent light bulbs is driving consumers to replace old incandescent light bulbs with compact fluorescent lamps (CFL), light emitting diode (LED) and electron stimulated luminescence (ESL) type lighting. This type of lighting, while very energy efficient, does not provide a linear load such as incandescent light bulbs provide. In fact, the ESL beats out the energy efficiency of the CFL and LED hands down but has a power factor of 0.95 to 0.99 where the CFL and LED are in the 0.5 to 0.8 range. Another new source of harmonic distortion comes from variable motor speed controls currently being introduced in many high-efficient heat pumps. These non-linear devices present a non-linear load to the power source causing large distortions to the source waveform as shown in Figure 3.

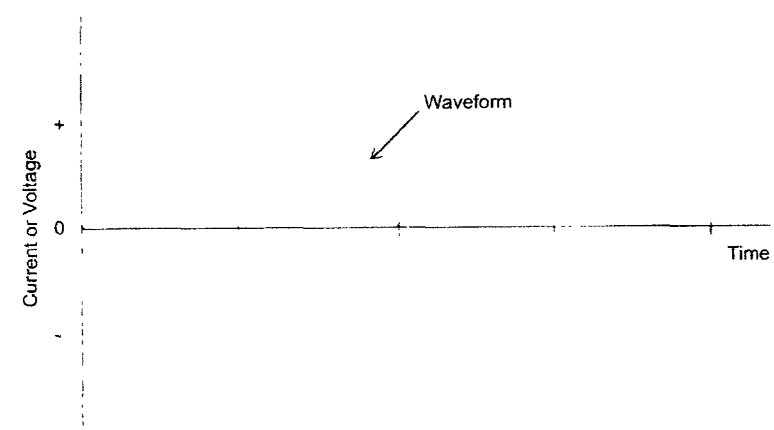

Figure 3. Distorted waveform caused by non-linear loads

Non-linear loads cause waveform distortion, drastically changing the shape of a power source's waveform. All sine waves are composed of harmonics which are multiples of the fundamental waveform. In the United States, the power line frequency is 60 Hz, so multiples of 60 Hz make up the sinusoidal power waveform. Harmonics can be defined as a steady state distortion of the *fundamental frequency (e.g. 60 Hz for power lines)*. It is important to point out that a sine wave is made up of both even and odd harmonics. Non-linear loads usually cause odd-order harmonics to be more pronounced and problematic in a power distribution system. This is because most electrical loads, except for half-wave rectifiers, produce symmetrical current waveforms. This means that the positive half of the waveform is a mirror image of the negative half. This results in only odd harmonic values being present. A half-wave rectifier can produce even harmonics in addition to the odd ones. The illustration shown in Figure 4 demonstrates the relationship between the fundamental and the odd harmonics caused by non-linear loads.

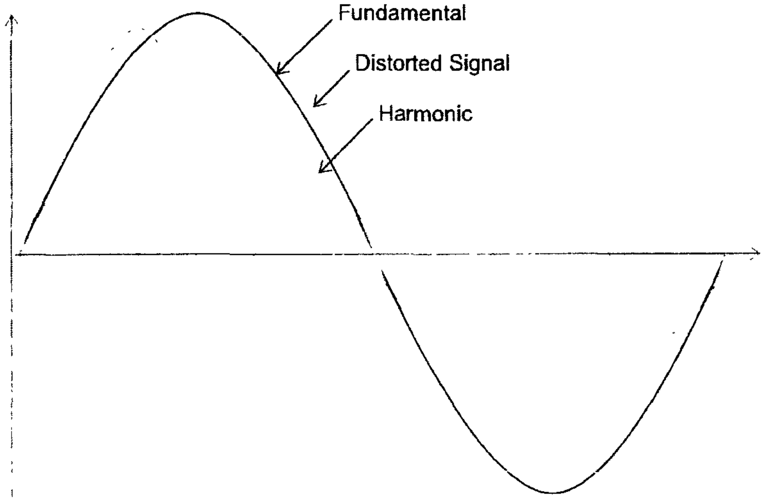

Figure 4. Relationship between the fundamental and odd order harmonics

Another factor that can sometimes cause an increase in harmonic problems are capacitor banks that are used to correct the power factor of inductive loads. If the capacitor resonance is at some multiple of the fundamental, it can actually magnify harmonic problems. Careful design and consideration is important when installing capacitor banks and it is also important to monitor THD and power factor because the inductive load may change from time to time as a result of new loads presented by customers.

The graph in Figure 5 shows the relationship of the fundamental frequency and some of the lower odd harmonics that add together to form the resultant.

