



HVDC Technology - Part 2

Course Number: EE-05-933

PDH: 5

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HVDC TECHNOLOGY – COMPLETE COURSE – PART 2

HARMONICS EFFECTS IN AC POWER SYSTEMS

Harmonics within a power system are expressed as the voltage or current modulation at an integer multiple of the fundamental frequency. Therefore, on a 50 Hz system, the presence of 5th harmonic voltage means that there is an extra 250 Hz component superimposed on the voltage waveform. This component will distort the voltage waveform. Voltage waveform is presented in Figure 1. The presence of harmonics in the power system can cause some unwanted effects on installed power system devices. The presence of harmonics can cause:

- Capacitor banks overheating
- Power electronic devices instability
- Generator overheating
- Communication systems interference

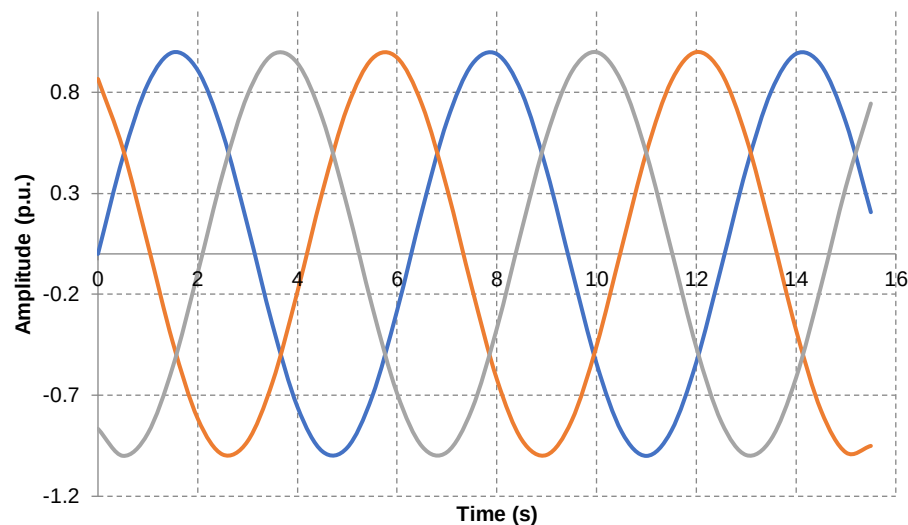


Figure 1. Three-phase fundamental frequency sine wave

AC POWER SYSTEMS HARMONICS SOURCES

All devices that contain a non-linear element and are connected to a power system can generate harmonics. This is a consequence of either their design or their operation. Examples of harmonics sources within a power system are:

- Domestic electronics (video, personal computers, television, etc.)
- Power converters (HVDC, SVC, drives)

Non-linear devices

- Voltage limiters
- Transformers
- Fluorescent lights
- PWM converters
- Rotating Machines

Typical network harmonic profile is presented in Figure 2.

