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Power quality (PQ) survey reporting: discrete disturbance limits

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Abstract
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power distribution faults, power supply quality

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Power Quality (PQ) Survey Reporting: Discrete Disturbance Limits

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***Abstract*—Discrete or event type power quality (PQ) disturbances mainly include voltage sags, swells, and the transients. An extensive literature survey suggests that there is no generally accepted method for characterization of these disturbances and suitable limits are not yet found in any international standard. One of the reasons for the lack of characterization methods is the difficulty of defining suitable site indices for each discrete disturbance type. In this paper existing characterization methods are reviewed and discussed. A new generalized approach is then given to show a better way of characterizing voltage sags, swells and transients. This is followed by a proposed new method of defining MV/LV distribution discrete disturbance limits for general utility networks and their suitability is shown by an examination of some Australian sites.**

***Index Terms*—Disturbance characterization, disturbance limits, indices, power quality monitoring.**

I. INTRODUCTION

POWER QUALITY (PQ) disturbances can be classified into two main categories, "continuous" or "variation type" and "discrete" or "event type" [1]. Continuous type disturbances are present in every cycle and typically include voltage level, unbalance, flicker and harmonics. The discrete type disturbances appear as isolated and independent events and can be given as series of diary entries, where for each event the date and time are recorded. They are identified during monitoring by exceedance of a defined threshold and characterized by a set of appropriate parameters for each event (i.e., rms or peak voltage magnitude and duration). These discrete disturbances mainly include voltage sags, swells and oscillatory and impulsive transients.

Many studies have been undertaken on continuous disturbance characterization and related indices. Comprehensive standards have been developed specifying objectives to be met with standard limits for all continuous disturbance types. However no generally acceptable method of characterization of discrete disturbances can be found in the literature and standard limits are not yet found in any international standard. One of the reasons for the lack of objectives for defining limits is the difficulty in defining suitable site indices. In the case of sags, there have been several papers referring to sag event indices, which will be detailed in the next section. However, those methods do not lead to a single site index that will enable us to rank sites for mitigation purposes. Recent CIGRE WG 36.07/CIRED and IEEE P1564 task force activities are focused on similar aspects [2] and still the problem remain unresolved.

This paper begins by reviewing the existing characterization schemes and their limitations. A new generalized approach is then given for developing a single site index for each discrete disturbance type that we have developed at the University of Wollongong (UOW). This is followed by a new methodology for defining MV/LV distribution system discrete disturbance limits based on existing survey data from many countries. The limits developed have been applied to Australian conditions with an application example.

II. REVIEW OF PRESENT CHARACTERIZATION METHODS

A. Voltage Tolerance Curves

Voltage tolerance curves, also known as power acceptability curves [3], are plots of equipment maximum acceptable voltage deviation versus time duration for acceptable operation. Various voltage tolerance curves exist but the most widely publicized is the CBEMA curve which has been in existence since the 1970s [4]. Its primary intent is to provide a measure of vulnerability of mainframe computers to disturbances in the electric 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 [3]. The CBEMA curve was revised in 1996 and renamed for its supporting organization Information Technology Industry Council (ITIC).

The CBEMA curve and ITIC curve differ in the way their regions are presented. CBEMA is a continuous curve, whereas ITIC has a series of vertical and horizontal lines. The ITIC curve has an expanded acceptable region compared to the CBEMA curve [3]. Both these curves have been accepted as standards and published in the latest versions of IEEE Std. 446 [5] and IEEE Std. 1100 [6]. These curves have been used by various PQ studies for discrete disturbance reporting and the development of indices [1], [3], [7]–[11].

B. Present Characterization Schemes

There are few methods that can be found in the literature for discrete disturbance reporting. These are essentially a table of logged entries or a choice of graphical formats.

One of the most common methods is to show disturbance voltages (rms or peak) and durations on a voltage-duration plot overlaid with the CBEMA or ITIC curves.

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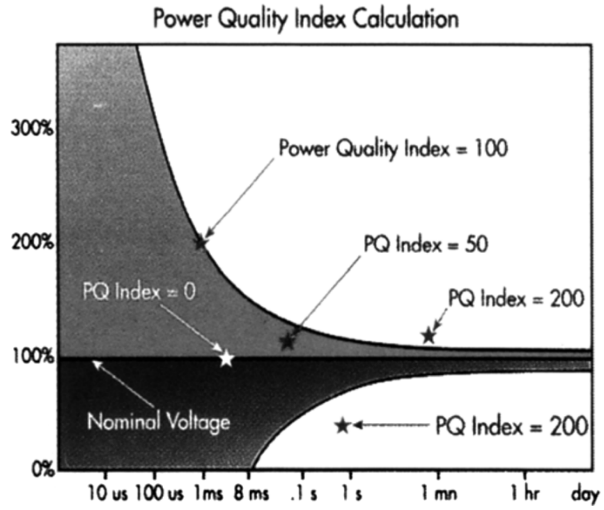


Fig. 1. RPM PQ Index [9].

