SHORT PAPER

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Power Quality Index for Continuous and discrete Disturbances

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Abstract- **In the field of power quality (PQ), characterizing and quantifying the disturbances by means of indices represent a key activity of electrical energy market . Disturbances must be characterized to assess system PQ performance & quantifying disturbance levels allows for benchmarking analysis.. Traditional PQ indices, such as voltage and current total harmonic distortion, Unbalance and SARFI, separately analyze PQ disturbances, ranging from continuous to discrete.. In some cases, instantaneous values of voltage, which contemporaneously include all disturbances, can be the main cause of failure or malfunction of electrical components. Moreover, a good PQ index can significantly reduce the enormous amount of stored data covering various types of disturbances. A single index allows internal and external benchmarking and easily quantifies the respect of items inside power quality contracts. This paper introduces a proposed matrix method considering continuous disturbances and voltage dip/sag indices relevant to a site so that a comprehensive ranking of the sites could be made.**

Index Term- **Power Quality, Power Quality Indices, Voltage sag, Continuous disturbances and events.**

I. INTRODUCTION

The interest of regulators and the gradual rise in awareness of the effect of power quality disturbances on equipment by customers has lead to many utilities beginning to take a much more pro-active stance toward the measurement of power quality levels on their networks. Combined with the continual connection of modern power electronics equipment which produces and/or is susceptible to power quality disturbances, routine power quality monitoring is becoming increasingly important for utilities in order to plan for and maintain acceptable power quality levels on their networks. When considering how to report power quality it is important to be mindful of what the utility is interested in or needs to know.[1-7]

II. TYPES OF CONTINUOUS DISTURBANCE INDICES

Continuous disturbance indices provide the basis for the overall indices. Further Continuous disturbance indices are classified as voltage (AVD), unbalance, flickers, harmonics and sags.[10-16]

A. Voltage (AVD)

Voltage level is not technically a disturbance and is the only primary power quality quantity for which the optimum measurement should not ideally be zero. Thus a method of voltage reporting is required that creates a condition whereby zero is the optimum result and increasing values indicate increasing levels of disturbance.

A method of calculating a voltage index that describes the absolute deviation of voltage levels around the centre of the voltage range has been developed. More succinctly, this method calculates the absolute difference between the measured voltage and the voltage in the middle of the desired range. This index is known as the Absolute Voltage Deviation (AVD).

B. Voltage Unbalance

There are two definitions of voltage unbalance factor (VUF), the international IEC definition and a USA IEEE definition. The IEC definition is becoming widely adopted and is given here. If a three phase set of voltages has positive and negative sequence components V_P and V_N,

This takes no account of zero sequence because it has no adverse effect on loads and is often absent at MV levels anyway. Perhaps a better name for VUF is "negative sequence unbalance factor". It can be calculated from simple line-line readings.

C. Voltage Harmonics

The measurement of voltage harmonics involves sampling of the voltage waveform many times a second, depending on how many harmonics are required to be determined. The FFT (Fast Fourier Transform) is then applied to find the fundamental component V_1 and harmonics V_2 etc, usually to the 40th order. These values are averaged over 10 minute intervals. The voltage THD is determined at the same time. It is recommended that any harmonic reported as a percentage of the time-varying fundamental voltage be modified to be reported as a percentage of the site nominal voltage, providing

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a consistent base for comparisons across sites.

III. TYPES OF DISCRETE DISTURBANCE INDICES

Discrete disturbance indices are classified as voltage sag and momentary interruptions, voltage swells, transients.[10-11]

A. Voltage sags and momentary interruptions

Balanced rectangular sags can be characterized by the voltage level and duration. The maximum voltage depth is taken if the voltage envelope is not rectangular. For unbalanced sags, the phase with the greatest sag depth is used to characterize the disturbance, a process called "phase aggregation".

