

A numerical investigation on the voltage harmonics from multi-level converters in smart grid system

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Abstract. The economic growth in Asia is now remarkable. Because of this, the energy consumption has also increased drastically. Under such condition, it is necessary for efficient use of energy to introduce smart grid. At that time, electromagnetic interference (EMI) generated by the voltage harmonics from power converters which are connected to the power system becomes one of the biggest issues. Therefore, to suppress voltage harmonics in the power converters is required. Although it can be realized by connecting passive filters, it leads to circuit enlargement. On the other hand, recently there are some suggestions that the multilevel converters will be miniaturized and integrated in the future. If such a converter is introduced, it is considered that the smart grid system with renewable energy sources can provide high-quality electricity without EMI. Therefore, in this paper, the voltage harmonics to the grid system by assigning multi-level converters is investigated.

1. The necessities of power converters in smart grid

Demand of energy has increased all over the world [1]. Especially in Asian countries, due to its highly economic development, the energy consumption has also increased drastically. Under such condition, the efficient use of energy is essential.

As one of the ways to satisfy the demand of energy, it is very important to introduce renewable energy sources, such as photovoltaic energy and wind energy. However, it is very difficult to manage the energy from these energy sources. Because of that, Smart Grid is expected as one of the key solutions.

However, the form of the output power of the renewable energy sources and that of electricity in the power system are different. Therefore, power converters are assigned to the renewable energy sources.

Currently, as for the power converters, converters with using switching are widely used. For this reason, the output voltage waveform is pulsed and contains many harmonics as shown in figure 1 (a). Simultaneously, its switching speed (dv/dt , di/dt) has become higher. Therefore, the electromagnetic interference (EMI) has been increased. Output LC filters and EMI filters (passive filters) are inserted to reduce these harmonics and EMI, however, the passive filters are composed of inductors and capacitors, therefore the filters are bulky [2,3].

On the other hand, there are some circuit topologies called multi-level converters. As shown in figure 2, there are 3 typical circuit topologies of multi-level converters; series-connected H-bridge converter, diode-clamped converter, and flying capacitor converter. Although there are many comparative investigations for the circuit topologies, in both cases, there is a feature that the output voltage can be



multi-leveled as shown in figure 1 (b). Although there are many investigations of 3-level converters, there are few investigations of the converters with the large number of levels [4,5].

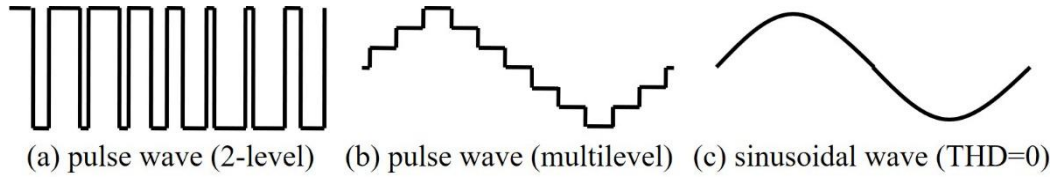


Figure 1. Waveforms.

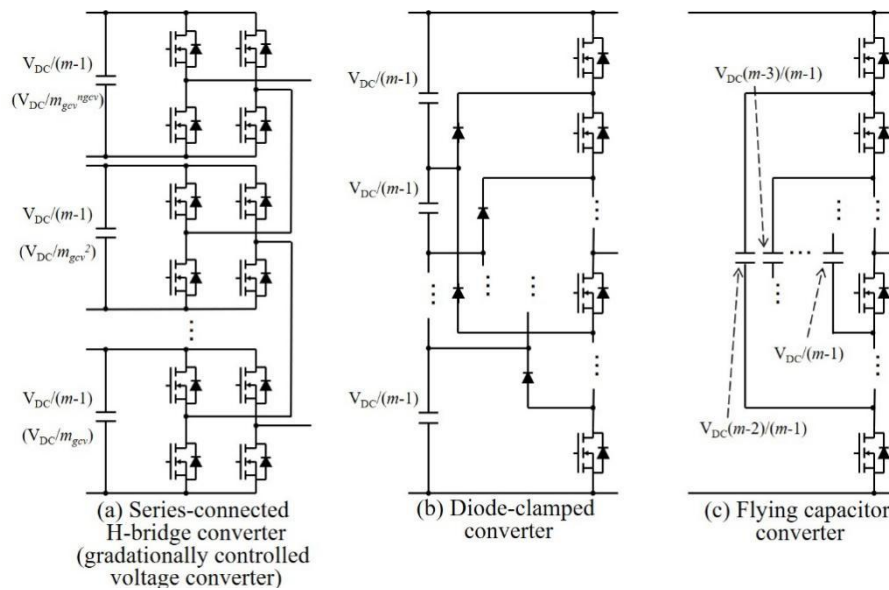


Figure 2. Multi-level circuit topologies.