Another set of methods adopted by Electric Power Research Institute (EPRI) known as EPRI 2D and 3D Histograms [7] and EPRI indices (e.g. SARFIx) [8].

Reliable Power Meters (RPM) has developed [9] a technique for determining an index using CBEMA curve overlays (Fig. 1) which is known as the Power Quality Index (PQI) that is used to cover both overvoltage and undervoltage events.

Suppose an under voltage or over voltage event has coordinates (t,V). Define the corresponding CBEMA voltage $\mathrm{V_{CBEMA}(t)}$ as voltage on the CBEMA curve corresponding to duration t.

The RPM PQI the event is given by

$$PQ\ Index = \left[\left|\frac{V - 100\%}{V_{CBEMA}(t) - 100\%}\right|\right] \cdot 100\%. \quad (1)$$

The RPM PQ Index corresponds to an event severity index [10] in which the deficiencies of RPM index have been addressed in [10] for the case of sags and in [11] for the case of impulsive transients.

There is a need for a method based on sound arguments leading to a single meaningful indicator from a disturbance site report, i.e., single site index for each disturbance type. The present characterization schemes available would not lead to give a single site index for each discrete disturbance type. A new method is proposed in the next section to overcome this difficulty which suggests a generalized characterization approach for all discrete disturbance types based on the voltage tolerance curves.

III. NEW PROPOSAL—DISTURBANCE SEVERITY INDICATOR

A. New Generalized Characterization Method

In [10] and [11], a discussion is given on reporting voltage sags and impulsive transients based on curve fittings to CBEMA and ITIC curves that suggests a better way of characterizing them leading to a single site index. The same approach been used here to develop indices for voltage swells and oscillatory transients.

The method of least squares was applied to the log plot of CBEMA/ITIC curves to give analytical expression that could be used for calculation purposes in connection with the curve fittings as shown in Fig. 2. A brief discussion of all of these indices is given below which is based on the graphical format of discrete disturbances as described in [12].

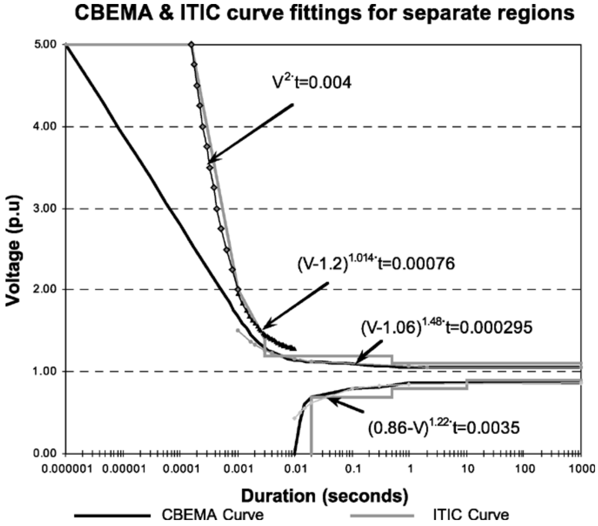


Fig. 2. CBEMA and ITIC curve fittings for different discrete disturbance types (i.e., voltage sags, swells, and transients).

Derivation of all discrete type disturbance indices described here are made on the basis of a constant customer complaint contours proportional to the CBEMA or ITIC curve. It is assumed that all the events causing identical customer complaint rate can be described by a contour in the voltage—duration plane. Curve fittings to CBEMA curve has been chosen for rms events (sags and swells) as the modern ITIC curve has sudden jumps in this region which are considered to be unlikely to give a smooth contour distribution for sags and swells. However, the modern ITIC curve has been used to characterize oscillatory and impulsive transients.

B. Disturbance Severity Indicator (DSI)

There is a need for a single indicator as a number which gives a relative ranking of discrete disturbances as regards its adverse effect on customer equipment. It can be thought as a number which gives a measure of the percentage of customers who are affected.

The DSI is a single indicator to characterize sags, swells and transients which leads to give a single site index for each disturbance type. We will describe below a standard approach for defining DSI's for all discrete disturbance types.