When there are several sags in quick succession, usually as part of protection operation, these are considered to be part of one customer event. The sag with the greatest depth is taken to be the one used for characterization. This process is called time aggregation and the aggregation period is usually taken as 1 minute.

B. Voltage swells

A voltage swell is described in as an rms voltage rise of up to 120% of the nominal voltage, with duration of up to 0.5s. Phase aggregation can be used as for sags. It is unlikely that several swells will occur in quick succession and time aggregation is not an issue.

C. Transients

IEC 61000-2-5 classification divides transients into two groups: oscillatory and impulsive. Oscillatory transients are the ringing which follows the switching in of power factor correction capacitors while impulsive transients are due to lightning strikes. Oscillatory transients can be characterized by magnitude, oscillatory frequency and decay time. Impulsive transients can be characterized by rise time, magnitude and decay time settings.

IV. CHARACTERIZATION METHODS FOR DISCRETE DISTURBANCES

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.[12-14]

A. Voltage Tolerance Curves

Voltage tolerance curves, also known as power acceptability curves , 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. 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. The CBEMA curve was revised in 1996 and renamed for its supporting organization Information Technology Industry Council (ITIC).

B. Disturbance Severity Indicator (DSI)

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.

C. Discrete Disturbance Limits

There are only two standards available at present that describes discrete disturbance limits, i.e., South African PQ Standard for voltage sag limits and Chilean PQ Standard 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 was primarily developed by utilities, although the process included customer forums hosted by South African National Electricity Regulator (NER) . 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.

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.

V. IEEE P1564, “VOLTAGE SAG INDICES”[15-18]

This proposed standard defines voltage dip indices but is only a draft. The aim is to present a framework for obtaining voltage dip indices from measured voltage waveforms. To give a value to the performance of a power system as far as voltage sags are concerned, a five-step procedure is proposed in IEEE P1564:

i. Obtain *sampled voltages* with a certain sampling rate and resolution.
ii. Calculate *event characteristics* as a function of time from the sampled voltages.
iii. Calculate *single-event indices* from the event characteristics.
iv. Calculate *site indices* from the single-event indices of all events measured during a certain period of time.
v. Calculate *system indices* from the site indices for all sites within the system.

The basic framework is shown in Fig. 1, where both measurements and calculations are indicated as possible sources of information.

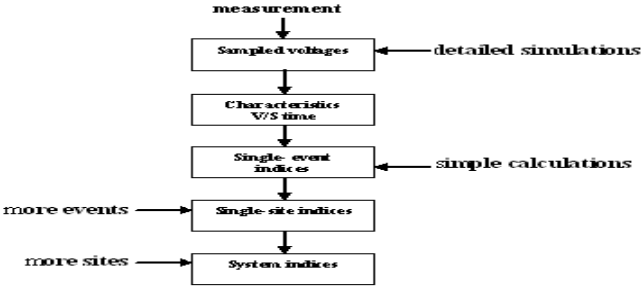

Fig. 1. A general framework for obtaining voltage sag indices.

A. SARFI Indices

A set of voltage sag indices has been proposed by CIGRE/CIRED working group CCU-02, "Voltage quality". Although these indices are not yet part of any standard document, they already are widely used and referred to, especially by US utilities. IEEE Project Group P1564 is discussing these indices for including in an IEEE recommended practice on voltage sag indices. The most commonly-referred to index is the System Average RMS variation Frequency Index or SARFI. The term RMS variation is used in US literature to indicate all events in which the rms voltage deviates significantly (typically: more than 10%) from its nominal value. This includes voltage sags, voltage swells, and short interruptions. The SARFI_X index (where X is a number between 0 and 100) gives the number of events with a duration between 10 milliseconds and 60 seconds and a retained voltage less than X%. Thus SARFI_70 gives the number of events with retained voltage less than 70%. Strictly speaking SARFI values are obtained as a weighted average over all monitor locations within a supply network or within part of the supply network. However the term is also used to refer to the event frequency at one location.

