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Moving Beyond Reliability Based KPIs.

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SUMMARY

For decades, reliability metrics have served the industry well. These metrics were sufficient and necessary when the electric power system generally moved power from central generation towards consumer load. However, the modern grid is changing from unidirectional power flow to one with high entropy. Power is not only being generated at large central generation facilities, but now is being produced even on the consumer rooftop. Necessarily, this new grid requires more nuanced metrics to ensure not only good reliability, but to be of sufficient quality which maintains the usability consumers have come to expect from the power system. Consequently, this paper discusses the costs of quality, the standards that outline quality metrics, and proposes some metrics for use in the future.

KEYWORDS

KPI, Performance, Metrics, Power Quality

Background
For decades, reliability metrics have served the industry well. These metrics were sufficient and necessary when the electric power system generally moved power from central generation towards consumer load as shown in Figure 1, below.

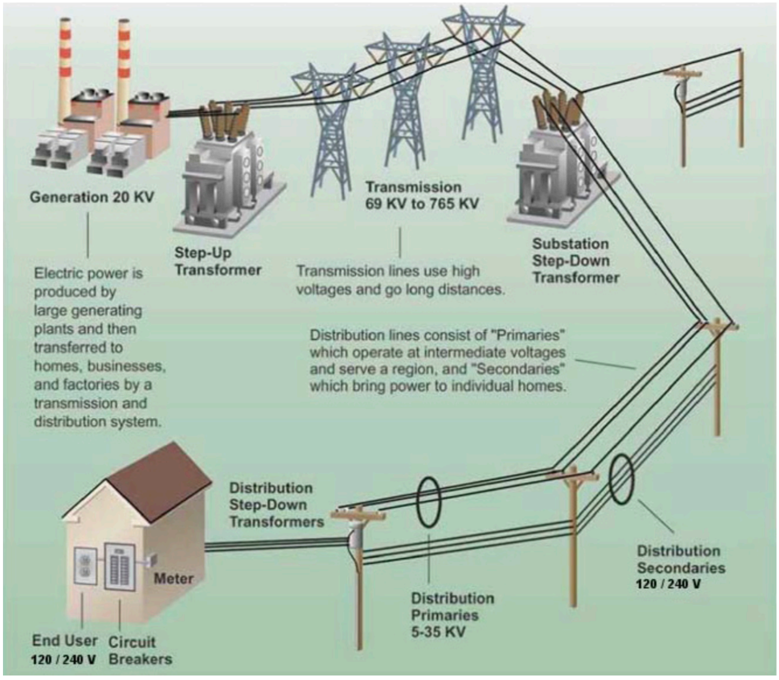

Figure 1- Traditional Power Grid [1]

However, the modern grid is changing from unidirectional power flow to one with high entropy. Power is not only being generated at large central generation facilities, but now is being produced, and stored, even at the consumer level as shown in Figure 2, below.


Figure 2 – Current Grid [2]

Necessarily, this new grid requires more nuanced metrics to ensure not only good reliability, but to be of sufficient quality which maintains the usability consumers have come to expect from the power system. Reliability, by definition, is a count the number of times the voltage went zero. When the utility is the sole provider of power this metric makes sense. However, when a consumer is producing their own power, how does this metric reflect the utility impact on the consumer? In short, it does not.

At the same time as the grid has evolved, so to have customer expectations of utility power. Not only should the power be reliable (always on), but equipment should operate correctly. Many anecdotes have surfaced about noise appliances make after a nearby solar inverter has been installed or radio noise due to abhorrent behavior of a failing component adjacent to a consumer property. In extreme cases, complaints of nuisance shock have also been reported. All of these challenges have the fact that the power being provided was outside of a planned specification. Figure 3 [3], below, shows an event where there was a resonant excitation on the 24th harmonic.

