CHAPTER 4 – BENCHMARKING RESULTS AND CONCLUSION: Results for SATHD, SATHD CP95%, SATHD CP99% and SATHDi are displayed and discussed in this section.

4.1 INTRODUCTION

Chapter 4 provides the results obtained from the programs, as explained in chapter 3. Each BI is discussed individually and cross examination of the indices are also done. It is essential to verify the work that was done, thus the measured VHTD data and robustness of the programs are also discussed and evaluated.

4.2 SATHD

SATHD is a calculated index, which uses VTHD measurements as basis. It describes voltage distortion for systems, which inherits various segments. The SATHD results for the North-West province are plotted in Figure 4.1. This graph displays a constant distortion level, except for the period Nov 07 to Feb 08. The drop in SATHD levels during this period is most likely caused by the severe load shedding South Africa experienced, which could have resulted in PQ recorders not measuring any voltage distortion.

Figure 4.2 illustrates the increase or decrease of SATHD values. This chart shows a steady increase in SATHD, and drops for the month of March 08/09. The SATHD readings for the Red phase during May 2008 were 0.1 higher than in May 2007. March 08/09 shows a decrease of 0.2.

SATHD presents a more informative data set, which can be used on managerial level. Distortion levels tend to be seasonal, but this will become more visible when the system assessment period is longer than 24 months.
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Figure 4.1: SATHD results.

Figure 4.2: SATHD Increase/Decrease graph.
4.3 SATHD_CP95%

SATHD_CP95% index is based on the VTHD value from the CP at 95% of all measurements per segment for each month, normalised by the connected apparent load (kVA). Continuous high distortion levels result in equipment failure; however peak distortion measurements vary with time. By taking the maximum measurements into account, distortion indices may not reflect the true level of distortion. By using CP95% values, it eliminates short period - high VTHD values and focuses more on distortion levels that will be present in a system for a sustained period. By following this principle, only 5% of the largest VTHD measurements are neglected.

Figure 4.3 shows the results of the SATHD_CP95% index and Figure 4.4 shows the increase/decrease chart. Compare the increase/decrease chart of SATHD and SATHD_CP95%. The SATHD results are lower than the results of the SATHD_CP95% chart. This clearly illustrates the difference between CP95% and mean-VTHD measurements used in respective index calculations. This is the reason why average SATHD values are lower than SATHD_CP95% values, because it is based on mean values. The SATHD_CP95% results are also more consistent per month if compared to SATHD. By means of the increase/decrease (Figure 4.4) chart the difference is also smaller compared to SATHD increase /decrease chart.

![Graphical representation of SATHD_CP95% results.](image-url)
4.4 SATHD_CP99%

Most equipment is sensitive to high distortion levels. The maximum VTHD values could also provide some information. Similar to SATHD_CP95%, the SATHD_CP99% index eliminates 1% of the highest distortion levels. This value eliminates any possible error that may be present in the recording of the maximum level. The SATHD_CP99% can be taken as the maximum THD recording.

Figure 4.5 and 4.6 shows the SATHD_CP99% and increase/decrease chart respectively. As in Figure 4.3 there is a steady increase in VTHD values for SATHD_CP95% and 99%. The increase/decrease chart shows 5 months with a small decrease in VTHD measurement, while the majority of the months show a higher increase.
Figure 4.5: Graphical representation of SATHD_CP99% results.

Figure 4.6: SATHD_CP99% Increase/Decrease graph.
4.5 SATHDi

The SATHDi is a frequency occurrence index, which returns a percentage value that is calculated by the number of VTHD values that exceeds a predetermined threshold. The SATHDi of each segment is normalised by the weighting factor (connected apparent power – kVA) value. Figure 4.7 to 4.10 show the results for each threshold value (VTHD > 1% to 4%), while Figure 4.11 to 4.14 display the monthly increase/decrease chart.

Most of the VTHD values exceed threshold limits of 1 and 2, but as seen in Figure 4.7 some of the VTHD values (less than 10%) do not exceed a threshold limit of 3. This also matches up with the SATHD_CP95% and 99% indices, which are between 2 and 3. From the increase/decrease charts it is noticeable that there is an increase of VTHD values that exceed the threshold per month. It can be concluded that VTHD is increasing by a small margin per year.
Figure 4.8: SATHDi with threshold limit set at 2%.

Figure 4.9: SATHDi with threshold limit set at 3%.
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Figure 4.10: SATHDi with threshold limit set at 4%.

Figure 4.11: SATHDi Increase/Decrease chart at 1%.
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Figure 4.12: SATHDi Increase/Decrease chart at 2%.

Figure 4.13: SATHDi Increase/Decrease chart at 3%. 
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4.6 COMPARISON STUDY

EPRI’s DPQ project was aimed at finding new ways to benchmark harmonic distortion in a distribution network [29]. They collected five million three-phase steady-state measurements, from 277 monitors across 24 electrical utility companies in the USA [29]. The sampling period was 24 months, the same as for this project [29]. Figure 4.15 illustrates SATHD results for EPRI’s DPQ project while Figure 4.16 shows the results for this dissertation. The results compare as follows:

Figure 4.14: SATHD Increase/Decrease chart at 4%.

Figure 4.15: Results obtained from the DPQ project [13], [29].
The results obtained from the DPQ project (Figure 4.15), appear to have the same cycle shape for all three years. It illustrates only one line intersection for Jul-Aug, 1994 to 1995. Figure 4.15 illustrates seasonal patterns while there is clearly an increase in SATHD [29].

