

ISSUES ON THE APPLICATION OF CHINESE HARMONIC STANDARD GB/T 14549

Rui XIANG
Tsinghua University – China
xiangrui0212@163.com

Yiwei ZHANG
Tsinghua University – China
ywzhang@mail.tsinghua.edu.cn

Yong MIN
Tsinghua University – China
minyong@tsinghua.edu.cn

Fei XU
Tsinghua University – China
xufei@tsinghua.edu.cn

Junfei HAN
Inner Mongolia Electric
Power Research Institute– China
hanjfly@sina.com

Jun TAO
Inner Mongolia Electric
Power Research Institute– China
taojun@impc.com.cn

ABSTRACT

“Quality of electric energy supply Harmonics in Public Supply Network GB/T 14549”, the first national harmonic standard in China, was released in 1993 and now has an age of 25 without revision. Based on reviewing the development history of Chinese harmonic standards, this paper discusses the main issues on the implementation of GB/T 14549, including harmonic voltage limits, measurement specifications, harmonic allocation principles and methods. This paper aims to clarify these issues so that they can be fully considered in the future development of harmonic standards.

DEVELOPMENT HISTORY OF HARMONIC STANDARDS IN CHINA

Chinese harmonic standards came from the demand to regulate harmonic in power grid. The first two standards, i.e. the industry standard SD 126-84 and the national standard GB/T 14549 were released in 1984 and 1993 respectively, mainly referred to UK’s harmonic standards G5/2 and G5/3. After that, many relevant technical standards were developed referring to IEC standards. In 2004, the National Development and Reform Commission carried out a research project on the systematic development of power quality standards, including systematic development of harmonic standards. In this paper, Chinese harmonic standards are divided into five categories, i.e. comprehensive ones, harmonic limits, planning assessment, monitoring assessment, technical management and supervision. The development history of relevant national and industry standards are shown in Table 1.

GB/T 14549, integrating the specifications of both harmonic limits and evaluation methods, has being the fundamental basis for the actual harmonic management in public supply network. When compared with international standards, GB/T 14549 clearly shows shortages [1,2]. But in a more comprehensive view of Chinese harmonic standards, it can be observed that later harmonic standards make strong supplement to GB/T 14549 in various aspects. In this paper, the existing major issues on harmonic limits, allocation principles and methods, management and supervision, and standard development are studied. This paper aims to clarify these issues so that they can be fully considered in the future development of harmonic standards.

Table 1 History of standard development for public grid harmonics

Year	Standards
Comprehensive standards	
1984	SD 126 Interim Provisions on Harmonic Management of Power Systems
1993	GB/T 14549 Quality of electric energy supply Harmonics in public supply network
Harmonic limits	
1998	GB 17625.1 Electromagnetic Compatibility-Limits-Limits for harmonic current emissions (equipment input current $\leq 16A$ per phase) (1995 IEC 61000-3-2)
2003	Revision (2001 IEC 61000-3-2)
2012	Revision (2009 IEC 61000-3-2)
2003	GB/Z 17625.6 (1998 IEC/TR 61000-3-4)
2006	Revising GB/T 14549 (unfinished)
2015	GB/Z 17625.8 (2004 IEC 61000-3-12)
2017	GB/Z 17625.14 Electromagnetic compatibility -Limits-Assessment of emission limits for harmonics, interharmonics, voltage fluctuations and unbalance for the connection of disturbing installations to LV power systems
Planning Assessment	
2000	GB/Z 17625.4 Electromagnetic compatibility-Limits-Assessment of emission limits for distorting loads in MV and HV power systems (1996 IEC 61000-3-6)
2014	DL/T 1344 Technical specification for connecting disturbing customer to power system
Monitoring Assessment	
1998	GB/T 17626.7 Electromagnetic Compatibility-Testing and measurement techniques-General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto (1991 IEC 61000-4-7)
2008	Revision (2002 IEC 61000-4-7)
2017	Revision (2009 IEC 61000-4-7)
2005	GB/T 19862 General requirements for monitoring equipment of power quality
2016	Revision
2012	GB/T 17626.30 Electromagnetic compatibility-Testing and measurement techniques-Power quality measurement methods (2008 IEC 61000-4-30)

Management and Supervision	
1998	DZ 211 Power quality technical supervision and management regulations
2004	National research project: Systematic development of power quality standards
2007	DL/T 1053 Technical supervision code for quality of electric energy
2017	Revision
2013	DL/T 1198 Regulations on power quality technical management for power system (Revision of SD 126)

HARMONIC VOLTAGE LIMITS

Harmonic voltage limits of power grid in GB/T 14549 are shown in Table 2, which classify 6 voltage classes U_N into 4 grid levels, i.e. low voltage, medium voltage, high voltage and transmission networks.

