United States
21, rue d'Artois, F-75008 PARIS
http://www.cigre.org

CIGRE US National Committee
2019 Grid of the Future Symposium

Quality – New Metrics for a New Grid

T.L. LAUGHNER
PowerGRID-RX, Inc.
USA

SUMMARY

This document provides a summary of different standards related to power quality. It also provides a very high-level introduction to power quality phenomena. Finally, the document provides some context as to why power quality is important to the electric industry in an interconnected grid.

KEYWORDS

Voltage Quality, Power Quality, IEEE 1250, EMC

theo@powergrid-rx.com

Introduction

If you were to perform an internet search on the phrase "importance of quality", you would find hundreds of articles on how most manufacturing industries place supreme importance on quality [1]. These articles will enumerate customer retention and profit as the primary drivers for the emphasis on quality. Conspicuously missing are references to the electric power industry in these conversations.

Meanwhile, electric utility customers are attempting to leave their suppliers. This departure takes on many forms – renewable integration, energy efficiency, but has largely been referred to as the "Smart Grid". The auspices of this industry shift are often stated as enabling customer choice or to enabling more "green" power generation. However, the underpinning message is clear – customers do not want utilities supplying their power anymore.

Little study has been performed to understand the psyche behind these decisions within the electric utility space, but other industries have already supplied the typical reasons why customers leave their existing suppliers [2]: they die, they are no longer buying or need the product, they are unhappy with the price, they are unhappy with the product, they are unhappy with their treatment. Certainly, energy efficiency products have reduced the demand from the customer. However, there is nothing to suggest that there is no demand for the energy. Meanwhile, customers are putting in co-generation, like rooftop solar, at higher total cost of ownership and risk, which suggests that the decisions are not purely financially motivated. This suggests customers are either unhappy with their treatment or the product. One thing is certain, customer needs and expectations are evolving.

Meanwhile, standards bodies like IEEE and IEC have worked to provide quantifiable descriptions of power quality phenomenon, measurement standards, and compatibility limits. Still many of these standards are known only to a surprising few within the utility industry. Even regulating bodies typically enumerate requirements around reliability and not quality.

Quality and reliability are different. Reliability generally carries the nuanced meaning of how dependable something is. In other words, it sets the expectation that the user can rely on the subject to be available. Many utilities have 5-9's of reliability which equates to less than 5 minutes of downtime a year. Most utility metrics track how often the utility supply is or is not available. It is impossible to have quality without reliability, but it is possible to have reliability without quality.

Quality, by contrast, is how well something conforms to a predetermined specification. Unsurprisingly, power quality determines the fitness of electric power to be used by consumer devices [3]. This legacy definition of power quality is good, but given the changes taking place on the grid, the definition needs to evolve to one that enumerates performance requirements.

Grid Changes

Every segment of the grid from Generation to the point of use is changing. The ramifications of these changes are not well understood or well modelled. More concerning is the lack of actual measurement data at different points on the grid to establish a baseline of grid performance ahead of significant change to understand the actual sensitivities to these changes.

Generation is being changed from large coal or nuclear facilities with large spinning mass to solar and wind generation which use DC to AC converters. Existing generation facilities are being retired. A natural consequence is that power is coming from farther away. This provides more exposure to power quality phenomenon from farther away. In other cases, roof-top solar is being used which has distinct exposure characteristics.

The transmission system is becoming a more active place. There are technologies which enable the utility to change the impedance of the power lines in order to optimize power flow. Capacitor banks and other reactive compensation devices are being deployed in order to support the voltage along the lines since nearby generation is being retired.

Consumer devices are becoming more active. Many large motors have active front end devices like Variable Frequency Drives. Home consumer devices like refrigerators and heat pumps are also using VFD technology as a means to increase energy efficiency. These components may produce interference with other systems on the grid. Clearly, specifications are needed.

