Triplen Harmonics in Electrical Distribution Systems

Nikita Ingle

ABSTRACT:- In an AC circuit, a resistance behaves in exactly the same way as it does in a DC circuit. That is, the current flowing through the resistance is proportional to the voltage across it. This is because a resistor is a linear device and if the voltage applied to it is a sine wave, the current flowing through it is also a sine wave. But most electronic power supply switching circuits such as rectifiers, silicon controlled rectifier (SCR's), power transistors, power converters and other such solid state switches which cut and chop the power supplies sinusoidal waveform to control motor power, or to convert the sinusoidal AC supply to DC. Theses switching circuits tend to draw current only at the peak values of the AC supply and since the switching current waveform is non-sinusoidal the resulting load current is said to contain Harmonics. we can say that "harmonics" are multiples of the fundamental frequency and can therefore be expressed as: 2ƒ, 3ƒ, 4ƒ, etc. Positive sequence harmonics (4th, 7th, 10th, …) causes overheating of transformer ,conductor power lines whereas negative sequence harmonics (2nd, 5th, 8th, …) circulates between phases producing additional problems in motor as opposite phasor rotation weakens rotating magnetic field required by the motor. There is another harmonics set called triplen means odd multiple of third harmonics (3rd, 6th, 9th, …), etc zero rotational sequence hence therefore zero sequence harmonics circulates between phase and neutral or ground.

Keywords: AC circuit, DC circuit, (SCR's), AC supply to DC, "harmonics", as: 2ƒ, 3ƒ, 4ƒ, (2nd, 5th, 8th, …),(3rd, 6th, 9th, …)

I. INTRODUCTION

In an AC circuit, a resistance carries on in the very same route as it does in a DC circuit. That is, the current moving through the resistance is relative to the voltage crosswise over it. This is on the grounds that a resistor is a linear gadget and if the voltage connected to it is a sine wave, the current moving through it is likewise a sine wave. By and large when managing substituting voltages and streams in electrical circuits it is expected that they are immaculate and sinusoidal fit as a fiddle with stand out recurrence worth, called the "Fundamental harmonics" being available, however this is not generally the situation. In an electrical or electronic gadget or circuit that has a voltage-current trademark which is not straight, that is, the current moving through it is not relative to the connected voltage. The substituting waveforms connected with the gadget will be diverse to a more noteworthy or lesser degree to those of a perfect sinusoidal waveform. These sorts of waveforms are generally alluded to as non-sinusoidal or complex waveforms.

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Complex waveforms are created by normal electrical gadgets, for example, iron-cored inductors, exchanging transformers, electronic counterbalances in glaring lights and other such vigorously inductive load and the yield voltage and current waveforms of AC alternators, generators and other such electrical machines. The outcome is that the present waveform may not be sinusoidal despite the fact that the voltage waveform is.

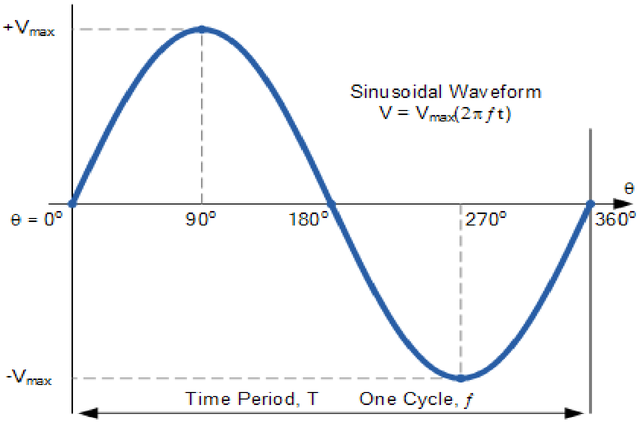
Additionally most electronic power supply exchanging circuits, for example, rectifiers, silicon controlled rectifier (SCR's), power transistors, power converters and other such strong state switches which cut and cleave the force supplies sinusoidal waveform to control engine power, or to change over the sinusoidal AC supply to DC. Postulations changing circuits tend to draw current just at the crest estimations of the AC supply and since the exchanging current waveform is non-sinusoidal the subsequent burden current is said to contain Harmonics.

