

**PROCEEDINGS OF THE INTERNATIONAL WORKSHOP ON ADVANCES IN
SURFACE MINING FOR ENVIRONMENTAL PROTECTION AND SUSTAINABLE
DEVELOPMENT 17 OCTOBER 2025, HA NOI, VIET NAM**



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Impact of large capacity solar power sources when connected near high-voltage power system supplying electricity to mining areas

Do Duc Thanh^{1,*}, Ngo Thanh Tuan¹

¹ Hanoi University of Mining and Geology, Hanoi, Vietnam

ABSTRACT

The paper studies the phenomenon of high-order harmonics appearing during power grid operation supplying electricity to mining areas when a solar power source is connected on a large scale. Pulse width modulation employed in a DC/AC converter will produce a huge amount of harmonic current emission to the power grid at the connection point. The propagation of this noise source in the whole system is directly related to the operating mode of the neutral point of the transformer star point. For a high-voltage power grid, the voltage quality criterion is limited to a total harmonic distortion of 3% and a maximum of 1.5% for each component. The frequency-dependent impedance characteristic of the network has to be investigated since it varies randomly due to the structure of the power grid varying over time. Moreover, a closed-open state of the transformer neutral points will affect the zero-sequence current and voltage components. Due to parallel or series resonance created by inductance and capacitance in the electric circuit, the network impedance characteristic appears at many extreme points. In some specific configurations, these resonant frequencies have values close to the harmonic frequencies in the power grid. This self-excitation (resonance) produces undesirable effects that affect the normal working mode and operation. In this situation, the total harmonic distortion of the voltage waveform probably exceeds a required limit. Therefore, analyzing the causes and simultaneously forecasting possible scenarios in real operating situations is necessary. Some theoretical conclusions are produced based on a representative high-voltage transmission line that is investigated with the integration of a large-scale solar power source.

Keywords: Solar power; Harmonic emission; Harmonic distortion; Transmission impedance; Mining area.

1. Introduction

During the operation of power grid, many disturbance factors affect its normal operation, especially high-frequency disturbances and high-order (Thango et al., 2021; Dewayalage et al., 2024; Pan, 2022; Caicedo, 2017). To ensure this, it is necessary to analyze and find the cause to overcome this phenomenon. Especially, a large distribution power plant as photovoltaic source is a harmonic source pollution due to pulse width modulation method of a DC/AC converter. Since applying renewable energy sources as an essential trend to compensate the exhaust of traditional fuels (coal, oil, gas, etc.). This solar power is partly to supply local

*Corresponding author.

E-mail address: ngothanhtuan@humg.edu.vn

mining loads and residual power will inject to high-voltage power grid. Since voltage quality criterion in a high-voltage power grid is restricted to 3% with total harmonic distortion (THD_v) and 1.5% for each individual component (MOIT, 2015). So, it is necessary the integration issue of a large solar power plant. To predict the behaviour of power grid as a harmonic emission, impedance characteristic has to be investigated carefully.

Zero-sequence voltage and current components play an important role and are common signal types used in relay protection and control systems (Do, 2001). Symmetrical components depend on the structure of the power grid, especially the transformer wiring and the transformer neutral connection mode (Korai and Erlich, 2017). Excitation with resonant frequencies in the network impedance characteristics leads to the appearance of high-order harmonic components with very large amplitudes (Torquato et al., 2016). These harmonics degrade the voltage quality and cause an electromagnetic interference, which can affect sensitive power electronic devices. Therefore, the main content of this study is to investigate the influence of transformer neutral connection mode in the case of representative grid configurations that can lead to undesirable phenomena. In which, effect of harmonic emission of a solar power plant are studied in more detail following operation scenarios of the power grid.

