Load Harmonic and Voltage Fluctuation Analysis Based on the ETAP Simulation

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Abstract. With the increasingly prominent problems of power quality, the study of power quality assessment is becoming more and more important. In this paper, the quantitative evaluation of various indexes on power quality is carried out according to the load characteristics and national standards. Firstly, the specific characteristics of the loads are analyzed, and the allowable values of the voltage fluctuations and harmonic currents are calculated. After that, a model to evaluate the impact of the loads on power quality is given, and it is built in the ETAP according to the user's system wiring diagram. Then the simulation analysis is carried out according to the limit operation condition, and indexes of the power quality are calculated. Finally, the measures to deal with the unqualified index are put forward.

1. Introduction
With the improvement of the national economy, the development of electrification and the application of various electronic devices, the problem of power quality is becoming more and more prominent. With the increase of precision instruments in users, the demand for power quality is higher and higher, and the attention of power supply enterprises to power quality problems is constantly improving.

Power quality assessment is based on the measurement or modeling simulation to obtain the basic data, to evaluate the power quality and to check whether it meets the requirements of the national standards. The purpose is to determine whether the power consumer can access the public power grid and how to deal with the unqualified index. Reference [1] written by S. Tao mainly described the various assessment methods of power quality and the importance of assessment. Reference [2] written by Y.Y. Liu conducted a comprehensive evaluation of power quality for each voltage grade bus in substation of the regional power grid. However, there was no power quality assessment for specific load characteristics in the literature [3-5].

This paper is to evaluate the power quality of a special power consumer. Firstly, the power distribution system and load characteristics of loads are analyzed in section I, and the type of power quality disturbance are determined. The allowable values of harmonic currents and voltage fluctuations are calculated in section 2. Then the simulation model is built to calculate the power quality index values under the limit conditions, and the evaluation conclusion is drawn by comparing it with the allowable value of the national standard in section 3. Finally the main conclusions are drawn in section 5.

2. Analysis of power distribution system and load characteristics of new customer
In order to better analyze the power quality problems that may arise during the load operation of the user, it is necessary to analyze the power distribution system and load characteristics.
2.1 The analysis of the power distribution system
The total electric loads of the new customer are declared to be 8000kVA. The substation provides two 10kV power supply lines to the user’s switch station, and each of them is available for 4000kVA. The high-voltage motor is directly supplied by the 10kV bus, therefore the isolation transformer with capacity of 4000kVA is installed on the power supply line, which ensures that the high-voltage motor will not produce large impact on the power grid when it works. At the same time, the total load of each power supply line should not exceed 4000kVA through internal deployment.

The distribution scheme of the new customer is shown in Figure 1. As shown in the figure, the loads of experimental pool are supplied by 3 pool transformers. The office building is powered by two transformers with the ratio of 10/0.4kV. The mould workshop and the measurement system are powered by a 10/0.4 kV transformer respectively.

![Figure 1. The distribution scheme](image)

2.2 Analysis of load characteristics
The main power loads of the new customer are distributed in 4 parts: the experimental pool, the high-voltage motor laboratory, the mould workshop and the office building. The list of main loads is shown in table 1.

| No. | name           | number | Single power(kW) | Total power(kW) | Frequency conversion | Start-stop frequency |
|-----|----------------|--------|------------------|-----------------|----------------------|---------------------|
| 1   | elevator       | /      | /                | 30              | Yes                  | Every day           |
| 2   | air conditioner| /      | /                | 849.4           | Yes                  | Every day           |
| 3   | living pump    | /      | /                | 7.5             | Yes                  | Every day           |
| 4   | motor A        | 16     | 110              | 1760            | Yes                  | 7-10 times / day    |
| 5   | motor B        | 24     | 5                | 120             | Yes                  | 7-10 times / day    |
| 6   | motor C        | 478    | 6.13             | 2930.14         | Yes                  | 7-10 times / day    |
| 7   | Large motor    | 1      | 3000/1000        | 3000/1000       | Yes                  | /                   |
| 8   | adjustable-speed motor | / | / | Yes | / |
| 9   | other motors   | /      | /                | No              | /                    |

