POWER QUALITY ANALYSIS OF THE ZHANGJIAKOU REGIONAL NETWORK IN CHINA

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ABSTRACT

Zhangjiakou regional network belongs to the Jibei power grid in Northern China and locates at the midway of the power transmission corridor from Inner-Mongolia to the rest of Jibei power grid. Zhangjiakou regional network consists of several area networks connected to the main network through 500kV stations. In recent years, renewable energy in rural areas has developed rapidly and electrified railway traffic traction in urban areas is developing rapidly, which cause a significant impact on the power quality of the power supply system and even the main transmission network. In this paper, harmonic standards for power system planning in China are introduced firstly. Then the parameters of the minimum operation mode and the power supply capacity in harmonic planning are discussed. With the present standards, the determination principles and calculation procedures of the two parameters are proposed, to deal with the rapid development of the power grid.

INTRODUCTION

Northern China is rich in wind and solar energy resources (RES). The speed development of wind farms and PV power stations brings challenges to the harmonic planning of many local power grids. Zhangjiakou regional network belongs to the Jibei power grid and locates at the midway of the power transmission corridor from Inner-Mongolia to the rest of Jibei power grid. In Zhangjiakou region, renewable energy has been developing rapidly for the last few years, resulting in a large amount of installed capacity of RES generation in power supply network, and causing severe impact on the quality of the power supply system. There induces an urgent need to analyse the emerging problems during power quality planning and to propose suitable measures for the planning and operation of power grid, facing the challenge of the sustainable renewable energy development and the development of electrified railway traffic traction (ERTS).

China national standard GB/T 14549-1993 "Quality of electric energy supply: Harmonics in public supply network" [1] was implemented in 1993. It has not been revised during last 24 years, although there have been various problems in its application. In 2000, the national guiding standard GB/Z 17525.4-2000 "Electromagnetic compatibility limit - Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems"[3], a translation version of IEC 61000-3-6:1996[3] was supplemented. In 2013, the power industry’s recommendation standard DL/T 1198-2013 "Regulation on power quality technical management for power system"[4] was published, in which power quality assessment processes and three-stage management methods are introduced. It is worth to point out that GB/T 14549-1993 is actually the core of the two latter standards. Among the three national standards, there exist some differences and even worse contradictions about the process of harmonic assessments. In fact, the development of GB/T14549-1993 was mainly for the industrial load development in the 90s of the last century and with not special attention to large-scale development of both ERTS and RES. While GB/Z 17525.4-2000 has not been updated along with IEC 61000-3-6:2008[5], the proposed evaluation method is theoretically comprehensible for understanding. But it is difficult for application due to the need of both long-time historical statistics and large amount of measurement data. DL/T 1198-2013 gives quite general principles for the power quality assessment during planning and operation. However, it is lack of detailed description about any relevant calculation methods.

With the large-scale development of renewable energy and urban ERTS in Zhangjiakou power grid, and the present situation of China harmonics standards, this paper proposed the determination principles of the minimum operation mode and the calculation approaches for the minimum short circuit capacity, and the allocation principles and calculation approach. Research in this paper can provide reference for the harmonic planning in China.

ZHANGJIAKOU REGIONAL NETWORK

Zhangjiakou regional grid belongs to the western part of Jibei power grid, and its 500kV main grid connects with the other regions of Jibei power grid and the Inner Mongolia grid. Zhangjiakou regional grid consists of five power supply areas, namely, Kb, Gy, Sy, Wq and Zn. Each area is connected to the main grid through 500kV stations, as shown in Fig. 1. Installed capacities of thermal/hydro generation, renewable energy, area loads are listed in Table 1.
Kb, Gy, Sy areas locate in sparsely populated rural areas and are away from Zhangjiakou urban areas. They are respectively constructed as a 35-110-220 kV radial grid of no conventional power and of large scale RES installation which is much more than local load. Figure 2 shows the access mode of RES and load in Gy area. With the integration of RES, power electronic devices as typical power quality interference sources influence seriously on the power quality of the local load and even the main grid. Wq and Zn areas are the two parts of Zhangjiakou urban power supply system, which are respectively composed of 220 kV loop network and local 110-35 kV radial network down from each 220 kV station. Fig. 3 shows the 220 kV loop network of Wq area, while Zn area has a similar configuration.

Although the capacities of conventional generation and local load are roughly equal for now, with the future development of RES and the ERTS development for the 2022 Winter Olympic Game, harmonic planning has become increasingly demanding. In fact, the above two cases, i.e. with fast urban development and large scale RES in power grid are typical cases for many regional grids in northern China.

**HARMONIC PLANNING**

In harmonic planning, GB/T 14549-1993 has long been the main reference standard for power utility in China. Based on IEC’s Electromagnetic Compatibility values, it provides the voltage distortion limits for the voltage levels of 0.38 kV, 6-66 kV, and 110 kV & above, which are quite similar to those of international standards. For a point of public coupling (PCC) at a specific voltage level, it provides the basic short-circuit capacity $S_{ho}$ and the corresponding h-th harmonic current limit $I_{hho}$.