2. Research Methodology

2.1. Research Object

The 220kV transmission line system of Son Dong Thermal Power Plant - TKV under Vietnam National Coal and Mineral Industries Group is being surveyed. The power plant consists of two transformer sets (10.5/230kV, $S_{NomG} = 125\text{MVA}$) and a 100MW synchronous generator ($U_{nom} = 10.5\text{kV}$, $S_{NomG} = 100\text{MW}$) connected to the 220kV intermediate transformer stations Hoanh Bo and Trang Bach (Figure 1). Transformer T_3 takes electricity from the 220kV system to supply 6kV electricity to the entire plant when the generator and transformer sets are not working. The length parameters of the lines are detailed in Figure 1. The 220kV transmission line uses ACSR2x330 wire, including two wires per phase, cross-section of 330mm^2 with the calculation parameters per unit length of wire taken as follows: $r_0 = 0.0869\Omega/\text{km}$, $x_0 = 0.306\Omega/\text{km}$, $b_0 = 3.70 \cdot 10^{-6}\text{S}/\text{km}$. The Hoanh Bo and Trang Bach intermediate transformer stations use 125MVA auto-transformers to supply power to 110kV busbar.

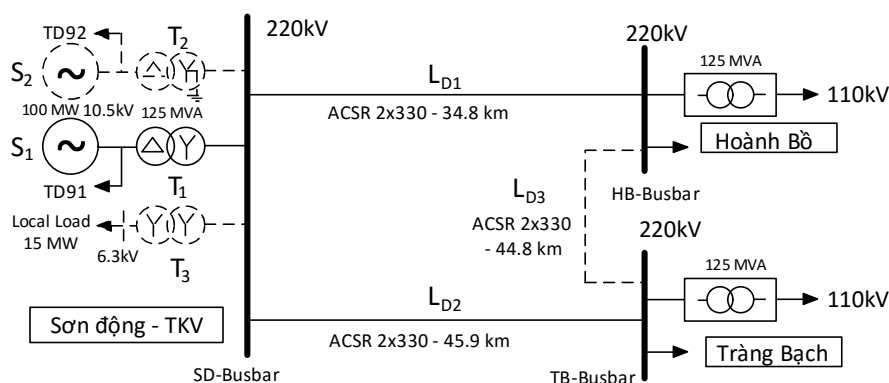


Figure 1. High-voltage transmission grid.

2.2. Research Methodology and Research hypothesis

2.2.1. Research methodology:

Using a theoretical analysis method and a simulation method using MATLAB software (Simulink simulation toolbox). In which a symmetrical component method is used to analyze the excitation of the power network mode parameters according to the current harmonic sources. The positive-sequence and zero-sequence components are separately studied depending on a specific operating mode of the transformer neutral point.

2.2.2. Research hypothesis:

To simplify the procedure of analyzing the influence of the neutral connection mode of the transformer, the research model only considers an operating generator-transformer combination (S₁-T₁). The power output to the grid is assumed to be 85MW. Generator S₁ is simulated using a simplified model, with a reactor and an electromotive force source equal to the generator voltage. Transformer T₃ is not considered because it does not operate when the generator and generator generate power to the 220kV transmission grid. Transformer T₁ has the following parameters: 125MVA 10.5/230kV ($u_n\% = 11\%$, $\Delta P_n = 380\text{kW}$). The zero-component parameters used for simulation: $R_{0D} = 2 \cdot R_{1D}$, $X_{0D} = 2 \cdot X_{1D}$, and $C_{0D} = 2 \cdot C_{1D}$ with R_{1D} , X_{1D} , and C_{1D} being the resistance, reactance and capacitance per length of the transmission line.

To study the influence of the neutral connection mode of the transformer, the Hoanh Bo and Trang Bach intermediate transformer stations use a simplified model consisting of a 125 MVA 230/110kV transformer ($u_n\% = 11\%$, $\Delta P_n = 380\text{kW}$) and an equivalent load on the 110kV low-voltage side is assumed to be 40MW.

