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Discussion on the Problems of Harmonics Evaluation in Power System

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Abstract: Harmonic evaluation in power system planning and operation is the key to the control of harmonic level in power grids. In order to prevent the level of harmonic voltage, for large and medium-sized non-linear grid access to the grid, in the power system planning in accordance with the relevant standards and regulations for harmonic assessment. In actual operation, it is also necessary to evaluate the harmonics voltage and the user's harmonic emission. Based on the harmonics standard and related regulations of our country and the actual situation of China's power grid development, this paper discusses the challenges of harmonic evaluation under the current grid development, including the limitation of harmonic voltage and responsibility, harmonic current limit, measurement evaluation and other issues for the development of China's harmonic standards and evaluation methods to provide a reference.

Key words: Harmonic standard; harmonic limit; harmonic management; power quality

0 Introduction

The harmonic level in the power system seriously affects the operational safety and economy of the grid equipment and user equipment. Harmonic level as an important indicator of power quality, one of its abundance can guarantee the necessary compatibility between the user equipment and the power grid, in the power grid planning and operation needs to conduct a reasonable assessment, management and control.

China issued in 1984, SD 126-84 "Interim Provisions on Power System Harmonics Management" [1]; 1993 recommended national standard GB / T-14549-1993 "power quality utility grid harmonics" [2]; 2000 issued a national standard guiding technical documents GB / Z 17625.4-2000 "in the high-voltage power system distortion load emission limit assessment" [3]; based on the revision of SD126-84, issued in 2013, the power industry standard DL / T 1198-2013 "power system power quality technology management regulations" [4]. The development of these standards and regulations for China's power system harmonic control plays an indispensable role. In China's power system planning and operation, the determination of harmonic limits mainly follow GB / T-14549-1993, but in different application scenarios there are still many problems [5-6].

It is generally believed that the harmonic voltage of the grid is caused by the harmonic current (harmonic source) flowing through the non-linear device (load device or power generation device) of the power grid to the network impedance at the harmonic frequency and causing the corresponding voltage drop. The harmonics in the power grid interact with each other, resulting in harmonic currents and harmonic voltages added to the phasor. There may be harmonic sources for each voltage level of the grid, for example:

- In the low-voltage distribution network, with a variety of input with the electrical load (household appliances, computers, charging piles, etc.) or power generation equipment (home photovoltaic power generation equipment)
- In the medium pressure, high voltage net-

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Table 1 Voltage Limits for Different Harmonics Standards

	Voltage level kV		Harmonics requirement
IEC	$U_n \leq 1$		Each 3 times & non-3 times odd times The even harmonics Total distortion rate
	$1 \leq U_n \leq 35$		
	$35 \leq U_n \leq 230$		
	$230 \leq U_n$		
	$U_n \leq 1$		Total odd harmonics Total distortion rate
	$1 \leq U_n \leq 69$		
	$69 \leq U_n \leq 161$		
	$161 \leq U_n$		
British	$U_n = 0.4$		Each 3 times & non-3 times odd times The even harmonics Total distortion rate
	$U_n \leq 36.5$		
	$66 \leq U_n \leq 132$		
	$275 \leq U_n \leq 400$		

work, industrial load (speed transmission), traction rectifier and other large independent sources, distributed new energy power generation (wind power and photovoltaic power generation);

- High voltage and ultra high voltage network, large-scale new energy power generation access (wind power and photovoltaic power generation); HVDC transmission lines;

Thus, the main factors affecting the level of harmonics are: power generation equipment, end-user equipment and power grid performance itself. These factors in the future power grid may be significant changes can be expected to power quality problems will also be significant changes [7]. It is expected that in the future, there will be more and more power electronic load (charging pile) and inverter-based power generation (photovoltaic power generation and wind power) access to the power grid, whether it is connected to the user equipment in the low-voltage power supply system, - ultra-high pressure transmission and distribution system, the harmonic interaction will be more significant, the harmonic problem in the future will be more serious, the level of control of the harmonic level of the power grid will be more severe.

