Research on the Calculation Method of Distributed Photovoltaic Access Capacity Considering Harmonic Characteristics

Junhu Su1,*, Zhaoguang Yang1, Xu Liu1, Jingyu Yang1 and Minghua Jiang2

1 State Grid GanSu Integrated Energy Service Company
2 Gansu Diantong Electric Power Engineering Design Consulting Company

*Corresponding author email: pls442305773@163.com

Abstract. To raise the maximum access ability of the maximal distributed photovoltaic system, based on the metering terminal of plant and station system for many years, a nonparametric estimation method based on kernel density is proposed to calculate harmonic probability distribution, this paper proposes the calculation method of superposition index and simultaneous coefficient suitable for distributed photovoltaic grid-connection, and puts forward the capacity calculation method considering harmonic constraints. An example shows that the proposed method can increase the maximum admittance capacity by at least 15% compared with the traditional method under the condition that the harmonic emission level does not exceed the threshold value of national standard, and realize the safe, stable and economic operation.

Keywords: Distributed photovoltaic; Harmonic emission level; Superposition index; Simultaneous coefficient; Access capacity.

1. Introduction

With the acceleration of smart grid, high-permeability new energy and ultra-high voltage AC/DC transmission technology in China, large-scale nonlinear equipment is integrated into public power grid, and harmonic sources are characterized by large number, large amount and wide distribution, etc., and harmonic pollution and harm are becoming increasingly serious. As the main energy utilization method[1], distributed photovoltaic power generation will cause a series of quality issues such as harmonic pollution in public places after connecting to the distribution network. Therefore, the calculation of access capacity[2-9] has become one of the critical technology research topics of new energy grid connection.

The harmonic standard of public power network[3-6] is a technical criterion for effectively controlling the level of harmonic emission and reasonably solving the electromagnetic compatibility between users and power network. On the basis of international standards and in combination with China's national conditions, the State Bureau of Technical Supervision has formulated the national standard for power quality[10-12] For the part not specified in the national standard, IEC61000-3-6[1-2,13-14] is adopted as the supplement of the national standard GB/Z 17625.4-2000. The implementation of national harmonic standard for many years has achieved a lot. For distributed photovoltaic, there are still the following problems: (1) Harmonic superposition index and Synchronous harmonic coefficients is not applicable to distributed photovoltaic power and need simulation analysis and verification; (2) Lack of in-depth analysis of emission limits of harmonic sources, and traditional national harmonic standards do not supplement the limits of new energy.
Currently, domestic and international academicians have done a lot of research on the access capacity of distributed photovoltaic. Wang Zhiqun et al. [4] discussed the nodal distribution network of IEEE33 accordingly, and a simulation model is established to conduct a specific study on the power capacity and access location. Fan Yuanliang et al.[15] discussed the voltage change and system loss change of distribution network nodes caused by the increase of photovoltaic access capacity. Li Naiyong et al.[16] discussed the change of voltage and system loss of distribution network nodes caused by the increase of photovoltaic power supply permeability.

The aim of this article is to study the distribution and statistical characteristics of distributed photovoltaic grid, the accuracy of the theoretical method is verified by simulation analysis and examples, and the unique harmonic law and statistical characteristics of wind power and photovoltaic are analyzed by numerical statistics method. An efficient method to calculate the relative phase Angle of harmonic voltage leading harmonic current is proposed. Combined with the case study is suitable for distributed photovoltaic grid harmonic superposition index and coefficient at the same time, the last is put forward based on the previous research results of distributed photovoltaic grid access capacity calculation method, and compared with national standard method, the feasibility and effectiveness of this method through examples.

2. Applicable to Distributed Photovoltaic Grid-connected Harmonic Superposition Index and Simultaneous Coefficient

2.1. Applicable to Distributed Photovoltaic Grid-connected Harmonic Superposition Index

At the PCC, the phase angle difference between the harmonic vectors is not known in a lot of situations. In view of the uniform distribution of phase angle difference, this paper proposes a harmonic summation algorithm based on probability distribution, which is used to calculate the probability that the amplitude of the sum of two harmonic vectors can exceed a certain value. Since the vector sum of the upper part of the circle is completely symmetric with the lower part, the density function of the uniformly distributed phase angle difference is:

\[ f(\theta) = \frac{1}{\pi}; \theta \in [0, \pi] \]  

(1)

Expection and standard deviation are as follow:

\[
E(\theta) = \int_0^\pi \theta \cdot f(\theta) d\theta = \frac{\pi}{2}; \quad \sigma(\theta) = \sqrt{\int_0^\pi \theta^2 \cdot f(\theta) d\theta - [E(\theta)]^2} = \frac{\pi}{2\sqrt{3}}
\]  

(2)

The phase Angle difference of negative standard deviation in statistical sense is given:

\[ \theta_{-\sigma} = E(\theta) - \sigma(\theta) = \frac{\pi}{2} (1 - \frac{1}{\sqrt{3}}) \Rightarrow 38.04^\circ 
\]  

(3)

In the conservative case, two harmonic voltage vectors \( U_{h1} \) and \( U_{h2} \) and negative standard deviation \( \theta_{\sigma} \) can be solved to get the vector sum \( U_{hE} \).

\[
U_{hE} = \sqrt{U_{h1}^2 + U_{h2}^2 + 2U_{h1}U_{h2}\cos38.04^\circ} = \sqrt{U_{h1}^2 + U_{h2}^2 + 1.575U_{h1}U_{h2}}
\]

(4)

Therefore, the probability that total of of two harmonic vectors may exceed a given value is:

\[
P_{U_{hE} > U_{hv}} = \frac{38.04^\circ}{180^\circ} = 0.2113
\]