The integration of a 100MW solar power can be considered as a harmonic current source at the connection point (Hoanh Bo busbar). The harmonic current source is studied with only odd harmonics (3,5,7, etc.), and the value of each individual component is constantly taken as 0.5% of the nominal current value on the 220kV voltage side of a generator capacity (a capacity of 100MW, a nominal current equal is to 262A). The considered maximum frequency is 1 kHz for Fast Fourier Transformation. Using a controlled sinusoidal current source model in MATLAB/Simulink toolbox to simulate an emission of the harmonic current source into the power network. In this case, each positive- and zero-sequence component is studied individually. A finite voltage source is added at Trang Bach busbar with short-circuit power assumed to be 500MVA (X/R ratio is equal to 10). The simulation model of the above representative power network is displayed in Figure 2.

3. Results and Discussions

3.1. Impedance characteristics of the network

Investigation of frequency-dependent impedance characteristics plays a crucial role in investigating resonant characteristics when the harmonic frequency is close to the natural frequency of the power grid.

The value of the resonant frequency by the inductance and capacitance loops in an electric power network is determined by an expression: $f_{ch} = \frac{1}{2\pi\sqrt{L_{eq} \cdot C_{eq}}}$, in which L_{eq} , C_{eq} are the total inductance and equivalent capacitance values of the positive- and zero-sequence diagrams, respectively.

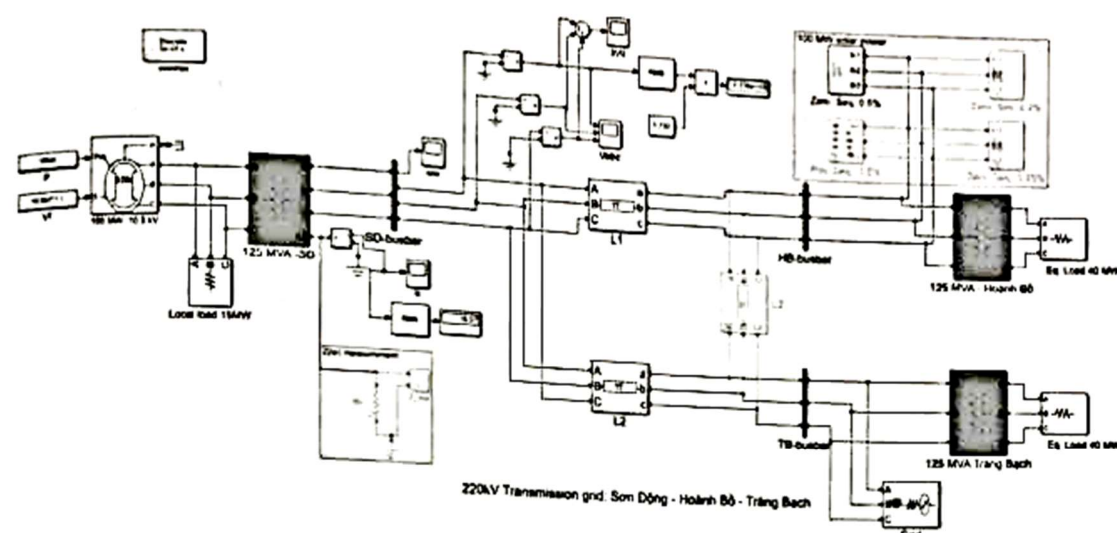


Figure 2. Simulation model in MATLAB/Simulink.

3.1.1. Alternative calculation diagram

The impedance characteristic of the positive-sequence component takes into account all the inductance values of the power network (L_{1eq} is relatively large), so the resonant frequency of the diagram is lower. For the zero-sequence component, the alternative calculation diagram for the zero-sequence depends on the neutral connection mode: isolated from ground (Y-connection, Figure 3a) and directly grounded (Y_0 -connection, Figure 3b). The transformer inductance value shall be taken into account when the neutral connection mode is direct grounding.