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

B. RPM Power Quality Index

Reliable Power Meters (RPM) has developed a technique for determining an index using CBEMA curve overlays (Fig.2)
which is known as the Power Quality Index (PQI) that is used to cover both over voltage and under voltage events.

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

The RPM PQI the event is given by

$$PQ\,Index = \left| \frac{V - 1}{V_{CMEMA/ITIC} - 1} \right| \quad (2)$$

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

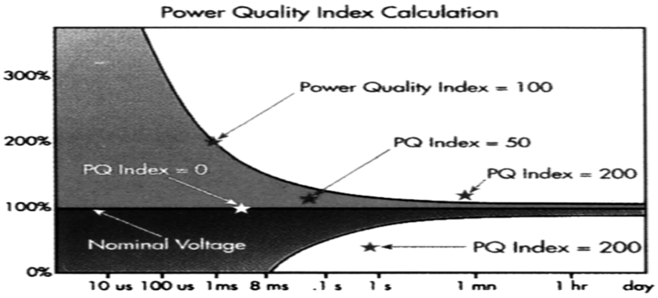

Fig. 2. RPM PQ Index

Because DSI is a simple event index, it is necessary to obtain an index that is able to characterize more events during the observation period in the monitored site. In general, the site index for each discrete disturbances type is calculated as the sum of all DSIs over the specified survey period (i.e. generally one or more years):

$$DSI_{Site,k} = \sum_{j=1}^{N_D} DSI_j \quad (3)$$

where k indicates the type of discrete disturbances (sag, swell, OT, IT) and N_D is the number of events of the same type arising during the survey period.

A quantification of discrete disturbance levels in a given area of an electrical system can be obtained using a System DSI index, defined as the weighted average of the DSI site indices from all monitored sites in the considered area:

$$DSI_{Sys} = \frac{\sum_{j=1}^{M} w_j DSI_j}{\sum_{j=1}^{M} w_j} \quad (4)$$

where w_j is the weighting factor of site *j*; DSI_j is the DSI index at *j*.th bus-bar; and M is the total number of monitored sites. Weightings could be applied according to the number of customers or the maximum demand of customers supplied by the monitored sites.

VI. GENERALIZED TECHNIQUE OF SITE POWER QUALITY EVALUATION AND RANKING

Power qualities an important issue in the deregulated power system. the available methods for the evaluation of power qualities are elementary and intuitive like RMS error method, AVG method and method of exceedance. The unified power quality index(UPQI) based on matrix method and permanent to evaluate the rank of size, this technique .this graphical method is simple effective and computer compatible for all type of power quality issue. This method is capable to rank the sites when the other methods fail to compare to rank the site. The generalized technique for power quality evaluation and ranking of sites having different values of individual power quality of attribute indices is shown in **figure.3.**

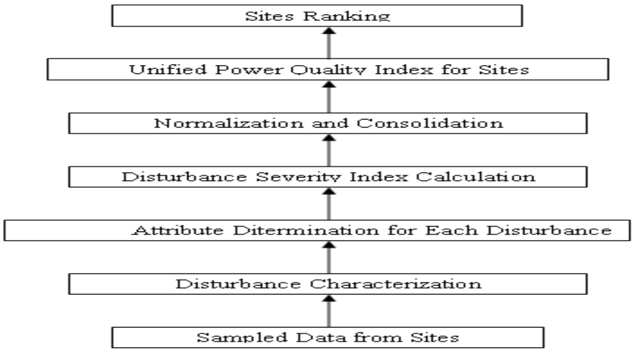

Fig.3. Generalized technique for power quality evaluation and ranking of sites

The sampled data is collected from the IED's for power quality monitoring. In next step distribution characterization is done to determine appropriate attribute for each disturbance type .From this data values of different power quality attribute are calculated which are compared with set limits and there severity indices are calculated. Normalization is the process of dividing an index by its maximum acceptable value ,so that it has the value 1 when it is at the limit of acceptability. Consolidation combine all normalize value for 1 disturbance type into a single index .The maximum value may be used as consolidated index.

