Measuring Reliability and Power Quality

What is reliability? As competition in the utility industry takes hold, defining reliability and standardizing methods of reporting on reliability will be one of the most important tasks facing industry regulators. Electric utilities have developed a variety of *reliability indices* that are used to report on system performance to reliability councils. These indices are based on sustained interruptions (different utilities use different definitions for a sustained interruption but it is usually somewhere in the range of one to five minutes).

However, there are many power quality variations other than sustained interruptions which can cause misoperation of customer equipment. Variations such as sags, swells, harmonic distortion, transient overvoltages, and steady-state voltage variations all need to be considered and coordinated with the specifications for equipment operation. A working group in IEEE was organized specifically for this purpose (IEEE P1346) and has already developed guidelines for evaluating the compatibility of equipment operation with the expected voltage sag performance of the power system.

Methods for characterizing all power quality variations are needed so that system performance can be described in a consistent manner from one utility to another and one system to another. The Electric Power Research Institute (EPRI) has sponsored a project to develop a draft set of indices that could be used for this purpose and a methodology for calculating the indices (Reliability Benchmarking Methodology - RBM). The project is managed by Ashok Sundaram (asundara@epri.com).

For purposes of this discussion, let's focus on voltage sags. The IEEE Gold Book (Standard 493-1990) already includes voltage sags in the definition of reliability:

> *Economic evaluation of reliability begins with the establishment of an interruption definition. Such a definition specifies the magnitude of the voltage dip and the minimum duration of such a reduced-voltage period that results in a loss of production or other function of the plant process.*

Voltage sags are generally the most important power quality variations affecting industrial and commercial customers. Characterizing voltage sag performance has become increasingly important as industries have automated their processes and become more dependent on sophisticated electronic equipment. Costs associated with a voltage sag event can range from tens of thousands of dollars at a plastics plant to millions of dollars at a semiconductor manufacturing facility. How can we describe the system performance so that customers can make economic evaluations of power conditioning requirements and evaluate alternative power supply proposals?

In defining indices for assessing voltage sag performance, we can use the work that has already been done in IEEE to define indices for both sustained and momentary interruption performance. These indices have been used by utilities for years, although they are not yet standardized by the IEEE. They are included in the proposed IEEE Standard P1366 which should go to ballot by the end of 1996. We should also work to coordinate the definitions used for these indices with the definitions in IEEE Standard 1159-1995*, Recommended Practice on Monitoring Electric Power Quality.* A sustained interruption is defined as a reduction in the rms voltage to less than 10% of nominal voltage for longer than 1 minute. P1366 uses 5 minutes for this definition.

The most basic index for voltage sag performance is described below. It provides the basis for most of the other indices as well.

System Average RMS (Variation) Frequency Index$_{Voltage}$ ($SARFI_x$)

$SARFI_x$ represents the average number of *specified* short-duration rms variation measurement events that occurred over the monitoring period per customer served from the assessed system. For $SARFI_x$, the specified disturbances are those rms variations with a voltage magnitude less than x for voltage drops or a magnitude greater than x for voltage increases. $SARFI_x$ is defined by:

$$SARFI_x = \frac{\sum N_i}{N_T} \qquad (1)$$

where

$X \equiv$ rms voltage threshold;
possible values - 140, 120, 110, 90, 80, 70, 50, and 10
$N_i \equiv$ number of customers experiencing voltage deviations with magnitudes above X % for $X > 100$ or below X % for $X < 100$ due to measurement event i
$N_T \equiv$ number of customers served from the section of the system to be assessed

$SARFI_x$ is calculated in a similar manner as the System Average Interruption Frequency Index (SAIFI) value that many utilities have calculated for years. The two indices are, however, quite different. $SARFI_X$ assesses system performance with regard to short-duration rms variations, whereas, SAIFI assesses only sustained interruptions. $SARFI_X$ can be used to assess the frequency of occurrence of sags, swells, and short-duration interruptions. Furthermore, the inclusion of the index threshold value, x, provides a means for assessing sags and swells of varying magnitudes. For example, $SARFI_{70}$ represents the average number of sags below 70% experienced by the average customer served from the assessed system.

SARFI can be broken down into sub-indices by the causes of the events or by the durations of the events. For instance, it may be useful to define an index related to voltage sags that are caused by lightning-induced faults. Indices have been defined for subcategories associated with instantaneous, momentary, and temporary voltage sags, as defined in IEEE 1159.

It is also useful to introduce the concept of aggregated events. Multiple voltage sags often occur together due to reclosing operations of breakers and characteristics of distribution faults. Once a customer process is impacted by a voltage sag, the subsequent sags are often less important. To account for this effect, a new index, the *System Average RMS (Variation) Aggregate Event Frequency Index* ($SARAEFI_x$) is calculated. This index is similar to SARFI except that there is only one count for multiple sags within a one minute period (aggregation period).

These indices can be estimated based on historical fault performance of transmission and distribution lines but system monitoring is required for accurate assessment of performance at specific system locations. Many utilities (Consolidated Edison, United Illuminating, Northeast Utilities, San Diego Gas & Electric, TVA, Entergy, Baltimore Gas & Electric) have already installed extensive monitoring systems to help characterize system performance on a continuous basis. Detroit Edison and Consumers Power have installed monitoring systems to track performance at specific customers (automotive plants) as part of the contractual requirements associated with serving these customers. These types of monitoring systems will be described in more detail in the next issue of Power Quality Assurance which will be dedicated to the topic of measuring power quality.

The information obtained using these indices can be valuable for many different purposes. Marek Waclawiak from United Illuminating (UI) described some of the applications already in place at UI. UI commercial and industrial customers consider PQ as the second highest service priority. UI found that the customer concerns were based on a perception of poor PQ rather than quantified assessment. In response to this perception, UI has installed power quality monitoring at 92% of their distribution substations and will have all the substations monitored by the end of this quarter. Data from the monitoring is available in real time to customer engineers, protection engineers, and operations engineers through the UI network. The data is used to calculate performance indices that become part of monthly and quarterly reports. SARFI is included as one of UI's company performance drivers along with SAIFI, SAIDI, and CAIDI (interruption-based indices). SARFI-based ranking of substations is used for prioritizing expansion and maintenance. If $SARFI_{90}$ exceeds specified thresholds in any period, a PQ investigation is recommended. In the future, steady state performance indices (voltage regulation, unbalance, harmonics) will also be included.

Other utilities already using the voltage sag indices to track system performance include Baltimore Gas & Electric and San Diego Gas & Electric.

We are in for a period of rapid change. Electric utilities need to take a customer focus in everything they do if they are going to survive in the deregulated world. Characterizing system performance in a manner that relates to the impacts on customer equipment is one good example.

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