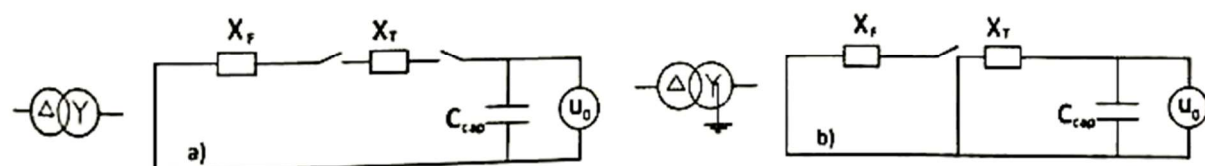


Figure 3. Zero-sequence model: a. Y-connection and b. Y_0 -connection

3.1.2. Impedance characteristic measurement

Using the Z impedance measurement block in MATLAB/Simulink will give the zero-sequence measured impedance characteristic at Sơn Động location (Figure 4b) in the situations of both Y_0 -connections (blue curve), only Hoàng Bồ side Y_0 -connection (orange curve), only Trảng Bách side Y_0 -connection (yellow curve), and both Y-connection (purple curve). In the case of both Y_0 -connections, the resonant frequency value is 726Hz (Figure 4a). With the transformer reactance value: $X_T = (1/2) \cdot u_n \% \cdot U_{Nom}^2 / (100 \cdot S_{NomT}) = (1/2) \cdot 11 \cdot 230^2 / (100 \cdot 125) = 23.28 \Omega$, we have $L_T = X_T / (2 \cdot \pi \cdot 50) = 23.28 / (2 \cdot 3.14 \cdot 50) = 74.12 \text{mH}$. Line inductance: $L_{CD1} = 2 \cdot x_0 \cdot L_{D1} / 314 = 2 \cdot 0.306 \cdot 34.8 / 314 = 67.82 \text{mH}$ and $L_{CD2} = 2 \cdot x_0 \cdot L_{D2} / 314 = 2 \cdot 0.306 \cdot 45.9 / 314 = 89.56 \text{mH}$. Line capacitance: $C_1 = b_0 \cdot L_{D1} / 314 = 3.70 \cdot 10^{-6} \cdot 34.8 / 314 = 0.41 \mu\text{F}$ and $C_2 = b_0 \cdot L_{D2} / 314 = 3.70 \cdot 10^{-6} \cdot 45.9 / 314 = 0.54 \mu\text{F}$. Therefore, the total inductance value $L_{eq} = L_T \cdot (L_{CD1} + L_{CD2}) / (L_T + L_{CD1} + L_{CD2}) = 74.12 \cdot (67.82 + 89.56) / (74.12 + 67.82 + 89.56) = 50.4 \text{mH}$ and the total capacitance $C_{eq} = C_1 + C_2 = 0.41 + 0.54 = 0.95 \mu\text{F}$. The theoretically calculated resonant frequency value is:

$C_2 = 0.41 + 0.54 = 0.95\mu\text{F}$. The theoretically calculated resonant frequency value is: $f_{0_Yres} = 1/(2 \cdot \pi \cdot \sqrt{L_{eq} \cdot C_{eq}}) = 1/(2 \cdot \pi \cdot \sqrt{50.4 \cdot 10^{-3} \cdot 0.95 \cdot 10^{-6}}) = 727.7\text{Hz}$ which is similar to the result by the measurement block in Matlab/Simulink. Thus, these impedance characteristics can be used to predict the system response in different operating scenarios.

Figure 4b displays the impedance measurement results at the neutral of the transformer on the Son Dong side for three operating cases: L₁-L₂ (blue curve), L₁-L₃ (orange curve), and L₂-L₃ (yellow curve). It has been extracted that in L₂-L₃ operating mode, the resonant frequency shifts to 684Hz.

