Related Elements Method to Evaluate Power Quality of AC-DC Converter Substation

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Abstract. With the development of the extremely high level voltage grid, such as Shanghai, Hangzhou and so on. There are more and more factories and AC-DC converter substations are involved into the city’s region, which causes much more power quality problems than before, so that many people begin to focused on the power supply. In this article, we analyzed some evaluation methods for power quality estimation, then we make a deep study about the characteristics in power supply for urban region and AC-DC converter substations. With the construction work of harmonic monitoring platform of State Grid, we can handle a real-time judgment for power supply substation. At last, we put forward a power quality estimate method for AC-DC converter substations. The method is based on the power quality parameters of power supply in AC-DC, it is established from four elements, which are: related harmonic voltage, related harmonic current, related power and voltage change, all these elements constitute a method to estimate the power quality of AC-DC converter substations. In the final, the result can be shown by a single figure, which includes all the related elements.

1. Introduction

In the past, people always focus on the power quality about new energy power supplies, factories and so on. But there are not many people care about the power quality in their own house, especially the area near the AC-DC converter substations.

In the past, the electric equipments are simple and easy, such as lamps, electrical motors, and so on, so people do not care about the power quality in the house. But with the development of domestic electric instruments, more and more precise equipment are used in the house, for example, high-class rice cooker, variable frequency air conditioner. All these electrical equipments are much more strict for power quality. And with the development of digital industry, more and more Big Data Centers are built in the cities. All these electric instruments require a much more rigorous power quality indexes.

Under this circumstance, the State Grid Company was building a harmonics monitoring platform in these years, which covers most area in China. Which made us can estimate the status by the monitoring devices in real-time. But when we were evaluating power quality for a single point, we cannot tell the users if the power quality of one point is qualified or not[3], due to the power quality involved so many indexes, and different regions of the grid structure, the power supply, load types are not identical, we can only tell users which indicator is qualified or not[1,6]. So that we need an easier method to estimate power quality for a single point or some particular points.

This article make an overview of all the differences between different power quality methods[4,5], generalized the representative influences caused by AC-DC converter substations, and collected various demands for all kinds of users. At last, we present a new program called “related elements evaluation” to make a quick evaluation for points near the AC-DC converter substations, which is based on the harmonics monitoring platform.
2. Emphasis of Power Quality for Users

During the process of electricity consumption, there are so many kinds of users, that the concerns of different users are all unlike. So that we need to distinguish every kind of users, and meet the requirements of all the consumers.

2.1 Kinds of Users

There are various kinds of users for power supply, such as domestic consumers, government sector, banks, big malls, instruments manufactures and so on, all the demands for power quality are different.

2.2 Emphasis of Diverse Consumers

The most important demand for domestic users is the stability of power supply, there are surveys show that, the limitation of tolerance for the domestic users is 10 minutes without notifications. And nowadays, there are more and more families pay attention to the power quality for their house, because more and more advanced electrical equipments are used in all the family, which are much more vital for power quality than the normal equipments.

For the Big Data centers, the most vital focus is harmonics, voltage dips, and short interruptions, so they always equip some treatment facilities. For these users, even 80ms voltage interruption or voltage dip can cause very huge economy lost for them.

And for the hospitals and banks, they mainly focused on the stability of power supply and stability of voltage, harmonics current and voltage. Because of the equipment they used, all the equipments are very sensitive to the power fluctuations and harmonics changes.

For the government sectors, the most important concerns are the reliability of power supply, so there are always several charging lines for the government.

For the precise instruments manufactures, the crucial thing is the harmonics voltage, harmonic current, voltage swells, and voltage unbalance. In the other hand, these users always produce lots of harmonics voltage and current in their manufacturing process.

3. Power Quality Monitoring Platform

3.1 Structure of Power Quality Monitoring Platform

Recent years, more and more power quality issues occurred, these issues caused lots of damage to the users. So that the power supply company realize that power quality had already became a serious problem for both consumers and the companies themselves. In this case, the harmonics monitoring platform was established, from 2006, more than 6000 monitoring devices are installed in all voltage levels of transformer substations. And the data scale became very huge for now, this gave us a firm foundation of data to analyze and estimate the status of power grid. As is shown in fig 1.

![Figure 1. Structure of power quality monitoring platform.](image-url)
3.2 Disadvantage of Harmonics Monitoring Platform

Form the structure, we can see that the platform is mainly focused on every single point of grid, there are lots of indexes of power quality. We have to check every index to make sure if it is qualified or not. This will take much time for a technician to judge the result when we were evaluating the power quality.

Especially when we wanted to evaluate the power quality for a period of some points, we must inspect all the indexes for the period which we want to check. And this obviously would take a very long time for the technician to finish this work. But if we can present a new indicator which can represent some vital indexes that we cared, it will reduce a lot of time to finish the evaluation.