The power quality evaluation based on attribute indices employs average method, maximum method, exceedance method. All this method propose a single number to give a simple measure of over all power quality of a site and to allow easy of site ranking. How ever all these methods fail to evaluate and rank the site having some values of average, maximum and exceedence.

The Sag Index is a measure of sag severity in terms of both depth and duration. The proposed matrix method is a unified approach that enables the optimum selection of a particular site among a number of alternative sites based on power quality attributes considering voltage dip/sag indices concurrently in an integrated manner. This method considering voltage dip/sag indices relevant to a site so that a comprehensive ranking of the sites could be made.

This procedure is characterized by the following steps:

a. The voltage-duration plane is segmented into a window format based on the available data, for instance, the well-known UNIPEDE DISDIP data or EPRI DPQ project data]. In Fig. 4, the voltage-duration plane is segmented into a window format based on the UNIPEDE DISDIP survey sag distribution chart; the windows are called A1, A2,….., C3, C4.
b. An average disturbance index $DSI_{avg,i}$ using a prefixed number of equally distributed disturbance is calculated for each disturbance window.[25,29,33]

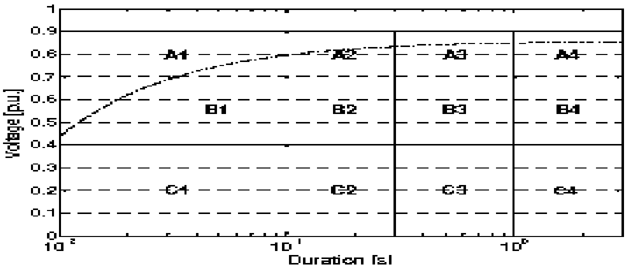

Fig 4. UNIPEDE DISDIP sag distribution chart

We calculate the average disturbance index $DSI_{avg,I}$ with reference to each window. This index has been obtained considering nine equally distributed disturbance events and using the relations of the CBEMA voltage reported. We also report the corresponding disturbance count Ni of each survey category from the available data.

The data of voltage sag of the medium voltage network is shown in table1 For the given data , calculated value of DSI are given in table 2

TABLE 1
95TH PERCENTILE OF VOLTAGE SAG OF THE MV NETWORK

Residual Voltage (%)	Voltage sag duration			
	upto 0.1 sec	0.1-0.5 sec	0.5-1 sec	1-3 sec
80-90	42	15	5	3
70-90	22	24	2	1
40-70	19	40	2	1
10-40	13	46	1	1
1-10	5	7	1	0

TABLE 2
RESULTS FOR DSI

Windows	DSI
A1	0.75
A2	1.05
A3	1.35
A4	1.30
B1	1.67
B2	2.49
B3	2.88
B4	3.17
C1	3.33
C2	4.5
C3	5.05
C4	5.55

VII. PROPOSED MATRIX METHOD

In this method various power quality indices relevant to a site are combining into a single measure so that comprehensive ranking of the site could be made. This methodology comprises of two phases .In first phase graphical model of system is prepared which is known as attribute diagraph .In second phase graphical model is converted into matrix known as attribute matrix. After that this matrix is expressed in the form of a function called variable permanent function (BPF). The attribute matrix is combination of two matrices named as attribute rating matrix and attribute relative importance matrix. Variable permanent function simply known as standard matrix function used in combinatorial mathematic, Marcus and Minc.

The variable permanent function of an attribute matrix is known as attribute variable permanent function.(ABPF). The quantitative value of ABPF is obtained by substituting the numerical values of each element of the attribute matrix in the ABPF itself .the numerical value is called Unified Power Quality Index (UPQI). The UPQI based matrix method gives good global power quality index for evaluation and ranking of the site considering continuous disturbances and events.

