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A Transient Index for Reporting Power Quality Surveys

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Abstract

Impulsive transients are often blamed for the destruction of customer appliances. Advances in Power Quality (PQ) monitors will soon make it feasible to incorporate impulsive transients into routine power quality surveys. This paper considers how the transient events captured over a period at many sites may be reported in a simple but useful manner. The paper first summarizes a recent publication by some of the authors, which attempt to give a complete framework for the analysis of utility PQ data. This framework provides a basis for evaluating existing transient characterization practices as well as for the proposed new transient index that will be discussed in the paper. A review of current transient characterization practices and their limitations, followed by the development of new transient index for use in site ranking is given. The application of the new transient index is illustrated through an example.

A TRANSIENT INDEX FOR REPORTING POWER QUALITY SURVEYS

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INTRODUCTION

Impulsive transients are often blamed for the destruction of customer appliances. Advances in Power Quality (PQ) monitors will soon make it feasible to incorporate impulsive transients into routine power quality surveys. This paper considers how the transient events captured over a period at many sites may be reported in a simple but useful manner.

The paper first summarizes a recent publication by some of the authors, which attempt to give a complete framework for the analysis of utility PQ data. This framework provides a basis for evaluating existing transient characterization practices as well as for the proposed new transient index that will be discussed in the paper. A review of current transient characterization practices and their limitations, followed by the development of new transient index for use in site ranking is given. The application of the new transient index is illustrated through an example.

FRAMEWORK FOR PQ DATA ANALYSIS

Power Quality Analysis Triangle

The amount of information obtainable from a routine PQ survey over a sample of distribution utility sites can be enormous and hence there is a need to determine appropriate data summary methods. It is proposed that the data be structured for reporting purposes in a number of layers, each layer providing a wider view in less depth than the one below. Data structured in this manner can be represented in the form of a triangle, which has been termed the power quality analysis triangle (PQAT) shown in Figure 1 [1]. The lower parts of the triangle show the data at one site being consecutively "compressed" to smaller and smaller amounts with a greater degree of summary at each higher level, a process called "time compression". This can be lead to a single power quality indicator for a site called the Unified Power Quality Index (UPQI – output of Block 9) [2].

At the base of the triangle is Block 1, are the raw voltage data at a particular site as obtained from the PQ monitor. Continuous disturbances (e.g. voltage, unbalance, harmonics and flicker) would be characterized by values averaged over 10 minutes [3]. Discrete or event-type disturbances (sags, swells and transients) would be characterized by diary entries of data, time and disturbance characteristics. At next higher level, the data is summarized for example by the 95% cumulative probability value for continuous disturbances. *Disturbance Characterisation* is the determination of appropriate parameters for each disturbance type. For continuous disturbances, this process is relatively straightforward, resulting in parameters being calculated for each sampled cycle (Block 2). There is one parameter for

each of voltage, unbalance and two for flicker and many for harmonics (V_2-V_{40} and V_{THD}).
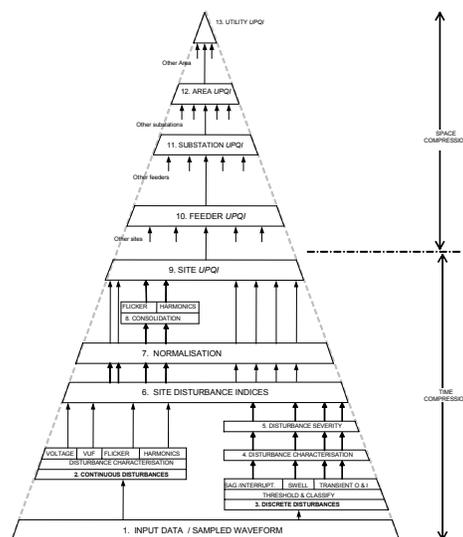

Figure 1. Power Quality Analysis Triangle (PQAT) [1]

The procedure for the discrete disturbances is considerably more complex. Each set of data needs to be compared with a threshold to determine which discrete events are present (Block 3). Block 4 then processes each identified disturbance according to its type and ascribes appropriate parameters, for example depth and duration in the case of a sag. There is no simple method of combining all these parameters directly into one overall index for the survey period. We postulate that the next logical stage is to determine a single number for each event to give a measure of its *Disturbance Severity*, represented by Block 5. This might be a simple 0 or 1 depending on whether the event lies inside or outside some region such as the CBEMA curve. But more sophisticated and useful approaches are possible [4].