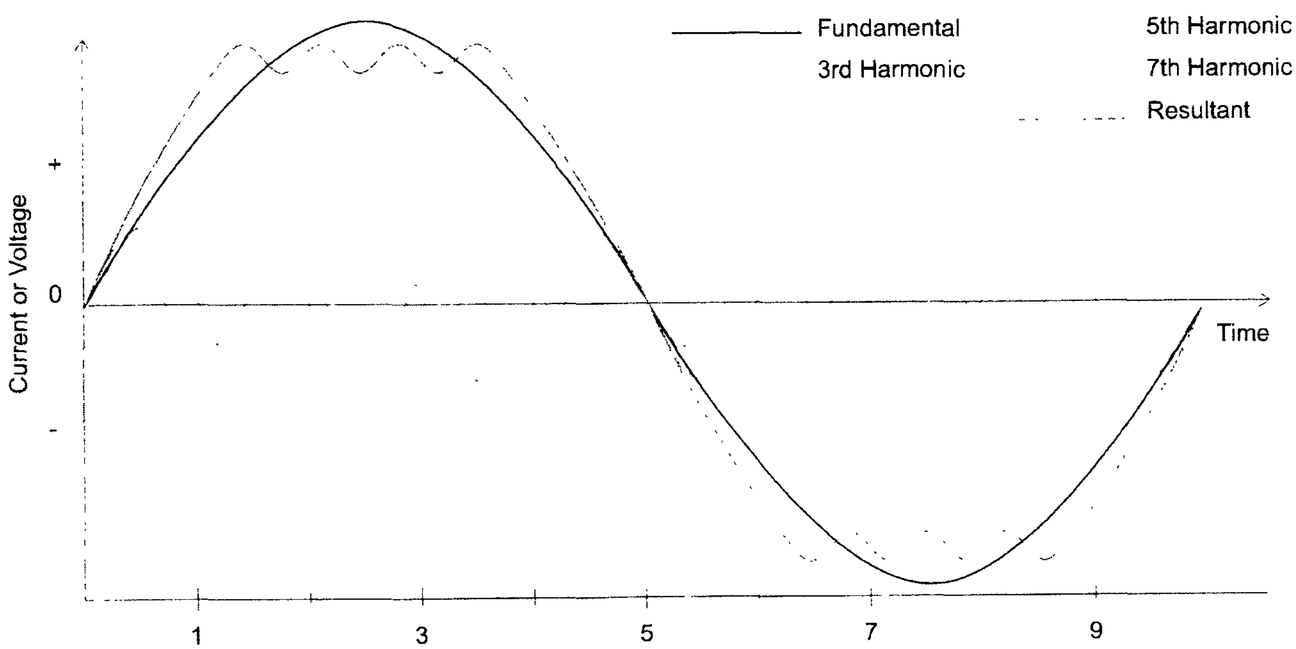

Figure 5. The relationship of the fundamental frequency and lower odd harmonics that add together to form the resultant

THD

Total harmonic distortion in reference to (F) fundamental represents the ratio, in percent, of the voltage/current harmonic components relative to the voltage/current of the fundamental. When the reference is not indicated (i.e. simply THD), then it is usually assumed the reference is fundamental and not THD-R which is a different measurement. For power systems, THD or THD-F is a better measurement to use. Below is an equation used to calculate THD where V_n is equal to the Magnitude of the nth harmonic.

$$THD = \frac{\sqrt{(V_2)^2 + (V_3)^2 + \dots + (V_\infty)^2}}{V_1}$$

One of the main reasons to measure THD and accurately assess its value is so the operator can evaluate and monitor the system's distortion level over time. This allows the operator to see what changes need to be made to the power system before the distortion levels elevate to a point where they could damage the system.

Some issues that high THD can cause are overheating transformers, issues with the proper operation of 3-phase motors, increase hysteresis losses, unacceptable neutral-to-ground losses, decreased kVA capacity, inaccurate power measurements, interference to communication systems such as telephone and radio, breaker tripping and fuse blowing, damage to capacitor banks, damage or interference to electronics, and the list goes on.

Technology and growth tend to progressively load the grid with more and more non-linear loads causing total THD to grow. It is very important to monitor the system to head off issues before they shut down the power system and result in damage to critical equipment. The increase in harmonic content may require some systems to be evaluated for proper transformer de-rating or upgrades to power distribution systems with K-rated transformers to reduce overheating or early-life failures.

With ProVision and most PMI recorders, accurate measurement can be taken and displayed on many facets of power quality including Total Harmonic Distortion. The ProVision default for THD is F or fundamental but if desired by the operator, THD-R can easily be displayed by right-clicking on THD-F while in the Harmonic Analysis Magnitude Graph mode. If more detail is needed on the harmonics, press the F key while the cursor is on the graph. This removes the fundamental frequency allowing the graph to scale making the smaller, higher harmonics clearly visible. This could be very useful in areas where THD presents an issue to power quality such as a power related-issue with a 3 phase motor overheating, or communication interference.

Figure 6 shows an example of a harmonic analysis report used to collect data on the LED lamp.

Harmonic Analysis Report

7 W LED 200 lumens bulb

Start: Apr 18, 2012 09:08:56
Stop: Apr 18, 2012 09:37:11
Duration: 0 days, 00:28:15
Firmware Version: 5.62 Unit Type: Revolution
Software Version: 0.00 Serial No.: 61277

Circuit Type: Wye
Voltage Scale Factor: x1.00
Current Scale Factor: x1.00
Current Range: 10 Amps
Interval Time: 1 second

Data computed from Waveform #1, 04/18/12, 09:08:55:33, starting point 1 (0.00 ms)
Harmonic phase refererence: Voltage channel one fundamental

	Vmag		Imag	
	Ch 1	Ch 2	Ch 1	Ch 2
THD, %Fundamental	2.21%	49.90%	144.2%	144.6%
THD, %Fund. Odds	2.21%	44.25%	143.7%	144.1%
THD, %Fund. Evens	0.11%	23.06%	12.73%	12.31%
THD, %Fund. Tnplens	1.78%	26.40%	101.9%	102.0%
THD, %RMS	2.21%	44.65%	82.18%	82.25%
THD, %RMS Odds	2.21%	39.60%	81.86%	81.95%
THD, %RMS Evens	0.11%	20.63%	7.25%	7.00%
THD, %RMS Tnplens	1.78%	23.62%	58.05%	58.00%
TIF	3.26%	37.44%	28.56%	28.82%
K-Factor	1.04%	228.5%	49.56%	49.55%

Magnitude

Figure 6. Example harmonic analysis report used to collect data from a Revolution on an LED lamp.