4. Programs of the Estimation of Power Quality

4.1 Programs of Power Quality Assessment

The work of power quality assessment is based on the parameters of the power grid, there are more than 10 standards for power quality, and there are always several indicators in one standard, so that there are more than 50 indicators for all the power quality. Obviously we cannot make an evaluation with all index, we need to select some more important indexes to finish the assessment.

Due to the power quality index is numerous, there are many ways to do the assessment[7], according to different application environment and the external conditions, different methods got very big distinction, rough classification of evaluation way as shown in figure 2.

As we can see from figure 2, a variety of power quality evaluation methods are put forward for now, according to different needs assessment object, methods also have very big difference. Therefore, we need to distinguish these methods in different areas, and adjust measures to local conditions to develop a suitable for this type of power quality system evaluation method[10].

4.2 Emphasis of Power Quality Estimation

The evaluation of the single index is a way for one index of power quality. It is always carried out to evaluate a specific index of power quality for particular aim[3]. The integration evaluation is based on the single evaluation, which integrates some of the similar indexes, and then gets a new quantitative evaluation result.

Quantitative evaluation and grade assessment are the methods used to evaluate different demands for application environments. The index quantification assessment is to compare the evaluation result of the index to the standard or the value in the contract between users and power supply company[4], so that we can get a more intuitive result. The grade assessment is based on the special requirements, always from consumers, and the index of the power quality are divided into different evaluation levels by the rules from users.
The methods of monitoring point evaluation and regional assessment are divided according to the area, which is to evaluate the difference between a point or an area. It is easy to understand, mainly focus on particular purpose.

User’s special demand and normal evaluation is mainly used for the users and power supply company. This two kind of methods are always carried out for some particular transformer substation, especially by users’ demand.

In this paper, we make a use of aforesaid method, which is based on the results of evaluation index of content, form three methods to the needs of users of the evaluation process, focus on accounts for the larger area of power quality system evaluation method has carried on the induction and summary[1].

5. Related Elements Evaluation Method

We present a related elements evaluation method, which is based on the harmonics monitoring platform.

5.1 Basic Indexes of AC-DC converter substations

According to the users, we consider the process of power quality assessment for AC-DC converter substations area should be mainly focused on the following aspects.

(1) Harmonic voltage, for an AC-DC converter substations, because of the diverse of power application, various electric equipments make influence to the others, especially the great use of inverter air-conditioner;

(2) Harmonic current, the same as the harmonic voltage, there is much harmonic current when the equipments are in operation, they all made influence to the others;

(3) Power deviation, for the Big Data center, banks and hospitals, these users are very sensitive to the power factor and power fluctuation, especially the stability of power;

(4) Stability of voltage, this element is very signification for precise manufactures, elevators in large shopping malls and Big Data center.

5.2 Related Elements Evaluation Method Composition

According to the characteristics of AC-DC converter substations area, we put forward a synthetical element evaluation method. First we choose 12 basic evaluation indexes for this method, and detailed indicators are shown in table 1. Then we conclude these 12 basic indexes into four more significant items that needed to be paid attention to, as is shown in table 1.

| 1 | Related harmonic voltage | 2 | Total harmonic voltage |
| 3 | Long time flickers | 4 | Related harmonic current |
| 5 | Total harmonic current | 6 | Negative sequence current |
| 7 | Power factor | 8 | Stability of power |
| 9 | Voltage deviation | 10 | Voltage dip |
| 11 | Voltage swells | 12 | Negative sequence voltage |

In this evaluation method, we induce these 12 basic indexes into four elements. And the classification method for these indicators is shown in figure 3.
5.3 Calculation in this method

After obtaining the value of the above 12 indexes, here we set it as “x”, then we compare these numbers with the standard values, here we set the standard values as “y”, then we can get a preliminary outcome. And the ways to calculate scores are shown in table 2.

Table 2. Calculation Formula.

<table>
<thead>
<tr>
<th>Calculation</th>
<th>Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{x}{y} &lt; 0.6 )</td>
<td>3</td>
</tr>
<tr>
<td>( 0.6 \leq \frac{x}{y} &lt; 0.9 )</td>
<td>2</td>
</tr>
<tr>
<td>( 0.9 \leq \frac{x}{y} &lt; 1 )</td>
<td>1</td>
</tr>
<tr>
<td>( \frac{x}{y} \geq 1 )</td>
<td>0</td>
</tr>
</tbody>
</table>

For example, there is a 220kV substation 5 time harmonic voltage is 1.2%, according to the national standard in the limit of 5 time harmonic voltage of 220kV is 1.6%, \( \frac{x}{y} = 1.2/1.6 = 0.75 \), according to the methods in table 2, then the assessment score is 2 points for this 220kV substation 5 times harmonic voltage.

