Using Color Codes to Simplify Power Quality Analysis

by Vanya Ignatova

Executive summary

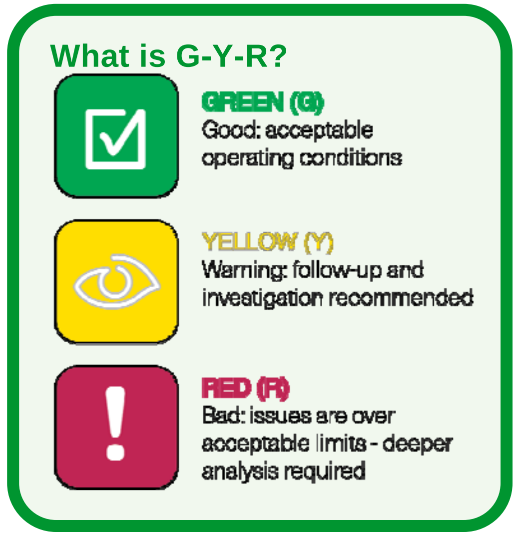
Even when power quality monitoring systems are in place, studies show users often have limited knowledge of power quality and its impact on equipment and installations. Thus, they may not fully understand, analyze and exploit power quality measurements. This paper introduces simple green-yellow-red *(G-Y-R)* indicators to gauge power quality issues; markers based on recognized power quality standards and statistical analysis, fully integrated in a power quality monitoring system. This paper also introduces a power quality rating that summarizes global power quality level within a facility.

998-2095-05-27-15AR0

Schneider Electric

Introduction

Today between 30 to 40 percent of all business downtime is related to power quality problems. In fact total cost to the European economy from poor power quality exceeds 150 billion €,[1] while in the US these losses are between $119 billion and $188 billion USD.[2] Still, even though these are sizeable numbers, investments in power quality measurement or corrective equipment are limited with only ten percent of total power quality loss costs invested in power quality mitigation solutions. While business investment priorities certainly affect these decisions, the main reason for this shortcoming is due to a lack of knowledge regarding power quality and its potential impact on an electrical installation.



Most facilities today have an installed power monitoring system or devices and can access at least some basic power quality measurements: total harmonic distortion, voltage and current unbalance, voltage levels, or power factor measurements for example. However, these fundamental measurements are often left unexplored because the provided metrics can be considered obscure and understandable only to power quality experts.

Yet the information that power quality provides can be meaningful and leveraged by people inside the facility not necessarily power quality specialists or consultants. For example, an energy procurement manager needs a simple power quality view to avoid penalties, and to adapt and optimize the energy contract. A plant manager needs to understand power quality, its impact on the facility and associated costs. A maintenance manager or technician needs quick, easy to understand power quality metrics for equipment diagnostic and downtime root cause analysis.

The difficulty in interpreting power quality measurements often comes from the variety of power quality problems and metrics, the volume of data, and the diversity of applicable standards. To simplify power quality analysis, a new methodology converts the multitude of power quality taxonomies into meaningful, unified and easy-to-understand green-yellow-red *(G-Y-R)* indicators for each specific power quality problem. Green indicates acceptable operating conditions. Yellow indicates a warning, and a further follow-up and investigation is recommended. A red indicator denotes real power quality issues over acceptable limits, where a deeper analysis is needed in order to investigate the root causes, estimate the impacts, and undertake appropriate corrective actions.

To add to this, a power quality rating calculation provides a practical 'at a glance' overview of a facility's global power quality. The industrial facility example at the end of this paper illustrates both the application of the green-yellow-red indications and the power quality rating. This method is easily integrated within power quality monitoring systems to help convert large data volumes into meaningful, understandable, and actionable information. Deep investigation of all metrics for a given power quality problem is still useful and needed, but only in the case of yellow and red indications. This method can also be a useful tool for power quality consultants, saving time and allowing them to focus on the areas where problems occur.