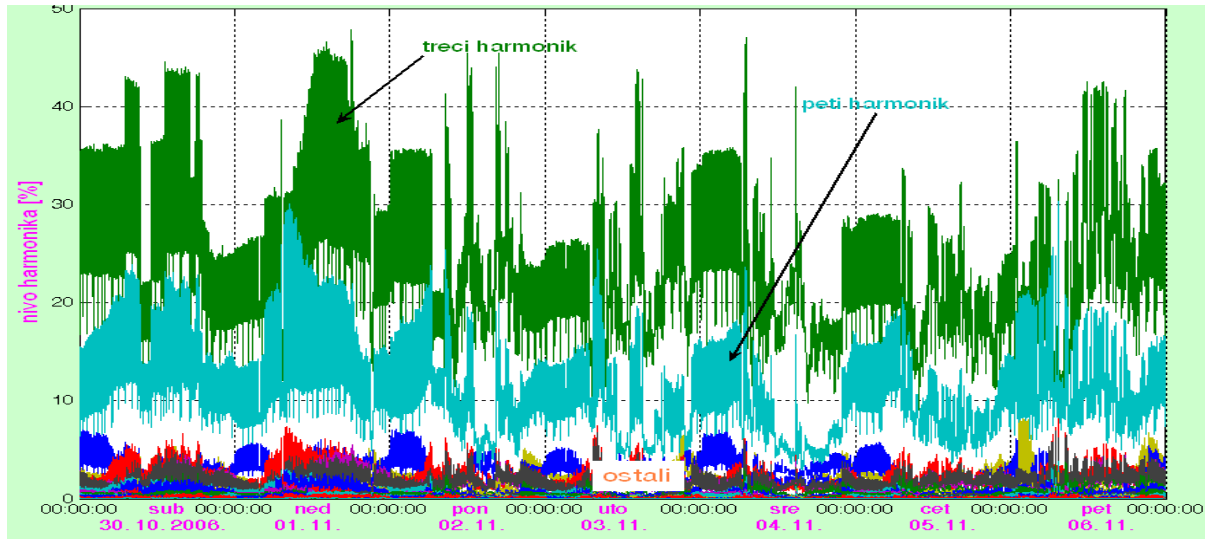


Figure 2. Harmonic profile in a typical power system

HOW CONVERTERS GENERATE HARMONICS

The AC/DC converter is a source of harmonics. This is because the converter connects the supply to the load for a controlled period of a fundamental frequency cycle. Therefore, the current taken from the supply is not sinusoidal. Looked from the AC side, a converter can be conceived as a current harmonics generator. This is shown in Figure 3. If looked from DC side, it can be conceived as voltage harmonics generator, as presented in Figure 4. The actual harmonics level produced by an AC/DC converter is a function of the duration over which a particular phase is needed to provide unidirectional current to the load. Therefore, the higher the converter “pulse number” (which means the more switching between phases within a cycle) the lower the harmonic distortion in both the AC line current and the DC terminal voltage.

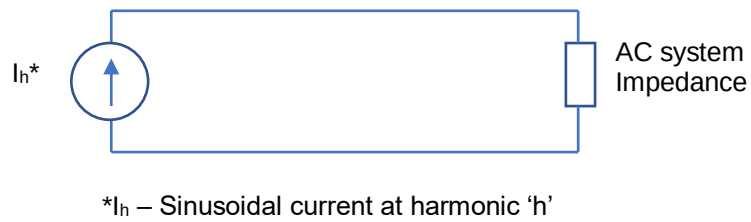


Figure 3. AC/DC converter shown as AC harmonic current source on AC side

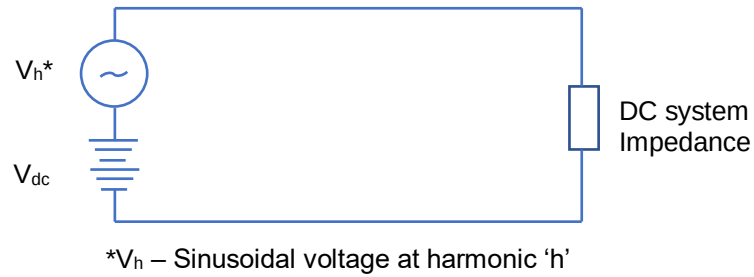


Figure 4. AC/DC converter shown as AC harmonic voltage source on DC side

PULSE NUMBER AND HARMONIC CANCELLATION

The main elements of a common HVDC converter terminal are presented in Figure 5.

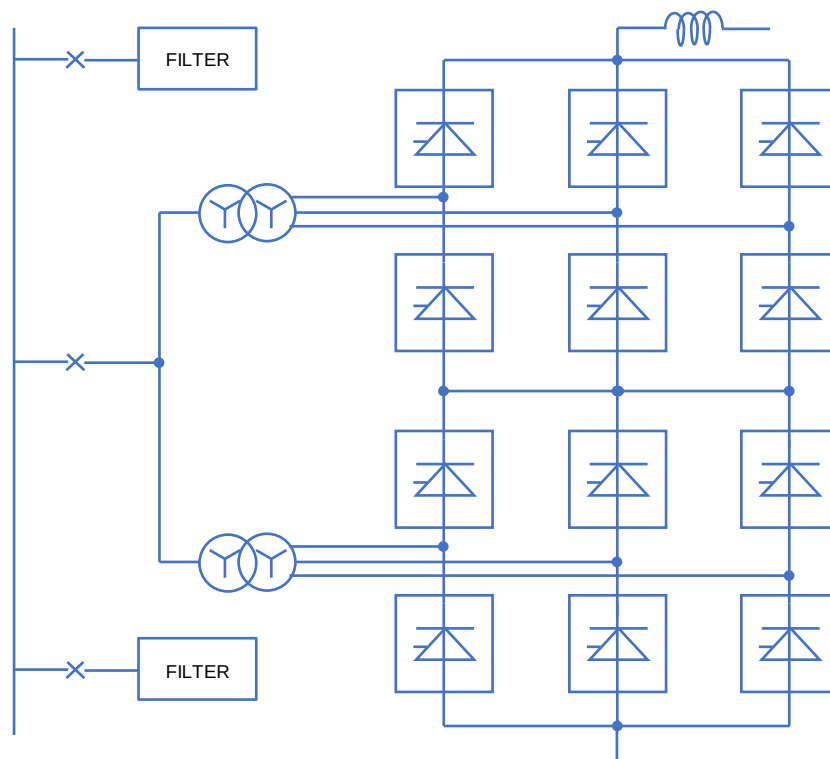


Figure 5. Common twelve-pulse converter bridge

The action of the thyristor sequential switching results in current waveforms in the transformer line side which consists of current “blocks” is presented in Figure 6.