Table 2 Harmonic voltage limits in GB/T 14549 (%)

Grid Level	U_N (kV)	THD*	ΣV_{Odd} *	ΣV_{Even} *
LV	0.38	5.0	4.0	2.0
MV	6, 10	4.0	3.2	1.6
HV	35, 66	3.0	2.4	1.2
Transmission	110	2.0	1.6	0.8

*THD: Total harmonic distortion; ΣV_{Odd} : Total distortion of odd harmonics; ΣV_{Even} : Total distortion of even harmonics

Voltage Classes and Grid levels

China has become a country with the most advanced voltage classes since GB/T 14549 was released. Now in China, it is quite common for urban distribution grid with a HV of 220kV and EHV transmission network directly connected to urban distribution networks. In 220kV grids, there are more and more direct connections from users; a lot of centralized wind farms have been connected to the HV grid in local distribution network or its transmission grid. The lack of harmonic voltage limits for 110kV and above grids in GB/T 14549 often makes harmonic management in HV and above power grids very difficult.

Harmonic order

Modern power electronic equipment connected to power grids inject a lot of high-order harmonics into the power grid, while GB/T 14549 only considers harmonic orders less than 25 and lacks of limitation on high-order harmonics, which makes it impossible to control the harmonic pollution from these power electronic equipment. Besides, GB/T 14549 only limits the total distortion rates, the total distortion rates of odd and even harmonics, i.e. THD, ΣV_{Odd} and ΣV_{Even} in Table 2, but no specific limit on each order harmonic, which leads to practical harmonic management difficulties from time to time.

Harmonic voltage limits

Compared with current international standards, harmonic limits in GB/T 14549 are stricter, which bring Chinese grid users more pressure on harmonic mitigation and high mitigation cost. Particularly electrified railway integrations into power grids are often difficult to meet the requirements. One solution is to integrate them to higher voltage grids and it often means higher cost. For now, determining harmonic voltage limits is a big challenge in the revision of GB/T 14549 and is difficult to get agreements among various stakeholders.

MEASUREMENT AND MONITORING

Compared with current international standards, requirements for measurement cycles and windows in GB/T 14549 are low, which are shown in Figure 1.

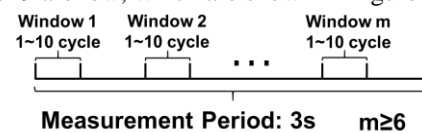


Figure 1 Measurement Window Illustration

Since national standards were developed in accordance with IEC 61000-4-7 and IEC 61000-4-30 in 1998 and 2012 respectively, measurement and data processing specifications are now consistent with international standards.

Monitoring assessment and planning assessment

In DL/T 1053-2007, harmonic assessment is divided into planning assessment during planning period and monitoring assessment during operation period, and further monitoring assessment into special monitoring and general monitoring. The division does not exist in GB/T 14549.

For planning assessment, carried out during planning period, harmonic pollution degree of power grid under normal operation mode is assessed. To ensure harmonic voltage margin, the minimum operation mode (i.e. the minimum short-circuit) and the maximum emission interference are combined as the worst situation. For monitoring assessment, DL/T 1053 suggests that the situation of small operation mode of power grid with the normal interference of non-linear equipment to be observed.

Special monitoring

Measurement of background harmonic voltage is used to evaluate the influence of new connected equipment on grid harmonic voltage. If only the grid harmonic voltage meets the requirements during the trial operation of the new equipment, the equipment can be formally connected to the grid. There are still situations difficult to handle. If the

background harmonic voltage is already excessive, can nonlinear device be allowed to connect to grid? If so, how to evaluate the device's effects on the grid harmonic voltage? In small and medium-sized power grids, large background harmonics can cause difficulties in harmonic mitigation. After all devices are fully in operation, responsibility allocating among operators and customers for harmonic voltage exceeding limits is normally difficult if not impossible.