---

[1] J. Manson, R.Targosz, *"European Power Quality Survey Report",* Leonardo Energy, 2008
[2] S. Bhattacharyya, S.Cobben, *"Consequences of Poor Power quality – an Overview",* Power Quality, book edited by Mr Andreas Eberhard (Ed.), ISBN: 978-953-307-180-0, InTech, 2011

Power quality disturbances insight

What is power quality?

In an ideal three phase power system, the voltages are at their nominal magnitude, at their nominal frequency, perfectly balanced and with a perfect sinusoidal waveform. Any disturbance on one of these parameters (magnitude, frequency, waveform, symmetry) is classified as a power quality problem. Power quality problems are among the main causes for business downtime, equipment malfunction, and equipment damage.

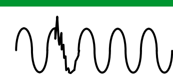
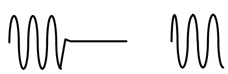
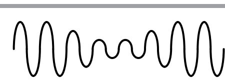
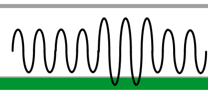
There are a number of different power quality disturbances; all of them can have a negative impact on the electrical system and equipment. However, regarding their nature and their impact, power quality problems can be separated into two broad classes:

- Short-term events, including transients and short-duration voltage variations, with duration inferior to 1 minute as defined by IEEE 1159-1995[3].
- Long-term power quality disturbances, including harmonics, unbalance, under- and over-voltages, frequency variations, voltage variations (flicker), and power factor.

Short-term events

Short term power quality events regroup voltage dips, swells and interruptions, usually associated with system fault conditions, as well as voltage transients, due mainly to lightning strikes and switching operations (capacitors banks, tap changing transformers). Short term power quality events have usually a visible and immediate impact in the electrical installation. Voltage dips and interruptions result in unscheduled downtime. Voltage swells and transients cause malfunction, damage, and reduced efficiency of electric equipment.

Table 1
Short-term power quality disturbances

Disturbance category	Waveform	Effects	Possible causes
Transients		Equipment malfunction and damage	Lightning or switching of inductive / capacitive loads
Interruption		Downtime, equipment damage, loss of data possible	Utility faults, equipment failure, breaker tripping
Sag		Downtime, system halts, data loss	Utility or facility faults, startup of large motors
Swell		Equipment damage and reduced life	Utility faults, load changes

Various power quality standards can be used to determine the impact of short-term power quality events. The most used and popular are:

1. CBEMA: developed by the Computer Business Equipment Manufacturers Association in 1977 to address the power acceptability for computer equipment
2. CBEMA - ITIC: modified version of the CBEMA power acceptability, developed in 1994 and revised in 2000, by the Information Technology Industry Council
3. SEMI F47: Specification for Semiconductor Processing Equipment Voltage Sag Immunity, originally published in 2000 and updated in 2006
4. IEC 61000-4-11: Voltage dips, short interruptions and voltage variations immunity tests, applies to equipment that draws current less than 16 amps per phase

[3] IEEE 1159-1995. "Recommended Practice For Monitoring Electric Power Quality"

5. IEC 61000-4-34: Voltage dips, short interruptions and voltage variations immunity tests; applies to equipment over 16 amps
6. Samsung Power Vaccine: developed by Samsung for semiconductor manufacturing equipment, focused on voltage dips and interruptions

Fortunately, all these power quality standards use the same principle as presented with the example of the CBEMA-ITIC curve here after. Based on the magnitude (vertical axis) and the duration (horizontal axis) of the events, they define (see **Figure 1**):

- an area in the center of the plot, where equipment is expected to operate properly (**1**)
- an area above the envelope, where there is risk of damage, overload, and malfunction for the equipment (**2**) caused by critical transients and swells
- an area below the envelope where voltage sags and interruptions are assumed to cause the load to drop out due to lack of energy (**3**)