After we get all the scores for indexes, we can make the final evaluation of this point. Here we set every element’s final score as “s”, and we set all the full marks as “m”. Then we can get an evaluation result, the meaning of results is shown in table 3.

Table 3. Evaluation Result.

<table>
<thead>
<tr>
<th>Value</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{s}{m} &lt; 0.6 )</td>
<td>Failed</td>
</tr>
<tr>
<td>( 0.6 \leq \frac{s}{m} &lt; 0.75 )</td>
<td>Qualified</td>
</tr>
<tr>
<td>( 0.75 \leq \frac{s}{m} &lt; 0.9 )</td>
<td>Good</td>
</tr>
<tr>
<td>( \frac{s}{m} \geq 0.9 )</td>
<td>Excellent</td>
</tr>
</tbody>
</table>

After we complete calculating of monomer level for four components, and we set four modes to allot the weightiness for every element. As it is shown in table 4.

Table 4. Weightiness Distribution

<table>
<thead>
<tr>
<th>Weightiness</th>
<th>Mode 1</th>
<th>Mode 2</th>
<th>Mode 3</th>
<th>Mode 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>0.35</td>
<td>0.35</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>D2</td>
<td>0.3</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>D3</td>
<td>0.25</td>
<td>0.2</td>
<td>0.25</td>
<td>0.2</td>
</tr>
<tr>
<td>D4</td>
<td>0.1</td>
<td>0.2</td>
<td>0.2</td>
<td>0.25</td>
</tr>
</tbody>
</table>
Here we choose mode by the environment of grid, the constitute of generation, and the mainly consumer of power, and the special need of users.

At last, we concluded these four elements into a final evaluation results, as shown in figure 4. And the formula for final result is the same as shown in table 3.

And if technicians prefer to use figures to show the result, we can give out the result in figures too.

6. Comparison of Related Elements Evaluation Method and Conventional Method

In a power quality evaluation case, when we finished measurement, all the result of every index is shown in different tables.

Table 5. Harmonic Voltage Result.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Phase A</th>
<th>Phase B</th>
<th>Phase C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Ave</td>
<td>Max</td>
</tr>
<tr>
<td>THDu (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fund. voltage(kV)</td>
<td>135.46</td>
<td>135.35</td>
<td>135.25</td>
</tr>
<tr>
<td>2</td>
<td>0.03</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>3</td>
<td>0.25</td>
<td>0.26</td>
<td>0.25</td>
</tr>
<tr>
<td>4</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>5</td>
<td>0.12</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>6</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>7</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>8</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>to 9</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>25</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Harmonic</td>
<td>0.09</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td>Voltage</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Percent</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Figure 4</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Long time flickers</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Figure 4. Finally Evaluation Results Composition.
For example, after we finish the assessment, if the result of harmonic current element shows qualified, it means the harmonic current is just eligible, but there is a lot of room to be improved.

But if we make the evaluation by the Related Elements Evaluation method, we can both know the result of every important index, and we can also tell the engineers which part of necessary measures needed to be done to prevent the loss caused by power quality issues.

From table 5 to 7, we can know the result of harmonic current, harmonic voltage and others parameters, but it is not very convenient for an engineer to make a quick overview of the total result. We can only know which index is qualified or unqualified, and we cannot judge the order of severity of every index, also cannot tell the user if there are some necessary measures to be done to prevent the loss caused by power quality issues.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>max</th>
<th>average</th>
<th>min</th>
<th>95% value</th>
<th>limit</th>
<th>result</th>
</tr>
</thead>
<tbody>
<tr>
<td>frequency (Hz)</td>
<td>50.0509</td>
<td>50.0273</td>
<td>49.9577</td>
<td>0.0198</td>
<td>±0.2</td>
<td>qualified</td>
</tr>
<tr>
<td>negative voltage percent(%)</td>
<td>0.98</td>
<td>0.8739</td>
<td>0.7877</td>
<td>0.9255</td>
<td>±2</td>
<td>qualified</td>
</tr>
<tr>
<td>fundamental active power(KW)</td>
<td>40785.898</td>
<td>36732.518</td>
<td>33570.613</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>fundamental reactive power(KVar)</td>
<td>-3434.6797</td>
<td>-3794.3299</td>
<td>-4330.4692</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>apparent power(KVA)</td>
<td>41033.688</td>
<td>36949.1819</td>
<td>33570.613</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>power factor</td>
<td>0.9943</td>
<td>0.9941</td>
<td>0.9939</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

From table 5 to 7, we can know the result of harmonic current, harmonic voltage and others parameters, but it is not very convenient for an engineer to make a quick overview of the total result. We can only know which index is qualified or unqualified, and we cannot judge the order of severity of every index, also cannot tell the user if there are some necessary measures to be done to prevent the loss caused by power quality issues.