(5)

The above method can be used to calculate the probability distribution and harmonic voltage vector sum under different superposition index. The results are shown in the Table 1, where \( \lambda \) is the superposition coefficient.
Table 1. Probability distributions of different superposition index.

| $\lambda$ | $U_{\mu \Sigma}$ | $p$  |
|---------|----------------|-----|
| 1.1     | 1.8779         | 0.2236 |
| 1.2     | 1.7818         | 0.3002 |
| 1.3     | 1.7044         | 0.3506 |
| 1.4     | 1.6407         | 0.3876 |
| 1.5     | 1.5874         | 0.4163 |
| 1.6     | 1.5422         | 0.4394 |
| 1.7     | 1.5034         | 0.4585 |
| 1.8     | 1.4697         | 0.4745 |
| 1.9     | 1.4402         | 0.4882 |
| 2.0     | 1.4142         | 0.5   |

2.2. Harmonic Simultaneous Coefficients for Distributed Photovoltaic Grid-connection

The simultaneous coefficient between different loads in a single day can be obtained by referring to the national standard method. The value of parameter FPW can be obtained from the load curve, which corresponds to the total power of WV(Wind Power) load in the peak period of photovoltaic load, and is expressed as the reference value $P_{\mu \mu}$ of WV peak load. Estimates for FPW are as follows:

![Figure 1. PV and WV load power curves.](image)

Figure 1 shows the daily load curve of photovoltaic system and WV system on a certain day. At the peak of photovoltaic load, the power of WV load was 65.38 kVA at 4:00 PM. Peak WV load: 133.34kVA at 1am. Therefore $F_{PW} = \frac{65.38}{133.34} = 0.49$.

However, it is difficult to acquire a synchronized universal regular relationship between the two types of distortion loads with only one day's data, which comes from over one year's history of the power station metering terminal. The frequency histogram of the simultaneity coefficient obtained by the important sampling method is as follows:
As can be seen from Figures 2 to 5, the values of the simultaneity coefficients are not set with a high confidence level and do not correspond to the classical distribution function, which is random. Therefore, it is necessary to perform a specific analysis in conjunction with the cumulative probability distribution plot of the simultaneity coefficients.

**Figure 2.** Frequency histogram of the simultaneity coefficient between wind power 197 and PV 193 (taking line 197 as the research object).

**Figure 3.** Frequency histogram of the simultaneity coefficient between PV 193 and wind power 197 (taking line 193 as the research object).

**Figure 4.** Frequency histogram of the simultaneity coefficient between PV 192 and PV 193 (taking line 192 as the research object).

**Figure 5.** Frequency histogram of the simultaneity coefficient between PV 193 and PV 192 (taking line 193 as the research object).

**Figure 6.** Cumulative distribution diagram of the simultaneity coefficient between PV 192 and PV 193 (taking line 192 as the research object).

**Figure 7.** Cumulative distribution diagram of the simultaneity coefficient between PV 193 and PV 192 (taking line 193 as the research object).
As can be seen from Figure 6 to 7, when the confidence level is 0.8, the simultaneity coefficient between distributed photovoltaic power generation is 1.

As can be seen from Figure 8, when the confidence level is 0.8, the simultaneous Coefficient of wind power electricity generation grid connection at photovoltaic power is 0.6. As can be seen from Figure 9 when the confidence level is 0.8, the simultaneous coefficient of photovoltaic power electricity generation in wind power electricity generation is 0.45.

To sum up, the simultaneous coefficient of sorting out various grid-connected loads is as follows:

**Table 2. Summary of simultaneous coefficients.**

| New energy types          | Harmonic source at grid connection | Simultaneous coefficient value |
|---------------------------|------------------------------------|-------------------------------|
| Photovoltaic power generation | Photovoltaic power generation       | 1                             |
| Photovoltaic power generation | Wind power generation              | 0.45                          |
| Wind power generation     | Photovoltaic power generation       | 0.6                           |
| Wind power generation     | Electric iron                       | 0.8                           |
| Wind power generation     | Other conventional loads            | 0.65                          |

3. Conclusions

Different from the traditional load side bulk harmonic source, distributed photovoltaic, as the bulk harmonic source of power supply measurement, has unique harmonic characteristics. For harmonic GB are controversial in the new energy applicability, extensive research and collect a large amount of measured data, this paper based on the harmonic voltage, current and phase Angle of distributed photovoltaic indicators such as the distribution and statistical characteristics, is proposed in this paper based on the probability distribution of harmonic superposition summation method and Monte Carlo sampling method, draw the frequency histograms and cumulative probability distribution. The superposition coefficient and simultaneous coefficient applicable to wind power and distributed photovoltaic are verified by simulation analysis and examples. Although the method is scientific and theoretical in calculating the harmonic superposition index based on the measured data, it needs to be further verified for practical engineering application. At last, the harmonic limit distribution and admittance capacity calculation methods for new energy grid connection are put forward, and the integrated calculation system is developed. This project can effectively improve the power supply quality of the power grid, reduce harmonic pollution and harm, effectively protect power equipment and power lines, prolong the service life of equipment, reduce operating costs, failure and power
outage costs, environmental protection costs, etc., by combining the harmonic distribution law and statistical characteristics of the network. At the same time, it can also provide a favorable reference for the planning and construction of new energy power plants. On the basis of ensuring the improvement of new energy generation, it can improve the economic benefits of power generation investment, improve the load capacity of lines and the safe and stable operation of the power grid, and avoid unnecessary economic waste. Compared with the national standard, it is more simple and efficient in theory and application, with simplified operation, and significant improvement in energy efficiency and considerable economic benefits.

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