Introduction, generation of harmonics, AC & DC Filters, Reactive power requirements at steady state, sources of reactive power, static VAR systems

Electrical energy transmitted through AC transmission or DC transmission is to be delivered at the consumer's terminals at specified voltage level of constant magnitude without deviation from the ideal waveform.

An HVDC transmission system generates harmonic currents on the AC side and harmonic voltages on the DC side during operation. The harmonic currents generated at the AC bus of the converter get transmitted to the AC network and then cause the following adverse effects.

a) Heating of the equipments connected.
b) Instability of converter control.
c) Generates telephone and radio interference in adjacent communication lines, thereby inducing harmonic noise.
d) Harmonics can lead to generation of overvoltages due to resonance when filter circuits are employed.

An HVDC transmission system consists of a rectifier and an inverter whose operation generates harmonics on AC and DC side of the converter. The three distinct sources of harmonics in HVDC systems are

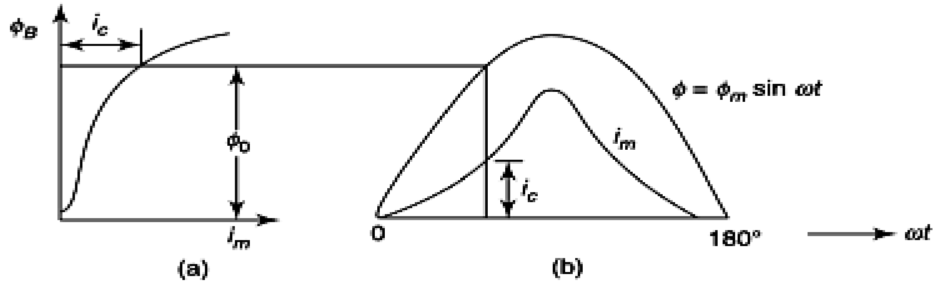
1) Transformer.
2) AC Generator.
3) Converter along with its control devices.

Transformer as source of harmonics

Transformers can be considered as source of harmonic voltages, which arise from magnetic distortion and magnetic saturation due to the presence of a DC component in its secondary. The magnitude of these harmonics depends upon the operating flux density. Converter transformers are usually operated at high flux densities than conventional 3-phase transformers, and therefore the possibility of generation of harmonics is more.

Although the waveform is usually good, an AC generator may be regarded as a source of balanced harmonics because of non-uniform distribution of flux on the armature windings.

The converter which forms the basic unit in HVDC transmission imposes changes of impedances in the current.

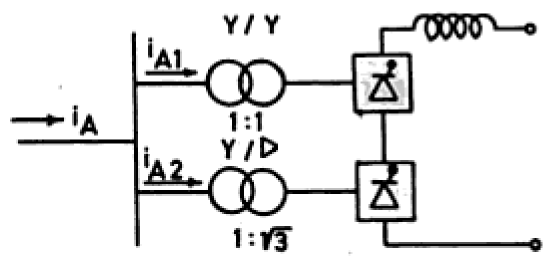


Transformer magnetisation (without hysteresis)
(a) Magnetisation curve (b) Flux and magnetisation current waveforms

When hysteresis effect is considered, then the non-sinusoidal magnetizing current waveform is no longer symmetrical which is mainly caused by triple n harmonics and particularly the third harmonic. Thus, in order to maintain a reasonable sinusoidal voltage supply, it is necessary to supply a path for triple n harmonics which is achieved by the use of delta-connected windings.

Harmonics due to Converters

A 12-pulse connection consists of two 6-pulse groups. One group having Y-Y connected converter transformer with 1:1 turns ratio and the other group having Y-Δ converter transformer bank with 1:√3 turns ratio.



Schematic Diagram of a 12 Pulse Converter Unit

Generation of Harmonics

The harmonics which are generated are of two types.

(i) Characteristic harmonics.

(ii) Non- characteristic harmonics.

Characteristic Harmonics

The characteristic harmonics are harmonics which are always present even under ideal operation.

In the converter analysis, the DC current is assumed to be constant. But in AC current the harmonics exist which are of the order of

$$h = np \pm 1$$

and in DC current it is of the order of

$$h = np$$

where n is any integer and p is pulse number.