Block 6 calculates a *Disturbance Index* for each disturbance type to give a measure of levels over the survey period. For continuous disturbances, the 95% cumulative probability level is used in many standards such as flicker and harmonics, and a similar approach can be applied to voltage and unbalance.

A *Site UPQI* is a single PQ index measuring the overall level of PQ disturbances and is accomplished in Block 9 from the individual disturbance indices. This cannot be simply done on the output of Block 6, as there is more than one number required to describe flicker and harmonics.

The higher stages of PQAT show the data from more and more sites being aggregated into indices summarizing the PQ behaviour of larger and larger areas, a process called "space compression".

The data format at the base of the PQAT might be used for close examination of one event for one disturbance type at one site. The data format at the apex gives an overall summary of all disturbance types at all monitored sites for an extended period and might be used for utility benchmarking purposes.

In this paper, we shall be building on the ideas of disturbance severity and disturbance index represented by Blocks 5 and 6 of Figure 1. In the case of transients, each event is characterized by several parameters. A *Transient Severity Indicator* is a single number for each transient event related to the degree of severity to customers. A *Transient Site Index* is the sum of all transient severity indices scaled to an agreed survey period, usually a year.

TRANSIENT CHARACTERIZATION

Overview

In order to characterize transient behavior at a site, it is necessary to define the disturbance duration and voltage magnitude of each transient. For the case of sags and swells, this task is relatively easy. However, for the transients the task is more complicated because there is no precise definition for the transient duration.

It is evident from the literature that there is much room available for the development of indices for transients. This can be determined from the rise time, peak magnitude and decay time. Transient standards tend to characterise the impact of an impulsive transient by the energy content assuming a constant impedance (R), as given by

$$E = \int \frac{[v(t)]^2}{R} dt \qquad (1)$$

where, *E*- Energy content of the transient, $v(t)$ – transient voltage as a function of time, *R*-Resistance equivalent to 50Ω [5]. However, some literature proposes $\int [v(t)]^2 dt$ as the measure of energy content of the transient, without specifying a value for *R* [6]. Several instruments record this latter value.

Voltage Tolerance Curves

Voltage tolerance curves also known as power acceptability curves [7] are plots of bus voltage deviation versus time duration. They separate the bus voltage deviation – time duration plane into two regions: "acceptable" and "unacceptable". Various voltage tolerance curves exist but the most widely publicized is the CBEMA curve. The CBEMA curve has been in existence since 1970's [8]. Its primary intent is to provide a measure of vulnerability of mainframe computers to the disturbances in the electric power supply.

However its use has been extended to give a measure of power quality for electric drives and solid state loads as well as a host of wide-ranging residential, commercial, and industrial loads [9]. The CBEMA curve was revised in 1996 and renamed for its supporting organization Information Technology Industry Council (ITIC). The CBEMA curve and the ITIC curve differ in the way the acceptable region is represented. CBEMA represents the acceptable region by a curve, whereas ITIC depicts the region in steps. The guiding principle is that if the supply voltage is within the acceptable region then the sensitive equipment will operate well. The ITIC curve has an expanded acceptable operating region compared to the CBEMA curve. Both these curves have been accepted as standards and published in the latest versions of IEEE Std. 446 – 1995 [10] and IEEE Std. 1100 –1999 [11].

The Upper left part of the ITIC curve that describes impulsive transients has been designed to give 80J minimum transient immunity level to protect information technology equipment from impulsive transients [12]. We find that this region can be best described mathematically by $V^2 \cdot t = 40$ (where, V is given as a percentage of the nominal voltage and t is time in seconds). The method of least squares was applied to the log plot of ITIC curve for this purpose. Figure 2 shows that the fitted ITIC curve matches the ITIC curve of both high and low end limits of the impulsive transients region.
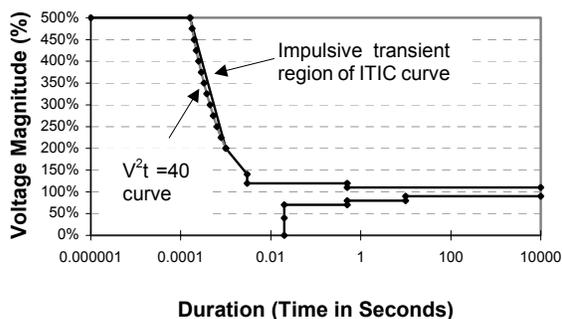