General monitoring

GB/T 14549 adopts 95% probability value for assessment, which is suitable to assess the steady-state harmonic thermal effects and unsuitable to assess the transient effects of steady-state harmonics. In addition, it's important to develop post-assessment of planning assessment using monitoring data. In fact, measured harmonic voltage may meet requirements simply because of a non-worst situation, which can't verify the planning assessment.

HARMONIC ALLOCATION PRINCIPLES AND METHODS

GB/T 14549 takes the principle of "fair treatment" for harmonic responsibility allocation. The specific process is as follows: calculating the harmonic voltage transmitted from the upstream grid; using the remaining harmonic voltage as an indicator, calculating the harmonic current limit I_h , allowed to be injected into PCC; allocating I_h to grid users according to the ratio of the contracted supply capacity S_i of user i to the total available supply capacity S_T of PCC. Every user at PCC is treated fairly according to its contracted power regardless of its time accessing to the grid. Harmonic current allocation is described as Eq. (1).

$$I_{hi} = I_h \left(\frac{S_i}{S_T} \right)^\alpha \quad (1)$$

where I_{hi} is the h order harmonic current limit of user i at PCC and α the phase superposition coefficient of harmonic current.

Uncertainty in harmonic current calculation

Calculation uncertainty of the harmonic current limit $I_{h,lim}$ comes from the hypothesis that the transfer coefficient of upstream grid harmonic voltage is defined as 0.8 and a simplified equivalent model is used to compute the h order harmonic impedance Z_h of PCC. To compute Z_h , the fundamental impedance Z_1 is obtained according to the short-circuit capacity S_k at the PCC; further assuming that Z_h is linear with Z_1 , i.e. $Z_h = hZ_1$. The calculation method is easy to implement, but sometimes the error could be too large. In fact, it is known there is no satisficing practical approach of measuring and calculating harmonic impedance parameters.

Allocation of harmonic current limits

The allocation approach by Eq. (1) also has the following questions.

- 1) In planning stage, it is generally impossible to determine how many devices to access grid in the future and difficult to accurately estimate S_i and S_T . If S_i is larger than the total contracted capacity $\sum S_i$ in the future, some harmonics may be un-allocated and result in waste. On the contrary, if $\sum S_i > S_T$, I_h may be excessively allocated, causing harmonic voltage to exceed the limits.
- 2) The "fairness" of the allocation principle neglects the differences among the characteristics of grid users. Thus linear devices are also assigned to harmonic emissions, resulting in harmonic allocation not fully used and harsher pressure on users having devices of characteristic harmonics.
- 3) The phase superposition coefficient α is a parameter that is difficult to determine, and is often not conservative or optimistic.
- 4) In actual practices, there are various ambiguities in the calculation of S_i and S_T . Grid users and operators often have different methods to account the S_i .

ASSESSMENT METHOD

With the increasing complex of modern power grids, a 3-stage assessment approach is proposed to accurately and efficiently assess harmonic. However, there emerge challenging scenarios for harmonic management, such as more distributed generation connected to distribution network, PCC in various complex grids.

Three stage assessment

These standards GB 17625.1, GB 17625.6, GB 17625.8 and GB 17625.14, issued after 1998 and for the access of low-voltage users, allow the direct connection to grid if a LV devices meet the requirements in the standards. In this way, allocation assessment actually consists of into two stages, similar to IEEE 519.

DL/T 1198 issued in 2013 specifies a 3-stage assessment method, i.e., direct connecting, simplified calculation and detailed simulation assessment, generally according to power quality requirements and emission effects of the assessed equipment. It also defines a staged assessment procedure for equipment connecting to the grid, but it gives no information about the 3th stage simulation algorithm. DL/T 1344 issued in 2014 gives a more general 3-stage assessment procedure, which fully pays attention to influence of the background harmonics. New equipment to be connected to the grids should take into account the effects of background harmonic voltage caused by existing equipment. In this way, the access of devices to the grid is not treated equally regardless of their accessing time.