The following pragmatic assumptions would made to allow an estimation of a contour distribution of each disturbance type:

1) PQ curves used by RPM [9] (or CBEMA or ITIC) scaled similarly to the proposal of RPM, represent a locus of constant customer complaint rate (except for the modifications described in 3) and 4)).
2) The customer complaint rate varies directly in proportion to the RPM index.
3) For each disturbance type equipment will begin to fail at their minimum voltage threshold levels ($\mathrm{V} = 0.9\,\mathrm{p.u.}$ for sags, $\mathrm{V} = 1.1\,\mathrm{p.u.}$ for swells, $\mathrm{V} = 1.2\,\mathrm{p.u.}$ for oscillatory

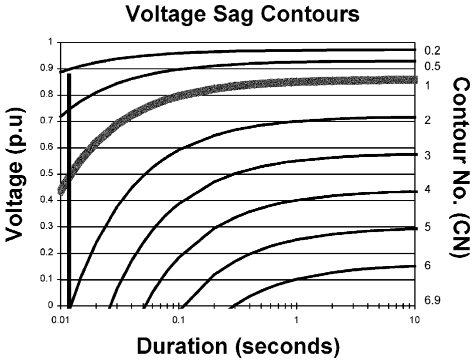


Fig. 3. Voltage sag contours.

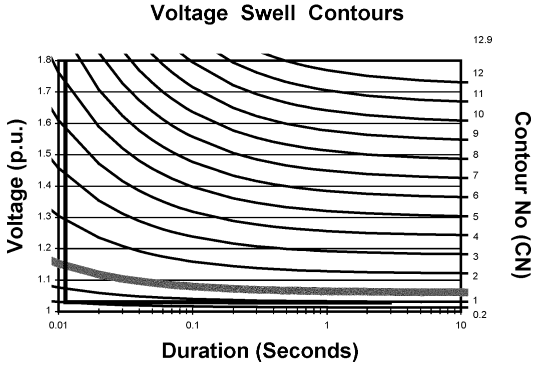


Fig. 4. Voltage swell contours.

transients and V = 2.0 p.u. for impulsive transients) and the respective durations as described in [12].

4) We assume following V and t values as the maximum thresholds for respective disturbances, Sags; V = 0 p.u., t = 3 s, Swells; V = 1.8 p.u., t = 3 s, Oscillatory Transients; V = 2 p.u., t = 0.01 s, Impulsive Transients; V = 5 p.u., t = 0.001 s and no equipment will survive an event more severe than their maximum threshold.

Based on the curve fittings shown in Fig. 2, we define CBEMA/ITIC voltage $V_{\mathrm{CBEMA/ITIC}}$ corresponding to duration T as,

Voltage sags;

$$V_{CBEMA-Sag}(t) = 0.86 - \left(\frac{0.0035}{t}\right)^{\left(\frac{1}{1.22}\right)} \tag{2}$$

Voltage swells;

$$V_{CBEMA-Swell}(t) = 1.06 + \left(\frac{0.000\,295}{t}\right)^{\left(\frac{1}{1.48}\right)} \tag{3}$$

Oscillatory transients;

$$V_{ITIC-Os.Trans.}(t) = 1.2 + \left(\frac{0.000\,76}{t}\right)^{\frac{1}{1.014}} \tag{4}$$

Following [9], for any point (t, V) on the voltage tolerance plane; we define the CBEMA or ITIC Contour Number (CN) as,

$$CN = \left[\left|\frac{V-1}{V_{CBEMA/ITIC}-1}\right|\right] \tag{5}$$

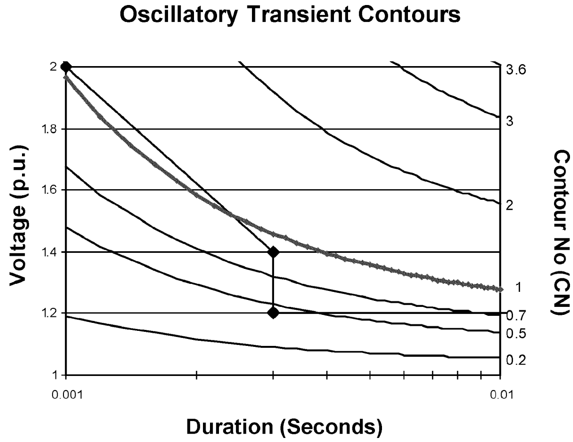


Fig. 5. Oscillatory transient contours.

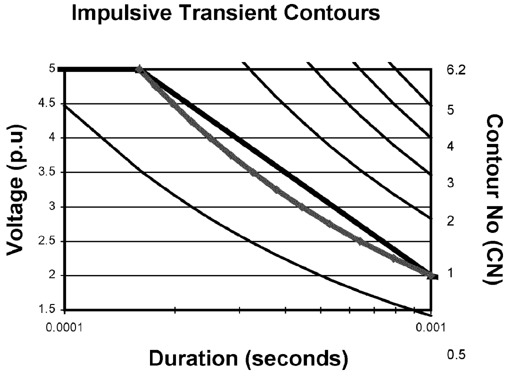


Fig. 6. Impulsive transient contours.