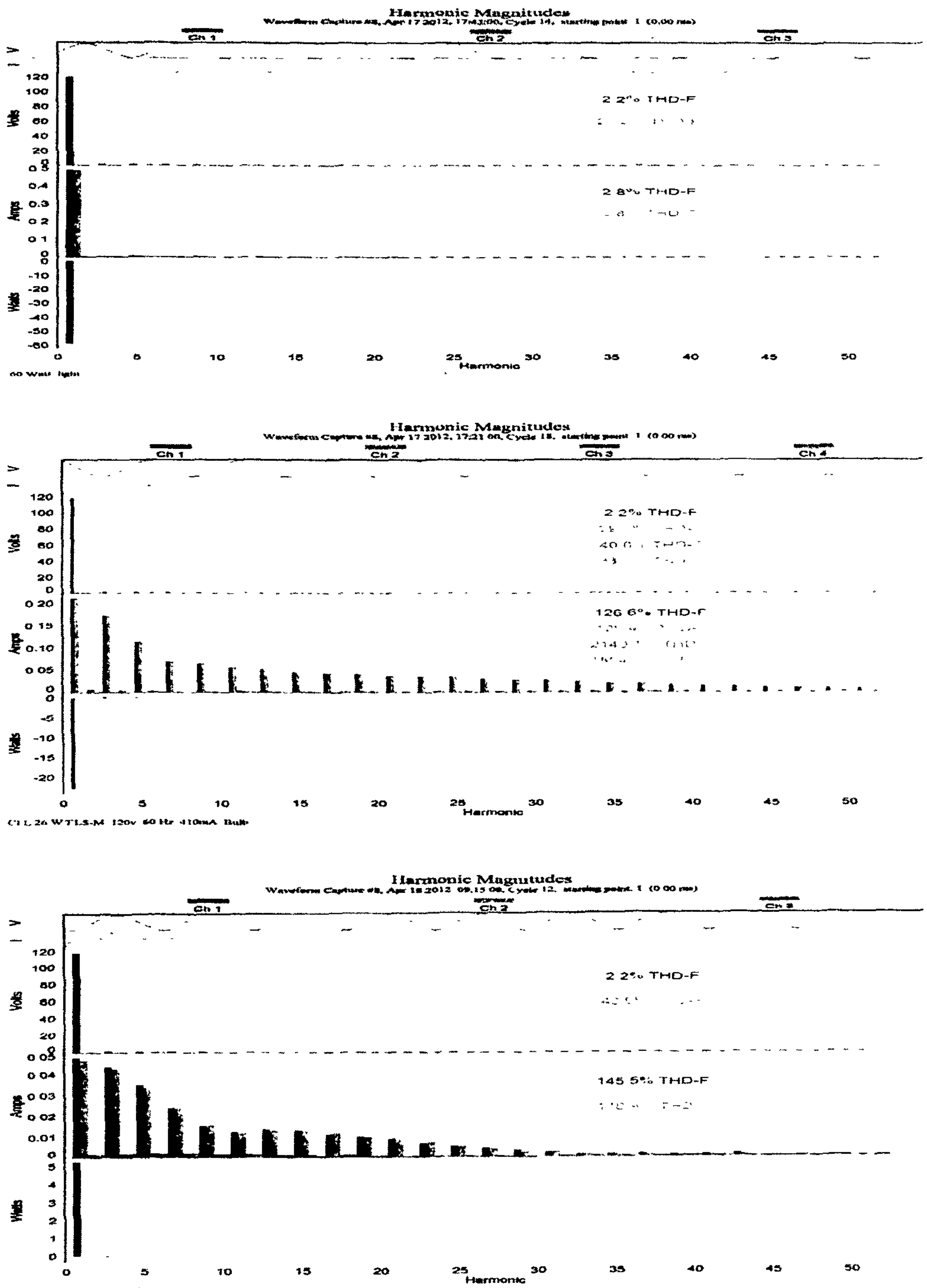

Figure 7. Data from a Revolution comparing THD of a regular incandescent 60 Watt bulb, a CFL and a LED type light.

Figure 7 shows a comparison of THD of a regular incandescent 60 Watt bulb, a CFL and a LED type light.

All PMI recorders with harmonic capability can record THD stripcharts, which gives a min, max, and average value for each interval period.

Figure 8 shows a mixed stripchart graph with voltage and current THD. The upper plot is channel 1 voltage THD, and the lower plot is channel 1 current THD. Looking at voltage and current THD together can help determine whether a monitored load is contributing to voltage THD, or just being affected by it. Figure 9 shows a Current THD Daily Profile. Like other daily profiles, the THD profile represents the average THD on a 15-minute basis throughout an "average" day, computed by averaging through the entire recording period. Here we see that the THD drops during the day, and rises during the night. This likely indicates more linear loads during the day, and as those turn off at night, the mix skews towards non-linear harmonic-producing loads. Unlike the THD stripcharts, THD Daily Profiles are always enabled in a recorder with harmonic capability, so they can be useful if THD becomes a question after a recording is complete.