Regarding the grid-connected power converters, inverters (DC/AC converters) are usually assigned. Therefore, in this paper, 2-level and multi-level inverters are investigated.

2. Voltage harmonics

2.1. Total harmonic distortion (THD) of the output voltage waveform

Because of the switching, there is harmonics in its output voltage waveform. This distortion factor is called total harmonic distortion (THD). If the form of waves is complete sinusoidal wave like figure 1 (c), THD is zero. THD of the output voltage waveform can be calculated from the harmonic distortion in a voltage and is defined as the ratio of the sum of the voltages of all harmonic components to the voltage of the fundamental frequency. Therefore, THD can be calculated by equation (1).

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} V_n^2(\theta)}}{V_1(\theta)} \quad (1)$$

2.2. 2-level and multi-level inverters

As shown in figure 1, the multilevel inverters can reduce the voltage fluctuation in each switching by increasing the number of levels of the output voltage. It can be also predicted that the output waveform

becomes closer to the sinusoidal wave and the harmonic component can be reduced by assigning the multi-level inverters.

3. Analysis of the voltage harmonics of 2-level and multi-level converters

To control the inverters, pulse width modulation (PWM) is usually applied. As for multi-level inverters, it depends on the circuit topologies or applications [4,5]. Therefore, both the conditions are investigated.

3.1. The voltage harmonics of 2-level and multi-level converters (without PWM switching)

THD without PWM switching is calculated. The calculation of THD without PWM switching is based on the Fourier series expansion as shown in figure 3.

3.2. The voltage harmonics of 2-level and multi-level converters (with PWM switching)

THD with PWM switching is calculated. The calculation is based on the simulated result using circuit simulation PSIM. The simulated waveforms and FFT analysed results are shown in figure 4.