GB/Z 17625.4 issued in 2000 is equivalent to IEC 61000-

3-6, in which harmonic voltage is used for harmonic allocation. Due to the complexity of harmonic voltage responsibility judgment, practical operability is poor. Using harmonic current to limit grid users' emission is recognized as a more advisable approach.

Distributed generation

The precondition of the harmonic current allocation using Eq. (1) is that grid users at the PCC are all generation devices or all electric load devices, in such case power supply capacity S_i of PCC can represent the possible contracted capacities of all downstream devices. If the downstream grid consists of both generating devices and electric load devices, S_i is no longer related to the possible $\sum S_i$ of downstream devices and therefore the harmonic current allocation method by Eq. (1) is no longer applicable.

In the grid of Figure 2, harmonic flow through the transformer. Both load and PV are harmonic sources, and contribute to harmonic flow. However, fundamental current through the transformer is obtained by subtracting PV flow from load flow, which can reduce the power supply demand of the transformer station. The transformer capacity represents the difference of load demand and PV power, which means that Eq. (1) is not available anymore in this case.

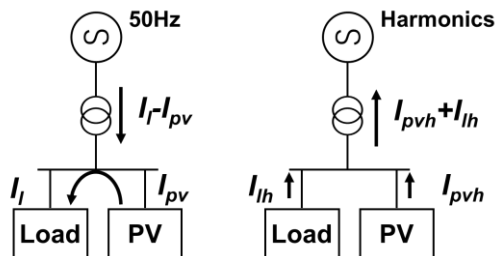


Figure 2 Flows of fundamental and harmonic currents in a grid with distributed generation

Assessment for Complex PCCs

Planning assessment by Eq. (1) actually assumes devices directly connected to PCC, considering neither the electrical distance from the device to PCC nor the electrical distances between devices in the same grid.

In the case of complex grid configuration, electrical distances of various nonlinear equipment to PCC is different, and the allocation approach by Eq. (1) is problematic. Figure 3(a)~3(b) show such cases, where the allocation of PCC's I_h does not guarantee the power quality of both the PCC and the equipment connection points.

Large-scale concentration of wind and photovoltaic generation is the development mode in China for the last few years. Ref. [3] shows that photovoltaic power is connected to 35kV power grid and wind power connected to 110kV and 220kV grids in one of regional grid in North

China. There is a large number of connected power stations in this area. Such a situation is quite common in the western China, where is sparsely populated and rich of renewable resources. Due to large-scale renewable generation connected to HV and UHV (35~500kV) grid, harmonic voltage level significantly increased. In addition, harmonics from HV and EHV networks transmit to local MV and LV distribution networks, resulting in severe background harmonic of the latter's, and causing huge harmonic mitigation pressure to distribution network users.

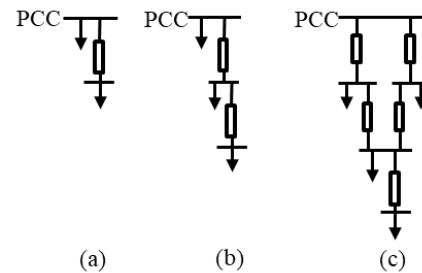


Figure 3 Complex configurations of PCCs

In the case of ring or meshed network, there exist several access points as show in Figure 3(c), and harmonics of each access point affects each other. Current harmonic allocation principle and assessment methods, without considering the coupling of multiple access points, makes it difficult to manage power quality of such a grid. If the current method for simple PCC is applied for the complex PCC, the risk of excessive harmonics is high. For multi-access point grids, assessment method is still an academic question.

MANAGEMENT AND SUPERVISION OF HARMONIC TECHNIQUE

Technical management and supervision standards

The earliest industry standard SD 126-84 came from the initiative commission to manage and control harmonic in power supply network. This commission has been continuing through the entire process of harmonic standardization development in power industry, and supports the implementation of GB/T 14549 and promotes the technology development of harmonic management. It is a very feature of China's harmonic standard development.