Non-sinusoidal complex waveforms are developed by "including" together a progression of sine wave frequencies known as "Harmonics". Harmonics is the summed up term used to portray the contortion of a sinusoidal waveform by waveforms of distinctive frequencies.

At that point whatever its shape, a mind boggling waveform can be split up scientifically into its individual segments called the essential recurrence and various "Harmonic frequencies". Be that as it may, what do we mean by a "Fundamental frequency".

II. FUNDAMENTAL FREQUENCY

A Fundamental Waveform (or first symphonious) is the sinusoidal waveform that has the supply recurrence. The basic is the most reduced or construct recurrence, ƒ with respect to which the mind boggling waveform is assembled and thusly the occasional time, T of the subsequent complex waveform will be equivalent to the intermittent time of the basic recurrenc Let's consider the basic fundamental or 1st harmonic AC waveform as shown.



Where: Vmax is the peak value in volts and ƒ is the waveforms frequency in Hertz (Hz).

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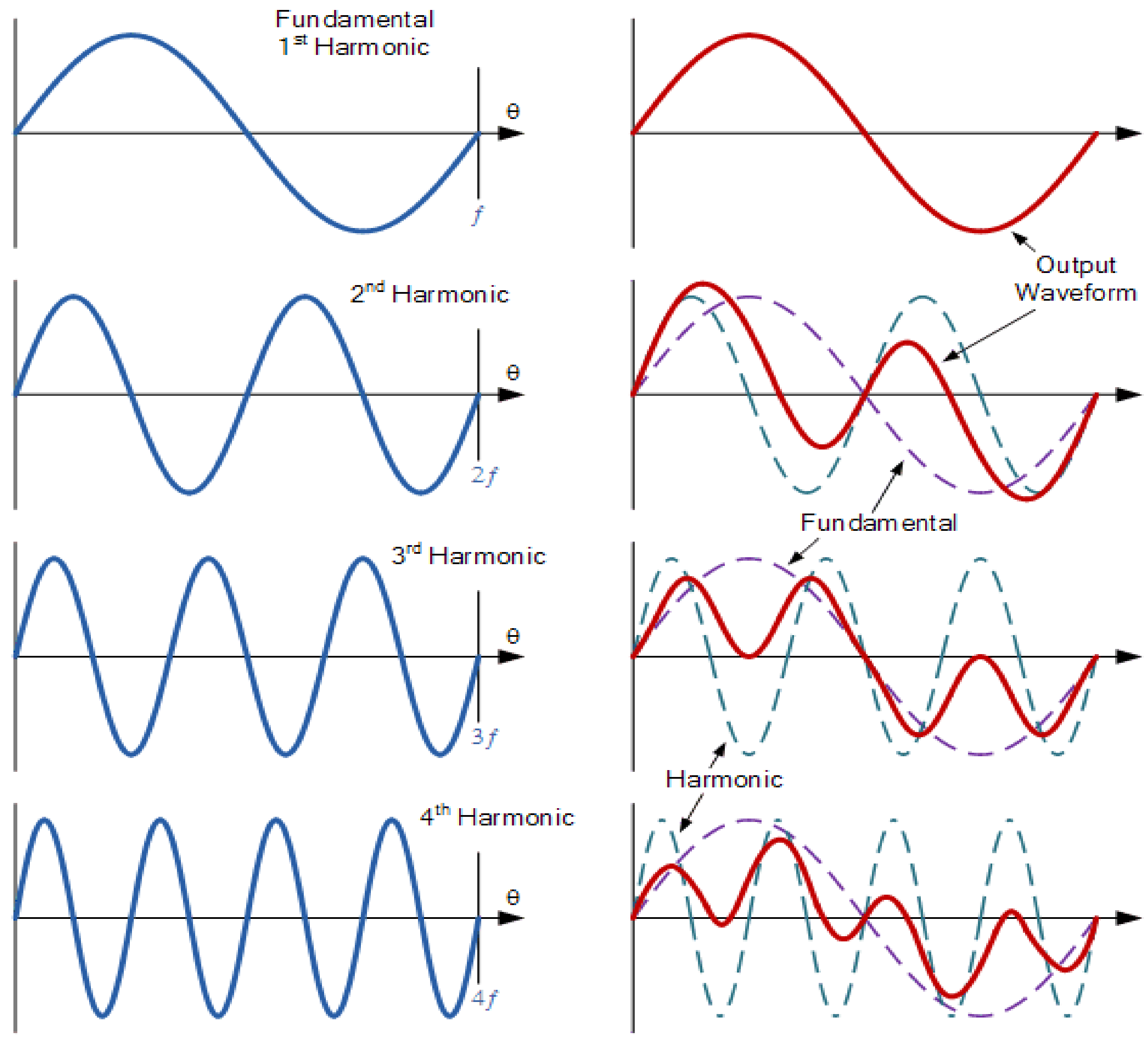
We can see that a sinusoidal waveform is an exchanging voltage (or current), which fluctuates as a sine capacity of edge, $2\pi f$. The waveforms recurrence, f is dictated by the quantity of cycles every second. In the United Kingdom this central recurrence is set at 50Hz while in the United States it is 60 Harmonics are voltages or currents that operate at a frequency that is an integer (whole-number) multiple of the fundamental frequency. So given a 50Hz fundamental waveform, this means a 2nd harmonic frequency would be 100Hz (2 x 50Hz), a 3rd harmonic would be 150Hz (3 x 50Hz), a 5th at 250Hz, a 7th at 350Hz and so on. Likewise, given a 60Hz fundamental waveform, the 2nd, 3rd, 4th and 5th harmonic frequencies would be at 120Hz, 180Hz, 240Hz and 300Hz respectively. So in other words, we can say that "harmonics" are multiples of the fundamental frequency and can therefore be expressed as: $2f$, $3f$, $4f$, etc. as shown.