Standards

Fortunately, standards bodies like IEEE and IEC have actively been working to establish definitions, measurement protocols, and limits around certain emissions. This document will largely focus on the IEEE related standards for power quality, but there are many IEC standards which are more frequently applied outside the United States. In some cases, the IEC and IEEE standards for power quality have been harmonized.

IEEE 1250-2018 [4] entitled "IEEE Guide for Identifying and Improving Voltage Quality in Power Systems" is a power quality primer for both utility and industrial professionals. It supplies several functions. First, it provides a sense of power quality from historical benchmarking studies. Second, it describes factors that affect power system performance. Third, it describes mitigation measures to improve power system performance. Forth, it serves as a directory to other power quality standards. Finally, more detailed treatment is given to phenomenon in cases where there is not sufficient material on a topic to produce a standalone standard.

All power quality phenomenon is broken down into two broad categories: steady state and event. Steady state phenomena are typically measured continuous basis and summarized in ten-minute bins. These bins will generally contain a minimum, maximum, and average value for the measurements recorded. Steady state measurements include voltage, current, harmonics, power, frequency, and unbalance. These measurements represent the normal operating environment of the system. The figure below shows an example steady state recording.

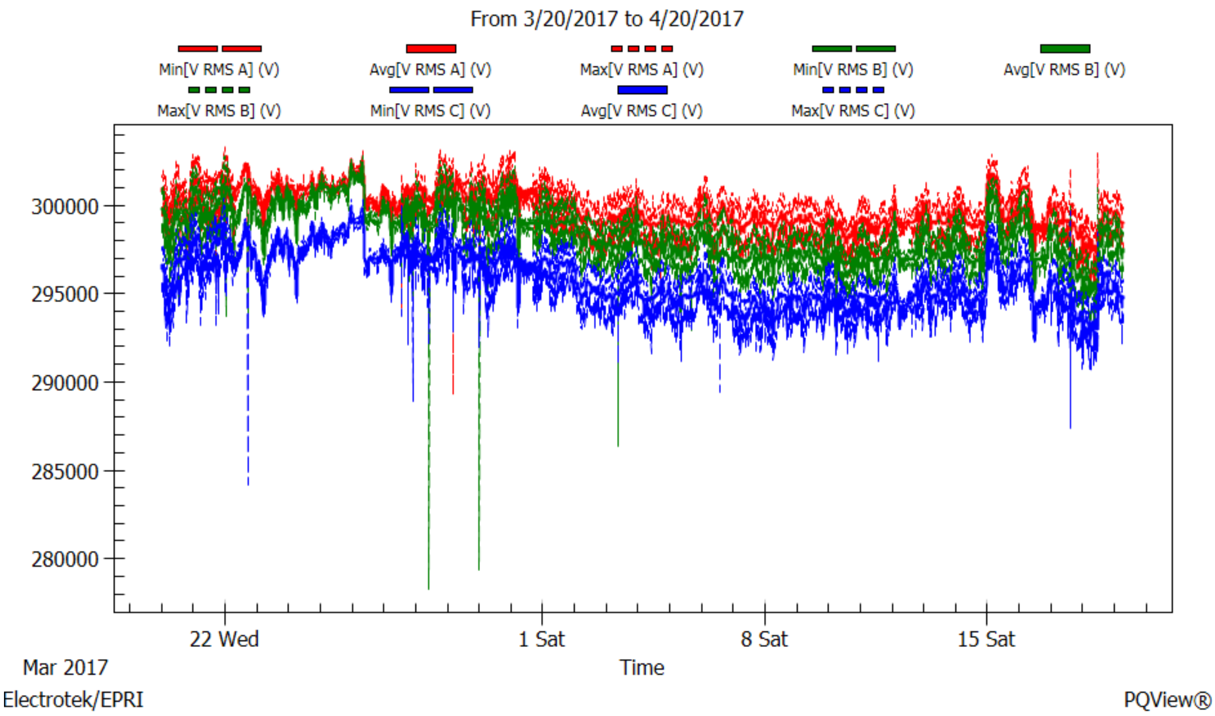

Figure 1 – Steady State Measurement

Events, by contrast, are recorded whenever a pre-defined threshold is exceeded. When the threshold is exceeded, many power quality instruments will record point-on-wave data at high fidelity. These high-resolution measurements are recorded throughout the lifecycle of the event based on the capability of the recording device. These measurements represent some abnormal operating condition like a fault or disturbance on the system. The figure below shows an example event capture.