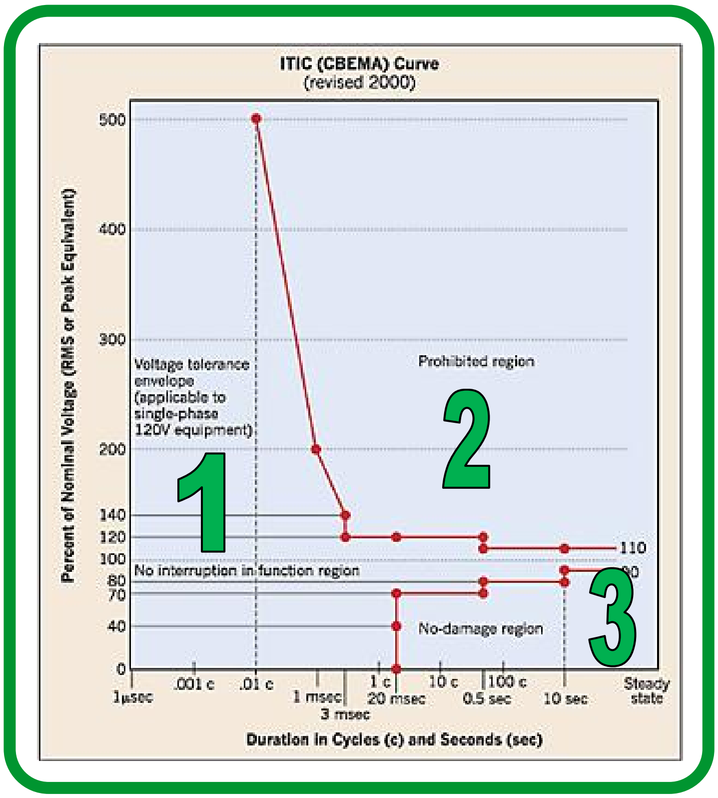
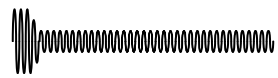
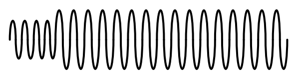
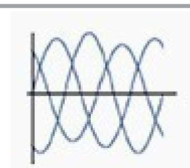
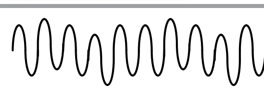
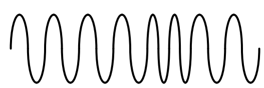
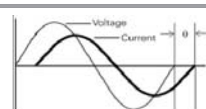


Figure 1
CBEMA-ITIC Power Acceptability Curve

Long-term disturbances

Long term power quality disturbances include steady state disturbances, such as voltage and current unbalance and harmonics, long-duration variations (undervoltages and overvoltages), and also intermittent voltage or frequency variations. The effect of this type of power quality disturbance is often quite negative: equipment failure, malfunction, overheating and damage.

Table 2
Long-term power quality disturbances

Disturbance category	Wave form	Effects	Possible causes
Undervoltage		Shutdown, malfunction, equipment failure	Load changes, overload, faults
Overvoltage		Equipment damage and reduced life	Load changes, faults, over compensation
Harmonics		Equipment damage and reduced life, nuisance breaker tripping, power losses	Electronic loads (non-linear loads)
Unbalance		Malfunction, motor damage	Unequal distribution of single phase loads
Voltage fluctuations		Light flicker and equipment malfunction	Load exhibiting significant current variations
Power frequency variations		Malfunction or motor degradation	Standby generators or poor power infrastructure
Power Factor *		Increased electricity bill, overload, power losses	Inductive loads (ex. motors, transformers...)