III. COMPLEX WAVEFORMS DUE TO HARMONICS



Harmonic Waveforms

Complex Waveform

Note that the red waveforms above, are the actual shapes of the waveforms as seen by a load due to the harmonic content being added to the fundamental frequency. The essential waveform can likewise be known as a first harmonics waveform. In this manner, a second harmonics has a frequency twice that of the fundamental, the third harmonics has a frequency three times the fundamental and a fourth harmonics has one four times the key as appeared in the left hand side segment.

The right hand side section demonstrates the perplexing wave shape produced as an aftereffect of the impact between the expansion of the major waveform and the harmonics waveforms at distinctive harmonic frequencies. Note that the state of the subsequent complex waveform will depend not just on the number and plentifulness of the harmonics frequencies present, additionally on the stage relationship between the central or base recurrence and the individual consonant frequencies.

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We can see that a complex wave is made up of a fundamental waveform plus harmonics, each with its own peak value and phase angle. For example, if the fundamental frequency is given as; E = Vmax $(2\pi f t)$, the values of the harmonics will be given as:

For a second harmonic:

$$E2 = V2max(2\times 2\pi f t) = V2max(4\pi f t), = V2max(2\omega t)$$

For a third harmonic:

$$E3 = V3max(3\times 2\pi f t) = V3max(6\pi f t), = V3max(3\omega t)$$

For a fourth harmonic:

$$E4 = V4max(4\times 2\pi f t) = V4max(8\pi f t), = V4max(4\omega t)$$

And so on.