Duration (Time in Seconds)

Figure 2. $V^2t=40$ curve fit on v-t plane of ITIC curve

Transient Duration

A PQ monitor typically reports the peak value of the transient overvoltage and its energy content as given by Equation (1). Consider a transient with a peak voltage (V_{peak}). We define an equivalent duration (*T*) for the transient such that,

$$E = V_{Peak}^2 \cdot T \qquad (2)$$

This definition is supported by the V^2t curve fit to the impulsive transient region of the ITIC curve discussed above.

As an example, assume that a transient waveform has a negligible rise time which can be expressed as $v(t) = V_{Peak} \cdot e^{-t/\tau} \cdot dt$. Its energy content is given by $E = V_{Peak}^2 \cdot \int_0^\infty e^{-2t/\tau} \cdot dt$. Substitution of *E* in equation (2) gives

he duration $T= \tau/2$.

TRANSIENT REPORTING

Overview

No information can be found in the literature on a reporting procedure leading to a site PQ index for transients to compare sites for their transient severity. Following sections will give a summary of some transient reporting practices and lead on to the development of a new index.

Existing Transient Reporting Practices

There are two methods that can be found in the literature for transient reporting. They are the CBEMA or ITIC overlays and the Reliable Power Meters (RPM) method.

CBEMA or ITIC overlays. In this method each transient will be represented on the CBEMA or ITIC curve. The pattern of points such as shown in Figure 5 is a way of presenting the full record of transient events. But such figures cannot be used for comparison different sites as illustrated later. The number of events outside the CBEMA or ITIC limits can also be used to summarize the site results.

RPM method. RPM has developed [13] a technique for determining an index using CBEMA curve overlays (Figure 3) which is known as the Power Quality Index (PQI). Although this PQI is used to cover both undervoltage and overvoltage events, we have used it only for transients, as described here.
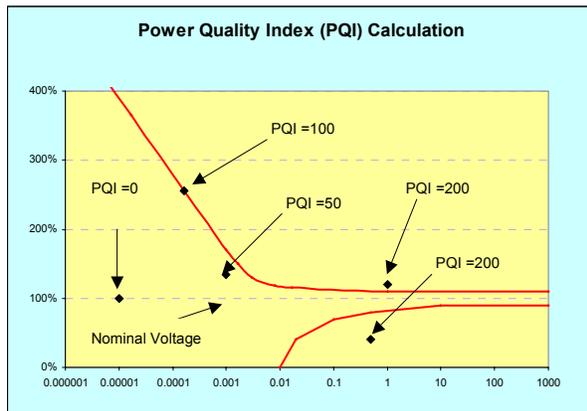

Figure 3. RPM PQ Index [13]

Suppose a voltage event has co-ordinates (T, V). Define the corresponding CBEMA voltage $V_{CBEMA}(T)$ as the voltage on the CBEMA curve corresponding to duration T. The RPM "PQ Index" for an overvoltage or undervoltage event is given by,

$$PQ\ Index = \left| \frac{V - 100\%}{V_{CBEMA}(T) - 100\%} \right| \cdot 100\% \qquad (3)$$

The RPM index corresponds to an event severity index (Block 5, Figure 1). A site index (Block 6, Figure 1) could be formed by summing up all the RPM indices of a site. Deficiencies of the "RPM site index" will be addressed later..

New Proposal for a Transient Index

The new proposal for a transient index is defined on the basis of a curve fit to impulsive transient region of the ITIC curve as described earlier.