Figure 4.16 represent the SATHD results obtained from this project. There are two line intersections (Feb-Mar, Apr-May) illustrated on this graph. If we compare the magnitude of the line intersection, to that of the DPQ project the difference is less than 0.05. However, with the benchmarking analysis we have one interception that drops in Feb 2009 from 1.45 to 1.2 in April. This shows a drop in SATHD that of the DPQ project the difference is less than 0.05. However, with the benchmarking analysis we have one interception that drops in Feb 2009 from 1.45 to 1.2 in April. This shows a drop in SATHD for these months and is not the expected trend, based on the DPQ project. Table 4.1 is a summary on the average BI calculated in this project. The DPQ project had average SATHD of 1.47 %, 1.55% and 1.49% for the year 1993, 1994 and 1995 respectively [13].

Table 4.1: Comparison table for benchmarking indices per year.

<table>
<thead>
<tr>
<th>Index</th>
<th>Phase</th>
<th>April 2007 to March 2008</th>
<th>April 2008 to March 2009</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>SATHD</td>
<td>Blue</td>
<td>1.30</td>
<td>1.32</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>White</td>
<td>1.38</td>
<td>1.44</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>Red</td>
<td>1.33</td>
<td>1.40</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>Avg</td>
<td>1.34</td>
<td>1.39</td>
<td>0.05</td>
</tr>
<tr>
<td>SATHD_CP95%</td>
<td>Blue</td>
<td>1.78</td>
<td>1.85</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>White</td>
<td>1.81</td>
<td>1.94</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>Red</td>
<td>1.82</td>
<td>1.93</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>Avg</td>
<td>1.79</td>
<td>1.88</td>
<td>0.10</td>
</tr>
<tr>
<td>SATHD_CP99%</td>
<td>Blue</td>
<td>2.00</td>
<td>2.07</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>White</td>
<td>2.02</td>
<td>2.18</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td>Red</td>
<td>2.00</td>
<td>2.11</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>Avg</td>
<td>1.98</td>
<td>2.08</td>
<td>0.10</td>
</tr>
</tbody>
</table>

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4.7 Methodology Evaluation

MathCAD is a structured language, which does not use basic text as code. Instead the calculation is typed in as if it was written down on a piece of paper. This reduces the chances of errors and simplifies debugging of the code. To evaluate the program code of the analytic method, dynamic and static testing were performed. Static testing involves the run down and explanation of each line of code to a third party until the third person understands the complete code.

Dynamic testing involves the execution of the model under various conditions. This is done by changing the input data and comparing the results with the original one. A top to bottom approach was used, and each sub-program was tested with unique input data. A typical example of dynamic testing was done by importing known mean, CP95% and CP99% values. These known values were compared to those obtained from the programs. The results of the analysis matched the known results. It is therefore concluded that the program 1 and 2 meet the design objective.

4.8 Data Evaluation

By visual inspection of the data it was noticed that some 10-minute recordings were missing. This is clearly represented in Figure 4.17, which displays the total number of measurements taken per month. Data could be extracted from the data basis by means of the trend viewer program. The same data is also available on Eskom’s QoS website [40]. The lowest number of VTHD measurements is April 2008 at 27328. On average, there are 3904 samples per segment, which are related to time recordings of 11.43 minutes. EPRI’s benchmarking methodology recommends a minimum sample time of 30 minutes [3]. Thus, for even less samples recorded than anticipated, the acquired recordings are still sufficient to calculate indices.
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4.9 ROBUSTNESS OF PROGRAMS

In this section the positive and negative aspects are discussed.

- Program 1 can be applied to any number of measurements and will be able to calculate the preliminary parameters needed for the indices.

- Program 2 is specifically designed to import data for only seven segments over 24 months. It is limited to these parameters, but can be adjusted.

- The South-African census of 2001 was used to calculate the connected apparent load (kVA). The census statistics could be out of date, thus impacting the results of the indices.

- Industrial and commercial power usages are not taken into consideration when calculating the weighing factors.

4.10 CONCLUSION

The NRS 048 [17] provides standards for harmonic distortion on MV and HV power systems as <6.5% and <3% respectively. This standard is defined for VTHD values calculated at the PCC. The system indices (SATHD, SATHD_CP95% and 99%) describe voltage distortion of a network and not at individual points. By applying this methodology, managers and companies will now be able to
make informed decisions based on the indices calculated for networks. If this process is applied every year, a conclusive database can be established. This will help PQ engineers to identify troublesome areas and assist in managing distortion levels in the network. From the results it is clear that BI can be incorporated into a PQMS.

With the growing increase of non-linear devices, harmonic distortion will also increase in time. By knowing the level of network distortion, effective counter measures and PQMS could be implemented to mitigate future effects. Continuous monitoring of harmonic distortion in a network is essential to assure that consumers and utilities adhere to the national standards, thus providing mutual benefits.

To conclude, the project objective was to reduce a large amount of VTHD measurements into useful information. From the results obtained, it’s clear that program 1 and 2 were designed to meet this objective. The calculated indices describe voltage distortion better than 741 000 VTHD measurements. These indices can be implemented on a much larger scale to give information on distortion levels for a larger grid. A modern power system requires effective PQMS and these indices provide a tool to assist PQ managers in monitoring the system performance in the presence of a large amount of data.

Today’s power systems are evolving due to more sophisticated equipment being connected to the distribution network. There are various PQ events that could degrade the quality of supply. The analysis done in this project is but one step to better understand voltage waveform distortion. This project confirms a new, effective way to assess harmonic distortion in a power system.

4.11 Future Work

This section provides suggestions for future work:

- The analysis program, which was designed for this project is based on several assumptions. It is specifically designed for data for only seven segments of the North-West province over 24 months. The methodology works and was proven in this project. For future projects, the analysis methodology can be implemented into an object orientated program which will have the ability to calculate distortion indices for multiple VTHD measurements over various segments.