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Tutorial Sheet 7

Ques 1. Define characteristic harmonics, non-characteristic harmonics, Inter-harmonics and sub-harmonics.

Ans 1. **Characteristic Harmonics :**

Characteristic harmonics typically are those that are derived from the Fourier analysis of a symmetrical three-phase current. For example, with ordinary six-pulse rectifiers, the characteristic harmonics are the 5^{th}, 7^{th}, 11^{th}, 13^{th}, etc (odd order multiples excluding the triplens). The characteristic harmonics of a particular waveform are those that are normal harmonic components of a waveform that has a certain type of symmetry.

Non-Characteristic Harmonics :

Non-characteristic harmonics typically are those that originate as a result of modulation. For example, the current to a cycloconverter typically will include components that are characteristic harmonics plus and minus sidebands that are a function of the difference between the base input frequency to the cyclo-converter and its base output frequency. The non-characteristic harmonics would not be present except to the extent that the waveform does not perfectly conform to the pattern of symmetry. These are not integer multiples of the fundamental power frequency.

Interharmonics :

Between the harmonics of the power frequency voltage and current, further frequencies can be observed which are not an integer of the fundamental. They can appear as discrete frequencies or as a wide band spectrum. Interharmonics of a waveform can be defined in terms of its spectral components in the quasi - steady state over a range of frequencies. Interharmonics can be found in networks of all voltage classes. It is a result of frequency conversion and is not constant; but varies with load.

Subharmonics :

The term subharmonic does not have any official definition but is simply a special case of interharmonic for frequency components less than the power system frequency. Subharmonic frequencies are frequencies below the fundamental frequency of an oscillator in a ratio of $1/n$, with n being a positive integer number.

Ques2. Define THD, TDD, Transformer K-Factor and Telephone Influence Factor.

Ans2. Total Harmonic Distortion (THD) :

Total Harmonic Distortion (THD) is defined as the ratio of the rms value of the harmonic components to the rms value of the fundamental component and usually expressed in percent. This index is used to measure the deviation of a periodic waveform containing harmonics from a perfect sine wave. It is a measure of the effective value of harmonic distortion.

$$THD = \sqrt{\sum_{2}^{hmax} Mn^2}$$

where,

Mn is the rms value of the harmonic component h of the quantity M.

$$RMS = \sqrt{\sum_{1}^{hmax} Mn^2} = M_1 \sqrt{1+THD^2}$$

THD provides a good idea of how much extra heat will be generated when a distorted voltage is applied.

Total Demand Distortion (TDD):

Total demand distortion is defined as the total harmonic current distortion in presence of the maximum demand load current (15 or 30 minute demand) at fundamental frequency at the point of common coupling (PCC), calulated as the average current of the maximum demands for the previous twelve months.

The total harmonic demand distortion is the ratio of the rms value of the harmonic content to the rms value of the rated or maximum demand fundamental current expressed as a percent.

$$TDD = \sqrt{\frac{\sum_{h=2}^{hmax} I_h^2}{I_L}}$$

where,

I_L = peak demand load current

Transformer K-Factor:

Transformer K-Factor is an index used to calculate the derating of standard transformers when harmonic currents are present. K-factors are a weighing of the harmonic load currents according to their effects on transformer heating.

$$K\text{-Factor} = \sum (I_h^2)\, h^2 \quad \text{—— (i)}$$

where,

I_h = load current at harmonic h. expressed in a per-unit basis such that the total RMS current is 1 A.

That is,

$$\sum (I_h)^2 = 1.0 \quad \text{—— (ii)}$$

The K-rated transformer is constructed to withstand more voltage distortion than standard transformers. It relates to the excessive heat that must be dissipated by the transformer.

Telephone Influence Factor:

Telephone Influence Factor (TIF) is a measure used to describe the telephone noise originating from harmonic currents and voltages in power systems. TIF is adjusted based on the ~~severity~~ sensitivity of the telephone system and the human ear to noises at various frequencies

$$TIF = \frac{\sqrt{\sum_{1}^{\infty} w_i^2 I_i^2}}{I_{rms}}$$

where,

w_i is a weighting accounting for audio and inductive coupling effects at i^{th} harmonic frequen

TIF is a variation of THD where the root of the sum of the squares is weighted using factors that reflect the response in the voice band.

Ques 3. Considering the philosophy of IEEE 519 standard for what corrective action is the end user responsible? For which corrective action is the supplying utility responsible?