For a non-linear load to be connected to the grid, its harmonic emission limit is assessed at the planning stage. The assessment process is mainly in two steps:

Firstly, determine the minimum short-circuit capacity $S_{k1}$ of the studied PCC, and calculate the corresponding harmonic current limit $I_{h1}$ by eq. (1).

$$I_{h1} = \frac{S_{k1}}{S_{k0}} \times I_{h0}$$  

(1)

Then, based on the user’s agreed capacity $S_{t}$ and the supply power capacity $S_{t}$ of the PCC, allocate the harmonic current limit by eq. (2), where $\alpha$ is a phase superposition coefficient.

$$I_{hti} = I_{h1} \left(\frac{S_{t}}{S_{k0}}\right)^{\frac{1}{\alpha}}$$  

(2)

For the minimum short-circuit capacity $S_{k1}$, and the supply power capacity $S_{t}$, GB/T 14549-1993 has not given clear definitions. From time to time and among different utilities, the interpretation and application of these parameters vary greatly, and sometimes it is even difficult to get an agreement about their interpretation among relevant stakeholders.

In common practice, $S_{k1}$ calculation is performed by the planning department of power utility. It is mostly based on
experience and with no formal procedure to follow. In a case of low proportion of nonlinear load in the power supply network, such an approach induces no difficulty to ensure power quality. But in a case of large-scale integration of nonlinear loads, it cannot ensure the power quality level under some operation conditions. Traditionally, power supply capacity $S_i$ is taken as the transformer capacity at a substation. However, this approach is no longer appropriate in some cases, such as a case of the low-voltage distribution network with large-scale RES.

In order to ensure that the harmonic voltage of power supply system meets the requirements defined by GB/T 14549-1993, it is necessary to properly understand and calculate the above two parameters in the power quality planning.

THE MINIMUM OPERATION MODE

Principle in determining the minimum operation mode

Similar to IEC-TR-61300-3-6-2008, principally, the minimum operation mode for harmonic planning is taken as the worst condition in normal operation. For the normal operation of the Zhangjiakou regional grid, it is found that maintenance and generator arrangement strongly influence the variation of short-circuit current, and therefore are taken into account for the determination of $S_{k1}$.

N-1 and N-2 conditions

Most of maintenances accompany with relevant line disconnection. However, there are specific maintenance arrangement in some maintenance, such as the maintenance of some primary transformers and important lines. All these operation conditions are classified in the N-1 conditions.

In maintenance arrangement, there may be two grid components in maintenance at the same time, especially when they are at different voltage levels. Such a condition is classified in the N-2 conditions of normal operation. But any N-2 condition with a change of the network topology is not included. In practice, a change of network topology often accompanies the arrangement of reducing RES output or load, which decreases harmonic source and their impact on the power grid.

Generator arrangements

For generator, half of the thermal power generators in any power plant in the region and nearby regions are arranged to be in service, while all hydro generators out of service. Generally, the utilization hours of hydropower in north China are quite low, thus all hydro power stations are out of service for harmonic planning.

Calculation of the minimum short-circuit current

In practice, convenience of engineering calculation is very important for power system planning. This section provides an efficient method searching for the minimum operation mode suitable for harmonic planning.

Partition for harmonic planning

In the harmonic planning of a large-scale power grid, applying enumeration method to search the minimum operation mode for a PCC is inefficient and almost impossible. A method to divide the regional grid into subgrid is supposed to ensure the validity and efficient of the harmonic planning. Node impedance matrix is used to quantify the electrical distances between buses and therefore the strength of harmonic transferring. Buses of close distances are grouped into a sub-region. In such a way, the operation condition changes outside of the sub-region induce ignorable variations of the short circuit currents inside the sub-region. The partition results of Zhangjiakou grid show that harmonic planning of the five area networks can be carried out separately.

Calculation with N-1 conditions

For $S_{k1}$ with N-1 condition, first find all the N-1 operation conditions of the local voltage level and the minimum operation mode of its upper voltage level. Calculate the corresponding short-circuit capacities and determine the minimum operation mode. The calculation procedure for all PCC in the whole region is shown in Figure 4.

![Flow Chat of the Calculation with N-1 Conditions](image)

Fig.4 Flow Chat of the Calculation with N-1 Conditions

**Calculation with N-2 conditions**

According to the calculation of N-1 conditions, the two
most serious N-1 conditions at the upper voltage level and those at the local voltage level are selected. Then the corresponding short-circuit capacities are calculated by the combination of two N-1 conditions at different level, then among the results the minimum operation mode for N-2 conditions is determined. In general, the computation procedures in N-2 conditions are much more complicated than in N-1 conditions.

**Calculation results**

In the normal, N-1 and N-2 conditions of Gy area, the calculation results of \( S_{k1} \) are listed in Table 2. It shows that \( S_{k1} \) of N-1 and N-2 conditions are about 60% and 57% of that under the normal condition.