In 1998, DZ 211 initiated the first step of harmonic supervision standardization. It focused on monitoring management procedures and monitoring equipment requirements, to ensure that harmonic voltage at PCC and harmonic current injected into the grid by nonlinear users (or equipment) meet the requirements of GB/T 14549. In addition, it also defines tasks, methods and technical management of power quality supervision for public supply grid. For harmonic, it specifies the supervision of grid company, grid users and power generation suppliers

during planning, construction and operation of devices. After supplementary revision, DZ 211 has officially developed into the industry standard DL/T 1053 which was issued in 2007 and revised version launched in 2017.

Here are some specifications in DL/T 1053:

- Whenever harmonics exceed the limits, the principle of dealing with such a case is “who causes it, who should be responsible for it”.
- Establish online monitoring system for the department of power quality technical supervision.
- Establish information system of interference sources, files for power quality accident events, analysis and processing. Specifications for the technical supervision of power quality accidents, include technical supervision procedures, accident investigation group and evidence collection requirements, accident cause analysis, suggestions for accident prevention and control.

DL/T 1198 was released in 2013 by China Electricity Council and is a revision of the first standard SD126 issued in 1984. This standard clarifies the basic process for power quality technical management and provides technical management regulations for the periods of planning, engineering design, project implementation stage and production operation.

Thanks to the initiative and continuous development of power quality technical management and supervision, along with development of harmonic mitigation technology, management and control of harmonics level, Chinese power grid has been continuously improved and quite successful over the past 30 years.

Open questions for responsibility

Technical management and supervision standards are of high operability. Similar to that of UK's G5 and IEEE 519, grid company has the priority to decide whether a new device is allowed to access to grid. But in some cases, there is still an open question worthy to discuss.

Harmonic voltage monitoring:

- When harmonic voltage exceeds and user emission does not exceed, the actual responsibility is an intractable problem.
- When harmonic voltage of power supply point exceeds (electromagnetic compatibility limit) and harmonic voltage of PCC does not exceed, the question is whether the power quality of power grid is qualified or not.

Harmonic current monitoring

- How to consider harmonic current caused by the background harmonic voltage?
- If the grid harmonic voltage has a margin to limits, could harmonic emission requirements be relaxed under certain conditions?

SYSTEMATIC DEVELOPMENT

In 2004, China initiated a study on the power quality standard system and divided the standards into terms, limits and basic requirements, assessment methods, equipment, mitigation device and management, in some aspects similar to the classification of IEC electromagnetic compatibility power quality research. After that, there are researches on more detailed systematic frameworks. In the future, we think it is a good way to revise the contents of harmonic limits, planning assessment, monitoring assessment, and measurement requirements in GB/T 14549 into separated standards, to avoid the difficulty of revising a comprehensive standard.

CONCLUSIONS

GB/T 14549 is the earliest public grid harmonic standard in China and also the basis of later relevant standards. It is an important criterion for current harmonic management of power grids. While in many the aspects GB/T 14549 lags far behind the development of Chinese power grid, the development of other standards has made up for its many shortcomings. For now, GB/T 14549 still has the following two demanding problems in the practice process:

- Revision of harmonic voltage limit. There needs negotiation and coordination by different stakeholders.
- Harmonic allocation method in complex scenario of PCC. There is no applicable method at present and needs further researchers' efforts.

The development process of Chinese harmonic standardization shows that, the conception of actively and effectively managing grid power quality, the continuous maintain and development of technical management and supervision standards can greatly help the success and the operability of harmonic management facing the challenge of modern power grid. Developing harmonic standards in a systematic way can better adapt to the grid transformation.

REFERENCES

- [1] IEC/TS 62749:2015, Assessment of power quality-- Characteristics of electricity supplied by public networks (2015 -04).
- [2] J. Meyer, M. Domagk, L. Kirchner, etc., "Survey on international practice of calculating harmonic current emission limits", *2016 17th International Conference on Harmonics and Quality of Power (ICHQP)*, Belo Horizonte, 2016, pp539-544.
- [3] Chaojie DING, Yiwei ZHANG, Xiaorong LI, etc. "Power quality analysis of the Zhangjiakou regional network in China", *Proceedings CIRED conference*, Glasgow, 12-15 June 2017.