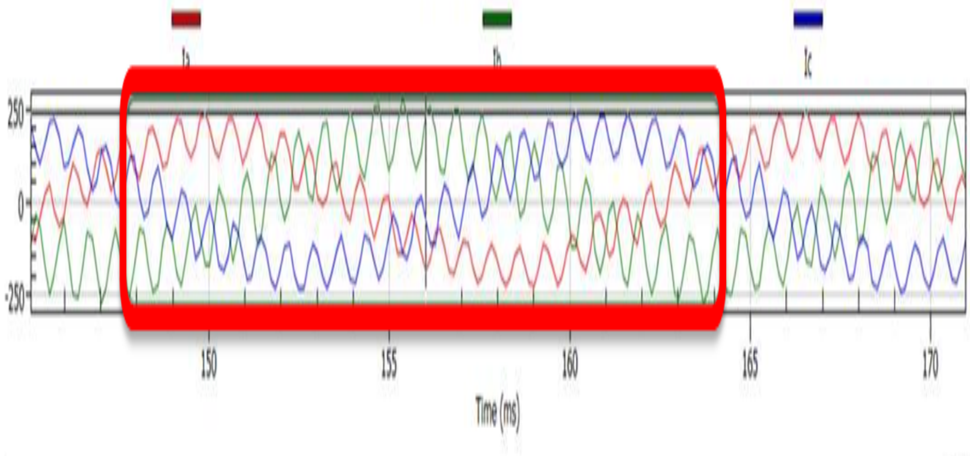

Figure 3 – 24th Harmonic Resonance

Enumerating The Costs Of Quality

Other industries have measured not only reliability, but quality metrics for years. Even with better optics on quality, they still have difficulty in measuring the total cost of quality to the enterprise. As a result, quality programs are often underfunded. This is even more true of the utility enterprise where reliability is often equated with quality. Without reliability, quality does not exist. However, it is possible to have reliability without quality.

According to the American Society on Quality[4], "Many organizations will have true quality-related costs as high as 15 to 20 percent of sales revenue, some going as high as 40 percent of total operations." According to EIA, the Electric Utility Industry is a $381B. At a minimum (15%), this suggests that the cost of PQ to the utility industry is approximately $52B.

As shown in Figure 4 [4], below, the costs of quality can be broken down into a tree. In manufacturing, the consequences of poor quality include: a) unplanned equipment downtime, b) resources needed for failure analysis, corrective action, and redesign, c) slow or ineffective fixes leading to an inefficient corrective action program, and d) executive time is spent on problems rather than pursing more strategic goals.

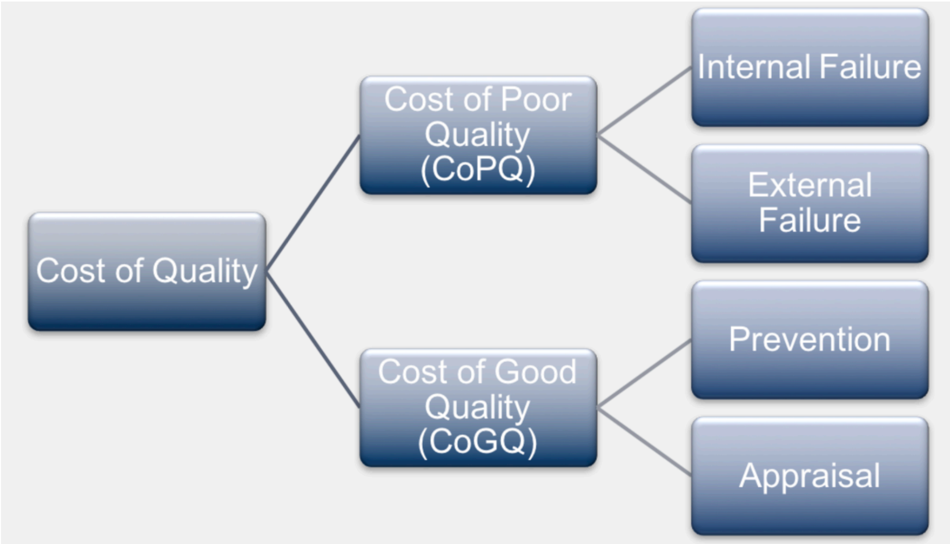

Figure 4 – Quality Cost Tree

Meanwhile, companies that make investment in quality see a good ROI. In manufacturing, the 1-10-100 rule is often applied. Meaning, a $1 investment in prevention yields a $10 savings to mitigate appraisal/regulation. Ultimately, that same $1 investment prevents a failure at a cost of $100. Measurement and mitigation are important, but what is the right specification for power?

