

12 Harmonics

In addition to the operation of transformers on the sinusoidal supplies, the harmonic behavior becomes important as the size and rating of the transformer increases. The effects of the harmonic currents are

1. Additional copper losses due to harmonic currents
2. Increased core losses
3. Increased electro magnetic interference with communication circuits.

On the other hand the harmonic voltages of the transformer cause

1. Increased dielectric stress on insulation
2. Electro static interference with communication circuits.
3. Resonance between winding reactance and feeder capacitance.

In the present times a greater awareness is generated by the problems of harmonic voltages and currents produced by non-linear loads like the power electronic converters. These combine with non-linear nature of transformer core and produce severe distortions in voltages and currents and increase the power loss. Thus the study of harmonics is of great practical significance in the operation of transformers. The discussion here is confined to the harmonics generated by transformers only.

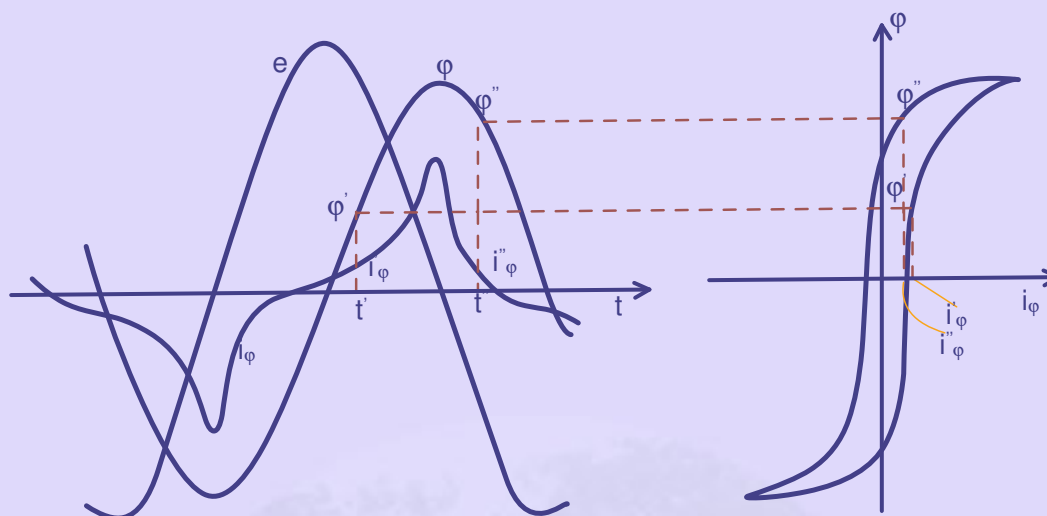


Figure 34: Harmonics Generated by Transformers

12.1 Single phase transformers

Modern transformers operate at increasing levels of saturation in order to reduce the weight and cost of the core used in the same. Because of this and due to the hysteresis, the transformer core behaves as a highly non-linear element and generates harmonic voltages and currents. This is explained below. Fig. 34 shows the manner in which the shape of the magnetizing current can be obtained and plotted. At any instant of the flux density wave the ampere turns required to establish the same is read out and plotted, traversing the hysteresis loop once per cycle. The sinusoidal flux density curve represents the sinusoidal applied voltage to some other scale. The plot of the magnetizing current which is peaky is analyzed using Fourier analysis. The harmonic current components are obtained from this analysis. These harmonic currents produce harmonic fields in the core and harmonic voltages in the windings. Relatively small value of harmonic fields generate considerable magnitude of harmonic voltages. For example a 10% magnitude of 3rd harmonic flux produces 30%

magnitude of 3rd harmonic voltage. These effects get even more pronounced for higher order harmonics. As these harmonic voltages get short circuited through the low impedance of the supply they produce harmonic currents. These currents produce effects according to Lenz's law and tend to neutralize the harmonic flux and bring the flux wave to a sinusoid. Normally third harmonic is the largest in its magnitude and hence the discussion is based on it. The same can be told of other harmonics also. In the case of a single phase transformer the harmonics are confined mostly to the primary side as the source impedance is much smaller compared to the load impedance. The understanding of the phenomenon becomes more clear if the transformer is supplied with a sinusoidal current source. In this case current has to be sinusoidal and the harmonic currents cannot be supplied by the source and hence the induced emf will be peaky containing harmonic voltages. When the load is connected on the secondary side the harmonic currents flow through the load and voltage tends to become sinusoidal. The harmonic voltages induce electric stress on dielectrics and increased electro static interference. The harmonic currents produce losses and electro magnetic interference as already noted above.