Some calculation results for \( Wq \) area are shown in Table 3.

| Table 2 \( S_{k1} \) of Gy Area |
|-----------------|-----------------|-----------------|-----------------|
| Bus | \( V_t \) (kV) | Normal (10^3*MVA) | N-1/Normal (%) | N-2/Normal (%) |
| Gy  | 500  | 22.56 | 78  | 63  |
| Gy  | 220  | 7.34  | 60  | 57  |
| Gy-A | 220  | 2.29  | 83  | 81  |
| Gy-A | 110  | 1.23  | 68  | 64  |
| Gy-B | 110  | 1.20  | 69  | 64  |
| Gy-C | 110  | 0.56  | 83  | 80  |

| Table 3 \( S_{k1} \) of Wq area |
|-----------------|-----------------|-----------------|-----------------|
| Bus | \( V_t \) (kV) | Normal (10^3*MVA) | N-1/Normal (%) | N-2/Normal (%) |
| Wq  | 500  | 33.51 | 79  | 69  |
| Wq  | 220  | 12.02 | 62  | 57  |
| Wq-A | 220  | 4.45  | 72  | 64  |
| Wq-C | 220  | 6.51  | 72  | 68  |
| Wq-D | 220  | 6.49  | 72  | 57  |
| Wq-F | 220  | 5.42  | 63  | 70  |
| Wq-A | 110  | 2.23  | 75  | 61  |
| Wq-C | 110  | 2.09  | 60  | 64  |
| Wq-D | 110  | 2.45  | 72  | 65  |
| Wq-F | 110  | 2.21  | 78  | 74  |

Calculation results show that the minimum short-circuit capacities of Gy, Kb and Sy is significantly lower than that of Wq and Zn. The reason is that the former is a radial network with no conventional power supply while the latter are urban loop networks with thermal power plants. Compared with N-1 conditions, \( S_{k1} \) of N-2 conditions are about 10%~20% less. Due to the calculation complex of N-2 conditions, a simple method is to estimate \( S_{k1} \) of N-2 conditions by using \( S_{k1} \) of N-1 conditions, and to be used to evaluate harmonics in a severer conditions of power grid.

**POWER SUPPLY EQUIPMENT CAPACITY**

For a PCC with pure load or generation, the power supply capacity \( S_T \) can be determined directly based on the transformer capacity \( S_T \) at substation. With the integration of large-scale RES, the total agreed capacities \( S_T \) of grid users may be greater than the transformer capacity at the substation, thus the above way of \( S_T \) determination is no longer applicable.

In principle, it is necessary to ensure the fairness of large and small users when allocate harmonic current limits. Therefore, after the calculation of \( S_T \) and \( S_T \), we take themax(\( S_T \), \( S_T \)) as the power supply capacity \( S_T \) of PCC.

In addition, harmonic voltage of PCC is not only related to the harmonic current emission of grid users but also greatly related to the background harmonic from other PCC, which is not considered in GB/T1454-1993. When assessing the harmonic voltage at a PCC, both the harmonic current injection of the grid users at that point and the transfer effect of harmonic injection from other points in the area should be taken into account. One way is to reformulate the calculation of the power supply capacity.

In general, transformer has an important role for harmonics suppression and thus we proposed that only the local PCCs within the same voltage level to be considered. Nodal impedance matrix is used to measure the electrical distances between the access points and to measure the effect of background harmonics.

Taking the 220kV bus at Wq 500kV station as an example. Nodal impedance matrices for 220kV of Gy-A and Gy are shown in Table 4.

| Table 4 Node impedance matrix of 220 kV in Gy |
|-----------------|-----------------|-----------------|-----------------|
| Bus | Gy-A | Gy |
| Wq-A | 0.415 | 0.129 |
| Gy | 0.129 | 0.130 |

The \( S_T \) of Gy substation and the renewable \( S_T \) are 1500MW and 1442MW respectively. The renewable energy capacity of 220kV Gy-A is 800MW. Then the user agreed capacity of 220kV Gy is calculated as Eq.(3).

\[
S_T = \frac{800}{64.75} \times 0.129 + 1442 = 1691MW
\]

The \( S_T \) of 220kV Gy is 1691MW with the calculation in Eq.(4).

\[
\text{max}(S_T, S_T) = \text{max}(1691,1500)
\]

In this way, the impact of the RES access from the Cabei 220kV bus is taken into account.

For a loop network, the influence of the background harmonics from other substations is similarly taken into account by the impedance matrix coefficient. It can improve the effectiveness of the harmonic planning.

**SUMMARY**

For a large-scale integration of wind power and PV power, proper and accurate harmonic planning is necessary for the harmonic current limits of the grid users, in order to ensure power quality of the grid.

For present, the development of harmonics standards in China is far behind the development of power grids. In such a situation, the principle of the minimum operation mode in harmonic planning is proposed, and also the calculation procedures of the minimum short-circuit capacity suitable for engineering implementation. The determination of the power supply capacity considering
the influence of background harmonics is provided in the case of large-scale renewable energy integration. National harmonics standards in China are in urgent need of revision. The following aspects needs to be concerned with: 1) Standards of Harmonics monitoring and evaluation for power grid operation; 2) Background harmonics of PCC from relevant stations; 3) At a substation, the total agreed capacity of grid users larger than the capacity of transformers.

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REFERENCES