Above (5) differs slightly from the method described in [9] as we prefer to represent voltage in per unit rather than as a percentage. This defines a series of curves which are scaled upwards or downwards as shown in Figs. 3–5. These curves have the characteristic that at the worst part of the plane, the CN = 6.9 (V = 0 p.u. & t = 3 s) for sags, CN = 12.9 (V = 1.8 p.u. & t = 3 s) for swells and CN = 3.6 (V = 2 p.u. & t = 0.01 s) for oscillatory transients.

As described in [11] the contour distribution for impulsive transients (Fig. 6) is less complicated and it is given by $V^2 \cdot t/0.004 = 1$ curve fit (i.e., CN = 1 = $V^2 \cdot t/0.004$) and below the maximum threshold of 6.2 (V = 5 p.u. and t = 0.001 s), with an exception to be given in transition region described in the next section.

We assume that the highest value for CN of each disturbance type corresponds to 100% of customers experiencing problems, and a linear relationship between CN and customer complaint rate. In general, the DSI is taken to be equal to the CN for each disturbance type, but with modifications to allow for assumptions in above 3) and 4) together with the transition region.

C. Transition Region

There is a difficulty with PQ monitoring of disturbances that are lying on the border of the set threshold of PQ monitor [10]. Many such events may or may not be recorded depending on the exact threshold setting of the monitor. This uncertainty can be rectified by adopting a transition region for each disturbance type as described below.

1) Voltage Sags: In the case of sags, the transition region is defined by assuming maximum threshold for sags as 0 p.u. and 3 s duration as described above. A consideration is given for small sag depths is that, many sag surveys utilize a threshold value of 0.9 p.u. [10]. A difficulty with voltage sags is that a sag on the border of the threshold of long duration could give a CN as high as 0.7. The transition region reducing the Disturbance Severity Indicator for sags $(\mathrm{DSI}_{\mathrm{Sag}})$ from the CBEMA Contour Number to zero linearly in the voltage range 0.8 to 0.9 p.u. by multiplying (5) by the term 10(0.9-V). Since it is assumed that all equipment has failed at the bottom right hand point of sags in Fig. 3, where the $\mathrm{DSI}_{\mathrm{Sags}}$ is limited to the maximum value of 6.9 as described above. The proposed $\mathrm{DSI}_{\mathrm{Sags}}$ can be written as

$$DSI_{Sag} = \min\{10(0.9 - V), 1\} \times \min\{CN, 6.9\}. \quad (6)$$

2) Voltage Swells: Similar to the case of sags, the transition region for swells is recorded between 1.1 and 1.2 p.u. A similar difficulty arises with swells as with sags that a swell on the border of the threshold of long duration would give a CN as high as 1.95. This can be rectified by multiplying (5) by the term 10(V-1.1). Based on the assumption that all the equipment has failed at the top right hand corner point of swells in Fig. 4, the $\mathrm{DSI}_{\mathrm{Swell}}$ is limited to the maximum value of 12.9. The proposed $\mathrm{DSI}_{\mathrm{Swell}}$ can be written as

$$DSI_{Swell} = \min\{10(V - 1.1), 1\} \times \min\{CN, 12.9\}. \quad (7)$$

3) Oscillatory Transients: Oscillatory transients also can be tackled in the same manner as sags and swells. It is observed that the events occur at the border of the threshold of short duration would give higher CN values than expected (Fig. 5). To be consistent with the sags and swells the value of $\mathrm{DSI}_{\mathrm{Os.Trans}}$ can be written as

$$DSI_{Os.Trans.} = \min\{(V - 1.2), 1\} \times \min\{CN, 3.6\}. \quad (8)$$

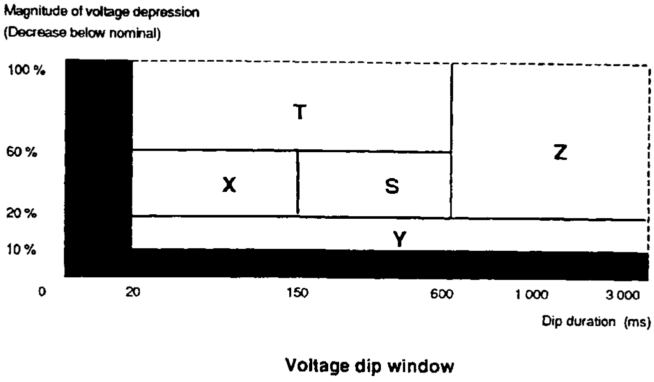
4) Impulsive Transients: The way the transition region described for impulsive transients is different to the method for sags, swells and oscillatory transients. This has been examined in [11] and transition region is defined between 2.0–2.3 p.u. and DSI of any impulsive transient event that falls in to this region will be applied with a weighting factor that lies between 0–1. As an example let a transient event has $\mathrm{V} = 2.25$ p.u. and $\mathrm{t} = 0.004$ s. First we define the contour number, i.e., $V^2 \cdot t/0.004 = 0.506\,25$, which is approximately the 0.51 contour. As the event lies in the transition region, it has to be multiplied by the weighting factor $= (2.25-2)/(2.3-3) = 0.8333$, which gives the $DSI_{\mathrm{IM}.Trans.} = 0.42$.