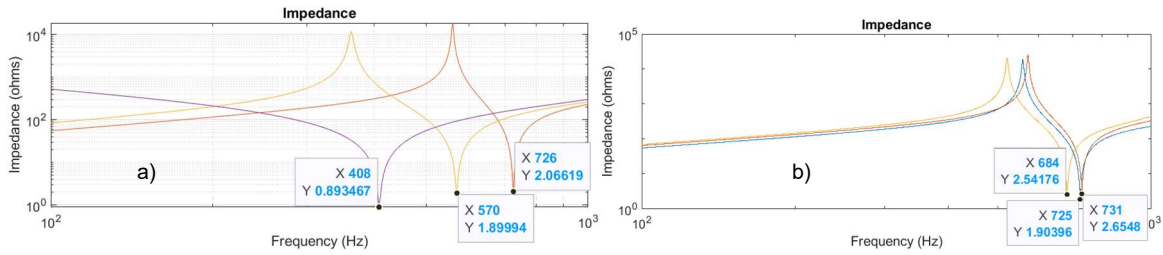


Figure 4. Impedance characteristic results: a. Neutral point mode and b. Line configuration

3.2. Excitation with harmonic current source

3.2.1. Positive-sequence current source

The results of the Fourier series analysis of the voltage wave at the terminal of the factory busbar are given in Figure 5a. The total harmonic distortion (THD_V) is 1.38%, which is within the allowable limit of the specified harmonic standard. The excitation frequency is close to the 9th harmonic (450Hz), which can be clearly seen when analyzing the Fourier series. The three-phase voltage waveform at the 220kV busbar on Son Dong side is shown in Figure 5b.

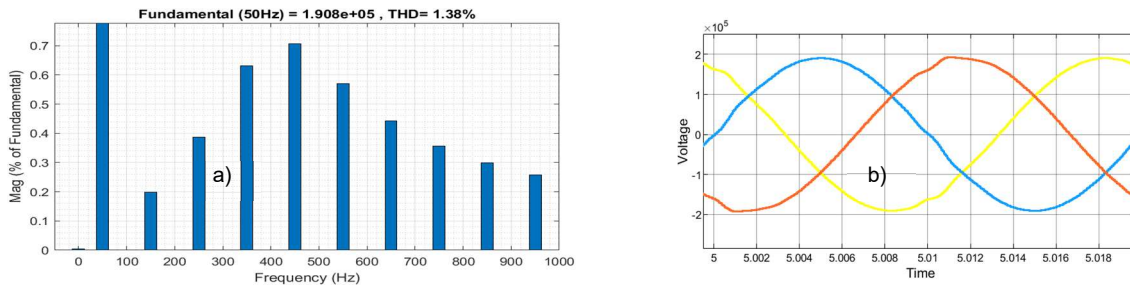


Figure 5. Effect of positive-sequence current source: a. FFT analysis and b. Voltage waveform

3.2.2. Zero-sequence current source

Depending on the different modes of the transformer star point, the operating voltage waveform will change according to the specific characteristic of the power grid. When the neutral connection mode of the transformer is Y₀, the voltage harmonic analysis results show that the total harmonic distortion is 3.14%, exceeding the specified value of 3% (Figure 6b). It can be clearly seen that the zero-sequence voltage has been excited with the 15th order resonant frequency or 750Hz (Figure 4a). The distorted voltage waveform result is shown in Figure 6b.

For each situation, the zero-sequence current can be measured at the grounding point of the transformer star point (Figure 2). In the case of all Y₀-connections, the zero-sequence current

has a root-mean-square value of 18.57A. For the other cases, its value may be higher and should be taken into account, as it significantly increases the total load.