Standards
Standards serve as the backbone for many utility quality programs. There are a variety of standards and brochures both in CIGRE, IEC, and IEEE that define common quality parameters around power. Some of those standards are more grid facing while others are more consumer facing.

Grid facing standards like IEEE 1453 and IEEE 519 provide guidance for flicker and harmonics. Additionally, IEEE 1564 provides guidance on voltage sag indices. Numerous brochures have been published by CIGRE on the topic of PQ Monitoring and Performance: CIGRE TB 596 – Guidelines for PQ Monitoring, CIGRE TB 718 – Benchmarking of PQ Performance, and CIGRE TB 719 – PQ & EMC issues with Future Networks.

There have also been IEEE committee working to provide customer facing requirements. For example, IEEE 1547 provides an interconnection standard for Distributed Energy Resources. IEEE 1668 provides a recommendation on industrial equipment ride-through capability.

Future Grid Metrics
It has been said "You cannot improve what you cannot measure." Necessarily, grid metrics need to evolve. The need to see the grid in a more granular and nuanced fashion is apparent. As the grid is changing at an ever-increasing rate, so to must the utility better understand exposure to particularly sensitive customers. Prosumers will demand more personalized reporting on the quality of delivered power. Finally, better grid visibility enables better benchmarking.

Grid Visibility Metrics
Grid Visibility could be measured in a couple of ways: sites monitored, and quantities measured. Most systems have tools that measure reliability in place but may not have power quality monitors installed at important locations. Important locations include: critical customer loads, customer complaint locations, and locations where problems are expected. This type of measurement would be easy to report as a simple number or percentage of sites monitored over a reporting period. For example, 25% of critical customer loads are measured.

Similarly, a simple metric identifying which quantities are measured at each site could be developed. Common power quality quantities include steady state voltage, current, power, frequency, flicker, harmonics, voltage unbalance, and current unbalance. Additionally, events like sags, swells, and transients can be measured. For example, 25% of all monitoring sites have all steady state quantities being measured.

Customer Exposure KPIs.
As the grid changes, so does the risk of an event which causes a problem that results in lost productivity to sensitive consumers. Classically, power quality engineers or planners have conducted studies around the Area of Vulnerability. This measure was typically performed when a new delivery point was commissioned. However, the retirement of large generation assets in favor of smaller wind or solar units has fundamentally changed the assumptions on which these studies were conducted.

Consequently, these types of studies should be redone, if possible, dynamically, as the system changes to understand exposure to sensitive loads. In Figure 5, below, the maps show highlighted lines which could create a voltage sag of up to 70% of nominal for a sensitive consumer before and after a proposed power system change. The exposure nearly triples in line miles. In areas where lightning exposure is directly correlated to line mileage, this could be a negative impact to the consumer productivity.