In general, site index for each discrete disturbance type is calculated as the sum of DSI's over the specified survey period (i.e., generally one year to give an annual site index for each disturbance type).

IV. NEW PROPOSAL—LIMITS

A. Introduction

The site indices developed are to be compared with objectives that can be defined in bilateral agreements between a network operator and a customer, set as self-imposed quality objectives by a network operator, or set by a regulator. However, there are no specific objectives that can be found in any international standard. European standard CENELEC EN 50160 [13] which considered as the most comprehensive PQ standard at present, gives only a guide line for number of sags per year, states that "Under normal operating conditions the expected number of voltage sags (dips) in a year may be from up to a few tens to up to one thousand." More specific objectives are used in South Africa and Chile, which will be discussed below. We will be developing a methodology for defining discrete disturbance limits based on the site indices structure described in Section III, along with the available PQ survey data of large scale power quality surveys that have been performed around the world.



Network Voltage	Number of voltage sags per year				
	Sag(Dip) Window Category				
	Z	T	S	X	Y
6.6 kV …….≤ 44 kV	20	30	30	100	150
6.6 kV …...≤ 44 kV (Rural)	49	54	69	215	314
> 44 kV …….≤ 132 kV	16	25	25	80	120
220 kV …….≤ 765 kV	5	6	11	45	88

Fig. 7. ESKOM voltage sag windows [14].

B. Relevant Standards

There are only two standards available at present that describes discrete disturbance limits, i.e., South African PQ Standard [14] for voltage sag limits and Chilean PQ Standard [15] for voltage sags and swell limits. Both these standards are developed based on their long term PQ monitoring data.

1) South African PQ Standard (ESKOM): The South African Standard NRS 048-2:1996 [14] was primarily developed by utilities, although the process included customer forums hosted by South African National Electricity Regulator (NER) [16]. In addition to the voltage quality requirements, the standard has prescribed utility voltage sag performance limits. In this aspect South Africa uses a two-dimensional scatter plot of the magnitude of voltage depression versus sag duration to present voltage sag data (Fig. 7).

2) Chilean PQ Standard: The Chilean PQ Standard DS 327: 1997 [15] gives limit values for the number of voltage sags and swells per year in different magnitude and duration ranges in connection with the different standard voltages than ESKOM Standard. However the number of sags per year is the same sag count as in the ESKOM Standard.

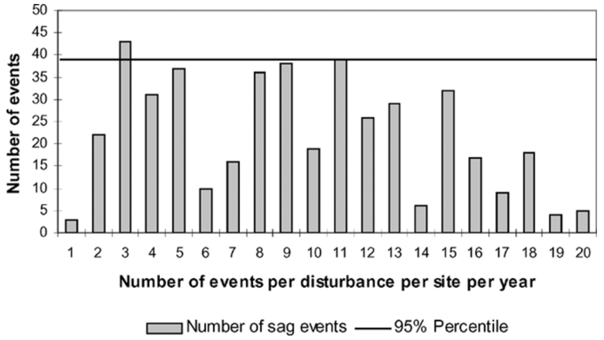


Fig. 8. Example of 20 sites for 95% CP statistic.

C. Discrete Disturbance Limits

It is necessary that the discrete disturbance limits need to be achievable that are consistent with long term PQ survey measurements of overall system. This may be a survey of sites participated by whole utilities. In the case of sags, the period of observation for the number of events needs to be at least one year [2]. The same period can be applied to all other discrete disturbance types due to the similar unpredictable behavior of all discrete events which cause environment etc. and other various system events vary from the location to location and season to season. The discrete event performance at customer supply point and customer requirements may vary from the customer to customer.

Similar to the South African (ESKOM) model for sags [14], [16], we recommend the all discrete disturbance limits defined as a number of customer events for a given survey category (MV or LV) that is met by 95% of sites measured (Fig. 8). The limits described below are based on the statistical information of large scale PQ surveys performed around the world. The combined information of all these surveys would give a good comparison between different countries and regions which may be helpful in developing global limits for discrete disturbances. After a period of observation (typically one to several years) statistical information of number of events is obtained. Large surveys of this kind have been performed in US, Canada, Europe and several other countries.

1) Voltage Sag Limits: Voltage sag limits described below are based on large scale survey data of many countries. There were many published data of different sag surveys performed around the world. However, we have chosen the survey statistics of UNIPEDE DISDIP survey [17] for our purpose as it was based on a measurement campaign of nine countries in Europe whereas others were based on individual country survey statistics.

