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A New Approach for Analysing Voltage Sag Severity Based on Power Quality Indices

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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. Traditional PQ indices, such as voltage and current total harmonic distortion, Unbalance and SARFI, separately analyze PQ disturbances, in some cases, instantaneous values of voltage, which contemporaneously include all disturbances, can be the main cause of failure or malfunction of electrical components. 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 voltage dip/sag indices.

Keywords: Power Quality, Power Quality Indices; Voltage sag; discreate disturbances; voltage sag severity.

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. 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.

III. CHARACTERIZATION METHODS FOR DISCRETE DISTURBANCE

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.

IV. 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.

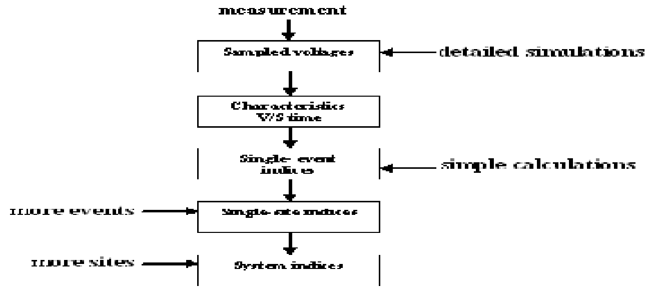

Fig. 1. A general framework for obtaining voltage sag indices.

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.

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

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

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

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.

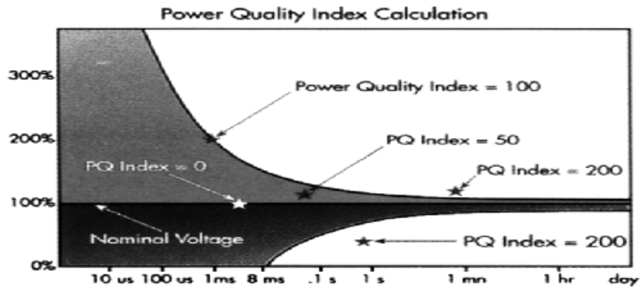

Fig. 2. RPM PQ Index.

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):

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

where k indicates the type of discrete disturbances (sag, swell, OT, IT) and ND 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:

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

where wj is the weighting factor of site *j*; DSIj 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.

V. GENERALIZED TECHNIQUE OF SITE POWER QUALITY EVALUATION

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.

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 exceedance.

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 power quality indices based on power quality attributes considering voltage dip/sag indices concurrently in an integrated manner.

VI. PROPOSED MATRIX METHOD

This procedure is characterized by the following steps:

a) The voltage-duration plane is segmented into a window(S_1-S_5) format based on the available data

b) The frequencies are normalized using the following relation:

$$A_T = \frac{F_T - F_K}{F_{MAX} - F_{MIN}} \qquad (5)$$

Where A_T is the attribute for frequency window
F_T is the sum of frequencies in all window
F_K is the frequency of Kth window
F_{MAX} is the maximum frequency in window
F_{Min} is the minimum frequency in window

c) An average disturbance index using proposed method is calculated for each disturbance window

We calculate the average disturbance index with reference to each window. The data of voltage sag of the medium voltage network is shown in TABLE .I For the given data , calculated value of voltage sag severity for disturbance window are given in Table 2.

Table 1. 95th percentile of voltage sags of the site.

Disturbance Window	Residual Voltage %	Voltage Sag Duration (ms)				
		20-100	100-500	500-1000	1000-3000	Total
S_1	85…90	41	16	6	4	67
S_2	70…85	24	25	2	1	52
S_3	40…70	19	43	2	1	65
S_4	10…40	12	44	1	1	58
S_5	1…10	6	9	1	0	16

The average sag severity index for the site can be calculated by adding the voltage sag severity for different disturbance windows (S_1+S_2+S_3……). Therefore for a site average sag severity index is 179.6.

Table 2. Results for voltage sag severity of site.

Disturbance Window	Voltage Sag Severity
S_1	33.334
S_2	43.194.
S_3	27.352
S_4	43.194
S_5	32.2605

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.

VII. ALGORITHM FOR THE PROPOSED METHOD

The following steps were followed to calculate voltage sag severity index of sites.

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.

VIII. CONCLUSION

The UPQI based on matrix method has been shown to be a good global power quality index based on voltage sag severity. The method is advantageous being simple, effective and computer compatible that addresses power quality issues related to voltage sag. It becomes more important that this method is capable to give the power quality index for discrete disturbance like voltage sag. The technique has been used for power quality evaluation of the sites considering some of discrete disturbances.

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