A NEW TECHNIQUE FOR POWER QUALITY BASED CONDITION MONITORING

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ABSTRACT

Power quality disturbances can interrupt production lines, cause damage to products and equipment, result in lost orders or transactions, corrupt data communication and storage, and cause an overall decrease in productivity. At present, there are no techniques that can effectively correlate the occurrences of the power quality disturbances to the failure of the sensitive equipments. Most of the time, the causes of the equipment failures were termed as unknown or nuisance tripping. Unlike a comprehensive electrical system survey, a power quality based condition monitoring focuses on a small set of parameters that can indicate the existence of power quality disturbances and predict possible critical load failures. The condition of the power at specific dates can be used to predict possible downtime of sensitive machinery. It is important to note that voltage fluctuation, harmonic distortion, and unbalance are good indicators to indicate the existence of these power quality disturbances. These data can also indicate the condition of the load and power system, and can be recorded quickly with little incremental labor using a power quality recorder. In this paper, a new technique for performing power quality based condition monitoring is presented. The new technique involves the use of advanced signal processing and artificial intelligence techniques. A sample case study is presented to demonstrate the effectiveness of this new technique.

Keywords—Power quality disturbances, signal processing, S-transform, artificial intelligence, SVM.

INTRODUCTION

Each of the power supply problems experienced by the customers has a different cause. Some power supply problems are a result of the shared infrastructure. For example, a fault on the network may cause a power quality event called voltage sag that can affect many customers and the higher the level of the fault, the greater the number affected, or a problem on one customer’s site may cause a transient that affects all other customers on the same subsystem. Other problems, such as harmonics, arise within the customer’s own installation and may or may not propagate onto the networks and so affect other customers connected in the same networks.

Normally, customers who experienced these problems would make complaints to the power utilities. The causes of these problems could only be identified after performing detail sites measurements and investigations. To improve their efforts in managing these disturbances, many power utilities are now installing on-line power quality monitoring system (PQMS) to perform continuous monitoring of the networks. The PQMS can immediately alert the engineers a few seconds after the occurrences of any power quality disturbances by sending the relevant information through the short message systems (sms). In many ways the needs of these facilities are similar to aircraft flight recorders. By providing event tracking and data recording, a re-creation of an actual event can be accomplished. From these data, an analysis can be made as to identify the real cause of an event. As a management tool this provides information for preventing or precluding future "crashes". For power quality, the same principal of recording and tracking of power quality is similar to that of the aircraft flight recorder. The waveform signatures recorded by the power quality recorders can provide excellent information for evaluating the condition of the power and in the analysis of possible causes of the equipment malfunction and to trigger the needs to conduct conditioned based monitoring (CBM) using thermal imaging, ultrasound detection or partial discharges in order to identify the actual causes of the problems.

In this paper, a new technique to perform power quality based condition monitoring is proposed. The new technique comprises the use of S-transform and Support Vector Machine. This technique will process the waveforms recorded and classifies them in order to identify the needs to proceed with conditioned based monitoring (CBM) or predictive maintenance activities.

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The objective of the proposed technique is to evaluate the condition of the supply systems and identify power quality trends to provide a baseline for establishing predictive maintenance activities in order to avoid interruptions of critical business activities. The new technique can also prompt the users on the needs for the investigations and corrective measures to prevent possible plant failure. The block diagram for the proposed technique is shown in Figure 1.
The process for the detection & classification of voltage is explained as follows:

- The power quality recorders will be programmed to record all types of power quality disturbances as defined in IEEE 1159 [1].
- All types of power quality disturbances will be processed using a signal processing technique. Features for all types of power quality disturbances or unknown events will be extracted.
- The next step is to classify the types of power quality disturbances and unknown using an artificial intelligence technique.

The explanation of the technique is presented below.

### Signal processing technique (S-Transform) for detection of events

The post processing of the signals will be performed using S-transform. The S-transform is a time-frequency representation known for its local spectral phase properties [2]. A key feature of the S-transform is that it uniquely combines a frequency dependent resolution of the time-frequency space and absolutely referenced local phase information. This allows one to define the meaning of phase in a local spectrum setting, and results in many desirable characteristics. The S-transform can be considered as an advancement of another signal processing technique called the Continuous Wavelet Transform (CWT) which produces a time-frequency representation of a time series signal [3]. It can uniquely combine a frequency dependent resolution that simultaneously localizes the real and imaginary spectra The basis function for the S-transform is the Gaussian modulation cosinusoids. The cosinusoids frequencies are used for the interpretation and exploiting the resulting time frequency spectrum. In the case of non-stationary waveforms with noisy data, the S-transform provides patterns that closely resemble a disturbance type. The S-transform for a function h(t) is given by,

\[
S(\tau, f) = \int_{-\infty}^{\infty} h(t) g(\tau - t, f) e^{-2\pi i t \tau} \, dt \tag{1}
\]

in which \( g(\tau, f) \) is the Gaussian modulation function, given by,

\[
g(\tau, f) = \frac{|f|}{\sqrt{2\pi}} e^{-\left(\tau^2 / 2\sigma^2\right)} \tag{2}
\]

In this paper, the S-transform will be used in the detection of the power quality disturbances. Features to characterize the respective power quality disturbances are extracted using the S-transform. The lists of the features selected are shown in Table 1.