A summary of rating of these attributes for 10 sites is presented in table 3

TABLE 3
SUMMARY OF RATING OF ATTRIBUTES

SITE NO.	40	60	51	22	18	2	10	66	48	62
VOLTAGE(V)	0.4	0.3	0.4	0.6	0.6	1.2	1.3	1.1	1.1	1.8
UNBALANCE(U)	0.4	0.4	0.2	0	0.2	0	1.4	2.1	1.6	1.2
FLICKER(F)	0.2	0.5	0.3	0.6	0.3	1.6	0.8	0.2	1.6	1
HARMONICS(H)	0.3	0.5	0.6	0.3	0.3	0.2	1.3	0.5	0.7	1.8

VIII. ALGORITHM FOR THE PROPOSED METHOD

The following steps were followed to calculate ranking of the site.

Step-1 Various attributes and their interconnectivity that controls the optimum selection of site are expressed in terms of nodes and edges, that is called as attribute diagram

Step-2 The deterministic values of the all identified attributes indices and their relative importance is stored in a matrix that is called as attributes matrix.

Step-3 Calculate variable permanent function know as permanent of attribute matrix that is used in combinatorial mathematics, Marcus and Minc using following algorithm

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A    $P \leftarrow 0$ ; $X_i \leftarrow a_{in} - 1/2 \sum a_{ij} (i=1,n)$; $sgn \leftarrow -1$
B    $sgn \leftarrow -sgn$ ; $P \leftarrow sgn$ ,
     Get next subset of (1,2,.......n-1) from NEXSUB ;
     If empty, go to C and if j was deleted then :
     $z \leftarrow -1$ ; otherwise $z \leftarrow 1$ ;
     $x_i \leftarrow x_i + z\, a_{ij}$ (i=1,n)
C    $P \leftarrow P.x_i$ (i=1,n); $p \leftarrow p + P$ ;
     If more subsets remain, go to B ;
     Permanent $\leftarrow 2(-1)^{n-1} p$ ; EXIT
Algorithm for NEXSUB
I    [First entry] $m \leftarrow 1$ ; $j \leftarrow 1$ ; $z \leftarrow 1$; exit
II   [Later entry] $m \leftarrow m+1$ ; $x \leftarrow m$ ; $j \leftarrow 0$.
III  $j \leftarrow j+1$ ; $x \leftarrow x/2$ ; if x is an integer go to III.
IV   $z \leftarrow (-1)^{x+1/2}$ ; if $m=2^n$ , final exit; EXIT.
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IX. RESULT AND DISCUSSIONS

The proposed matrix method was applied for evaluation and ranking of the site. The UPQI (matrix method) is obtained for the sites as shown in the table-4

TABLE 4
SUMMARY OF RATING OF SITES

Rank	Site Number Ranked By				
	Average Method	Maximum Method	UPQI(Exceedance Method)	UPQI(Proposed Method)	Attribute Matrix Value
1	40	40	40/60/51/22/18	40	12.36
2	18	60	60/51/22/18/40	18	12.52
3	51	51/22/18	51/22/18/40/60	22	12.80
4	60/22	22/18/51	22/18/40/60/51	60	12.85
5	22/60	18/51/22	18/40/60/51/22	51	18.21
6	2	10	2	2	18.72
7	66	2/48	10	66	20.75
8	10	48/2	66	10	32.92
9	48	62	48	48	34.75
10	62	66	62	60	38.81

For the various sites shown in table 3, data for voltage sag has been collected and DSI was calculated for respective sites. Using these results the ranking of sites can determine by proposed UPQI matrix method.

X. CONCLUSION

The UPQI based on matrix method has been shown to be a good global power quality index for evaluation and ranking of site. The method is advantageous being simple, effective and computer compatible that addresses all type of power quality issues. It becomes more important that this method is capable to rank the sites when the other alternative available methods fail to compare and rank the site. The technique has been used for power quality evaluation and ranking of the sites considering some of the continuous disturbances and this method also can be used to ranking of sites for discrete disturbances.

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