Then the equation given for the value of a complex waveform will be:

$$E_T = E_1 + E_2 + E_3 + \ldots\ldots E_{(n)} \text{ etc.}$$

$$E_T = V_{1max}\sin(2\pi f t) + V_{2max}\sin(4\pi f t) + V_{3max}\sin(6\pi f t)\ldots\text{etc.}$$

Harmonics are generally classified by their name and frequency, for example, a 2nd harmonic of the fundamental frequency at 100 Hz, and also by their sequence. Harmonic sequence refers to the phasor rotation of the harmonic voltages and currents with respect to the fundamental waveform in a balanced, 3-phase 4-wire system. A positive sequence harmonic (4th, 7th, 10th, …) would rotate in the same direction (forward) as the fundamental frequency. Where as a negative sequence harmonic (2nd, 5th, 8th, …) rotates in the opposite direction (reverse) of the fundamental frequency. Generally, positive sequence harmonics are undesirable because they are responsible for overheating of conductors, power lines and transformers due to the addition of the waveforms. Negative sequence harmonic then again flow between the phases making extra issues with motor as the opposite phasor revolution debilitates the turning attractive field require by engines, and particularly induction motor, making them create less mechanical torque. Another set of special harmonics called "triplens" (multiple of three) have a zero rotational sequence. Triplens are the odd multiples of the third harmonic (3rd, 6th, 9th, …), etc, hence their name, and are therefore displaced by zero degrees. Zero sequence harmonics circulate between the phase and neutral or ground. Unlike the positive and negative sequence harmonic currents that cancel each other out, third order or triplen harmonics do not cancel out. Instead add up arithmetically in the common neutral wire which is subjected to currents from all three phases. The result is that current amplitude in the neutral wire due to these triplen harmonics could be up to 3 times the amplitude of the phase current at the fundamental frequency causing it to become less efficient and overheat. Then we can summarise the sequence effects as multiples of the fundamental frequency of 50Hz as:

Harmonic Sequencing

Name	Fund.	2nd	3rd	4th	5th	6th	7th	8th	9th
Frequency, Hz	50	100	150	200	250	300	350	400	450
Sequence	+	–	0	+	–	0	+	–	0

Note that the same harmonic sequence also applies to 60Hz fundamental waveforms.

Sequence	Rotation	Harmonic Effect
+	Forward	Excessive Heating Effect
–	Reverse	Motor Torque Problems
0	None	Adds Voltages and/or Currents in Neutral Wire causing Heating

The third harmonic has brought about much power quality issue in the nutral of distribution system. Silent pole synchronous generator has been perceived as one of the triplen/third harmonic sources. This examination is gone for concentrating on the normal for third harmonic from generator coursing through the load specifically, by means of transformer and shunt association with rectifier. Lab scale trials have been led to change load impedance and transformer winding setup. At the point when generator is joined specifically to a consolidated resistive and inductive load, the third symphonious current and voltage rely on upon the load impedance magnitude and phase angle. Since the third harmonic voltage created by generator are in phase or zero sequence in nature, the third harmonic current rely on upon transformer winding setup, the load impedance magnitude and phase angle. At the point when full-wave bridge rectifier is shunt joined in the middle of generator and load, the third harmonic current at both rectifier and load are really originating from generator that rely on upon load impedance magnitude and phase angle. It is prescribed that the study on third harmonic voltage and current performing so as to engender from generator ought to be finished harmonic estimation and examination at all parts of the system. Third harmonic voltage and current extent alone may not give right sign to their seriousness in light of the fact that they are vector amount and depend on zero arrangement system, load impedance magnitude and phase angle.