Neglecting overlap, primary currents of Y-Y and Y-Δ connection of the transformer are considered taking the origin symmetrical where

$$\left.\begin{aligned} i &= I_d \text{ for } -\pi/3 \le \omega t \le \pi/3 \\ &= 0 \text{ for } \pi/3 \le \omega t \le 2\pi/3 \text{ and } -\pi/3 \le \omega t \le -2\pi/3 \\ &= -I_d \text{ for } -2\pi/3 \le \omega t \le -\pi \text{ and } 2\pi/3 \le \omega t \le \pi \end{aligned}\right\} \text{for Y-Y connection converter transformer}$$

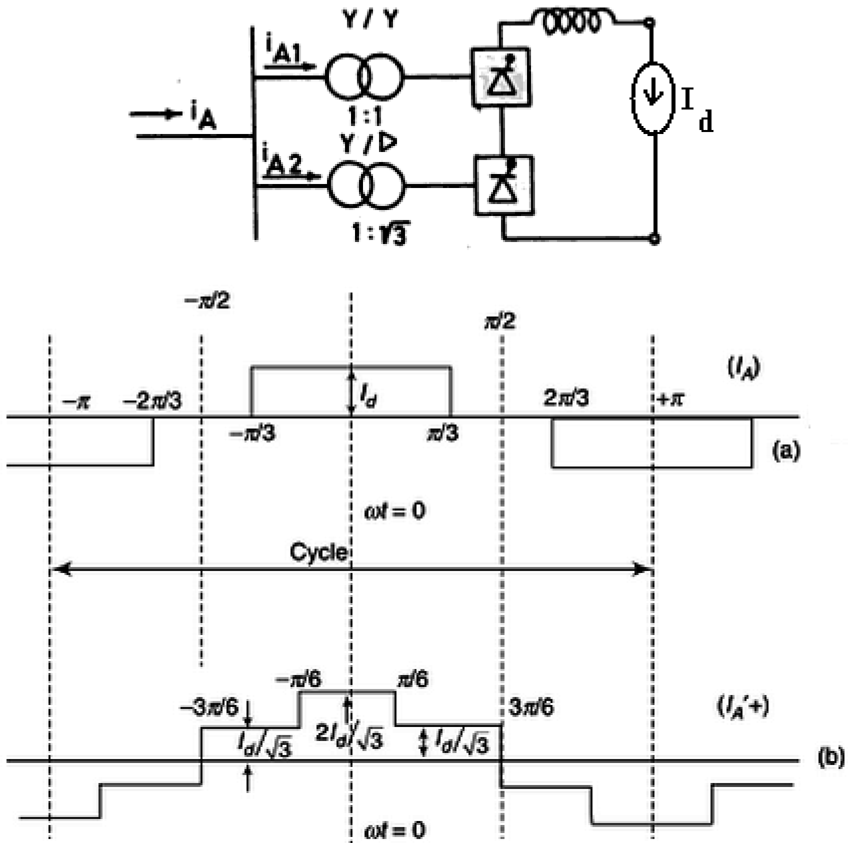


Figure (a): Phase current on primary side of Y-Y connection converter transformer

Figure (b): Phase current on primary side of Y-Δ connection converter transformer

For convenience, the ordinate axis (corresponding to ωt = 0) is chosen such that the waveform has even symmetry. So, generally, by fourier series

$$f(t) = \frac{1}{2}a_0 + \sum_{n=0}^{\infty} a_n \cos n\omega t + \sum_{n=0}^{\infty} b_n \sin n\omega t$$

As positive and negative half cycle cancel each other, so $a_0 = 0$ and as it is (waveform is) even symmetry, so $b_n = 0$ due to which f(t) becomes

$$f(t) = \sum_{n=0}^{\infty} a_n \cos n\omega t (or) \sum_{n} a_n \cos n\omega t$$

$$\text{Therefore, } i_{A_1} = \sum_{n} a_{n_1} \cos n\omega t$$

$$\text{where, } a_{n_1} = \frac{2}{T} \int_{0}^{PeriodOfConduction} f(t)dt$$

Here total time period is T = π and period of conduction is π/3

So,

$$a_{n_1} = 2X \frac{2}{\pi} \int_{0}^{\pi/3} I_d \cos n\omega t d(\omega t)$$

(Here as it is symmetry)

$$a_{n_1} = \frac{4I_d}{\pi} \int_{0}^{\pi/3} \cos n\omega t d(\omega t) = \frac{4I_d}{\pi} \left(\frac{\sin n\omega t}{n} \right)_{0}^{\pi/3}$$

$$a_{n_1} = \frac{4I_d}{n\pi} \left(\sin n \frac{\pi}{3} \right)$$

For triplen harmonics, $a_{n_1} = 0$

Questions

1) Derive the relationship between pulse conversion and harmonics generated.

2) What are the various sources of harmonics generation in a HVDC line?

3) (a) Discuss the effect of pulse number and overlap angle on harmonics generated by HVDC converters.

(b) Using fourier analysis show that the lowest order voltage harmonic present in Graetz circuit output voltage is six.

4) Analyze the harmonics in the AC current during 6-pulse and 12-pulse operations using fourier analysis. What orders of harmonics predominate in the current wave?