Transient Severity Indicator (TSI). We shall assume that impulsive transients which have the same energy content causing an identical customer complaint rate lie on a V^2t contour on the voltage-duration plane.
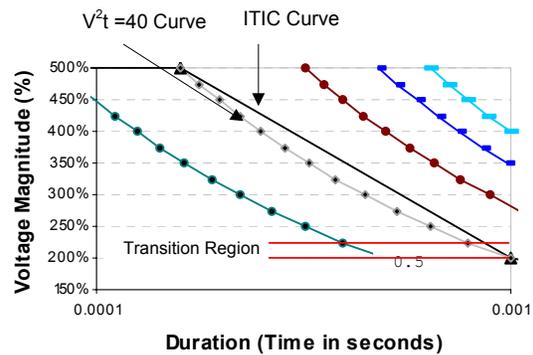

Figure 4. V^2t contours on the voltage-duration plane
[$V^2t =40$ corresponds to fitted ITIC curve]

The following pragmatic assumptions will be made to allow an estimation of the V^2t contour distribution.

(i)   We assume that the $V^2t = 40$ be the base line where the equipment will begin to fail and give it a TSI of 1. In general, TSI is given by the value of $V^2t/40$ with an exception to be discussed in (ii).

(ii)   Different PQ monitors may have slightly different event capture capabilities, even though their set threshold limit is the same. As an example two different instruments with lower transient threshold set at 200% nominal peak voltage may not respond exactly at the set threshold. To avoid this technical difficulty and to smooth out the differences involved, we define a transition region between 200% - 230% of nominal peak voltage (230% being arbitrarily chosen) and the TSI of any event that falls into this region will be applied with a weighting factor, which lies between 0-1. As an example, let a transient event have V= 225 % and t= 0.0004 seconds. First we define the contour number, i.e. $V^2t/40 = 0.50625$ which is 0.51 contour. As the event lies in the transition region, it has to be multiplied with the weighting factor = (225-200)/ (230-200) = 0.8333 which gives the TSI = 0.42.

This new proposal has some advantages compared to RPM site index as follows,

(i) As it is based on energy, the effect on customer's equipment is better represented.

(ii) It takes care of the differences in the way different instruments with the same threshold settings respond.

It is worth noting that the difference between the TSI based on the energy and the index based on the RPM method through an illustrative example. Let us consider two transients with the same equivalent duration but having twice the energy as the other, i.e. V = 300% and 425%, t=0.0007 Seconds. The new index gives values of TSI_1=1.575 and TSI_2=3.16 whereas RPM_1=2.35 and RPM_2=3.81. Thus TSI_1: TSI_2=2:1 and RPM_1: RPM_2=1.6:1.

ILLUSTRATIVE EXAMPLE

We have constructed synthetic data for 4 sites by modifying a set of actual data collected over a one-month survey [14] to express the capability of V^2t transient index for ranking sites on their transient severity (See Table 1).

TABLE 1 - One month transients survey data of four sites
(V in % and t in seconds)

Site 1		Site 2		Site 3		Site 4	
V	t	V	t	V	t	V	t
400	.000021	230	.00003	320	.000002	220	.000001
400	.000034	360	.0001	340	.000003	210	.000001
475	.0009	450	.0003	400	.0006	225	.000002
450	.0003	425	.0001	350	.0002	380	.000004
325	.0002	325	.0006	300	.0007	500	.0003

Existing Transient Site Characterization Approaches

Let us now consider above synthetic data as ITIC overlays (Figure 5) to illustrate one of the site characterization schemes based on event count.

