

Study Committee C4

Power System Technical Performance

Paper 10527

Review of Harmonic Characteristics in the Japanese Electric Power System

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Introduction

- In Japan, the target values of the harmonic environment level for THD (total harmonic distortion) are 5% for the MV (medium voltage) power supply and 3% for the HV (high voltage) power supply. A similar concept has been called compatibility levels in IEC 61000-2-2 and IEC 61000-2-12. Based on this, it has been considered necessary to maintain or suppress the harmonic current generated from the equipment at an appropriate level.
- Currently, "JIS C 61000-3-2" [1] and "the Application Guide for Evaluation of Harmonic Currents Emitted by Consumers of Medium or High Voltage Power Supply" [2] are contributing to maintaining the target value of this harmonic environment level.
- This paper reviews harmonic characteristics in the Japanese electric power system.

Harmonic Voltage Characteristics

- In Japan, despite the increase in harmonic generators, the grid's harmonic voltage has been on a downward trend since around 1999 as a whole [3].

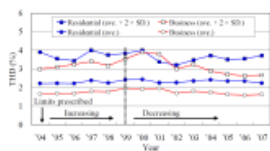


Figure 1. Annual trends of THD from 1994 to 2007 [3].

- Figure 1 shows annual trends of THD from 1994 to 2007. The two kinds of limits that were prescribed by the MITI (the then Ministry of International Trade and Industry) in 1994 are as follows.
- One is for electric appliances and general-purpose electrical products, and they are almost the same as those specified in IEC 61000-3-2.
- The other kind of limit is for large consumers who are supplied with electricity at a voltage greater than or equal to 6.6 kV.

Analysis of Trends

- Despite the increase in harmonic generating equipment, the system's harmonic voltage has been on a downward trend since 1999 in Figure 1. Also, the harmonic voltage tends to be lower overall in the daytime with a heavy load than in the night-time with a light load (Figure 2).

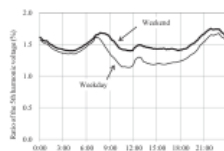


Figure 2. Variation of the ratio of the 5th harmonic voltage (Average of 100 measuring points) [4].

- These are seemingly unnatural take into account a load curve between a residential area and an industrial area (Figure 3).

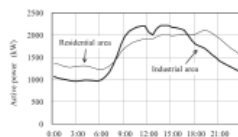


Figure 3. Difference in a load curve between a residential area and an industrial area [4].

- According to JIS C 4304 [7], many transformers of customers such as buildings connected to medium voltage of distribution network in Japan mainly use Y-Δ transformers. On the other hand, LV single-phase load uses line to line voltage. From this fact, it is expected that the 5th and 7th harmonics generated from these customers will cancel each other. These conditions have been understood in theory [8] but not in the investigation of the network.
- Focusing on the 5th harmonic, which has the highest content and is the main cause of failure [9], for these unnatural phenomena, it can be explained by classifying the loads into two groups according to the connection of transformers (Figure 4). Harmonic currents generated from these load groups were found to cancel each other out throughout the system by analysis of the measured harmonic currents.

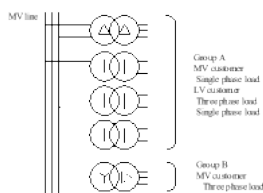


Figure 4. Transformer winding for single phase, LV three phase and MV three phase loads in Japan [10].

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Analysis of Trends (continued)

- Referring to [3] and [11], the recent trends from 1994 to 2017 of harmonic distortions in the Japanese network are shown in Figure 7 and Figure 8.
- This trend is realized by cancellation with MV-three-phase load and LV single-phase load. For the trends of voltage harmonic distortions in 6 kV networks of industrial and commercial areas (Figure 8), recently, the slope has become gentle, but it is still on a downward trend.

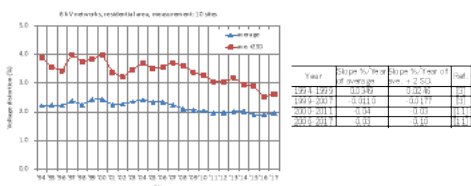


Figure 7. Trends of voltage harmonic distortions in 6 kV networks (residential area).

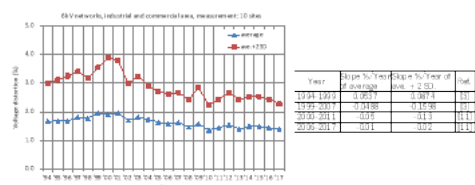


Figure 8. Trends of voltage harmonic distortions in 6 kV networks (industrial and commercial area).