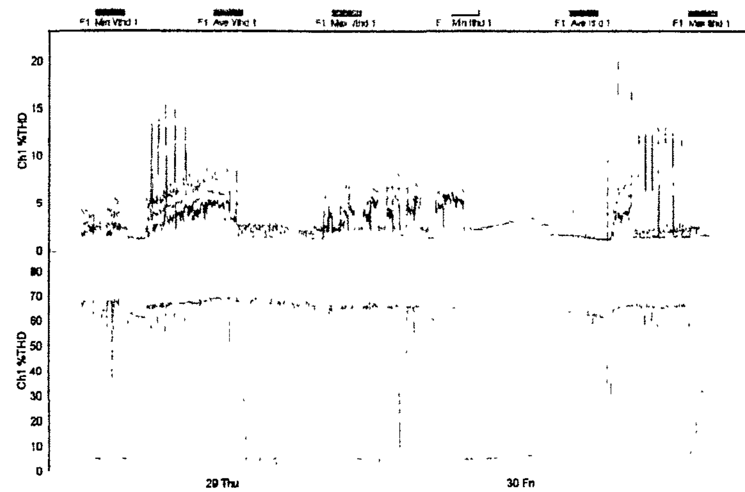

Figure 8. Mixed stripchart graph with voltage and current THD

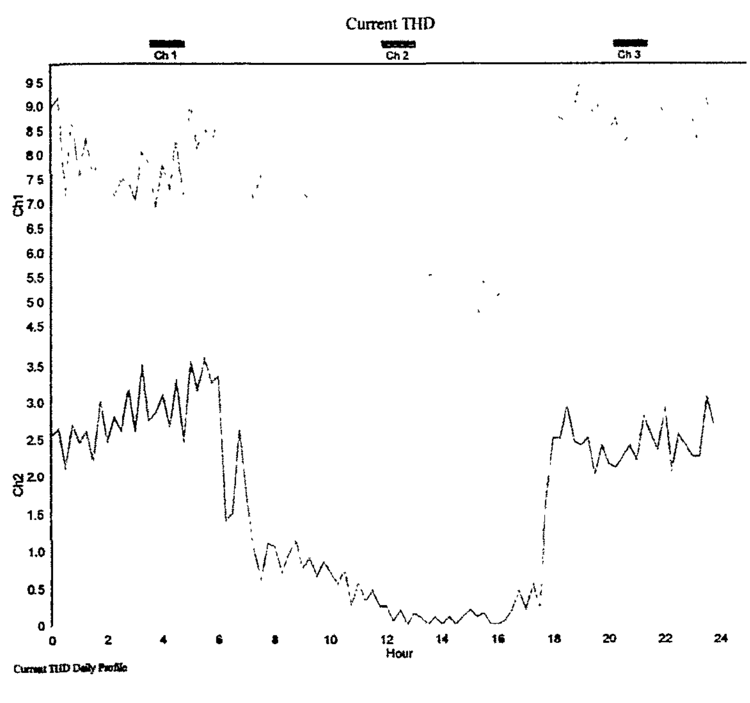

Figure 9. Current THD daily profile

CONCLUSION

THD, simply put, is the measurement of the amplitudes of the harmonics that a nonlinear system introduces relative to the amplitude of the fundamental frequency.

As new regulations are put into place to help conserve our natural resources by improving system efficiency, it is essential to have the proper monitoring systems in place to evaluate the power distribution system. Sometimes improvements in one area can cause problems in another area. Harmonics that are caused by nonlinear loads can cause issues such as transformer failures, excessive heating of motors, electronic device failures, and communication issues related to RFI and noise ingression into the communication system. With the right monitoring equipment and integrated software, and an understanding of power quality fundamentals, it is possible to continually and effectively assess overall system health and prevent potential system failure.

Cowles Andrus
Communications Specialist
Power Monitors Inc.
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candrus@powermonitors.com
http://www.powermonitors.com

WHITE PAPER:
TDD AND IEEE 519:2014

Contributed by David Horning, June 2016

ABSTRACT

IEEE standard 519 was first released in 1982 and was then updated in 1992 and 2014. It defines limits on Total Harmonic Distortion (THD) as well as Total Demand Distortion (TDD) with regards to both voltage and current. The voltage distortion thresholds are limits for the utility on the voltage applied to their customers (the end users of electric power). **The current thresholds are limits on those customers for the loads they apply to the utility voltage. The physics behind delivering electric power dictates that increasing current distortion leads to increased voltage distortion. Because of this fact, the underlying premise behind the IEEE 519 standard is that if all customers meet the current TDD limits, then it will practical for the utility to meet their voltage limits. Consequently, Total Demand Distortion is an important parameter to check for IEEE 519 compliance.**

Harmonic distortion is typically introduced into utility lines through customer non-linear loads installed in various types of manufacturing facilities. Such equipment consists of variable frequency drives, uninterruptible power supplies, and other types of rectifiers used to convert power from AC to DC.

TOTAL DEMAND DISTORTION

Total Demand Distortion (TDD) is defined in the IEEE 519 Standard as "The ratio of the root mean square of the harmonic content, considering Harmonic components up to the 50th order and specifically excluding interharmonics, expressed as a percent of the maximum demand current. Harmonic components of order greater than 50 may be included when necessary."

The Total Demand Distortion is shown with the following formula:

$$I_{TDD} = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + I_5^2 \ldots}}{I_l} \times 100\%$$

Where IL is the maximum demand current which is the sum of the currents corresponding to the maximum demand during each of the twelve previous months divided by 12.

Total Demand Distortion is often a better measure for analyzing distortion effects on a system and determining the need for power harmonic filters. A small current can have a high Total Harmonic Distortion but not be a significant problem because the magnitude of the harmonic current would also be small. By scaling the distortion to the maximum demand, the reading is more indicative of the resulting voltage distortion created from that current. The maximum demand current is closely correlated to the system impedance at that point, and thus correlated to the voltage distortion the current distortion may produce across that impedance.

At maximum load, the Total Demand Distortion and the Total Harmonic Distortion will be the same. As the load changes, the relative values of the Total Demand Distortion to corresponding Total Harmonic Distortion will change also. Although the Total Harmonic Distortion values may appear high, the Total Demand Distortion values may never be a problem. Current harmonic distortion isn't generally a problem if the absolute harmonic levels are small relative to the max demand current at that location, which is generally related to the size of the transformer that is installed.

Total Harmonic Distortion values can fluctuate with changes in the mix of harmonic vs. non-harmonic loads. Total Demand Distortion on the other hand, is normalized such that pure 60Hz current changes don't affect the output, so changes in non-harmonic loads don't cause the TDD value to vary.

RECORDER SETTINGS

In order for ProVision to calculate Total Demand Distortion, the recorder must be setup to record all the necessary data. First you need a device capable of recording the data. Many of the available Power Monitors, Inc. devices are capable of recording this data, including the Eagle, Guardian, and Revolution. The examples in this paper are generated with a Revolution Power Quality Monitor.

Next you have to initialize the recorder for Total Demand Distortion calculations. Locate the device to be configured in ProVision's device tree and from the menu choose "Initialize". Choose the "Advanced" button to show the advanced configuration options. Under "Interval Graphs" tab, select the "I THD" checkbox. Then make sure "I Harmonics Magnitude" is selected, then enter "1" for Selected Harmonics. This is the minimum configuration for Total Demand Distortion. These steps are shown in Figure 1.