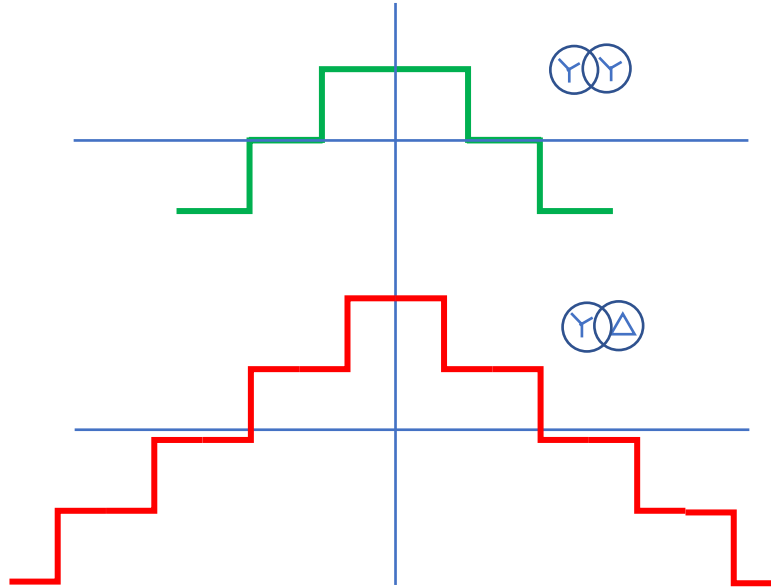


Figure 6. Idealized line winding currents in a twelve-pulse bridge

If a Fourier analysis is completed on the idealized waveforms presented in Figure 6, the next results are found:

$$I = \frac{2\sqrt{3}}{\pi} \times I_d \times \left[\cos \omega t - \frac{1}{5} \cos 5\omega t + \frac{1}{7} \cos 7\omega t - \frac{1}{11} \cos 11\omega t + \frac{1}{13} \cos 13\omega t \dots \right] \dots Y/Y \quad (1)$$

$$I = \frac{2\sqrt{3}}{\pi} \times I_d \times \left[\cos \omega t + \frac{1}{5} \cos 5\omega t - \frac{1}{7} \cos 7\omega t - \frac{1}{11} \cos 11\omega t + \frac{1}{13} \cos 13\omega t \dots \right] \dots Y/\Delta \quad (2)$$

It can be noted from equations (1) and (2) that each six-pulse bridge produces harmonic orders $6n \pm 1$, $n = 1, 2, 3 \dots$. There are no triplen harmonics (3rd, 6th, 9th...) and that for $n = 1, 3$, etc., the harmonics are phase shifted by 180° . The idealized magnitudes of the six-pulse harmonics are presented in Table 1. By combining two six-pulse bridges with a 30° phase shift between them, i.e. by using Y/Y and Y/Δ transformers as presented in Figure 5 and summing equations (1) and (2), a twelve-pulse bridge is found. The idealized magnitudes of the twelve-pulse harmonics are presented in Table 2.

Table 1. Idealized harmonic magnitudes in a six-pulse bridge

Fundamental	50 Hz	1
5 th	250 Hz	0.2
7 th	350 Hz	0.14
11 th	550 Hz	0.09
13 th	650 Hz	0.08
17 th	850 Hz	0.06
19 th	950 Hz	0.05
23 rd	1150 Hz	0.04
25 th	1250 Hz	0.04
n	n x 50 Hz	1/n

Table 2. Idealized harmonic magnitudes in a twelve-pulse bridge

Fundamental	50 Hz	1
5 th	250 Hz	-
7 th	350 Hz	-
11 th	550 Hz	0.09
13 th	650 Hz	0.08
17 th	850 Hz	-
19 th	950 Hz	-
23 rd	1150 Hz	0.04
25 th	1250 Hz	0.04
n	n x 50 Hz	1/n

The current waveforms presented in Figure 7 appear in the typical connection to the transformers presented in Figure 5.

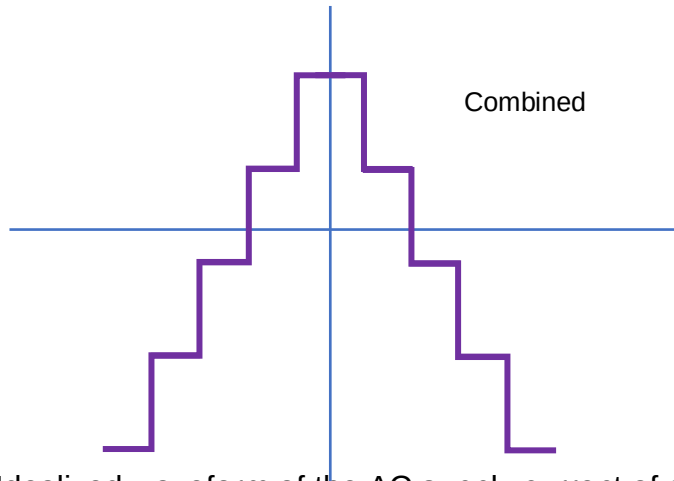


Figure 7. Idealized waveform of the AC supply current of a twelve-pulse bridge

If a Fourier analysis is completed on this idealized waveform, the following result is found:

$$I = \frac{4 \times \sqrt{3}}{\pi} \times I_d \times \left[\cos \omega t - \frac{1}{11} \cos 11\omega t + \frac{1}{13} \cos 13\omega t - \frac{1}{23} \cos 23\omega t + \frac{1}{25} \cos 25\omega t \dots \right] \dots (3)$$



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