In the energy transformation and the development of smart grid situation, in view of the above problems, the relevant agencies and researchers around the world carried out a large number of research work, mainly in the harmonic standard, harmonic evaluation methods, and achieved a certain degree of results The This article will combine the internationally recognized harmonics standards, including the International Electrotechnical Commission (IEC) 2008 edition IEC 61000-3-6 technical report [8], the United States 2014 harmonics standard IEEE 519-2014 [9], the British 2005 edition of Harmony Wave standard G5 / 4-1 [10], published in 2015 IEC TS 62749 “public power grid power quality limit and its assessment method” [11], to discuss the current in the power system planning and operation, the application of GB GB / T -14549-1993 and related regulations for harmonic assessment of the main

problems. This paper will discuss the harmonic voltage limit, the harmonic current limit and the responsibility distribution, the evaluation method and the international research direction.

1 Harmonic voltage limit and electromagnetic compatibility

On the harmonic voltage limit, the world based on IEC electromagnetic compatibility values and the actual situation, the development and implementation of harmonic constraints to consider the power quality standards. The overall trend is that the non-linear device access to the grid when the harmonic voltage planning value should be IEC issued by the harmonic electromagnetic compatibility value [12] as a benchmark.

For the planning level of the harmonic management of the grid, Table 1 lists the IEC 61000-3-6, the US IEEE-519, the British standard G5 / 4-1 and China GB / T 14549-1993 gives some of the harmonic voltage limit information. It can be seen from the table that the voltage limits of IEC, US and UK are basically defined by four voltage levels, namely, low voltage, medium voltage, high voltage grid and transmission grid.

China's power system voltage level development has been at the forefront of the international, but the national standard GB / T-14549-1993 voltage level division, the lack of high pressure - UHP level harmonic voltage limit distribution. At present, for China's large-scale focus on access to renewable energy development areas (such as the three northern regions), power network planning harmonic assessment may encounter a relatively large challenge. Figure 1 shows the northern Hebei power grid in a region power generation and load situation diagram. On the one hand, due to the large-scale wind power access 110kV and 220kV power grid, seriously affect the regional power grid harmonics level, and even affect the upstream 500kV transmission network and downstream distribution network harmonic level; the other hand, 35kV power grid access to a large number Photovoltaic power generation, the upstream and downstream power grid harmonics have a great impact. For such a large-scale non-linear equipment, power grid access, there are two challenges: non-linear equipment access to the grid not only affect the regional power grid harmonics, but also on the upstream and downstream power grid harmonic voltage impact; Renewable energy power generation access to high voltage - ultra high voltage power grid, the harmonic management problems more and more prominent, urgent need for harmonic voltage limits in the various voltage levels for a reasonable allocation. In fact, the IEC does not give an electromagnetic compatibility value for the high voltage-to-high voltage class.