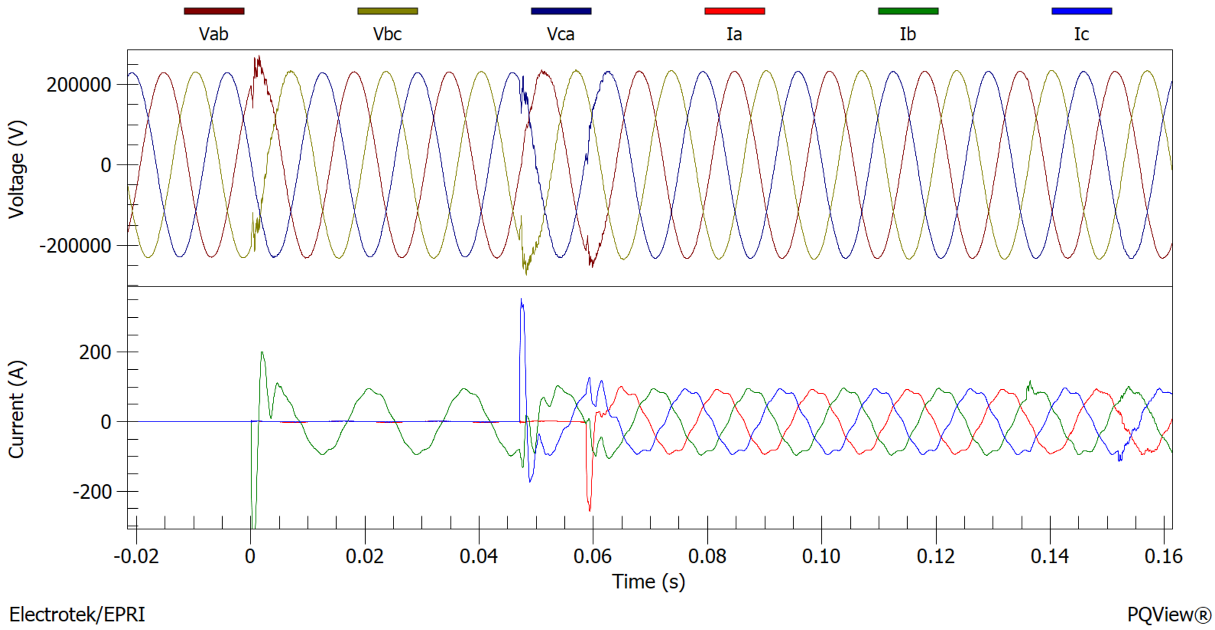

Figure 2 – Event Measurement

IEEE 1159-2019 [5] entitled "IEEE Recommended Practice for Monitoring Electric Power Quality" provides descriptions of a variety of power quality phenomenon. The table below shows a variety of the phenomenon described in the document.