The UNIPEDE DISDIP survey was carried out for a period of three years, either on LV networks as close as possible to the LV bus bars of MV/LV substations or on MV lines to which MV/LV substations were directly connected. Results were produced for sites of nine European countries, with the period of measurement being at least one year in almost all cases which considered to be reasonable in defining voltage sag limits. The survey results were given for Underground (U/G) and mixed (Mix) networks where a Mix network defined with varying proportions of overhead lines and U/G networks. The measurements were taken place in normal operating conditions (Table I and II) where our objectives are limited to those conditions. Rural networks have not been considered as to the unavailability of data. However, the method can be applied to any network upon the availability of such data.

TABLE I
UNIPEDE DISDIP SURVEY VOLTAGE SAG INCIDENCE
U/G NETWORKS—95% PERCENTILE

V \ t	0.01-0.1 s	0.1-0.3 s	0.3 - 1 s	1 - 3 s
70-90%	23	19	3	1
40-70%	5	19	1	0
0-40%	1	8	1	0

TABLE II
UNIPEDE DISDIP SURVEY VOLTAGE SAG INCIDENCE
MIX NETWORKS—95% PERCENTILE

V \ t	0.01-0.1 s	0.1-0.3 s	0.3 - 1 s	1 - 3 s
70-90%	61	68	12	6
40-70%	8	38	4	1
0-40%	2	20	4	2

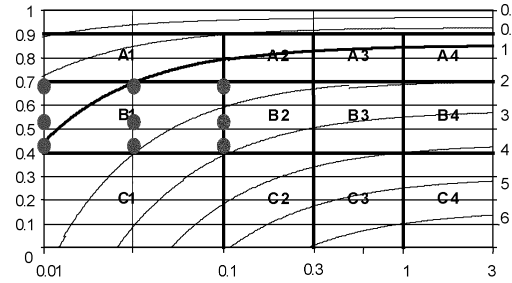


Fig. 9. UNIPEDE DISDIP survey sag distribution chart with sag contours.

One consideration given in defining voltage sag limits is the sensitivity of voltage sags less than 90% of magnitude and of short duration (less than 3 s) as the most sag events occurred in all these surveys were reported with in this boundary. The other consideration is that we have segmented the sag contour chart into a window format based on UNIPEDE DISDIP survey sag distribution chart and named them as A1, A2,. . . . . . . .C3,C4 windows as shown in Fig. 9.

For each sag window, we have defined average sag index, i.e., UOW sag index using equally distributed nine sag events (9 is arbitrarily chosen). As an example let us consider B1 window (Fig. 9). The worst sag in B1 window occurs at the coordinates (0.1, 0.4). Placement of all 9 sags at this worst point is pessimistic in the development of sag limit for B1 window. The average UOW sag index, on the contrary, is obtained by placing the 9 sag events in the B1 window as indicated by the dotted bold points in Fig. 9, i.e., $\mathrm{Average\ Sag\ Index\ of\ B1\ Window} = \sum \mathrm{DSI}/9 = (0.6+1+1.5+0.8+1.5+2.3+1.1+2+3)/9 = 1.533$. Then this average sag index of each window is multiplied by the respective sag count of each survey category, to get the sag limit for each window, i.e., for U/G and Mix networks separately as shown in Table III.

The last two rows of the Table III, the sum and the maximum window limits of successive survey categories are given (e.g.

TABLE III
UNIPEDE DISDIP SURVEY DISTRIBUTION CHART IN WINDOW FORMAT (95% CP STATISTICS OF NINE EUROPEAN COUNTRIES)

Voltage Sag Window	Av. UOW sag Index	U/G Networks Survey Sag Count	Window Sag Limit	Single Sag Limit for U/G Networks	Mix Networks Survey Sag Count	Window Sag Limit	Single Sag Limit for Mix Networks
A1	0.683	23	15.709	100	61	41.663	200
A2	1.15	19	21.850		68	78.200	
A3	1.341	3	4.023		12	16.092	
A4	1.392	1	1.392		6	8.352	
B1	1.533	5	7.665		8	12.264	
B2	2.188	19	41.572		38	83.144	
B3	2.95	1	2.950		4	11.800	
B4	3.048	0	0.000		1	3.048	
C1	2.688	1	2.688		6	16.128	
C2	4.50	8	36.000		17	76.500	
C3	5.15	1	5.150		1	5.150	
C4	5.394	0	0.000		3	16.182	
Sum		**81**	**138.999**		**225**	**368.523**	
Max			**41.572**			**83.144**	

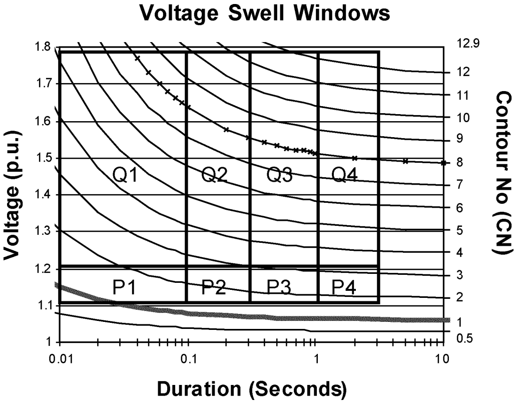


Fig. 10. Voltage swell chart embedded in contours.

the sum and the maximum of U/G networks are 138.999 and 41.572, respectively).