In general, for the high-voltage DC transmission side

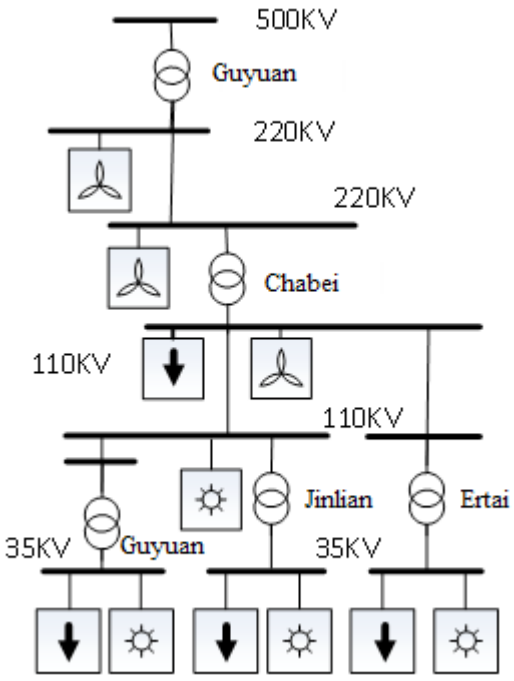

Figure 1 Regional equipment for large-scale access to non-linear devices

of the grid access, generally have strict rules [13], requiring the DC transmission system even in the harshest power grid operating conditions, the filter performance can meet the basic requirements of grid access. However, for large-scale renewable energy access to high-voltage - UHV power grid situation, as a conventional non-linear device or as a specific non-linear equipment, to carry out harmonic management is a clear problem.

2 Current limit and distribution of harmonics

In principle, to ensure the power quality of the grid to make the grid equipment and grid users' safe and normal operation, is the bounden duty of the power system. However, some of the power quality of the grid (including harmonics, flicker and three-phase voltage

Table 2 Different standard harmonic current limit calculation steps

	Harmonic current limit calculation	
	Step 1	Step 2 New network equipment
IEC	Calculate PCC point $I_{h,pcc}$ according to the minimum short circuit capacity of normal operation	Consider the future of all PCC point equipment by capacity fair share $I_{h,pcc}$
China	Calculate PCC point $I_{h,pcc}$ method according to the minimum short circuit capacity of normal operation	Consider the future of all PCC point equipment by capacity fair share $I_{h,pcc}$
US		According to the equipment capacity requirements / PCC point of the normal operation of the maximum short circuit capacity calculation
British	PCC point total equipment capacity does not exceed the specified value, direct access equipment	When the total capacity of the device exceeds the limit, the harmonic current limit of the new device is calculated according to the harmonic voltage limit

imbalance, etc.) are mainly caused by the interference of the grid users. Therefore, the power quality requires the grid and the grid to share the corresponding responsibility. During the planning of the power grid, in order to ensure the planning level of the harmonics of the power grid, it is necessary to determine the low-frequency harmonic emission limit for the non-linear devices connected to the power grid as the harmonic evaluation conditions when the equipment is running.

In [12], the current limits in IEC, IEEE and British harmonics are described in detail. This paper will compare the different current limit to determine the way and the principle of the distribution of responsibilities.

For a large number of small grid users, with a simple assessment can be network conditions that are, taking into account the small capacity, harmonic current without special restrictions. However, with the future development of photovoltaic power generation at home, its impact on the surrounding power equipment cannot be ignored, under special circumstances need to strengthen the low-voltage network equipment for harmonic assessment of drift restrictions.

For a long time, the harmonics of the power grid are mainly affected by the medium-sized nonlinear devices connected to the medium voltage network, and the harmonic current transmission of the latter needs to be restricted.

Table 2 shows the general steps for the PCC point harmonic current emission for different standards. There are several points to note:

- It is worth mentioning that, although the steps and principles of IEC and Chinese standards look the same, but there is a big difference between how to determine the “minimum short-circuit capacity for normal operation”.
- US standard equipment harmonic current limit, and PCC point other equipment capacity has nothing to do, so its procedures are operational. According to the maximum short-circuit current of the PPC point of the grid, the harmonic current limit of the network equipment is determined. However, how to ensure the harmonic voltage level of the power grid under the worst operating conditions is the responsibility of the harmonic control. This greatly increases the harmonic Wave control responsibility.
- British standard equipment access has a “first to dominate” principle, on the one hand make full use of the power grid to absorb the harmonic capacity, on the other hand for the access to the power grid equipment, the harmonic emission may be severely restricted, with “Unfair” nature.

For high voltage - ultrahigh voltage network harmonic control, the general need for more complex assessment methods, but there is no practical and effective general method. No matter what kind of responsibility distribution principle to determine the harmonic current, the complexity of more and more prominent. For example, IEC TR 61000-3-6 provides the basic criteria for assessing the level of harmonic emission, but the detailed method of determining the level of harmonic emission is very complex and difficult to use. In recent years, many techniques have been proposed to determine the level of harmonic emission, but for a variety of reasons have not been widely used in practice, the most important are that these methods need to know the actual harmonic frequency analysis of the required data, including system harmonics Wave impedance data.