Ans: The IEEE 519 standard divides the responsi-bility of limiting harmonics between both end users and the utility. End users will be responsible for limiting the harmonic current injection, while the utility will be primarily responsible for limiting voltage distortion in the supply system.
The harmonic current and voltage limits are applied at the point of common coupling. This is the point where other customers share the same bus or where new customers may be connected in the future. The standard seeks a fair approach to allocating harmonic limit quota for each customer. The standard allocates current injection limits based on the size of the load with respect to the size of the power system, which is defined by its short-circuit capacity. The short-circuit ratio is defined as the ratio of the maximum short-circuit current at the PCC to the maximum demand load current at the PCC as well.

The basis for limiting harmonic injections from individual customers is to avoid unacceptable levels of voltage distortion. Thus the current limits are developed so that the total harmonic injections from an individual customer do not exceed the specified maximum voltage distortion for various system voltages. Smaller loads are allowed a higher percentage of harmonic currents than larger loads with smaller short-circuit ratio values. Larger loads have to meet more stringent limits since they occupy a larger portion of system load capacity. The current limits take into account the diversity of harmonic currents in which some harmonics tend to cancel out while others are additive.

Since voltage distortion is dependent on the system impedance, the key to controlling voltage distortion is to control the impedance. The two main conditions that result in high impedance are when the system is too weak to supply the load adequately or the system is in resonance. Therefore, keeping the voltage distortion low usually means keeping the system out of resonance. Occasionally, new transformers and lines have to be added to increase the system strength. Out of the two phenomenon, the system being in resonance is generally more common.

Ques 4. Can power factor correction capacitor be neglected in harmonic studies? Explain.

Ans 4. Power factor can be viewed as the percentage of total apparent power that is converted into real or useful power.
It is also seen as the displacement between the voltage and the current waveforms.
The displacement power factor is given as under:

$$P.F. = \cos\phi$$

The presence of harmonics results in waveform distortions and hence result in true power factor being different from the displacement power factor.
Appliances have motors that result in lagging power factor (current lags the voltage, thus resulting in positive ϕ).
To compensate for this lagging power factor, capacitor banks are put in place that result in leading power factor (current leads the voltage, thus resulting in negative ϕ).
Large power factor correction capacitors can result in flow of capacitive current eventually resulting in increased voltage.
Capacitor banks are designed to operate at a maximum of 110% of their rated voltage and 135% of their rated KVARs. Large voltage and current harmonics result in ratings getting exceeded and hence significant loss. Reactance of capacitors is inversely proportional to their frequency, so high

frequency harmonics easily find a low reactance path into the capacitor banks causing overload and subsequent failures. A more serious condition with potential for much larger damage is harmonic resonance which happens when the inductive and the capacitive reactances become equal on one of the harmonic frequencies.

The capacitive effects are normally neglected on utility distribution systems and industrial systems, because at the fundamental frequency, the power systems are primarily inductive to reduce various power system losses.

Ques 5. How important is the representation of skin effect on harmonic ~~st~~ study? Explain.

Ans 5. The consideration of skin effect is important in harmonic studies because harmonic currents ~~are~~ of electronic circuits, especially power electronic and FACTS devices are observed to be drastically increasing due to the skin effect.

Ideally, the inductance of FACTS devices are taken to be of a constant magnitude, but with the introduction of the skin effect, it is observed that the inductance of FACTS devices decreases with ~~to~~ the increasing harmonic frequency. Due to skin effect, the actual losses will be

much higher than the calculated values. When the skin effect occurs, the effective cross-sectional area of the conductor decreases; increasing the resistance and the I^2R losses, which in turn heats up the conductors and anything connected to them. This heating effect causes the circuit breakers to trip, neutral and phase conductors to heat up to critical flashover temperatures, and premature failures of motors and transformers. This is costly in terms of down-time, loss of production, repair and possible reconstruction.
This problem of skin effect becomes more pronounced in case of three-phase applications, as the harmonics get more complicated in terms of components, as here we have to not only deal with phase conductors, but also the neutral conductor, triplen (odd multiples of 3) harmonics, and sequence harmonics. The triplen harmonics (3rd, 9th, 15th, etc) are the major cause of heat because they add together in the neutral conductor. The magnitude of the harmonic current produced by the triplens can approach twice the phase current. This causes overheating of the neutral conductor. Also, the combination of positive and negative sequenced harmonics produces abnormal amounts of heat in motors especially, causing premature failure.