Taking the variable frequency motor C as an example, the harmonic distribution is shown in figure 2.
Figure 2. The harmonic distribution of variable frequency motor C

It can be seen from the load list that a large number of inventers and motors are included in the electrical loads of the new customer. During the working process of the transducer, harmonic currents will be emitted, resulting in harmonic pollution to the power grid. Motor start will cause voltage fluctuation at the Point of common coupling (PCC). As the loads of the new customer are mainly expressed as harmonic sources or wave sources, the impact of the user on the harmonic pollution and voltage fluctuation is evaluated in this paper.

3. The calculation of national standard allowable value for the power quality indice

In the evaluation of power quality, it is necessary to calculate the user’s allowable value according to the actual power supply. It is used to compare with the simulation results of the actual system. In view of the characteristics of the loads, the allowable values of harmonic currents and voltage fluctuations need to be calculated.

3.1 The calculation of allowable harmonic currents

The basic data required to calculate the allowable value of the user's harmonic current are the voltage of the PCC, the minimum short circuit capacity of the PCC, the capacity of the power supply transformer and the user’s protocol capacity. The calculation formula is as follows:

$$I_{h} = \frac{S_{k1}}{S_{k2}}I_{hp}$$  \hspace{1cm} (1)

In the formula, $S_{k1}$ is the minimum short circuit capacity of the PCC (MVA); $S_{k2}$ is the reference short circuit capacity (MVA); $I_{hp}$ is the allowable value of $h$th harmonic current in the standard (A); $I_{h}$ is the allowable value of the $h$th harmonic current when the short circuit capacity is $S_{k1}$ (A).

When multiple users are connected to the same PCC, the allowable harmonic currents of the $i$th user can be calculated according to formula (2):

$$I_{hi} = I_{h}(S_{i}/S_{p})^{1/\alpha}$$  \hspace{1cm} (2)

In the formula, $I_{h}$ is the allowable value of $h$th harmonic current obtained by the formula (1) (A); $S_{i}$ is the power capacity of the $i$th user (MVA); $S_{p}$ is the capacity of the power supply transformer (MVA). The $\alpha$ is phase superposition coefficient, and the corresponding values are obtained according to the different harmonics in the standard.

According to the above method, the allowable harmonic currents of the user are shown in table 2.
Table 2. The results of the allowable value for harmonic currents

| Harmonic order | Allowable current(A) | Harmonic order | Allowable current(A) |
|----------------|----------------------|----------------|----------------------|
| 3              | 6.158                | 15             | 2.439                |
| 5              | 6.957                | 17             | 3.569                |
| 7              | 6.319                | 19             | 3.212                |
| 9              | 4.045                | 21             | 1.725                |
| 11             | 5.058                | 23             | 2.677                |
| 13             | 4.504                | 25             | 2.439                |

3.2 The calculation of the allowable voltage fluctuations

The allowable values of voltage fluctuations caused by fluctuate loads are related to fluctuate frequency and voltage level. According to the national standard, the allowable values of voltage fluctuation for the 10kV bus are shown in Table 3.

Table 3. The allowable values of voltage fluctuations

| r/h (time/hour) | d/% | r/h (time/hour) | d/% |
|----------------|-----|----------------|-----|
| r≤1            | 4   | 10<r≤100       | 2   |
| 1<r≤10         | 3   | 100<r≤1000     | 1.25|

Note:
1. The r stands for fluctuate frequency of voltage.
2. When the frequency of voltage fluctuation is very low (less than once a day), the allowable value of voltage fluctuations can also be increased.
3. For stochastic voltage fluctuations, it is based on 95% probability.