3 Evaluation method

The industry standard DL / T 1198-2013 released in 2013 is based on the revision of SD 126-84 and is further extended to power quality technology management regulations. Which proposed to different times the power quality technology management is divided into “planning feasibility study, engineering design, project implementation, production and operation” four stages, and provides a management process for each period. Can also be seen as planning and running two different periods of assessment procedures.

3.1 Level 3 assessment of the planning period

DL / T 1198-2013 to determine the planning feasibility of the stage in accordance with the “grading assessment” principle of power quality prediction and evaluation. Provisions should consider the impact of the project on the power quality of the public connection point, according to the relevant standards to determine the power quality assessment indicators. Evaluate the power quality according to the “grading evaluation” principle. Users who access the grid should be treated by the power company according to the principle of three-level management of harmonic problems.

1. The first level assessment includes a low-pressure, small-capacity general power load that satisfies the following conditions, which can be considered to be a slight increase in the power quality and direct access to the grid without evaluation.

- 380V / 220V low voltage users;

- 6kV ≤ V ≤ 20kV, capacity S ≤ 0.63MVA and non-rectified users;
- V = 35kV, S ≤ 2MVA non-rectified users.

2. The second level assessment includes an electrical user who meets the following criteria and generally uses a simplified method of assessment.

- Does not meet the requirements of the first assessment;
- V <20kV, 0.63MVA <S <6.3MVA power users;
- V = 35kV, 2MVA <S <40MVA power users.

3. The third level assessment includes power users who meet the following criteria. Third-party assessment of the detailed calculation, the general use of power system simulation software, the assessment results do not meet the requirements should be put forward feasible power quality control measures and recommendations, and give improvements.

- Does not meet the second level of assessment conditions and the second level of assessment results do not meet the requirements of the power users;
- 66kV and above power users

[14] summarizes the differences in the harmonics of the harmonics in IEC, IEEE international standards and British harmonics standards. Compared with these three-level assessment methods, China's three-level assessment methods in the details of the existence of many differences, but the basic principle is the same, as the industry standard is officially promulgated to our current harmonization of the harmonics and enrichment. According to our understanding, the third level of the harmonic assessment can have two characteristics: in the network and the higher voltage level of the grid, the need to consider the interaction of the harmonic source; need harmonic distribution in the grid calculation, analysis with the assessment.

In the application of this provision, there are the following problems:

- Provides that there is no given "simplified calculation" and "complex calculation" of the assessment method gives a clear definition;
- In the assessment of the basic situation in the determination of the grid, asked to give "background power quality level" information. This requires an effective historical measurement and evaluation of the actual grid;
- In the complex calculation of the third level assessment, the need for detailed modeling of the power grid, the industry is still lack of recognized modeling data requirements and modeling methods.
- Technical limitations of harmonic measurement (CT and VT) and sensitivity analysis (measurement error, system impedance estimation error);

3.2 Harmonic voltage evaluation during grid operation

The harmonics of the previous section of the harmonic evaluation, mainly based on the planning level of the harmonic voltage limit, the purpose is to meet the power system in a variety of operating conditions to meet the conditions of electromagnetic compatibility. For the actual operation of the power system when the public power grid quality assessment, on the one hand from the regulatory needs to monitor the power grid to maintain power quality requirements to ensure that the interests of grid users. On the other hand, changes in the load type of the access grid, the characteristics of unconventional generators with power electronic interfaces, and the anticipated increase in load / storage (eg, electric vehicles), and increase pressure on grid operation. The need to monitor and record changes in network performance for the planning of new equipment access when the harmonic assessment.