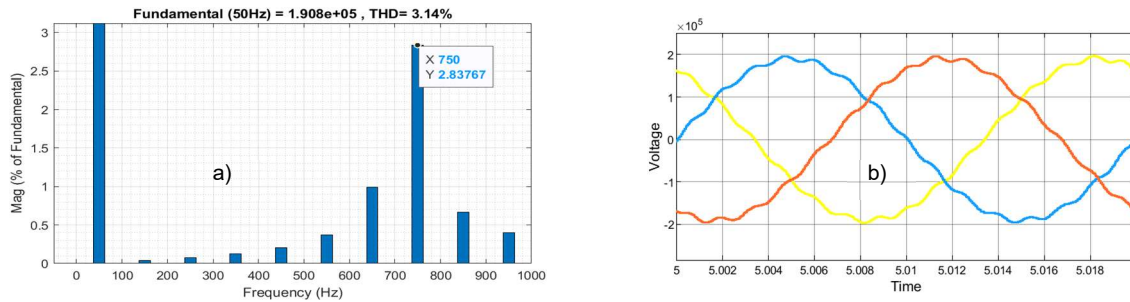


Figure 6. Effect of zero-sequence current source: a. FFT analysis and b. Voltage waveform

3.3. Changing of the grid structure

3.3.1. Adjusting the neutral connection mode

Considering the different neutral connection modes of the transformers at the intermediate substations of Hoanh Bo and Trang Bach. In the case of an open state only at the Hoanh Bo side, the total harmonic distortion is 5.75% and the resonant frequency is 550Hz (Figure 7a). The results are similar to the Trang Bach side; the THD_V value increases strongly to 10.38%. With a high level of waveform distortion, the voltage amplitude will increase, which can affect the insulation of the lines and the equipment connected to the transmission grid.

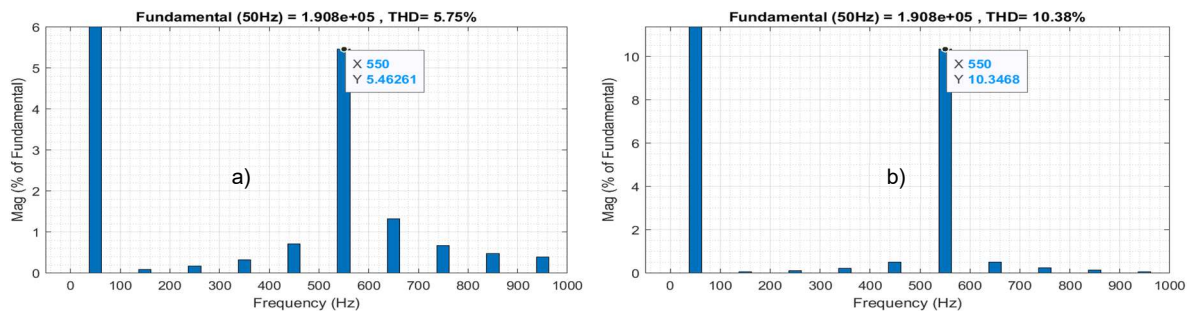


Figure 7. Open neutral mode of transformers: a. Hoanh Bo side and b. Trang Bach side

3.3.2. Line switching

To examine the change in the grid impedance characteristics, different line operation scenarios were studied. The neutral connection mode of the transformers is direct grounding. The results of the voltage harmonic waveform analysis are shown in Figure 8a (L_1 - L_3 case) and Figure 8b (L_2 - L_3 case). For operating the L_1 and L_3 lines, the total harmonic distortion increased to 3.75%. On the contrary, the harmonic distortion decreased to 2.28%, which is smaller than the limit value of 3%. However, the 13th harmonic component (650Hz) with a value of 1.82% is still larger than the specified value of 1.5%.