Categories			Typical Duration
Transients	Impulsive	Nanosecond	> 50 nanoseconds
		Microsecond	50 nanoseconds to 1 millisecond
		Millisecond	> 1 millisecond
	Oscillatory	Low Frequency	0.3 milliseconds to 50 milliseconds
		Medium Frequency	20 microseconds
		High Frequency	5 microseconds
Short Duration Variations	Instantaneous	Sag	0.5 cycles to 30 cycles
		Swell	0.5 cycles to 30 cycles
	Momentary	Interruption	0.5 cycles to 3 seconds
		Sag	30 cycles to 3 seconds
		Swell	30 cycles to 3 seconds
	Temporary	Interruption	3 seconds to 1 minute
		Sag	3 seconds to 1 minute
		Swell	3 seconds to 1 minute

Categories		Typical Duration
Long Duration Variations	Interruption (sustained)	> 1 minute
	Undervoltages	> 1 minute
	Overvoltages	> 1 minute
Voltage Imbalance	Voltage Unbalance	steady state
Waveform Distortion	DC Offset	steady state
	Harmonics	steady state
	Interharmonics	steady state
	Notching	steady state
	Noise	steady state
Voltage Fluctuations	Voltage Fluctuations	Intermittent
Power Frequency Variations	Power Frequency Variations	> 10 seconds

Figure 3 – PQ Phenomenon

IEEE 1453-2015 [6] entitled "IEEE Recommended Practice for the Analysis of Fluctuating Installations on Power Systems" provides information on light flicker produced by fluctuations in demand caused by disturbing loads like electric arc furnaces. The document defines flicker, describes how to measure flicker, how to conduct flicker studies, and provides guidance on emission limits. The image below shows a typical flicker measurement.

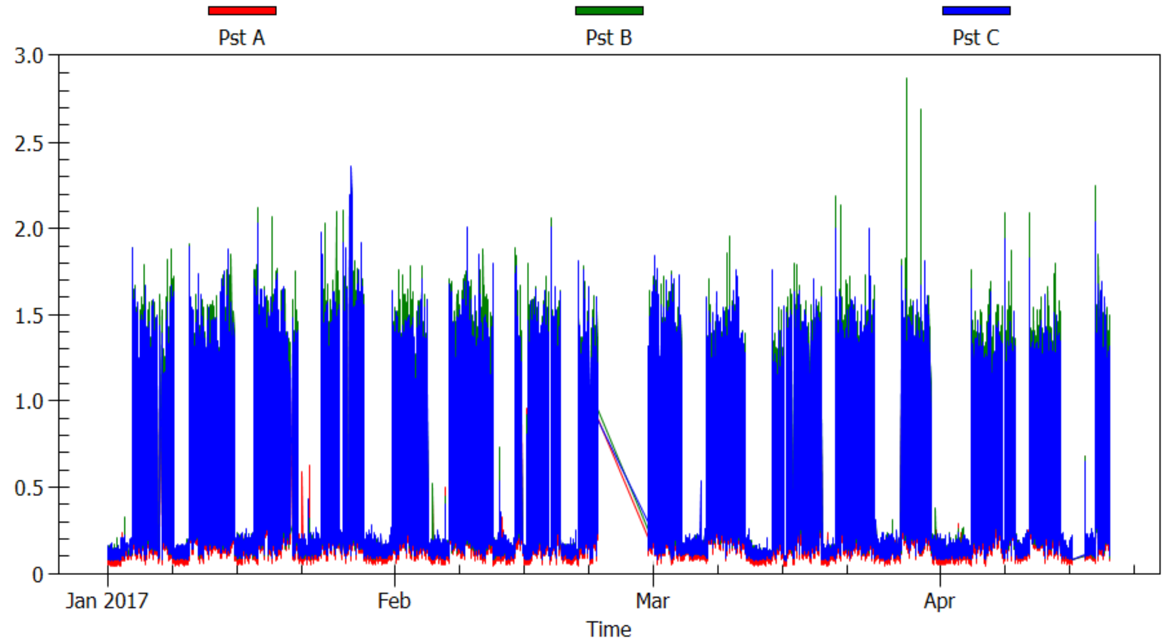

Figure 4 – Typical Flicker Measurement

IEEE 519-2014 [7] entitled "IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems" provides guidance on managing distortion on the power system. The guidance includes a definition of harmonics, harmonic measurements, and prescribes limits based on bus strength. Generally, harmonics occur as a result of some injection on the power system. Historically, these was the result of harmonic currents being used by a load on the system. Generation was rarely a source of this type of phenomena. However, most renewable resources utilize active conversion technologies which can inject these types of currents. The graph below shows the impacts of injecting harmonics at different frequencies to the system.

