**HARMONICS**

**Introduction:**

* Any periodic non-sinusoidal waveform can be resolved into a fundamental sine wave and several other sinusoidal waveform of higher frequency order called as “Harmonics”.
* Harmonics are analysed by fourier series.
* Any electrical component with multiple frequency is called as “Harmonic Component”.
* All the currents are operated at 50Hz frequency , then these currents are called as “Fundamental currents”.
* Even harmonics are absent due to symmetry.
* The odd harmonics are presented in 3-phase system having two groups

Odd harmonics are 3, 5 , 7 , 9 , 11 , 13.........

* The fundamental currents are presented in a 3-phase system whose displacement will be 120o.

i.e., (0o, 120o, 240o)

Basic property of 3-phase system is sum of instantaneous currents are zeros

i.e., ia + ib + ic=0

If any current presented in a line, remaining two currents are provided return path due to 120o displacement.

* If 5th harmonic current in a 3-phase system ,

Frequency of 5th harmonic =5W

Displacement=(0\*5 , 120\*5 , 240\*5)

= (0o, 600o , 1200o) = (0o , 240o , 120o)

It is opposite to fundamental phase sequence.

* If 7th harmonic currents in a 3-phase system ,

Frequency of 7th harmonic = 7W

Displacement = (0\*7 , 120\*7 , 240\*7)

= (0o , 840o , 1680o ) = (0o , 120o , 240o)

7th harmonic of phase sequence is same as fundamental phase sequence.

* The 5th and 7th harmonic phase sequence are opposite , the 7th harmonic current flows from source to transformer, the 5th harmonic current flows from transformer to source.

Both are opposite but cannot cancelled due to different frequency.(i.e., +ve , -ve sequence current involved).

* If 3rd harmonic component in a 3-phase system,

Displacement = (0\*3 , 120\*3 , 240\*3) = ( 0 , 0 , 0)

So it having cophasal nature.

**Generation of Harmonics:**

* In electrical system, the harmonics are electric voltage and currents that appear an electrical power system , which are because of uncertainity in loads.
* In a normal system, voltage varies sinusoidally at a specific frequency , under these conditions when the linear load is connected it draws the current at same frequency.
* If in case of non-linear load connected to H.V.D.C system like rectifier or inverter are connected then the system draws a non-sinusoidal current which loads to generation of harmonics in the H.V.D.C transmission converter.

i.e., harmonics are generated by HVDC converter.

* It should be noted that these harmonics will be not cause any harm to the converter but they travel along the transmission path.

**Effects of Harmonics:**

The harmonics generated by the converter will not interfere with it but the harmonics will flow through the transmission line and causes the following effects.

1. Over heating of machines like generators, induction motors.
2. Over heating of transformer.
3. Extra power losses capacitors , transformers , rotating machine, AC filters.
4. Over voltages and over currents are generated
5. Insulation failure , tripping of circuit breakers.
6. Radio interference problem.
7. Telephone interference problem.
8. Due to harmonics disturbance , inaccuracy and instability is created in the control system of converters.
9. Due to overheating , the life span of the electrical equipments is decreased , due to this cost of installation increases.
10. The power factor is very poor.
11. Harmonics are effects on speed-torque characteristics.

**Methods to minimize Harmonics:**

The following methods are used to minimize the harmonics in D.C & A.C waveform.

1. By increasing pulse number.
2. DC smoothing reactor.
3. AC harmonic filter.
4. DC harmonic filter.

* Generally the filter consists of land C parameters . At the resonant frequency the filters offer low impedance path for harmonic frequencies & high impedance path for the frequency which are of the order other than the harmonic frequency.
* Smoothing reactor reduces the ripple from DC current waveform generally it is a high inductance coil. It is connected between converter bridges & DC link.
* The AC filters are connected in parallel to AC bus bars.
* DC harmonics filters are tuned for a particular frequency for which it offers a low impedance path.

**Effect of increased pulse number:**

* This method is used in static converters.
* The current harmonics injected into an AC network by static converter have the order pq+­1.

Where p is the pulse number at DC side of the converter & q is the integer.

* The higher the pulse number, higher the frequency of the lowest order harmonic produced. i.e., the harmonic frequencies generated depend on the pulse number of the rectifier circuit.
* As the harmonic frequencies increases, their amplifier decreases & they are eliminated.
* The 5th  and 7th  harmonics are produced over heating in 6 pulse converter station . In order to overcome these problems, the pulse number is increased.

**Types of Harmonics:**

In HVDC system, basically two types of harmonics are presented.