New Sag Limit: Voltage sag limits of each window for successive survey category (U/G or Mix) are based on the 95% sag statistic of all surveyed sites of nine countries. Therefore, it is evident that single annual sag index of any chosen site lies between the sum and the maximum of all window limits for the given category. Assuming similar sag variations occur for any site of given category, we suggest that the proposed single sag limit value for each category is to be between the sum and the maximum window limit, i.e., a single sag limit value of between 138.999 and 41.572 for U/G networks and a value of between 368.523 and 83.144 for Mix networks. Geometric mean of those values suggests 80 for U/G networks and 180 for Mix networks. We prefer the single sag limit of 100 and 200 for U/G networks and Mix networks respectively.

TABLE IV
VOLTAGE SWELL LIMITS

Swell Window	**P1**	**P2**	**P3**	**P4**	**Q1**	**Q2**	**Q3**	**Q4**	**Sum**
Average swell index for each	1.41	2	2.25	2.4	4.76	6.67	7.46	7.86	
EPRI count	114	58	20	12	2	1	0	0	207
Window limit	**161**	116	45	29	9.5	6.7	0	0	**367**
Single Voltage Swell Limit									**250**

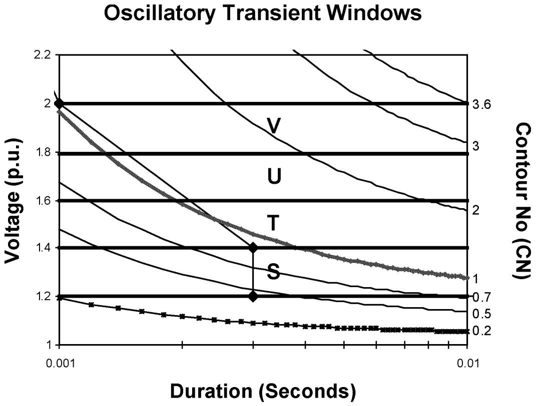


Fig. 11. Oscillatory transient windows.

2) Voltage Swell Limits: A similar approach is used to develop swell limits (Fig. 10) as we did it for sags. As with sags, swells are usually associated with system fault conditions, but they are not as common as sags, representing only about 2% to 3% of all power quality problems occurring to industry studies [18]. As there were very little survey data available for swells our limits are based only on EPRI DPQ project data [19] and may not give such an accuracy as it with sag limits which are based on the survey data for 9 countries. Therefore, it is recommended to review these limits in the future upon the availability of swell data from many countries.

Similar to the sag limits, the swell limit is to be lie between the sum and the maximum of the swell windows (Table IV), i.e., a value between 367 and 161. Geometric mean of these values suggests 242. However, we prefer 250 as the single swell limit.

3) Oscillatory Transient Limits: We will be following a similar procedure for defining oscillatory transient limits (Fig. 11) as to sags and swells. One of the common symptoms of oscillatory transients related to utility capacitor switching is that the problems appear at nearly the same time each day. The resultant oscillatory transients due to capacitor voltage overshoot will be in the range of 1.0 p.u. to 2.0 p.u.. However, the typical utility capacitor switching transients are in the range 1.3 p.u. to 1.4 p.u., but have also been observed near the theoretical maximum [18].

Oscillatory transient limit described here also based on the EPRI DPQ project [20] data. As there are no other published survey data, we have to rely only on EPRI survey data in this occasion. Hopefully the situation will improve in the future with more surveys being lined up. The limits are defined in the same manner and the value between sum (60.694) and maximum (37.107) of window counts in Table V. Geometric mean gives a value of 47.48. Our preferred value for the single oscillatory transient limit is 50. However these values given here are subjected to a revision in the future upon the availability of more survey data from different countries.