<table>
<thead>
<tr>
<th>Features</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>Maximum/mean value of the S-matrix</td>
</tr>
<tr>
<td>F2</td>
<td>Minimum/mean value of the S-matrix</td>
</tr>
<tr>
<td>F3</td>
<td>Standard deviation of the S-matrix</td>
</tr>
<tr>
<td>F4</td>
<td>Median absolute deviation value of the S-matrix</td>
</tr>
</tbody>
</table>

The features will then be used in the classification of the power quality disturbances using artificial technique called SVM.

### Classification technique using Support Vector Machine (SVM)

Support Vector Machines is a powerful methodology for solving problems in nonlinear classification, function estimation and density estimation which has also led to many other recent developments in kernel based methods in general [4]. Originally, it has been introduced within the context of statistical learning theory and structural risk minimization. A special property of SVMs is that they simultaneously minimize the empirical classification error and maximize the geometric margin; hence they are also known as maximum margin classifiers. Viewing the input data as two sets of vectors in an n-dimensional space, an SVM will construct a separating hyperplane in that space, one which maximizes the "margin" between the two data sets. The overall process flowchart for the classification of power quality disturbances using SVM is shown in Figure 2.

The first step is to differentiate between a voltage sag and non voltage sag. The next step for voltage sag classification is to classify for three phase sags, two phase sags and single phase sags. For non voltage sags, the voltage events will be classified for harmonics, transients and unknowns.
Examples of the classification accuracy for the SVM which was conducted based on 100 sets of power quality data monitored at one of the utility’s substations are shown in Table 2.

### Table 2: Classification accuracy of SVM

<table>
<thead>
<tr>
<th>PQ events</th>
<th>Number of events based on visual inspection</th>
<th>% accuracy of data classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage sag</td>
<td>55</td>
<td>100%</td>
</tr>
<tr>
<td>Voltage sag &amp; swell</td>
<td>12</td>
<td>100%</td>
</tr>
<tr>
<td>Transient</td>
<td>9</td>
<td>100%</td>
</tr>
<tr>
<td>Notches</td>
<td>1</td>
<td>100%</td>
</tr>
<tr>
<td>Harmonics</td>
<td>14</td>
<td>100%</td>
</tr>
</tbody>
</table>

Once all the power quality disturbances have been classified, the next step is to identify their causes by performing conditioned based monitoring activities such as thermal scanning and ultrasound techniques. Once identified, the source of the problem will then be rectified.

### A CASE STUDY FOR POWER QUALITY CONDITION BASED MONITORING

To illustrate the use of this new technique, a sample case study is presented. This case study was conducted at one industrial plant in Malaysia. Previously, the plant complained of frequent occurrences of nuisance trippings and damages to the production equipment for the last 1 year and put the blame to the power utility. To first understand the problem, the overall condition of the power supply network need to be evaluated. A power quality recorder was installed in the plant for 3 month. The data recorded were then processed using S-Transform. From the results, 2 voltage sags (Figure 3), 1 transient (Figure 4) and 12 unknown events (Examples are shown in Figure 5 & 6) were recorded. The causes of the voltage sags were due to lightning strokes on the utility power lines. The cause of the transient events (Figure 4) was found out after the implementation of a thermal scan at the main switch board conductors due to loose connection one of the blue phase conductors. The results in Figures 5 and 6, showed frequent occurrences of incipient faults at the red phase of the factory supply schemes. Overall 12 events were recorded at the red phase.
An ultrasound scan was proposed to be conducted at the factory electrical installations. From the scan, it was found out that one of the cable terminations (red phase) had signs of electrical tracking (Figure 7). Rectification was done by replacing the cable termination. The power quality recorder was left for another 1 month and the results which were downloaded later showed no sign of the incipient faults (Figure 8). The signal processing technique had accurately monitored the condition of the power supply and detected the existence of incipient faults.

CONCLUSION

The waveform signatures recorded by the power quality recorders can provide excellent information for monitoring the condition of the electrical power supply.

REFERENCES


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