Other options such as "V THD", "V Harmonics Magnitude" and additional harmonics may be helpful additional information. Additionally it will be helpful to go to the Interharmonic section and select "Harmonic subgroups", "THD Harmonic Subgroups" and "THD Interharmonic Subgroups".

See the white paper " " for more information about other IEEE 519 issues and harmonics.

PROVISION AND TDD DATA

ProVision has a report and graph for displaying Total Demand Distortion calculated data. Part of the TDD formula is the maximum demand current. The maximum demand current has to be entered into ProVision for TDD calculations. When a Total Demand Distortion report or graph is requested the user is prompted for this information as shown in Figure 2. The entered value is stored in the recording so that future requests default to this value in the prompt.

The recommended value for the maximum demand current, according to IEEE 519, is to use the average current of the maximum demand for the year prior. This can be extrapolated from historical data, but can be adjusted if the load is subject to future changes.

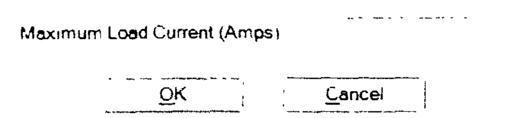

Figure 2. Maximum load current prompt

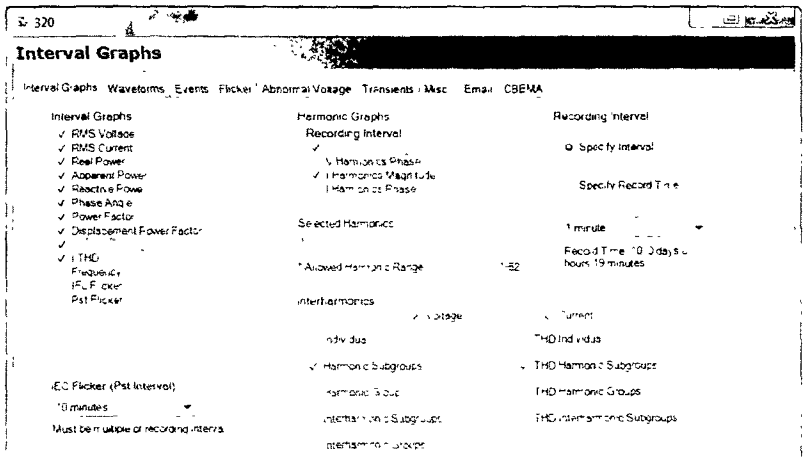

Figure 1. Initialization recorder dialog for TDD

ProVision calculates the Total Demand Distortion from the trace data from the first harmonic and current THD. If the first harmonic is not present then the TDD are approximated by using the values from RMS current. Current THD trace is always required for the calculation.

To display the Total Demand Distortion data choose "Total Demand Distortion" from either the graph or report menus. Figure 3 shows a "Total Demand Distortion Graph" and Figure 4 shows a "Total Demand Distortion" report generated in ProVision.

APPLYING THE IEEE 519 LIMITS

The TDD limits in IEEE 519 depend on the ratio of the short circuit current Isc to the maximum load current IL, as shown below for systems from 120V through 69 kV:

I_{sc}/I_L Ratio	95th, 10 min	99th, 10 min	99th, 3 sec
< 20	5.0%	7.5%	10.0%
20 < 50	8.0%	12.0%	16.0%
50 < 100	12.0%	18.0%	24.0%
100 < 1,000	15.0%	22.5%	30.0%
> 1,000	20.0%	30.0%	40.0%

There are separate limits for 3 second very short time and 10 second short time readings, and also separate percentile aggregations for a full analysis. The 3 second measurements will always be higher than the 10 minute readings, so if the 3 second values are less than the 10 minute limits, the 10 minute readings will be in compliance also. Also, if every data point is below the limit, then there is no need to compute a percentile value - if there is no single reading over the limit, then the 99th or 95th percentile will both be within the limit too.

CONCLUSION

IEEE standard 519 defines limits on Total Harmonic Distortion (THD) as well as Total Demand Distortion (TDD) with regards to both voltage and current. **Total Demand Distortion is often the most important parameter to check for IEEE 519 compliance, as without each customer staying within limits, it will be difficult or impossible for the utility to meet the voltage requirements.** The method for recording the required data and viewing it in ProVision has been described here.

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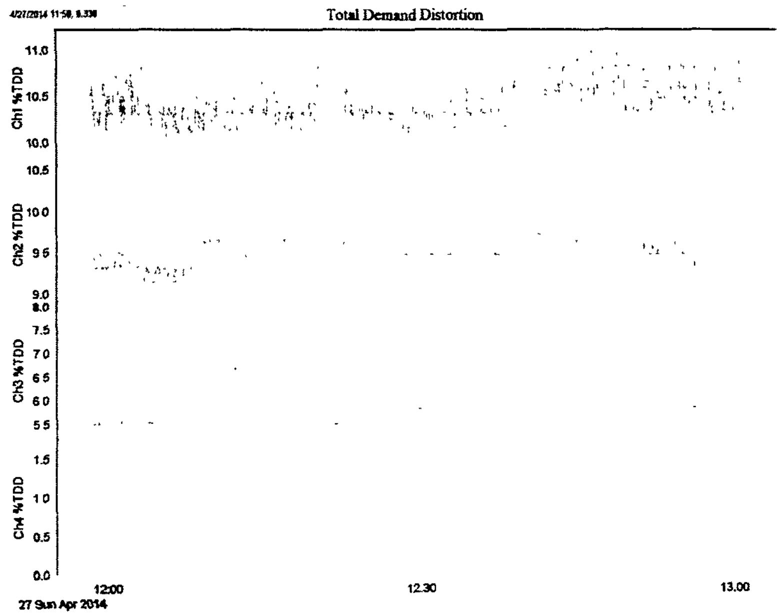

Figure 3. TDD graph (above)

Total Demand Distortion Report

Start Apr 27, 2014 11 58 13
Stop Apr 27, 2014 13 00 42
Duration: 0 days, 01.02 29
Firmware Version 5.69 Unit Type Revolution
Software Version 1.61 5220 Serial No 14165