** Considered a PQ problem by end users, but not from a standards perspective.*

There are specific standards or regulations for each long-term power quality disturbance. For some disturbances, there are various standards that can be applied, for others the available recommendations are more restricted. Some examples include:

- Harmonic limits are specified by standards such as IEC 61000-2-4 and IEEE 519, 2014 revision
- Recommendations for unbalance deviations are provided by ANSI C84.1 and NEMA MG-1, but there are no international standards recommendations regarding current or voltage unbalance
- Frequency variation limits are fixed by the European norm EN50160, IEC 60034 for generators, but also by national regulations in all most every country.

G-Y-R power quality indicators

These simple G - Y - R power quality indicators are based on recognized power quality standards and international statistical results. In the same say that short term and long term power quality disturbances are not analysed and qualified, by using the same tools, two different methods are also used to determine the G-Y-R indicators. The first method is dedicated to short term events and is based on the association of power quality acceptability curves and statistical data. The second method is for long term disturbances, based on trend analysis and power quality standards recommendations. Both methods are simple, reliable, flexible, and adapt well to the sensitivity and the requirements within any facility.

Short term events:

For short term power quality events, the approach is first to classify each event to one of two possible categories (no impact, certain impact) based on standards or experimental curves. Then, for a given time period, the green-yellow-red indicator is estimated based on the number of events with certain impact and representative statistical results (see **Figure 2**).

Figure 2
Short term event method: CBEMA Curve plus international stats equals green, yellow, or red status

To classify each event, we use the CBEMA-ITIC power acceptability curve (**Figure 1**) or equivalent, on which we plot the magnitude and duration of each individual power quality event to catalog it within two categories:

- No impact: for events inside the power acceptability curves. (area 1 in **Figure 1**)
- Certain impact: for events outside the power acceptability curves. (areas 2 and 3 in **Figure 1**)

As the indicators are usually built for a given time period – week, month or year – the next step is then to define the number of events with "certain impact" per time period (the events with "no impact" are ignored). This number is benchmarked with results coming from a database that comprises more than 800 end user facilities worldwide, in order to provide a meaningful colour code indication to the end user about the precision of its power quality ranking regarding short-term power quality events.

For example, a voltage dip of 40% magnitude for 100 millisecond duration is classified as an event with "certain impact" according to the CBEMA-ITIC power acceptability curve. A voltage dip of 80% magnitude and duration of 100 milliseconds is classified as an event with "no impact".

If for one-month period five events are recorded from which two are classified as critical, the voltage sag indicator will be red to signal this abnormal operating condition.

Long term disturbances:

For long term power quality disturbances, the green-yellow-red indicator is evaluated directly for a given time period by using trend analysis and thresholds from power quality standards or other recommendations (see **Figure 3**).

Figure 3
Long term event method: Trend analysis plus international (IEEE, IEC) limits equals green, yellow, or red status

It is also critical to select the right metrics to track. Usually, it is more suitable to select metrics on voltage quality than on current quality, as they are more representative and the limits are easy to determine. For example, for harmonic distortion it is better to follow THDu than THDi, as THDi limits often depend on electrical installation parameters (ex. short-circuits power).

Fixed limits for yellow and red colour indicators are based on the standards or other recommendations presented on **page 5**. If these yellow/red limits are exceeded for a period longer than 5% of the recorded time, the indicator becomes respectively yellow/red. This time limit of 5% was selected to avoid measurement errors and to be more representative of the impact that the disturbance may generate (a single exceed of the fixed limits is not necessarily impacting the electrical installation and equipment).

For example, the green-yellow-red indication for harmonic distortion is based on the THDu value. Yellow/red limits are fixed according to the IEEE standard: 3% for yellow indication and 5% for red indication. For a period of 24 hours, if the yellow limit was exceeded for more than 72 minutes, the colour-code indicator becomes yellow. If the red limit was exceeded for the same time period the indicator becomes red. Otherwise, the indicator remains green.

Power quality rating

The Power Quality Rating is an at-a-glance overview of the power quality level. It is a summary of all individual power quality indicators, expressed in percentage: 0% indicates the worst power quality; 100% an optimal power quality. It can be defined for a specific metering point, or for an area within a facility, or even the entire facility (taking into account measurements from several metering points). In this case the Rating is computed by software, which receives and compiles information from several available sources.