IV. STAR-STAR (Y-Y)CONNECTION

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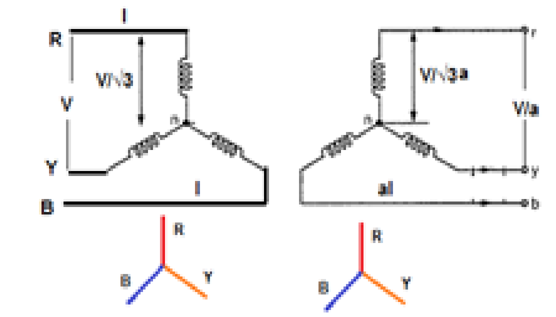
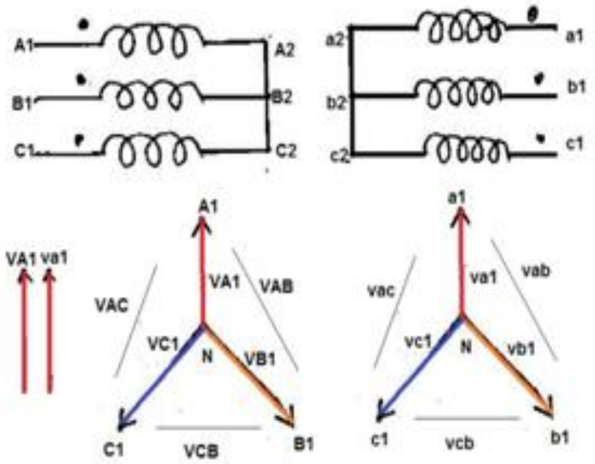
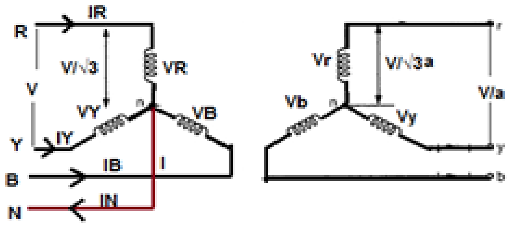


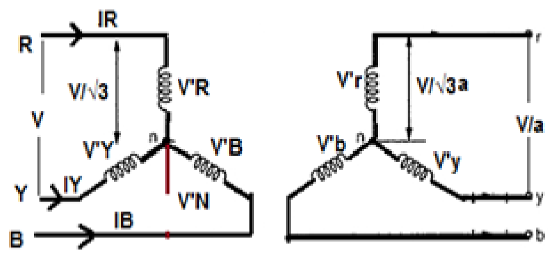
- In Primary Winding Each Phase is120°electrical degrees apart from the other two phases.
- In Secondary Winding Each Phase is120°electrical degrees apart from the other two phases.
- Each primary winding is magnetically linked to one secondary winding through a common core leg. Sets of windings that are magnetically linked are drawn parallel to each other in the vector diagram. In the Y-Y connection, each primary and secondary winding is connected to a neutral point.
- The neutral point may or may not be brought out to an external physical connection and the neutral may or may not be grounded.



- Transformer magnetizing currents are not purely sinusoidal, even if the exciting voltages are sinusoidal. The magnetizing currents have significant quantities of odd-harmonic components. If three identical transformers are connected to each phase and are excited by 60 Hz voltages of equal magnitude, the 60 Hz fundamental components of the exciting currents cancel out each other at the neutral. This is because the 60 Hz fundamental currents of A, B, and C phase are 120° out of phase with one another and the vector sum of these currents is zero.
- The third, ninth, fifteenth and other so-called zero-sequence harmonic currents are in phase with each other; therefore, these components do not cancel out each other at the neutral but add in phase with one another to produce a zero-sequence neutral current, provided there is a path for the neutral current to flow.
- Due to the nonlinear shape of the B-H curve, odd-harmonic magnetizing currents are required to support sinusoidal induced voltages. If some of the magnetizing current harmonics are not present, then the induced voltages cannot be sinusoidal.
- **Y-Y Connection with Grounded Neutral :**
- Figure Show the situation where the primary neutral is returned to the voltage source in a four-wire three-phase circuit. Each of the magnetizing currents labeled IR, IY, and IB contain the 60 Hz fundamental current and all of the odd harmonic currents necessary to support sinusoidal induced voltages.