In recent years, with the development of viable technologies (monitoring equipment, communication technology, data storage and processing, etc.), it is possible to carry out large-scale monitoring and recording of almost any parameter of interest. In addition, pressure from customers and regulators requires information on the actual level of power quality. These factors make the number of power system power quality monitoring significantly increased. Harmonic voltage and current monitoring can provide information about its network performance for the overall system as well as for individual locations and customers.

In 2015, IEC issued IEC TS 62749 "Public Grid Power Quality Limits and Their Evaluation Methods" [11], including harmonic limit assessment, monitoring records and statistical methods, and monitoring the contents of the equipment communication protocol.

Table 3 shows the recommended harmonic voltage limits, the voltage limit of the medium and low voltage

grid, the basic and electromagnetic compatibility limits, and compare the planning level given in Table 1 is very different. It is worth mentioning that the high voltage grid widely used capacitive voltage transformer [15], but for the harmonic measurement of harmonic transmission characteristics [16], it is difficult to meet the measurement accuracy, so the high voltage grid harmonic voltage limit is only specified to 13th harmonic. In fact, the assessment of high-order harmonic emissions is still a challenge.

Table 3 IEC 62749 Harmonics Voltage Limits for Common Power Grids

Voltage level	Total harmonic distortion (%)
Low	8
Medium	8
High	3～6

At present IEC and IEEE are required to use the interval of 200 milliseconds 3s ultra-short time records, and calculate the 10min interval within the average root for short-term recording. For the evaluation of the PCC point, the IEC recommends continuous measurements on a weekly basis and on a rolling basis. The IEEE recommends that the 3s base record be counted and evaluated on a daily basis and that the 10min record is evaluated on a weekly basis and does not mention what Connection evaluation. For the impact of different assessment methods on the assessment results, see [17].

IEC / TS-62749 for the first time to determine the systematic assessment of the method, the use of “mean and sample standard deviation” approach. The basic principles and methods of systematic assessment are put forward, which should be instructive to the harmonics evaluation of countries and regions in the world. It is also worthy of reference in the future research of harmonics evaluation of systematic public grid.

3.3 On-line harmonic current monitoring and evaluation

In general, after the planning period of the harmonic evaluation of the grid, the grid and grid users signed an agreement to ensure that the power quality of the grid. At the same time, the grid needs to be based on the on-line monitoring and continuous assessment of the low-frequency harmonics of the existing user equipment on the grid; and the statistics of the results must be continuously evaluated, rather than a single (at some time) or two steps (before and after installation) The While the need to assess the responsibility for harmonic harassment. In recent years, many techniques have been proposed to determine the level of harmonic emission, but for various reasons have not been widely used in practice, that is, these methods need to know the actual network data, that is, the system harmonic impedance data. In short, the system at the level of harmonic source positioning, harmonics over the responsibility of the distribution, is still a major challenge in harmonic research.

With the continuous development of on-line harmonic monitoring and evaluation of the power grid, the on-line data will provide the most effective and direct basic data for harmonic evaluation of power network planning.

4 Technical guidelines of the status quo

IEC, IEEE and some European countries in the harmonization of the standard at the same time, generally also provide the relevant harmonics standard technical report or application guide. The latter on the one hand can give detailed application guidance, on the other hand can be closely adjusted according to industry development, so the update frequency is higher. In the future development of our harmonized standards and its specifications, it is worth considering the development and timely revision of supporting technical documents to guide and support the power grid personnel to better achieve power quality control. Below we will discuss the IEC, IEEE and the United Kingdom is currently the relevant research projects and related issues.