It is seen that the sites 1, 2 and 3 have three transient events within the boundary and two events outside the boundary of ITIC curve whereas site 4 has only one event outside the boundary and all other four events within the boundary. We can only distinguish site 4 from the sites 1, 2 and 3 and no clear differentiation can be found between sites 1, 2 and 3. Therefore, it is clear that ITIC overlays may not give a clear differentiation of the four sites.
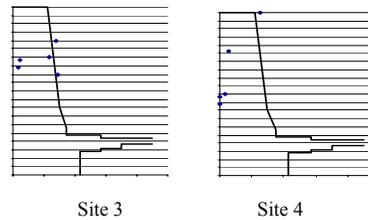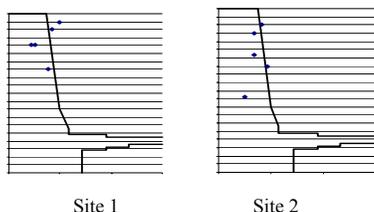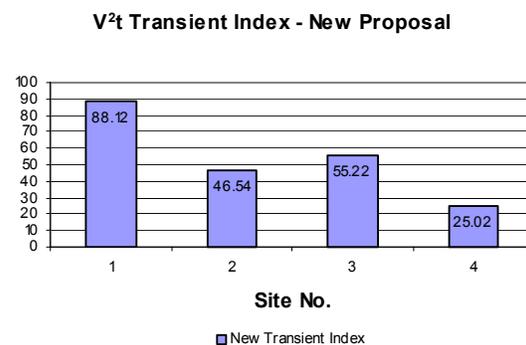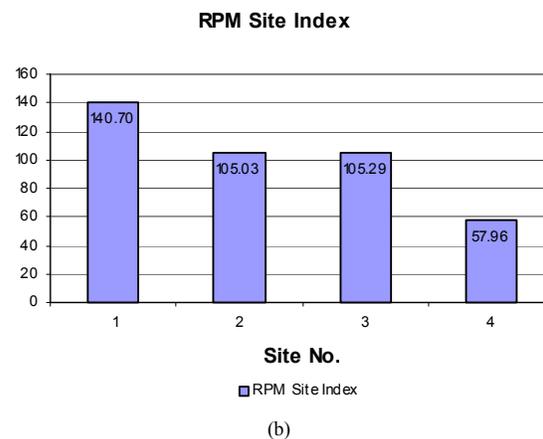

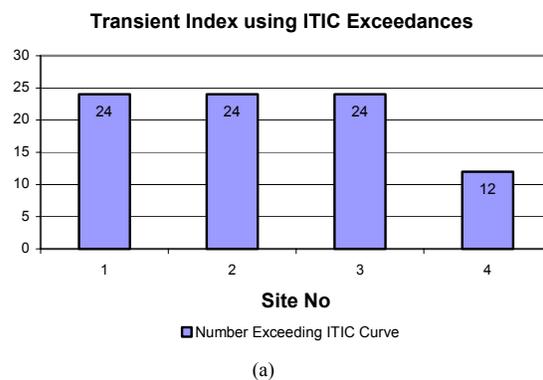Site 1   Site 2

Site 3   Site 4

Figure 5. ITIC overlays of each site data

Transient Site Index Approaches

The count of the number of incidents, which exceed the ITIC curve, is annualized [4] and is shown for four sites by a bar graph in Figure 6(a).

Transient Index using ITIC Exceedances

(a)

RPM Site Index

(b)

V^2t Transient Index - New Proposal

(c)

Figure 6.   A comparison between different transient index characterizations for sites 1- 4. (a)Number exceeding ITIC Curve, (b) RPM site index and (c) V^2t transient index, scaled to a one year.

As explained above in ITIC overlays, the sites 1, 2 and 3 have the same PQ index by this measure where only the site 4 can be ranked against the sites 1, 2 and 3. Therefore, all sites cannot be effectively compared and ranked by this measure.

The RPM site index as per the bar graph in Figure 6(b) would give a better approach than the ITIC exceedences, but the sites cannot be distinguished effectively.

The Proposed V^2t transient index has been applied to the data and displayed as a bar graph in Figure 6(c). This shows the clearer distinction between the sites for their transient severity and possible ranking of sites for remedial work.

CONCLUSIONS

Utility network reporting methods need to be oriented to give a clear view of the relative transient severity across many sites. A PQ data analysis framework has been summarized in which the work required in the development of transient severity index was highlighted.

A new proposal has been presented for determining a transient index from transient event records. V^2t transient index is fundamentally based on a linear relationship between different contours where the event severity can be established by simple linear extrapolation or interpolation.

Present transient event characterization practices such as ITIC overlays and RPM method do not lead to an adequate comparison of sites for their transient severity. The ITIC count approach does not distinguish transient events which are closer to the ITIC curve from those which are far from it. The RPM site index approach is better than the ITIC exceedances, but not very effective. The V^2t transient index offers an attractive way of characterizing transients and ranking sites for their transient severity.

The transient index for impulsive transients that has been discussed in this paper only gives a partial completion of a complex framework, which is systematically identified in the PQ analysis triangle. Further research is aimed at developing a Unified Power Quality Index (UPQI) for discrete disturbances and a UPQI for overall PQ condition of a site.

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