It is possibile to associate weight factors to each power quality problem in order to customize the power quality rating. This will allow the end user to adapt the power quality rating according to the unique sensitivities of the installation. The power quality rating can be graphically represented through a quantitive scale or an A/B/C/D/E/F graph (see **Figure 4**).

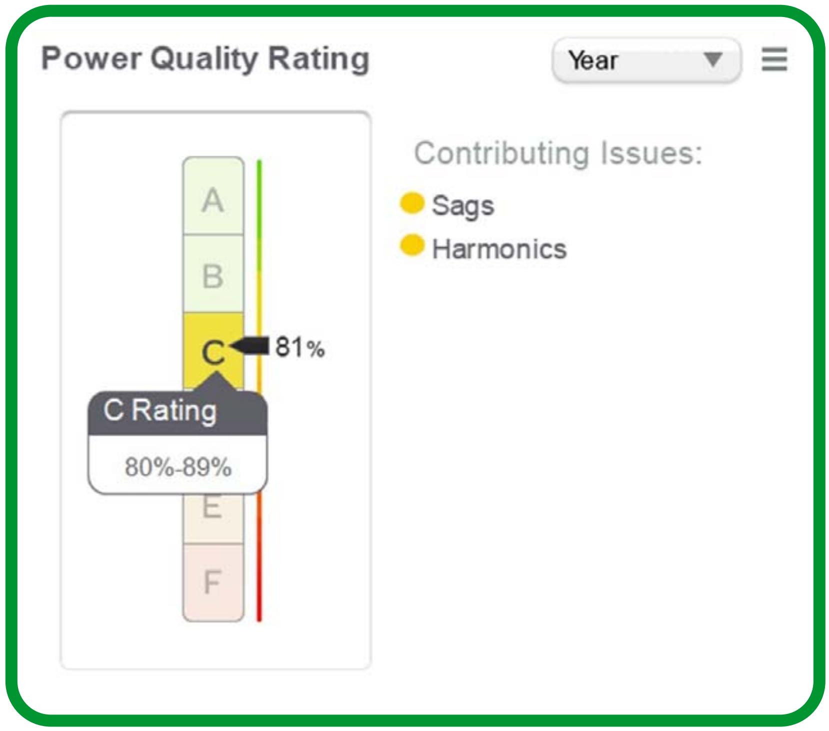


Figure 4
Power quality rating: example of a graphical representation

Application example

In this example, a power quality monitoring system was installed in an industrial facility. Power quality events and long-term disturbances were recorded and red-yellow-green indicators computed.

On a monthly basis the majority of power quality indicators were green, indicating there was no critical issue except for the voltage sag and power factor indicators, for which the colour codes were respectively red and yellow (see **Figure 5**). Further analysis on “what happened”, its cause and the impact for those two disturbances was required.

Figure 5
Power quality indicators - Industrial case study

A deeper analysis shows that for the recorded period, several voltage sags with impact on the process were detected, which turns the voltage sags indicator in red (see **Figure 6**).