Circuit Type Wye
Voltage Scale Factor x1 00
Current Scale Factor x1 00
Current Range 200 Amps
Interval Time. 1 second

Maximum Load Current (Amps): 60

Date	Time	Ch1 TDD%	Ch2 TDD%	Ch3 TDD%	Ch4 TDD%
04/27/2014	11 58:13	10 6	9.5	5.5	0 0
04/27/2014	11 58 14	10 6	9 3	5 5	0 0
04/27/2014	11 58.15	10 6	9 3	5 5	0 0
04/27/2014	11 58 16	10 5	9 5	5 5	0 0
04/27/2014	11 58 17	10 1	9 3	5.5	0 0
04/27/2014	11 58 18	10 5	9 3	5 5	0 0
04/27/2014	11 58 19	10 5	9 3	5 5	0.0
04/27/2014	11 58 20	10 5	9.3	5 5	0 0
04/27/2014	11 58 21	10 5	9 3	5 5	0 0
04/27/2014	11 58 22	10 5	9 5	5.5	0 0
04/27/2014	11:58 23	10 5	9 3	5 7	0 0
04/27/2014	11 58 24	10 5	9 3	5 5	0 0
04/27/2014	11 58 25	10 6	9 3	5 5	0 0
04/27/2014	11 58 26	10 6	9 3	5 5	0 0
04/27/2014	11 58 27	10 7	9 3	5 5	0 0
04/27/2014	11 58 28	10 5	9 3	5 5	0 0
04/27/2014	11.58 29	10 5	9 3	5 5	0 0
04/27/2014	11 58 30	10 5	9 3	5 5	0 0

Figure 4. TDD report

WHITE PAPER:
INTERPRETING THD

Contributed by Chris Mullins February 2013

ABSTRACT

Total Harmonic Distortion (THD) is a way of quantifying the amount of harmonic content in a voltage or current waveform. In addition to measuring the amount of distortion, THD can also be used to help track down the source of harmonic distortion. Although recording individual harmonics allows for a more detailed analysis, a full harmonic recording consumes a very large amount of memory, resulting in a shorter recording time, or very large data files. Recording just voltage and current THD instead of a full set of harmonics doesn't take up much extra memory – little enough that it's worth recording "just in case", even on non-harmonic investigations. Relationships between THD and RMS values to help understand and track down harmonic sources are described below.

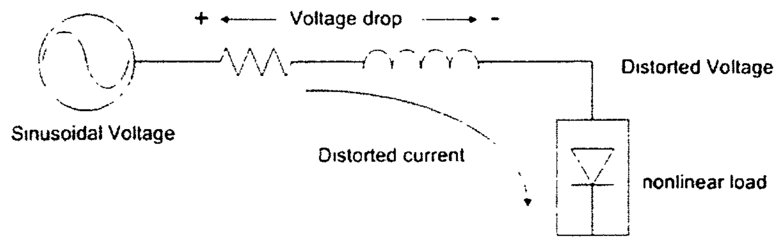

Figure 1.Harmonic currents result in corresponding voltage drops along the distribution wiring and across transformer

As defined the whitepaper Understanding THD, THD is a measure of harmonic distortion. Expressed as a percent, the THD is a comparison of the 60Hz fundamental magnitude to the total of all harmonics. A value of 0% indicates a pure 60Hz sinewave with no distortion. Typical voltage THD levels are 0.5 to 5%, while current THD ranges from 0.5% to 80% or more, depending on the type of load. The sizeable difference in those ranges is due to the system impedance and the relationship to voltage and current in the distribution system.

Utility voltage is generated as a pure 60Hz sine wave, with no harmonic distortion. When nonlinear loads are attached, harmonic currents flow. These harmonic currents result in corresponding voltage drops along the distribution wiring and across transformers, due to their non-zero impedances (Figure 1). In a typical distribution system, the voltage source impedance is very low (ideally zero) compared to the load impedance. Stated another way, the available short circuit current is much higher than the typical (or even maximum) load current. At 60Hz, this difference insures that voltage sags due to high load current are a small percentage of the line voltage. Similarly, harmonic voltages developed from harmonic currents are correspondingly smaller, and the resulting voltage THD is much smaller than the current THD causing the distortion.

If the voltage has a non-zero THD, even a perfectly benign linear load (e.g. electric heater, incandescent lighting) will draw harmonic currents, in proportion to the harmonic voltage. In this case, the current THD will be similar in magnitude to the voltage THD, rather than much higher. In general, if the current THD is roughly

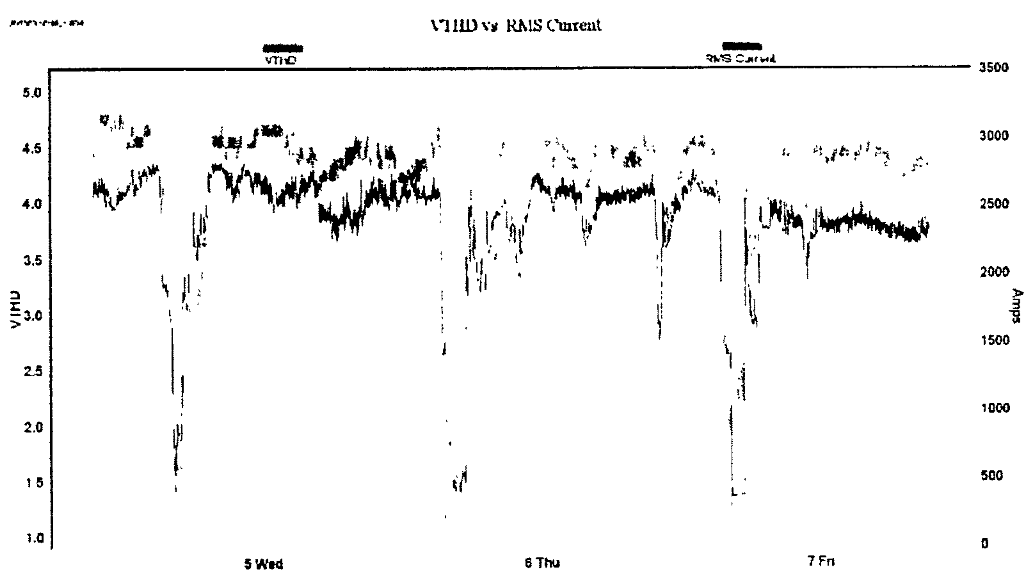

Figure 2. RMS current is graphed with the voltage THD.