According to the information provided by the user, the loads in the two experimental pools are started 7334.5 times a year; and the loads in the mould workshop is started 8832.5 times a year; and the loads in the high voltage motor laboratory is started 936 times a year. Therefore, the user starts the motor 17103 times a year, and the number of starting times per hour is about 2 times.

According to the national standard, the allowable voltage fluctuations of the user is 3%.

4. Case study results

4.1 The method of simulation and calculation

On the basis of the user's system wiring diagram and load distribution, the limit operation conditions can be designed for each power quality index according to the operating conditions of the load. Through simulation, the influence of load input on power quality is calculated. Compared with the allowable values calculated in the fourth section, the final assessment conclusion is obtained.

In this paper, the index values are calculated by Electrical Transient Analysis Program (ETAP). In the ETAP software, a single line graph model of the actual system is built according to the operating conditions. Then, the harmonic current sub module and the motor starting analysis sub module in ETAP can be used to calculate the two indexes of the harmonic current and voltage fluctuation caused by the actual load operation of the user. Finally, the evaluation conclusion can be drawn from the comparison with the allowable value of the national standard.

4.2 The calculation of the actual power quality value

According to the system wiring diagram of the new customer, the system model of analyzing voltage fluctuations and harmonics is built in ETAP simulation software.

The harmonic sources of the new customer mainly include 5 types: trailers, wave makers, high voltage variable frequency motors, air conditioners and general variable frequency motors. The harmonic analysis model is set up in ETAP, and the actual working limit condition is set up to simulate the corresponding harmonic currents. The results are shown in Table 4.
| Harmonic order | Allowable current (A) | Current of No.1 bus (A) | Current of No.2 bus (A) |
|----------------|----------------------|--------------------------|------------------------|
| 5              | 6.957                | 6.885                    | 16.602                 |
| 7              | 6.319                | 3.419                    | 0.800                  |
| 11             | 5.058                | 2.361                    | 0.329                  |
| 13             | 4.504                | 1.209                    | 0.135                  |
| 17             | 3.569                | 0.106                    | 0.037                  |
| 19             | 3.212                | 0.117                    | 0.023                  |
| 23             | 2.677                | 0.410                    | 0.010                  |
| 25             | 2.439                | 0.393                    | 0.010                  |

When the voltage fluctuation is simulated, the theoretical analysis shows that the starting current of the direct starting and step-down starting is larger, and the variable frequency starting usually limits the current to the rated current. Therefore, when analyzing the voltage fluctuation, the motors starting directly and the motors starting with reduced voltage are mainly considered. In addition, other motors are not allowed to start when the high voltage motor is started. For different combinations of starting modes, a set of working conditions with the most serious impact on voltage fluctuation is obtained and simulated. The results are shown in Figure 3.

4.3 The results of evaluation

By comparing the allowable values and actual values, the following conclusions can be drawn: Under the limit condition, the 5th harmonic current of the user injected into the No.2 bus exceeds the allowable value, and the other harmonic currents are not exceeding the standard. Under the most severe starting combination mode, the voltage fluctuation caused by motor startup is less than 3%, which meets the requirements of national standards.

4.4 Suggestions on harmonic control

Active power filter (APF) is a new type of power electronic device for harmonic suppression and reactive power compensation. APF can compensate harmonics with varying amplitude and frequency, and the compensation effect can reach more than 90% if capacity allows. Therefore, a suitable APF can be installed at the low voltage side of the transformer to suppress harmonics, so as to meet the requirements of the national standard.

5. Conclusion

This paper firstly gives the overall objectives and tasks of the power quality assessment, and then analyzes the characteristics of a user's loads and the potential power quality problems caused by the load operation. And the allowable values of the national standard for the user's harmonics and voltage fluctuations are calculated. Finally, through the simulation, the harmonic currents and the maximum voltage fluctuations are calculated under the limit conditions, and the reasonable suggestions are given.
for the harmonics exceeding the standard.

Reference
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