4.1 IEC technical report of the research project

International Conference on Power Grid CIGRE and International Conference on Power Supply CIRED established a joint working group WG C4.40 [18] in 2015 with the mandate to revise some IEC technical reports on the assessment of emission limits for harbor harassment equipment, including IEC 61000-3-6. The current version of the 61000-3-6 is written by the SC-C4-CIGRE-WG-C4.103 Working Group and published in 2008 and its text will be close to the maintenance cycle. Taking into account the significant changes in the development of the grid and the many changes in equipment launch and immunity, the Working Group considered it necessary to consider revising these documents. For the technical report on the subject of content changes, the main influencing factors for the power supply system changes: the smart grid technology caused by the grid reconfigurable function, in different voltage levels in the distributed power gen-

eration access and cooperation (especially in the low pressure and other traditional radiation type); the emission characteristics of the change is mainly high-frequency harmonics, this part is not included in the current technical report. In addition, the planning level allocation method for determining the user emission limit may be too complex (or even inappropriate) for the case of refactoring factors and distributed resources. Target tasks include:

- For systems containing distributed power supplies, evaluate the applicability of the general rules for limit allocation and propose changes;
- For reconfigurable systems, assess the applicability of existing indicators and limits (eg, 95% probability large values) and suggest changes;
- Evaluate the applicability of the existing distribution limits method to high frequency harmonics (above 2 kHz) and propose amendments (mainly for 61000-3-6 and -3-14).
- Investigate the current version of the industry experience, based on recent usage and experience, to propose amendments.

The final report of the working group is scheduled to be published in 2018.

4.2 IEEE Application Guide for Research Projects

After the publication of IEEE 519-2014 in the United States, the application of its standard application guidelines began in 2016 [19]. In some ways, the application guide is equivalent to the technical report of IEC 61000-3-6. The project focuses on the application of IEEE 519-2014 recommended limits, providing application information so that new standards can be applied correctly. Mainly to explain the following aspects:

- Provide common harmonics assessment procedures for different categories of customers (industrial, commercial, residential) and public grid equipment;
- Example of how to evaluate the harmonic level of a public access point (PCC). Examples of PCC concept, harmonic current flow direction, average maximum load current demand, short circuit ratio SCR and total demand distortion rate;
- Example of a measurement program that provides PCC harmonic voltage and current. The measurement procedure shall describe the time-varying and statistical characteristics of the harmonics;
- Examples of harmonization of harmonics for old users and new users;
- Examples of harmonization methods on the customer side and the grid side. Describe the possible problems with the filter application, and may interfere with each other.

The project study period is two and a half years and is expected to be submitted to IEEE 519.1 in January 2018. In fact, the US IEEE 519.1 research project and the European CIGRE-WG C4.40 research project is almost simultaneously. It is noteworthy that the major researchers in the US IEEE 519.1 project are also involved in the CIGRE-WG C4.40 research project.

In summary, IEC, IEEE project involved in the research should also be related to the relevant researchers and professionals facing the problem, it is worth tracking the development of its international research, but also for the development of China's power grid to carry out the corresponding research, Should consider China's grid voltage level higher, longer transmission distance, renewable energy access areas such as the characteristics of the development of suitable for China's harmonic assessment of the general principles and suitable for regional special circumstances, with operational procedures.

5 Conclusion

In the future development of the power grid, distributed and centralized renewable energy accounted for a substantial increase in the proportion of new non-linear load increases, non-linear power equipment across the grid at different levels. In some specific areas of China, power system planning and operation of the harmonic management tasks will be more severe. Control of harmonic pollution in the grid requires the joint efforts of equipment manufacturers, equipment users and the grid, as well as the need for relevant standards and regulators, and government agencies to face challenges. Around the world and China's harmonized management standards and research, in the past 30 years to get a lot of experience and results. However, in the face of the current situation and future development of China's power system, there is still a need for in-depth and meticulous research and coordination. The development of harmonic standards and regulations needs to take into account the special needs of China's power grid development, Harmonics assessment requirements, especially for high-voltage and high voltage grid harmonics management, in terms of harmonic limits, assessment methods and the principle of responsibility allocation, should be studied

and the establishment of more practical and detailed rules to guide and support the grid planners for better control of the power quality of the grid to meet the safety and economy of grid operation.

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