But if we make the evaluation by the Related Elements Evaluation method, we can both know the result of every important index, and we can also tell the engineers which part of necessary measures needed to be done to prevent the loss of power quality.

For example, after we finish the assessment, if the result of harmonic current element shows qualified, it means that the harmonic current is just eligible, but there is a lot of room to be improved. If the result of stability of voltage element shows excellent, then it means there is not much room to be improved. This will offer a lot of help for an engineer to make the improvement plan for the user.
7. Application of Related Elements Evaluation

We take an application for 220kV substation for example in this article, which is in the AC-DC converter substations area and there are several factories supplied by this substation, so that the harmonic voltage and harmonic current is much more important than the others. In this example, we choose mode 1 to calculate.

As it is shown in the figure 5, the fluctuation of active power is very obvious.

![Figure 5. Power Curve Graph.](image)

As can be seen from the figure 6, the harmonic current contents is different, the related harmonic current of the substation is 3, 5, 7, 11 and 13 times. The figures are shown in table V, here we got 19 indicator, so the full score is 57(3*19=57).

![Figure 6. Harmonic Current Scattergram.](image)

Table 8. Harmonic Current of Substation Result.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Phase A</th>
<th>Phase B</th>
<th>Phase C</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Related Harmonic current (A)</td>
<td>3</td>
<td>1.2</td>
<td>1.3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>7.7</td>
<td>9.2</td>
<td>16.4</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>2.2</td>
<td>3.3</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>2.7</td>
<td>2.4</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>1.7</td>
<td>1.6</td>
<td>3.1</td>
</tr>
<tr>
<td>THDi(%)</td>
<td>13.5</td>
<td>17.4</td>
<td>14.45</td>
<td>3</td>
</tr>
<tr>
<td>Negative sequence current (A)</td>
<td>90.29</td>
<td></td>
<td></td>
<td>17.49</td>
</tr>
</tbody>
</table>

Table 9. Harmonic Current of Substation.

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>INDEX</th>
<th>SCORE</th>
<th>RESULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harmonic current</td>
<td>Related Harmonic Current</td>
<td>30</td>
<td>0.53</td>
</tr>
<tr>
<td></td>
<td>THDi</td>
<td>0</td>
<td>(Failed)</td>
</tr>
<tr>
<td></td>
<td>Negative sequence current</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
As we can see from table 9, the element of harmonic current score is 30, the full score for the element is 57, so that the result for this element is 0.53, means failed. We choose mode 1 in this calculation.

Table 10. Four Components Scores.

<table>
<thead>
<tr>
<th>Element</th>
<th>Point</th>
<th>Weightness</th>
<th>Result</th>
<th>Final result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harmonic voltage</td>
<td>0.58</td>
<td>0.35</td>
<td>0.203</td>
<td>0.625</td>
</tr>
<tr>
<td>Harmonic current</td>
<td>0.53</td>
<td>0.3</td>
<td>0.159</td>
<td>Qualified</td>
</tr>
<tr>
<td>Power</td>
<td>0.72</td>
<td>0.25</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>Stability of voltage</td>
<td>0.83</td>
<td>0.1</td>
<td>0.083</td>
<td></td>
</tr>
</tbody>
</table>

According to the formula in table 2 and table 3, we can get results for all the four elements, and so that the final results, as we can see in table 10 and figure 7.

As it is shown in figure 7, the elements of harmonic voltage and harmonic current needed to be improved a lot, because it shows “Failed” for both two elements, which means the index of harmonic voltage and current are much beyond the limits. And the element of power also can be improved, because it shows “Qualified”, which means the values of power are within the standard range. And the stability of voltage does not to be improved, as is shown “Good”.

According to the evaluation result, the engineer can focus on the consumer of this substation, especially the nonlinear users, which can cause much harmonics. After the engineer make sure the source of harmonic voltage and current, the measurements of improvement can be easily determined.

8. Conclusion

In this article, we put forward a “related elements evaluation” method to assess power quality of substations nearby an AC-DC converter. This method classified 12 basic indexes into four elements. Then we assign different weightiness for each element based on the grid structure and the composition of power generation in the area. And we also give a few formula to calculate every indicator and each element, which are very easily to understand and implement. At last, we estimated a 220kV substation by using “related elements evaluation” method, as shown in table 10 and fig 7, we can tell the advantage and disadvantage of the substation, this shows that the “Related Elements Evaluation” method is simple and feasible to be used in the power quality monitoring platform.

References