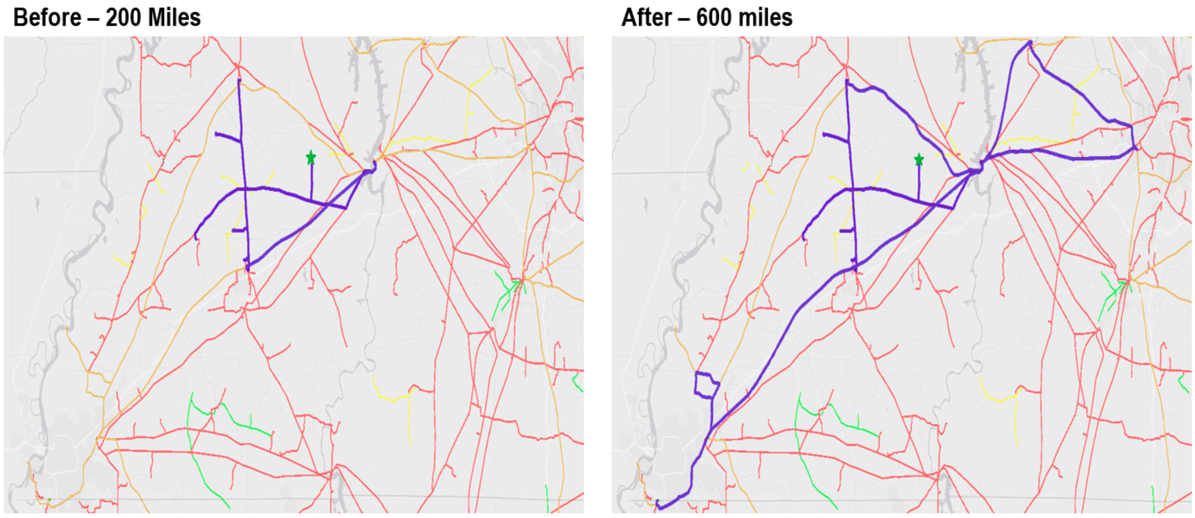

Figure 5 – AOV Maps Before and After System Change

Individualized Consumer Metrics
As consumers become more discerning about the difference between quality and reliability, more nuanced reports will likely be needed. Already, some utilities are being asked about voltage balance and harmonics. Figure 6 shows a conceptual report outlining some key metrics for more discerning customers. The report contains metrics on voltage regulation, voltage balance, harmonic performance, flicker performance and voltage sag metrics. In addition, the conceptual report attempts to quantify a risk based overall score based on the preceding metrics. Finally, the report shows some recommended corrective actions. While conceptual, it is likely future customers will demand this level of detail.

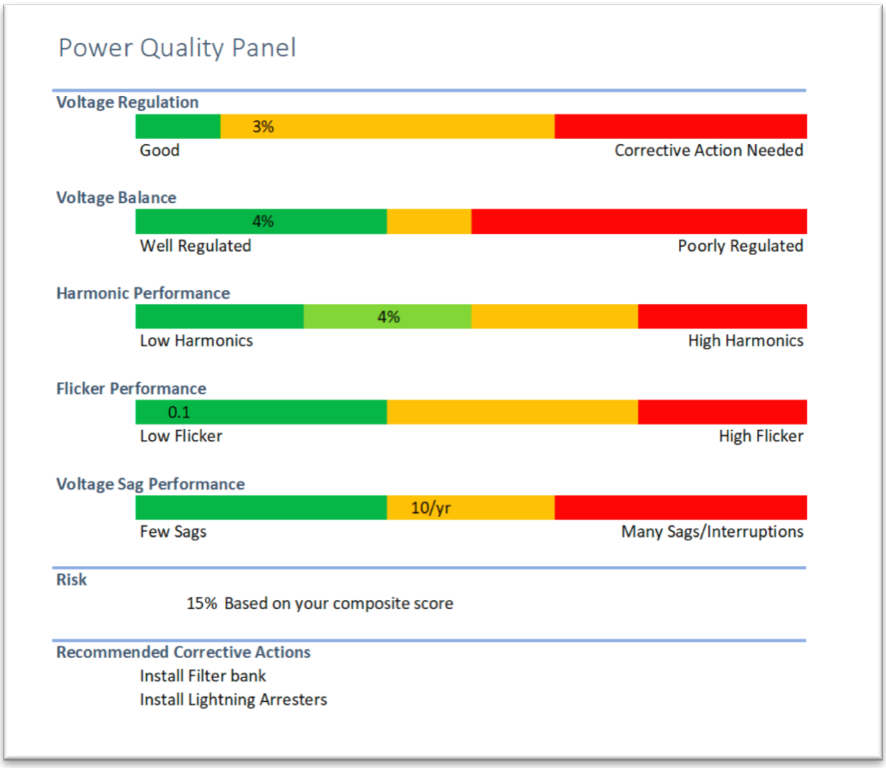

Figure 6 – Example Consumer PQ Report

System Reporting
Utility operations staff may want to understand how compliant an individual site or their system is with regards to any prescribed metric. At the most basic level, compliance should be measured at each site. Then the sites can be aggregated into a system level metric. The system level metric can, in turn, be use for system benchmarking and for making more strategic investments in system improvements.