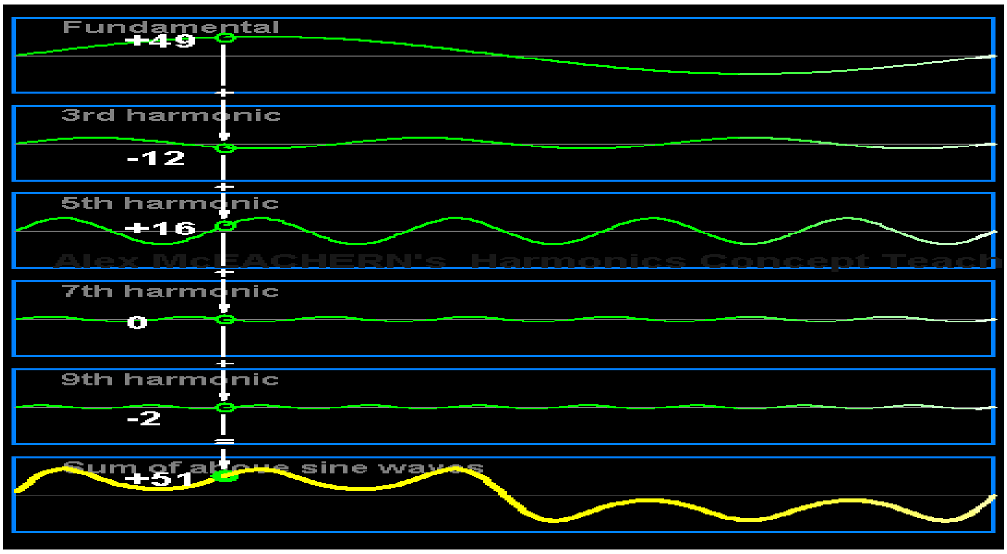

Figure 5 – Harmonics

IEEE 1547-2018 [8] entitled "IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power System Interfaces" provides specifications for connecting DER devices to the power system. Included in the standard are requirements for response to abnormal conditions, power quality, and islanding. In addition, test specification and requirements for design production, installation, commissioning and testing are supplied.

Conclusion

While the grid is changing in response to evolving customer expectations, the metrics (reliability) that are typically employed to monitor grid performance have remained. Numerous power quality standards exist and should be employed to better understand the performance of the modern grid.

BIBLIOGRAPHY

Type here the bibliography at the end of your text, according to this presentation (see sample references below). Font to be used is always Times or Helvetica 11 or 12.

[1] Quain, S. (2019, Feb 12). *Why is Quality Important For Business.* Retrieved from https://smallbusiness.chron.com/quality-important-business-57470.html

[2] Elias, B. (2018, May 25). *Why Customers Leave: the 4 Reasons that Might be Killing Your Customer Retention.* Retrieved from https://www.activecampaign.com/blog/why-customers-leave

[3] Wikipedia contributors. (2019, August 19). Electric power quality. In *Wikipedia, The Free Encyclopedia*. Retrieved from https://en.wikipedia.org/w/index.php?title=Electric_power_quality&oldid=911471572

[4] *IEEE Guide for Identifying and Improving Voltage Quality in Power Systems*, IEEE 1250-2018,2018.

[5] *IEEE Recommended Practice for Monitoring Electric Power Quality*, IEEE 1159-2019,2019.

[6] *IEEE Recommended Practice for the Analysis of Fluctuating Installations on Power Systems*, IEEE 1453-2015, 2015.

[7] *IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems*, IEEE 519-2014, 2014.

[8] *IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power System Interfaces*, IEEE-1547-2018, 2018.