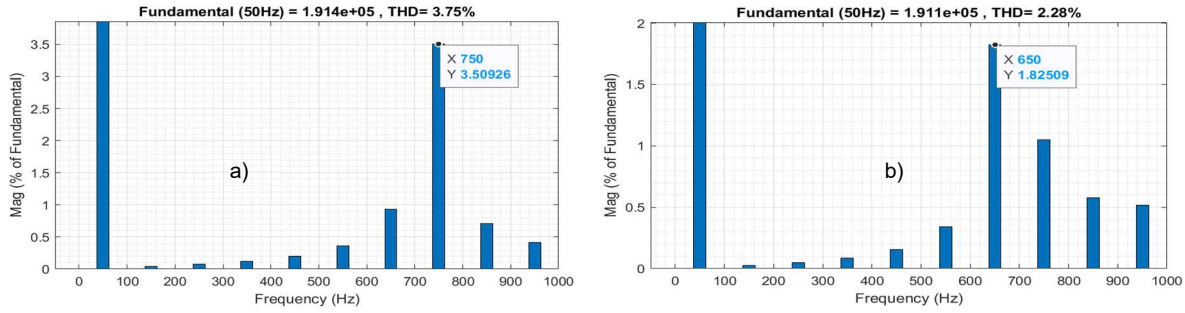


Figure 8. Line configuration: a. L_1 - L_3 case and b. L_2 - L_3 case

3.3.3. Reducing the source of current harmonics

To ensure the total harmonic distortion value of the voltage waveform, it is necessary to reduce the value of the harmonic current source to 0.2% and 0.25% of the amplitude of the nominal current $I_{Nom} = 262A$. The results of the harmonic analysis are given in Figure 9a and Figure 9b. Thus, the harmonic amplitude value of about 0.25% of the amplitude I_{Nom} ($\sim 0.66A$) will be able to ensure the requirement of the individual harmonic current amplitude value not exceeding 1.5%. In this case, the RMS value of the total zero-sequence current is 9.29A.

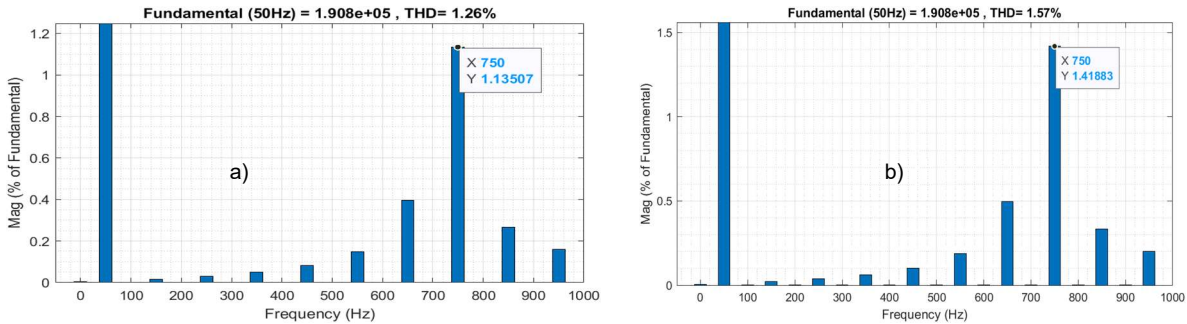


Figure 9. Current source decrease: a. 0.2% amplitude and b. 0.25% amplitude

4. Conclusions

Based on simulation results for a representative high-voltage power grid, some conclusions are deduced as follows:

- Integration of a large-scale solar power source can produce some issues with the operation of a high-voltage power grid since it can be considered as a source of harmonic current emission.
- The voltage waveform is distorted strongly following the excitation, which occurs when the frequency of the current harmonic emission is close to the natural resonant frequency of the impedance characteristic.
- Depending on the neutral connection mode of the transformer star point, the impedance characteristic of the entire system will change:
 - + The non-harmonic excitation following a particular frequency depends on the grid structure.
 - + In some specific cases, the quality index of the voltage harmonic can be violated: the total harmonic distortion (THD) exceeds 3% and the magnitude of the harmonic components exceeds the allowable value of 1.5%.

- Reduce the harmonic current emission of distribution power sources and building appropriate operating scenarios are mainly tasks to solve the problem of voltage harmonic quality on the high-voltage transmission system.

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