- The zero-sequence magnetizing currents combine to form the neutral current IN, which returns these odd harmonics to the voltage source. Assuming that the primary voltage is sinusoidal, the induced voltages VR , VY , and VB (in both the primary and secondary) are sinusoidal as well.
- The connection of primary neutral to the neutral of generator has an add advantage that it eliminates distortion in the secondary phase voltages. If the flux in the core has sinusoidal waveform then it will give sinusoidal waveform for the voltage. But due to characteristic of iron, a sinusoidal waveform of flux requires a third harmonic component in the exciting current. As the frequency of this component is thrice the frequency of circuit at any given constant. It will try to flow either towards or away from the neutral point in the transformer windings. With isolated neutral, the triple frequency current cannot flow so the flux in the core will not be a sine wave and the voltages are distorted. If primary neutral is connected to generator neutral the triple frequency currents get the path to solve the difficulty. The alternative way of overcoming with this difficulty is the use of tertiary winding of low KVA rating. These windings are connected in delta and provide a circuit in which triple frequency currents can flow. Thus sinusoidal voltage on primary will give sinusoidal voltage on secondary side.
- This situation changes if the neutrals of both sets of the primary and secondary windings are not grounded.
- **Y-Y Connection without Grounded Neutral:** If the neutrals of both the primary and the secondary are open-circuited and so there is no path for the zero-sequence harmonic currents to flow and the induced voltages will not be sinusoidal.



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- V'R, V'Y, and V'B will not be sinusoidal. This results in distortions of the secondary voltages. The resulting voltage distortion is equivalent to a Y-Y transformer with zero-sequence currents allowed to flow in the primary neutral with an imaginary superimposed primary winding carrying only the zero-sequence currents 180° out of phase with the normal zero-sequence currents.
- Analysis of the voltages induced by the ‘‘primary windings’’ is greatly complicated by the fact that the core is highly nonlinear so that each of the individual zero-sequence harmonics currents carried by the phantom primary windings will induce even higher-order harmonic voltages as well.
- Fourier analysis can be used to arrive at an approximation of the secondary voltages with an open primary neutral. Taking one phase at a time, the normal magnetizing current for a sinusoidal exciting voltage is plotted from the B-H curve of the transformer. The normal magnetizing current is converted to a Fourier series and then it is reconstructed by removing all of the zero-sequence harmonics. The resulting exciting current will have a shape different from the normal exciting current, which is then used to construct an induced voltage using the B-H curve in there verse manner that was used to construct the original exciting current. This process is rather laborious, so suffice it to say that if a Y-Y transformer does not have a neutral path for zero-sequence exciting currents, there will be harmonic voltages induced in the secondary even if the exciting voltage is purely sinusoidal.

V. ADVANTAGE OF Y-Y CONNECTION

- **No Phase Displacement:** The primary and secondary circuits are in phase; i.e., there are no phase angle displacements introduced by the Y-Y connection. This is an important advantage when transformers are used to interconnect systems of different voltages in a cascading manner. For example, suppose there are four systems operating at 800, 440, 220, and 66 kV that need to be interconnected. Substations can be constructed using Y-Y transformer connections to interconnect any two of these voltages. The 800 kV systems can be tied with the 66 kV systems through a single 800 to 66 kV transformation or through a series of cascading transformations at 440,220 and 66 kV.
- **Required Few Turns for winding:** Due to star connection, phase voltages is (1/√3) times the line voltage. Hence less number of turns is required. Also the stress on insulation is less. This makes the connection economical for small high voltage purposes.
- **Required Less Insulation Level**: If the neutral end of a Y-connected winding is grounded, then there is an opportunity to use reduced levels of insulation at the neutral end of the winding. A winding that is connected across the phases requires full insulation throughout the winding.
- **Handle Heavy Load:** Due to star connection, phase current is same as line current. Hence windings have to carry high currents. This makes cross section of the windings high. Thus the windings are mechanically strong and windings can bear heavy loads and short circuit current.
- **Use for Three phases Four Wires System:** As neutral is available, suitable for three phases four wire system.
- **Eliminate Distortion in Secondary Phase Voltage:** The connection of primary neutral to the neutral of generator eliminates distortion in the secondary phase voltages by giving path to triple frequency currents toward to generator.
- **Sinusoidal voltage on secondary side:** Neutral give path to flow Triple frequency current to flow Generator side thus sinusoidal voltage on primary will give sinusoidal voltage on secondary side.
- **Used as Auto Transformer:** A Y-Y transformer may be constructed as an autotransformer, with the possibility of great cost savings compared to the two-winding transformer construction.
- **Better Protective Relaying:** The protective relay settings will be protecting better on the line to ground faults when the Y-Y transformer connections with solidly grounded neutrals are applied.