TABLE V
OSCILLATORY TRANSIENT LIMITS

Oscillatory Transient Window	S	T	U	V	Sum
Average index for each window	0.7	1.16	1.6	2.05	
EPRI osillatory transient count	53.01	15.39	2.109	1.1514	71.6604
Oscillatory transient limit for each window	**37.107**	17.8524	3.3744	2.36037	**60.694**
Single Oscillatory Transient Limit					**50**

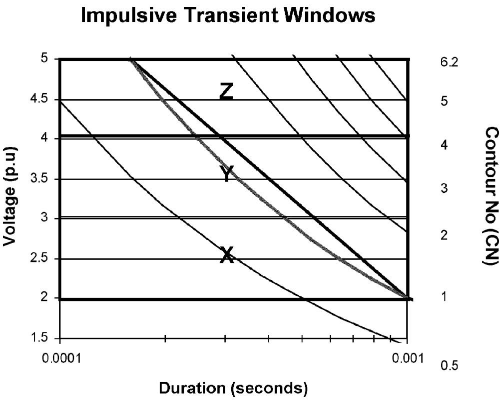


Fig. 12. Impulsive transient windows.

4) Impulsive Transient Limits: The impulsive transients that are mainly due to lightning can also be tackled in the same manner as sags, swells and oscillatory transients (Fig. 12). Similar to the swells and oscillatory transients, impulsive transient limits are also based on EPRI DPQ survey data. The values from Table VI suggests that limits be between sum (129.428) and maximum (104.738). The geometric mean of these two values is 116.43 and our preferred value of single impulsive transient limit would be 120. The limits described here also needs future revision upon the availability of more survey data from different countries.

V. APPLICATIONS TO FIELD DATA

The analysis given below has been carried out using data of four Australian sites and limited to sags. The measurements took place over a one year, sufficient to give useful results for voltage sag performance. The available data was collected from two Australian distributors which would be able to give a reasonable result.

A. Existing Characterization Approaches

The field data was analyzed and reported to illustrate some of the discussed characterization schemes. Sag data from four sites is included in Figs. (13a) and (13b), overlaid with sag Contour Numbers (CN $= 1$ giving the fitted CBEMA curve).

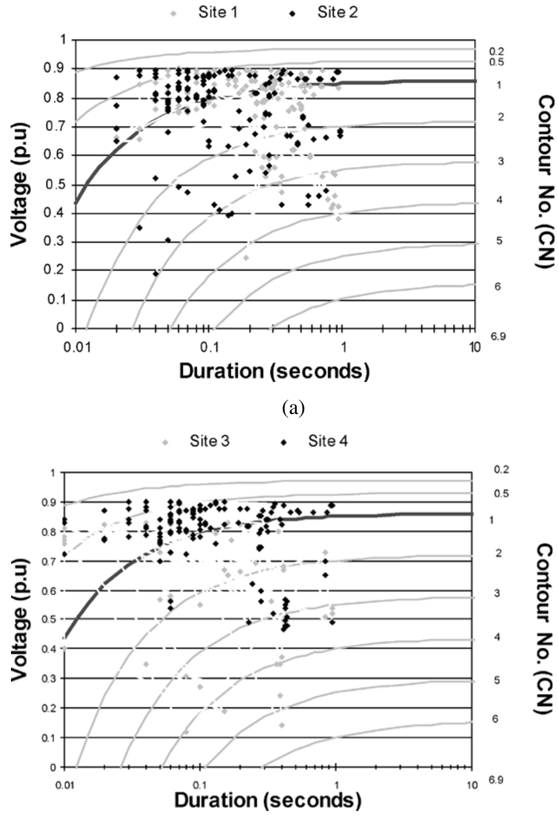
It is evident that there is no possibility of differentiating sites as to their acceptable sag limits other than the general acceptance of CBEMA limit exceedance.

B. Site Index Approach With Sag Limits

It is clear from Fig. 14, that the new method will give a clearer differentiation of sites of their limits of acceptability where the sites can be ranked for their mitigation purposes. Other important feature is that the customers living in the area supplying distributor "A" is more vulnerable to sags than the customers of distributor "B."

TABLE VI
IMPULSIVE TRANSIENT LIMITS

Impulsive Transient Window	X	Y	Z	Sum
Average impulsive transient index	0.750	1.450	2.380	
EPRI impulsive transient count	139.650	12.350	2.850	154.850
Impulsive transient limit for each window	**104.738**	17.908	6.783	**129.428**
Single Impulsive Transient Limit				**120**



(a)

(b)

Fig. 13. (a) Distributor "A" sags overlaid on the CBEMA. (b) Distributor "B" sags overlaid on CBEMA.

Fig. 14. Sag site index with limits.

VI. CONCLUSIONS

Existing discrete disturbance characterization methods are reviewed and discussed. A generalized approach has been proposed to characterize discrete disturbances which fundamentally based on DSI proportional to the customer complaint rate. A representative distribution of customer complaint contours could not be found directly from available measurements and scaled versions of fitted CBEMA and ITIC curve have been used as a working hypothesis until more survey data available in the future.

A new method is proposed to define disturbance limits based on overseas survey data and the limits has been applied to Australian conditions with an application example.

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