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Harmonic Calculation Considering Inverter-Based Resources (IBRs)

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Motivation

In recent years, with the development of inverter technology, in addition to conventional rectifiers, distributed power generation that applies inverter technology, chargers for electric vehicles, and storage battery systems have been introduced to customers' equipment. These types of equipment may affect the impedance characteristics in harmonics calculation. In order to analyze the harmonic generation factors of the distribution system, it is necessary to examine how to evaluate the influence of the characteristics of the equipment applying the inverter technology on the formation of harmonics in the harmonic calculation is there. Therefore, it is necessary to examine the influence of the characteristics of the equipment applying the inverter technology.

Extension of Harmonic Calculation

The general harmonic calculation has been described by using the node admittance matrix. In this section, a method for extending the node admittance matrix to calculate harmonics considering the control of grid-connected inverter equipment will be explained.

An extension of harmonic calculation is shown in Figure 1. Inverters include LC filters for suppressing harmonics and grid-tie transformers for interconnection to the system. These circuit elements will be incorporated into the Y matrix as a harmonic calculation model. The element G for controlling the inverter is incorporated as an extended part of the node admittance matrix as a control transfer function.

Impact Analysis of IBRs

The extended harmonic calculation was used to calculate the impedance characteristics including the characteristics of the inverter looked from the harmonic current source in Figure 1. Figure 2 shows frequency-impedance characteristics viewed from harmonic current sources.

The resonance around 200 Hz is due to the shunt capacitor with a 6% series reactor. Influences of the interconnection of inverters on harmonic impedance characteristics are shown below.

(a) Without the inverter, the impedance increases monotonously at frequencies above 210 Hz.
(b) In the gate block of the inverter, the impedance increases in the range of 210 Hz to 881 Hz and decreases in the area exceeding 881 Hz. This is due to the added characteristics of the inverter filter.
(c) During inverter operation, it can be confirmed that the impedance stands sharply in the range of 1,110 Hz to 1,371 Hz. This is due to the addition of inverter control characteristics in addition to the inverter filter.

Instability Analysis of IBRs

By using the extension of harmonic calculation, we can show open loop transfer functions of the inverter feedback control. We get the frequency and open loop gain when a phase is 180 degrees. Based on experimental results, voltage distortion can see at the frequency where the gain exceeds 0 dB.

Reference

[1] Naotaka Okada, "Extension of Harmonic Calculation Considering Grid-Connected Inverter", CIRED 2021 Conference, Sep. 2021.
[2] Naotaka Okada, Kentaro Fukushima, Kenichiro Sano, "A Method to Consider Voltage Distortion Caused by Interaction Grid-Connected Inverter and Distribution System", 2020 23rd International Conference on Electrical Machines and Systems (ICEMS), November 2020.