Estimating Central Part of the Downtown Area

- On the other hand, by using a harmonic current estimating model in reference [12], assuming the central part of the downtown area where the ratio of MV consumers is extremely high, the harmonic currents were estimated by synthesizing the harmonic current vectors (5th and 7th) of each load group (Figure 9).

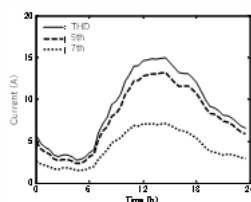


Figure 9. Estimated 5th and 7th harmonic currents of central part of the downtown area.

- In this case, the harmonic current was maximized during the daytime in conjunction with the time transition of demand. Since the harmonic current at this time is mainly generated from the MV three-phase device, it became clear that the harmonic cancellation cannot be expected.
- In order to improve the harmonic voltage caused by such a harmonic current, it is necessary to suppress the harmonic current mainly generated from the MV three-phase equipment.
- Recently, there is a tendency for harmonic disturbances to occur, especially in downtown areas and rural areas, so it is necessary to investigate such obstacles and consider countermeasures in the future.

Investigation of Downtown Area in summer of 2020

- The voltage distortion in the distribution line in the downtown area measured at 53 different sites in the summer of 2020 was analyzed, and the following was clarified.
- The total voltage distortion in downtown Japan is often 1.0% to 2.0%, with an average value of 1.84%, but it is also distributed to 4.0% to 6.0% (Figure 10).

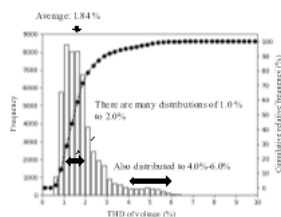


Figure 10. Frequency distribution of THD of voltage in downtown area in summer 2020 (Frequency: 53,035).

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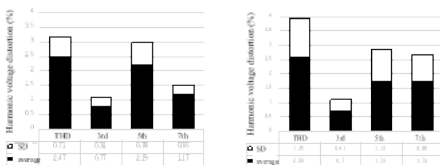
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Investigation of Downtown Area in summer of 2020 (continued)

- From the statistics, as components, the 5th and 7th harmonics tend to be larger, and the 7th tends to be higher than the results measured at the Electric Technology Research Association in the past [9] (Figure 11).

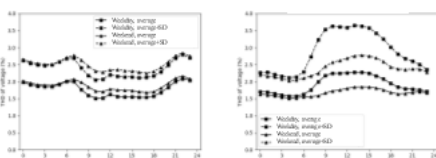


(a) Report on 2005 [9]

(b) Summer 2020

Figure 11. Japanese statistics on harmonic voltage distortion in downtown areas.

- The representative value of Japan in the downtown area increased from 3.76 % of the reference [9] to 5.46 %, and it became clear that it exceeded the target value 5% of the harmonic environment level in MV networks. The representative value is 95th percentile of all sites calculated from 95th percentile of each site for THD of voltage.
- The characteristics of the total voltage distortion in the downtown area of the reference [9] for each day of the week tended to be higher on weekends than on weekdays. In the summer of 2020, the THD of voltage on weekdays tends to be higher than on weekends (Figure 12).
- The THD of voltage of the reference [9] was small during the daytime when the amount of harmonics generated was large, and tended to increase around 7:00 and 22:00 (Figure 12 (a)). In the summer of 2020, the tendency is different from the past [9], and the daytime is larger than the night-time (Figure 12 (b)). This is consistent with the estimates Figure 9. This is explained by three-phase loads being larger than single-phase loads.



(a) Report on 2005 [9]

(b) Summer 2020

Figure 12. Hourly characteristics of THD of voltage in downtown.

Conclusion

- This paper reports on the harmonic characteristics of the Japanese power system, especially based on the standards related to the background of harmonic voltage in Japan.
- In the central part of the downtown area, where the ratio of MV consumers is extremely high, 5th and 7th of the harmonic current are maximized during the daytime in conjunction with the time transition of demand. Since the harmonic current at this time is mainly generated from the MV three-phase device, it became clear that the harmonic cancellation cannot be expected. In order to improve the harmonic voltage caused by such a harmonic current, it is necessary to suppress the harmonic current mainly generated from the MV three-phase equipment.
- The voltage distortion in the distribution line in the downtown area measured in the summer of 2020 was analyzed. The representative value of Japan in the downtown area increased from 3.76 % in the past investigation to 5.46 %, and it became clear that it exceeded in small measure the target value 5% of the harmonic environment level in MV networks. It is thought that some measures are necessary for this matter.

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