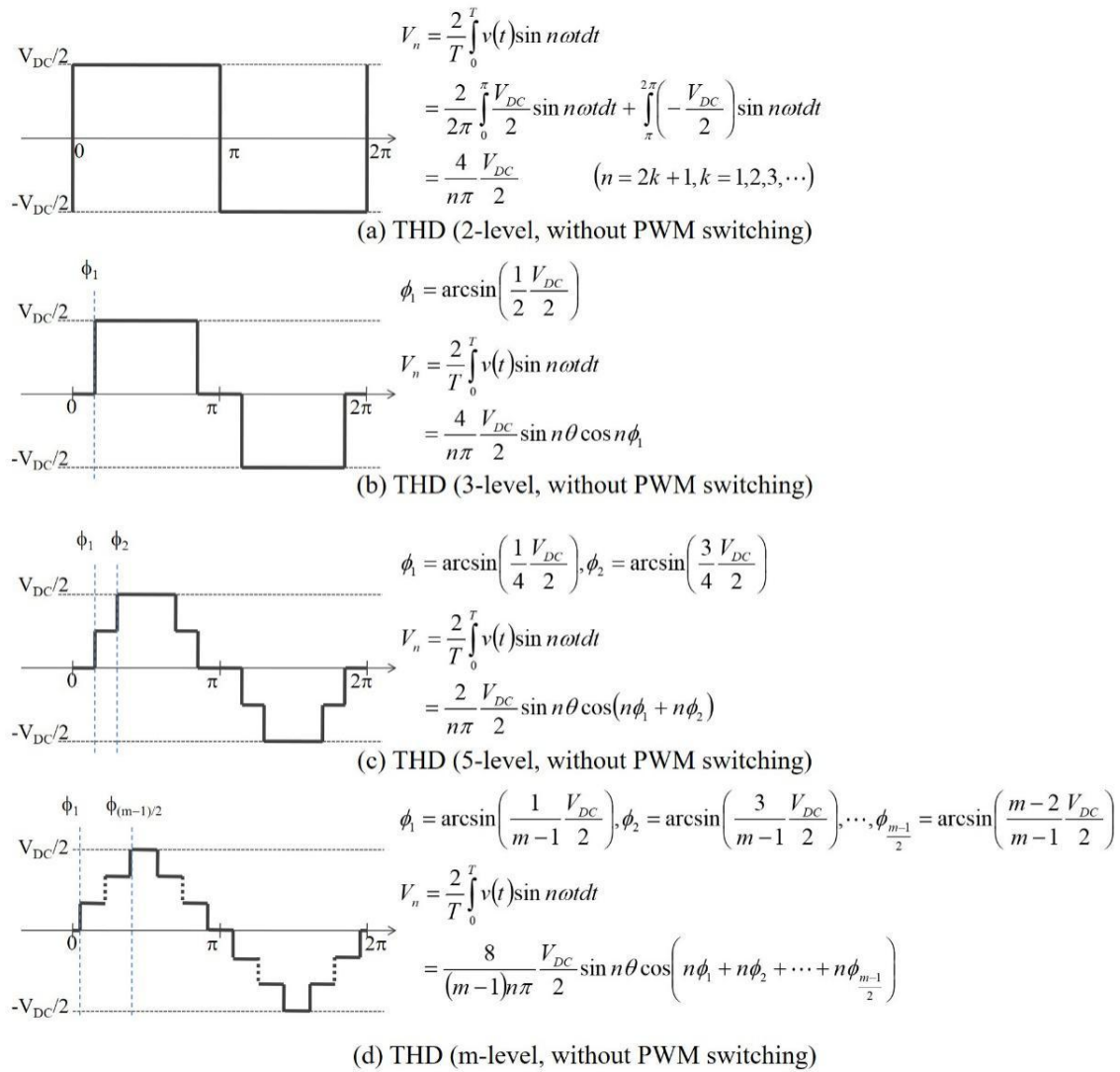


Figure 3. THD of 2-level and multi-level converters (without PWM switching).