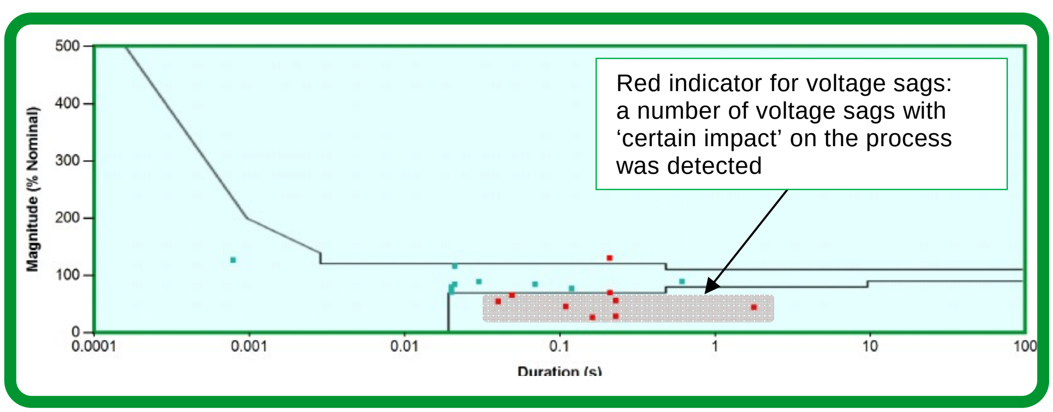


Figure 6
CBEMA-ITIC Power Acceptability Curve – Industrial case study

Detailed data for each voltage sag is further required in order to determine the event:

- **Origin**: with Disturbance Direction Detection (a capability available in some power quality meters), it is possible to identify disturbance location relative to the meter's location (upstream / downstream). When a meter is located at the incomer, this feature indicates whether the disturbance originates at the energy provider source or is generated on-site.
- **Cause:** when the event is due to an internal fault, the analysis of affected phase(s), waveform, event time and duration, as well as data coming from neighbouring meters allows end users to identify and localise the source.
- **Impact:** if a process or equipment stoppage has occurred at the period immediately after a voltage sag event, this stoppage is certainly due to the voltage sag event. The estimation of stoppage duration and cost due to power quality issues should be taken into account to select the appropriate corrective actions.

Table 3
Analysis of individual power quality events

Incident		Meter	Time	Type	Phase	Duration (s)	Magnitude (%)
5	Incident	NorthSub.MainIncomer	1/27/2014 10:54:09 PM	Sag * Exceeds Tolerance	V2	2,155.690	40.15
6	Incident	NorthSub.MainIncomer	1/27/2014 11:30:05 PM	Swell * Exceeds Tolerance	V3	2,729.264	111.73
7	Incident	NorthSub.MainIncomer	1/28/2014 12:49:45 PM	Sag * Exceeds Tolerance	V1	0.162	26.64

The power factor indicator is yellow, as the recorded power factor was below the expected 0.94 limit for more than 5% ot the analysis period (see **Figure 7**). This low power factor may result in an increase of the electricity bill due to penalties or extra-charges from the utility. In addition, low power factor may lead to overload of cables and transformers, an increase of power losses, and voltage drops. Power factor correction equipment (if available) should be carefully checked.

Figure 7
Power Factor and THDU trend analysis –Industrial case study

In total, ten power quality disturbances were followed, one was red, one yellow and eight green. The weight factors for the power quality problems are set at 1 (default values), the power quality rating is at 85%.

Conclusion

Power Quality surveys and studies show that most end-users – even those with power quality monitoring system in place – have limited knowledge of power quality and its possible negative impacts. As this paper details, there is a methodology available to determine a green-yellow-red ranking for each power quality disturbance, along with a global power quality rating. Easy to understand and integrate in a power quality monitoring system, this methodology and the global power quality rating are based on recognized power quality standards and statistical analysis.

It can be integrated reliably into a power quality monitoring system or within consultant tools. Ultimately, such monitoring will improve power quality on a continuous basis, increase electric installation uptime, and optimize equipment performance, efficiency, and life span.

About the author

Vanya Ignatova (PhD, Power Quality) is the Power Quality Marketing Expert for Schneider Electric, working on power quality solutions creation for Industry, Critical Buildings, and Utility applications. Vanya received her PhD from Institut National Polytechnique de Grenoble in 2006, receiving the award for the year’s Best PhD from the Laboratory of Electric Engineering. She joined Schneider Electric in 2006 as an expert on electrical installation calculation and sizing, and since 2010 has specialized in Solutions Offer Creation for energy management and power quality.