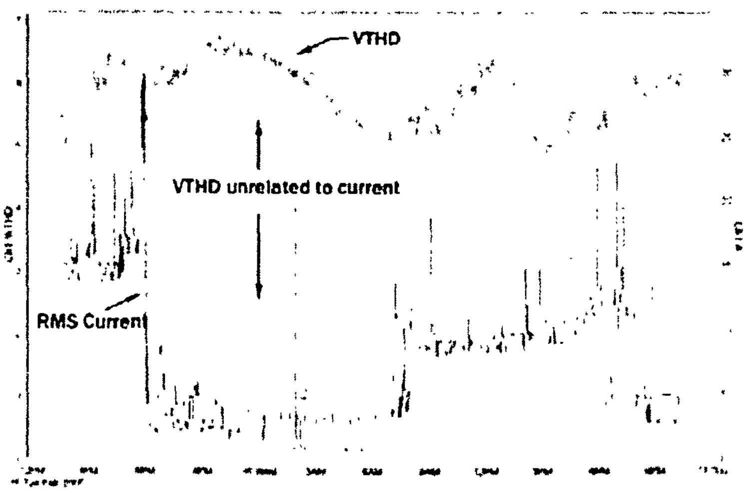

Figure 3. The voltage THD is over 6%, but shows little correlation to changes in RMS current.

similar in size to the voltage THD, it's likely that the monitored load is not responsible for the voltage THD.

Unfortunately, the current THD is often much higher than the voltage THD. In these cases, examining the voltage and current THDs along with the load current can provide some clues as to the source of harmonics. In Figure 2, the RMS current is graphed with the voltage THD. There's a clear correlation between the voltage THD and current – the voltage THD jumps from a mildly elevated 1.5% to a very high 4.5-5% when the large 2500A load turns on. The high load current is a significant faction of the short circuit current, and thus has a large influence on the voltage THD.

The opposite case is shown in Figure 3. Here, the voltage THD is over 6%, but shows little correlation to changes in RMS current. This is a strong indication that the monitored current is not the cause of the voltage THD. There are large step changes in current with no change in voltage THD, and the voltage THD varies over a wide range with no change in load current.

The voltage THD and current relationship is not always so clear-cut. If the current is a mix of linear and nonlinear loads, RMS current shifts can produce unexpected voltage THD changes. To illustrate this effect, an AC voltage source and two loads, one linear and one nonlinear, were used to produce a test recording. The nonlinear load is 1.6A, with a THD of 68% (Figure 4). The voltage THD with just this load is around 2% (with no load, the voltage source is less than 0.3%). The linear

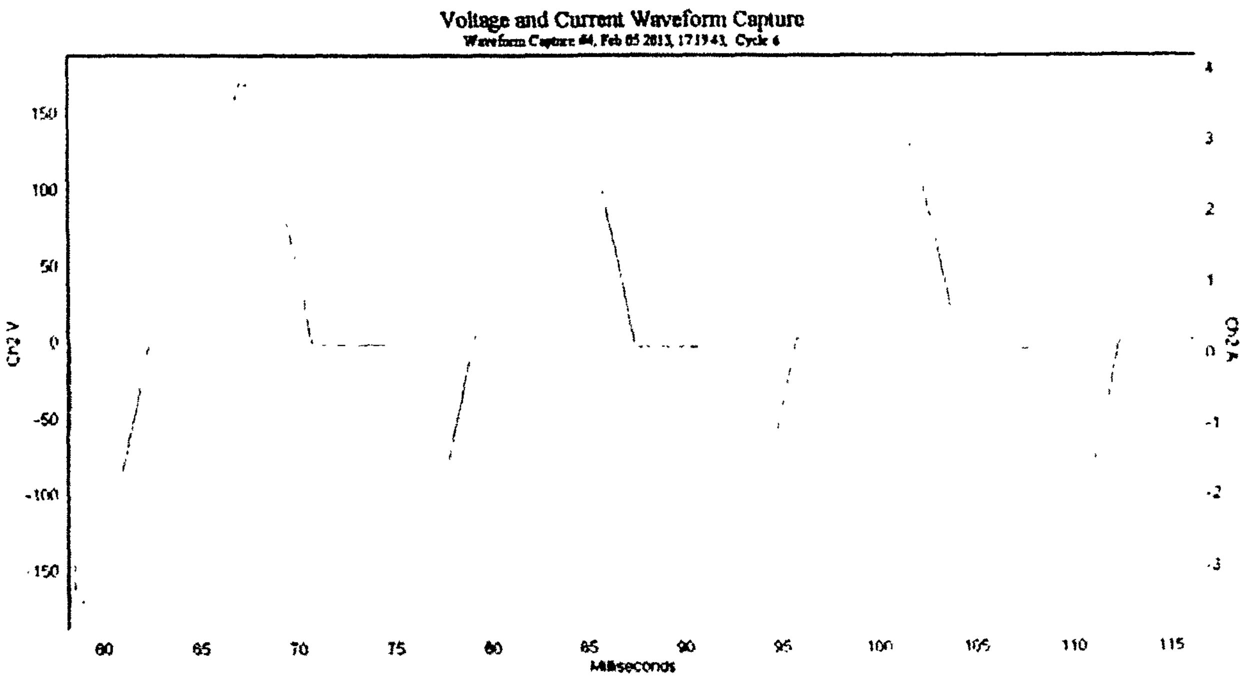

Figure 4. The nonlinear load is 1.6A, with a THD of 68%

load is 5.3A, and its current waveform is an exact replica of the voltage source, by definition. Figure 5 shows a waveform capture that starts with the nonlinear load, then the linear load is also switched on. The current THD is the 68% value with just the nonlinear load, but the combination of the two is actually more sinusoidal – the current THD drops to around 12%. The composite current waveform still contains the harmonic currents from the nonlinear load, but the much larger 60Hz current tends to mask them.