The formula shown in Figure 7 [5], below, is an example calculation on performing system wide PQ compliance index. The formula is simply the difference between the total number of sites and the number of sites that were not compliance divided by the total number of sites. A ratio of 1 would be full system compliance.

$$I_T = \frac{N_E - N_T}{N_E}$$

Where:

I_T = The system PQ compliance index for event-based disturbance;
N_E = The total number of sites that were monitored; and
N_T = The total number of non-compliant sites.

Figure 7 – Simple Compliance Index.

To illustrate how this approach could be used, the following example is supplied. A utility has 100 sites measuring flicker. IEEE 1453 states that PST should have a CP 95 below 1.0 for each monitored site. If the utility has 5 sites that do not meet the IEEE 1453 recommendation, then the Flicker compliance index for the utility would be .95.

This approach could be extended to aggregate multiple indices into a simple system health index. If there are 4 compliance indices for a utility: voltage regulation, voltage balance, voltage THD, and flicker, then the total number of sites that are not compliant for each metric against the total number of sites would provide a means of creating a simple system health index.

Using the example utility from before, they are still monitoring 100 sites. They have 2 sites that are not compliant with their voltage regulation metric, 3 sites that not compliant with their voltage balance metric, 1 site that is not compliant with their voltage THD metric, and the 5 sites that were not compliant with the flicker metric. This results in 11 sites that are out of compliance for a compliance index of .89.

This approach could be further extended to weight different metrics based on importance. Table 1, below, shows how the metrics could be aggregated into a weighted metric. The resulting weighted system index would be .969.

Table 1 – Weighted Health Index Example

Metric	Non-Compliant Sites	Weight	Index	Weighted Index
Voltage Regulation	2	1	.98	.98
Voltage Balance	3	2	.97	1.95
Voltage THD	1	3	.99	2.97
Voltage Flicker	5	4	.95	3.8

Benchmarking

CIGRE C4.27 [6], recommends benchmarking the following quantities: PQ disturbances, harmonics, flicker, unbalance, sags, and swells. In benchmarking, a temporal component is added to the system health indexes described in the previous section. Instead of just indicating a site has been in or out of compliance, the recommendation is to add the total number of non-compliant site weeks. Figure 8, below, shows the recommended formula for performing this type of benchmarking.

$$I_C = \frac{\sum_{i=1}^{N}(N_i - W_i)}{\sum_{i=1}^{N} N_i}$$

Equation 4.1

Where:

I_c = The system compliance index;

W_i = The number of weeks of non-compliance conditions at Site i;

N_i = The number of all weeks of valid data gathered by measurement at Site i; and

N = The total number of monitored locations.

Figure 8 – C4.27 Benchmarking Formula

When benchmarking, it is important to capture additional information about each metric. Examples include the voltage class, breaker configuration, event detail, and system topology. These are needed so that benchmarks are compared against like systems. For example, a distribution system has different exposures and protection elements than a transmission system does. It would be inaccurate to compare the quality metrics of a distribution low voltage radial feeder with a high voltage transmission network line.

Conclusions

The grid is increasing in complexity. As a result, reliability alone is no longer a sufficient measure of utility quality. The first step is getting better optics on the power system. With an investment in better monitoring subsequent failure may be avoided or at least root cause analysis will be easier both reduce cost to the utility. This makes investment in power quality a strategic investment for utilities not only to facilitate better operations, but to provide better benchmarking. Better quality leads to higher customer satisfaction and loyalty.

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