12.2 Three phase banks of single phase transformers

In the case of single phase transformers connected to form three phase bank, each transformer is magnetically decoupled from the other. The flow of harmonic currents are decided by the type of the electrical connection used on the primary and secondary sides. Also, there are three fundamental voltages in the present case each displaced from the other by 120 electrical degrees. Because of the symmetry of the a.c. wave about the time axis only odd harmonics need to be considered. The harmonics which are triplen (multiples of three) behave in a similar manner as they are co-phasal or in phase in the three phases. The

non-triplen harmonics behave in a similar manner to the fundamental and have $\pm 120^\circ$ phase displacement between them. The harmonic behavior of poly-phase banks can be discussed now.

Dd connection In three phase banks with mesh connection on both primary side and secondary side a closed path is available for the triplen harmonics to circulate currents. Thus the supply current is nearly sinusoidal (but for the non-triplen harmonic currents). The triplen harmonic currents inside the closed mesh winding correct the flux density wave to be nearly sinusoidal. The secondary voltages will be nearly sinusoidal. Third harmonics currents flow both in the primary and the secondary and hence the magnitudes of these currents, so also the drops due to them will be lower.

Dy and Yd connection (without neutral connection) Behavior of the bank with mesh connection on one side is similar to the one discussed under Dd connection. The harmonic currents and drops and the departure of the flux density from sinusoidal are larger in the present case compared to Dd banks.

Yy connection without neutral wires With both primary and secondary connected in star no closed path exists. As the triplen harmonics are always in phase, by virtue of the Y connection they get canceled in the line voltages. Non-triplen harmonics like fundamental, become $\sqrt{3}$ times phase value and appear in the line voltages. Line currents remain sinusoidal except for non-triplen harmonic currents. Flux wave in each transformer will be flat topped and the phase voltages remain peaked. The potential of the neutral is no longer steady. The star point oscillates due to the third harmonic voltages. This is termed as "oscillating neutral".

Yy connection with neutral wires When a neutral wire is provided the triplen har-

monic current can flow and the condition is similar to the single phase case (with a star connected 4 wire source or with the system earth). The neutral wire carries three times the triplen harmonic current of one transformer as these currents are co-phasal. Unloaded secondary neutral will not be operative. Other polyphase connections not discussed above explicitly will fall under one type or the other of the cases discussed. In a Yy connection, to obtain third harmonic suppression one may provide a third winding which is connected in mesh, which can be an unloaded winding. It is called a tertiary. This winding improves the single phase to earth fault detection also. Further, this winding can be used to feed some permanent station loads also. Such transformers are designated as Yyd transformers. If the neutral wires are provided and also mesh connected winding is present, then triplen harmonics are 'shared' between them depending upon their impedances.

12.3 Three phase transformers units

As against a bank of three single phase transformers connected to three phase mains, a three phase transformer generally has the three magnetic circuits that are interacting. The exception to this rule is a 3-phase shell type transformer. In the shell type of construction, even though the three cores are together, they are non-interacting. Three limb core type 3-phase transformer is the one in which the phases are magnetically also linked. Flux of each limb uses the other two limbs for its return path. This is true for fundamental and non-triplen harmonics. The triplen harmonics being co-phasal cannot use other limbs for the return path (this holds good for zero sequence, unbalanced fundamental mmf also). The flux path is completed through the air. So substantially large value of the mmf produces a low value of third harmonic flux as the path of the flux is through the air and has a very

high reluctance. Thus the flux in the core remains nearly sinusoidal, so also the induced emf. This happens irrespective of the type of connection used. The triplen order flux, sometimes links the tank and produces loss in the same.

Other harmonics can be suppressed by connecting tuned filters at the terminals. Harmonic current compensation using special magnetic circuit design is considered to be outside the scope here.