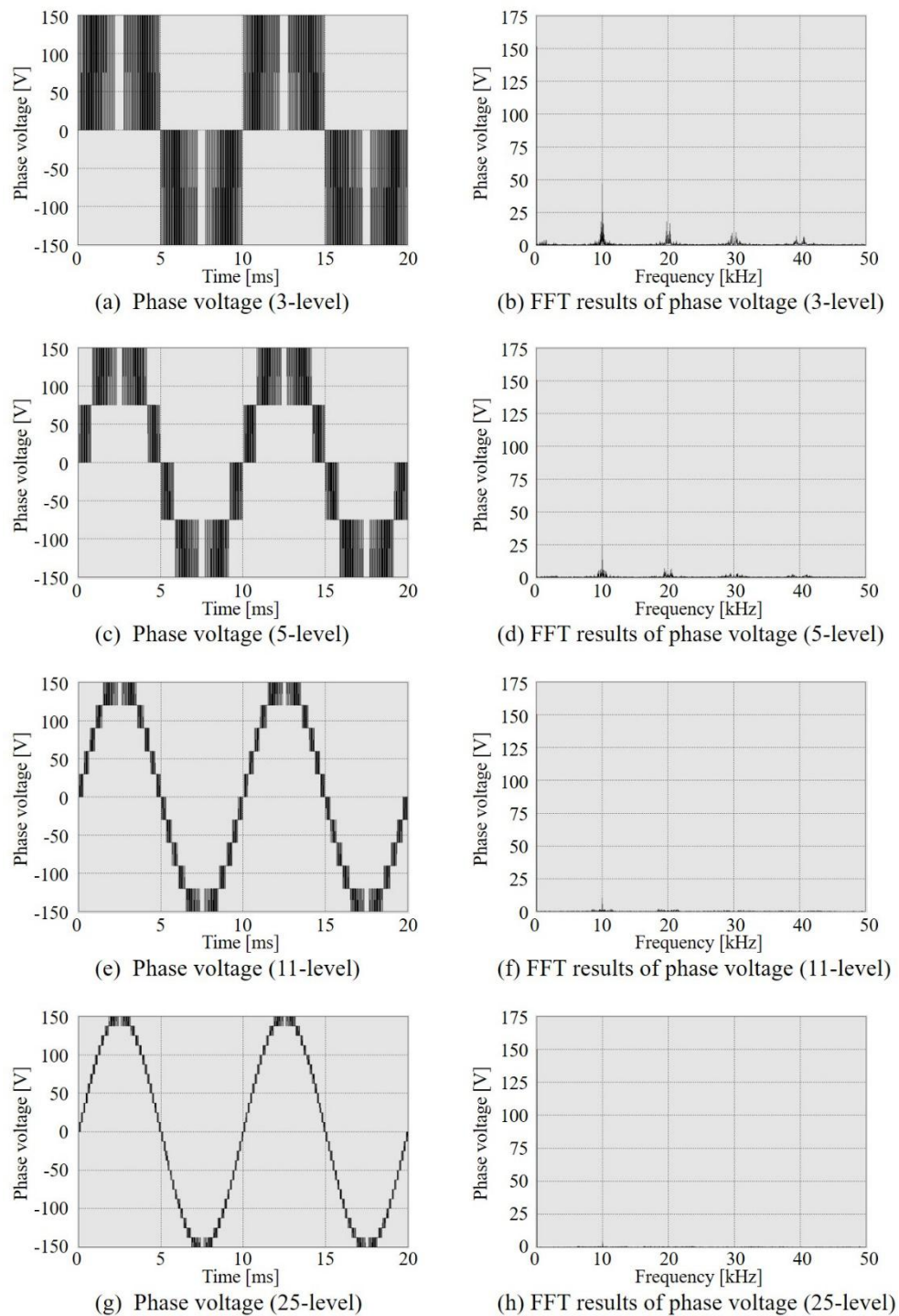


Figure 4. THD of 2-level and multi-level converters (with PWM switching).

4. Discussions

Figure 5 shows the relationship between the number of levels and THD of the output voltage. This result can be explained as following.

- THD can be reduced by increasing the number of the levels. The reduction of THD is approximately inversely proportional to $m-1$ (m means the number of levels). This is because the voltage value of the harmonic is inversely proportional to $m-1$.

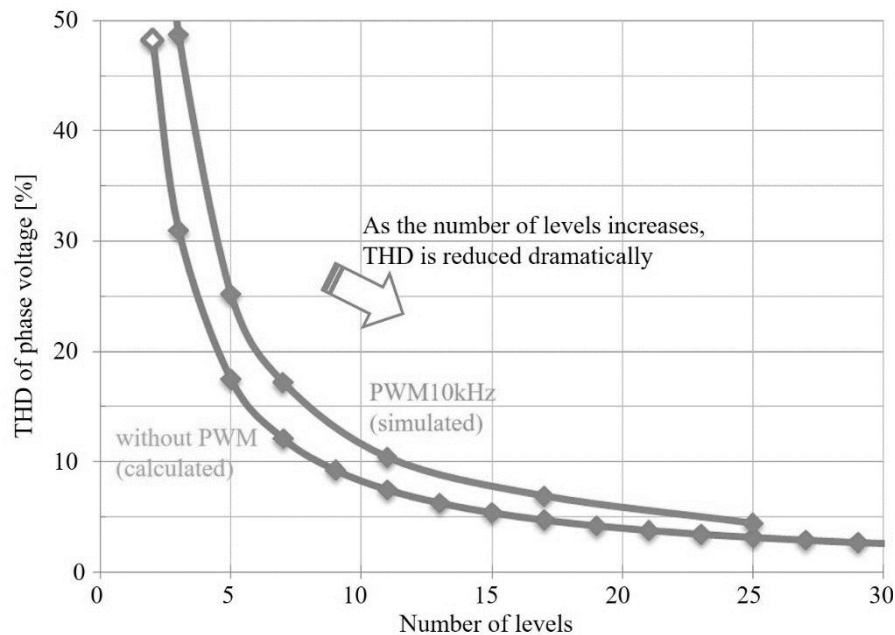


Figure 5. The relationship between the number of levels and THD.

- Comparing the case of using PWM switching and the case of not using PWM switching, the former case is better. However, when the PWM switching is used, since the harmonic order increases in proportion to the PWM carrier frequency, the output LC filters can become small even though the output LC filters are still assigned.
- The output voltage with less than 5 % THD can be realized when the number of levels is larger than or equals to 17-levels without using PWM switching or 25-levels with using PWM switching. For example, according to the regulations of the power system in Japan, this can be directly connected to the power system without the output LC filters [2].

5. Conclusion

In this paper, the voltage harmonics to the power system by assigning multi-level converters is numerically investigated.

As a result, the relationship between the number of levels and THD is shown. It can be realized that THD which is less than 5% with assigning 17-levels or more when not using PWM switching or 25-levels or more when using PWM switching.

References

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