1. Characteristic harmonics
2. Non-characteristic harmonics.
3. **Characteristic Harmonics:**

The converters at sending end and at receiving end in a transmission line produces harmonics, which are caused due to distortion in voltage and current. The harmonic current produces heat which raises the temperature of a neutral conductor causing over voltage problems, tripping of circuit breakers. The system is under ideal operation at balanced AC voltage, symmetric 3-phase network with equidistance pulse, then converter produces some harmonics.

Such type of harmonics is called “characteristic harmonics”.

* In AC system the characteristic harmonic are given by,

n=pq±1

where p is the pulse number

q is the integer

n is the order of harmonics

* In DC system the characteristic harmonic are given by ,

n=pq

**Assumptions:**

1. Alternating voltage on the primary side of converter transfer is only fundamental component & as no higher order harmonics.
2. AC supply voltage primary side of converter transformer is 3-phase sinusoidal, balance, +ve sequence.
3. Delay angle for all the value arms are equal.
4. Overlap angle is neglected.

**Characteristics harmonic in AC currents:**

The equation for general waveform,

(i)

For a symmetry, Bn value is absent.

* **For a 3-pulse converter:**

Ao =

=

=

An=

An=

From eq (i) , we get

For a +ve pulses,

For a –ve pulses,

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Fourier series for both the pulses (i.e., +ve & -ve pulse)

F(wt) = F1 (wt) + F2(wt)

Harmonic current for 3-pulse converter,

The above equation is called as primary current of a 3-pulse converter.

* **For a 6-pulse converter:**

Put X=in the above primary current eq.

* **For a 12-pulse converter, Equation of primary current:**

The 12 pulse converter can be obtained by connecting two 6-pulse converters. Converter (1) transformer is connected as a Y-Y & harmonic current Ih1 is given by,

Converter (2) transformer is connected as a Y-∆ harmonic current Ih2 is given by,

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The total harmonic current in a 12-pulse converter is given by, Ih = Ih1 + Ih2

* **Characteristic harmonics in DC Voltage:**

The equation of general waveform,

Where

α is the delay angle in electrical degrees

µ is the commutation angle or overlap angle.

* **Non characteristic Harmonics:**

The harmonics that can’t eliminated & the order of which is other than characteristics harmonics are known as Non-characteristic harmonics.

**Causes:**

* Variation in firing angle of three arms of two 6-pulse converters.
* Variation in reactancy of 3-Ф.
* Unequal transformer leakage reactances.

**Effects:**

* Non-characteristic harmonic are not eliminated by A.C filters. The presence of non-characteristic harmonics having following problems.

1. Increasing telephone interference.
2. Possible instability in constant current control of converter.
3. Noise in communication system.
4. The influence of non-characteristic harmonic is less when compared to characteristic harmonics.
5. The amplitude of non-characteristic harmonic is very small when compared with lower order characteristic harmonic.
6. As the order of harmonics increases, the amplitude of both characteristic & non-characteristic harmonics will almost equal.
7. The magnitude of higher order harmonic is determined by measuring the amplitude only.

Non-characteristic harmonics are cause due to imbalance operation of bridges.

1. If unbalance in A.C voltage, variation in firing angle in converter & unequal leakage impedances in transformer.

**Telephone influence factor:**

The telephone influence factor of a current or voltage waveform in the power line conductor is a measure of the influence of harmonics on the telephone communication in the nearby circuits.

It is defined as the root-sum-square of the weighted harmonic voltages.

Where Ih = harmonic current injected

Zh = harmonic impedance of the system.

**Harmonic Distortion:**

* Harmonic distortion is the change in the waveform of the supply voltage from the sinusoidal voltage.
* Harmonic distortion is the production of harmonic frequencies by an electronic system when a signal is applied at the input. They are caused by interaction of distorting loads with the impedance of the supply network.
* If the input signal goes through some non-linear load, it includes some unwanted frequencies which are known as “harmonic distortions”.
* These are present in both voltage & current waveform.
* There are two types of harmonic distortion.

1. Even-order harmonic distortion
2. Odd-order harmonic distortion.

* i. If the frequency of distortion is even multiples of the centre frequency, then they are termed as “even order harmonic distortion”.
* ii. If the frequency of distortion is odd multiples of the centre frequency, then they are termed as “odd order harmonic distortion”.
* The effect of harmonic distortion includes the heating of induction motor, shunt capacitors, and transformers.
* The measure of the harmonic distortion present in the signal is given by total harmonic distortion.

It is expressed by,

Total harmonic distortion =

Where Ih is harmonic current injected

Zh is harmonic impedance of voltage

V1 is fundamental component of voltage

K is highest order harmonic considered

* When single harmonic considered, then harmonic distortion is given by