The RMS values and THDs for voltage and current are graphed in Figure 6. The "nonlinear" and "both" annotations are when the respective loads are energized. The voltage THD (green trace on lower graph) is around 1.8% with just the nonlinear load, produced from the 1.6A and 68% THD in the load. The source impedance (known to be 2 ohms here) is much lower than the load impedance (120V/1.6A = 75 ohms), so the 68% THD translates to just 1.8% THD on voltage. When the 5.3A linear load turns on ("both"), the voltage and current THDs both drop. The current THD is around 12% now – since the linear load's 5.3A is much higher than the nonlinear load, the proportion of 60Hz current vs. the harmonics is higher, resulting in a lower overall current THD. The total harmonic current is unchanged, but as a proportion of the total current, it's less. The voltage THD is caused by the harmonic currents dropping voltage across the 2 ohm source impedance, so it must reduce if the current THD does. Here it drops from 1.8% to 1.5%.

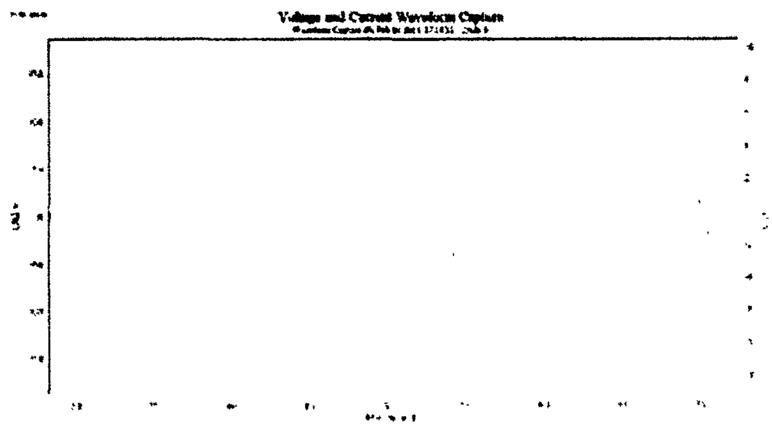

Figure 5. waveform capture that starts with the nonlinear load, then the linear load is also switched on

Even though the voltage THD has improved a bit, the RMS voltage has dropped significantly (from 117V to 108V), possibly introducing another PQ issue Any 60Hz current change that's large enough to actually improve the THD is likely to be so large as to sag the voltage a noticeable amount.

In this stripchart, we have the voltage and current THDs dropping in response to an RMS current increase. Despite the opposite movement of that shown Figure 2, the monitored current is actually producing the THD. It's combined with linear current that's reducing the THD (although the underlying harmonic magnitudes

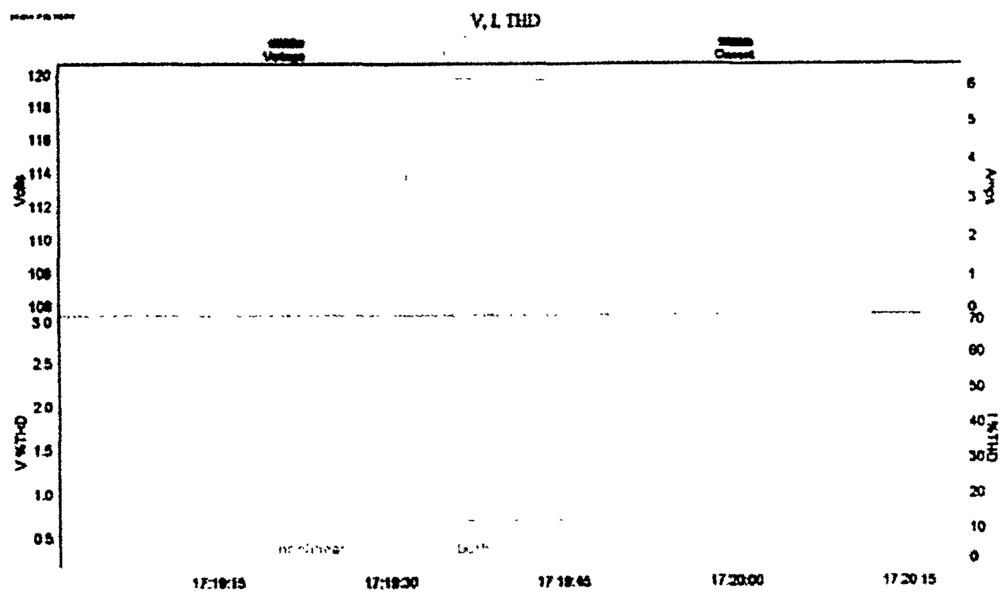

Figure 6. RMS values and THDs for voltage and current

are unchanged), making the interpretation less straightforward.

The key point from this example is that monitoring a complex mix of loads can result in differing correlations between THD and RMS current, as various types of loads switch off and on. When the linear load switches off and on, there's a very marked change in current and voltage THD, but that load is not causing any harmonics – rather, it serves to mask the offending load by lowering the overall THD. By carefully following the timeline of voltage and current THD, and voltage and current RMS values in the stripchart, a complete harmonic picture may be pieced together.

Voltage and current THD are essential in quantifying and tracking down harmonic loads. The relationships between RMS voltage and current, and voltage and current THD can be complex, but offer important clues pointing to the root harmonic offender. By keeping in mind the fundamental voltage and current relationship in Figure 1, the contributions from various loads can be untangled and used to estimate the source of harmonics.

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EXHIBIT D