VI. DISADVANTAGE OF Y-Y CONNECTION

- **The Third harmonic issue:** The voltages in any phase of a Y-Y transformer are 1200 apart from the voltages in any other phase. However, the third-harmonic components of each phase will be in phase with each other. Nonlinearities in the transformer core always lead to generation of third harmonic. These components will add up resulting in large (can be even larger than the fundamental component) third harmonic component.
- **Overvoltage at Lighting Load:** The presence of third (and other zero-sequence) harmonics at an ungrounded neutral can cause overvoltage conditions at light load. When constructing a Y-Y transformer using single-phase transformers connected in a bank, the measured line-to-neutral voltages are not 57.7% of the system phase-to-phase voltage at no load but are about 68% and diminish very rapidly as the bank is loaded. The effective values of voltages at different frequencies combine by taking the square root of the sum of the voltages squared. With sinusoidal phase-to-phase voltage, the third-harmonic component of the phase-to-neutral voltage is about 60%.
- **Voltage drop at Unbalance Load:** There can be a large voltage drop for unbalanced phase-to-neutral loads. This is caused by the fact that phase-to-phase loads cause a voltage drop through the leakage reactance of the transformer whereas phase-to-neutral loads cause a voltage drop through the magnetizing reactance, which is 100 to 1000 times larger than the leakage reactance.
- **Overheated Transformer Tank:** Under certain circumstances, a Y-Y connected three-phase trans- can produce severe tank overheating that can quickly destroy the transformer. This usually occurs with an open phase on the primary circuit and load on the secondary.
- **Over Excitation of Core in Fault Condition:** If a phase-to-ground fault occurs on the primary circuit with

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the primary neutral grounded, then the phase-to-neutral voltage on the un faulted phases increases to 173% of the normal voltage. This would almost certainly result in over excitation of the core, with greatly increased magnetizing currents and core losses

- If the neutrals of the primary and secondary are both brought out, then a phase-to-ground fault on the secondary circuit causes neutral fault current to flow in the primary circuit. Ground protection re- laying in the neutral of the primary circuit may then operate for faults on the secondary circuit
- **Neutral Shifting:** If the load on the secondary side unbalanced then the performance of this connection is not satisfactory then the shifting of neutral point is possible. To prevent this, star point of the primary is required to be connected to the star point of the generator.
- **Distortion of Secondary voltage:** Even though the star or neutral point of the primary is earthed, the third harmonic present in the alternator voltage may appear on the secondary side. This causes distortion in the secondary phase voltages.
- **Over Voltage at Light Load:** The presence of third (and other zero-sequence) harmonics at an ungrounded neutral can cause overvoltage conditions at light load.
- **Difficulty in coordination of Ground Protection:** In Y-Y Transformer, a low-side ground fault causes primary ground fault current, making coordination more difficult.
- **Increase Healthy Phase Voltage under Phase to ground Fault:** If a phase-to-ground fault occurs on the primary circuit with the primary neutral grounded, then the phase-to-neutral voltage on the UN faulted phase's increases to 173% of the normal voltage. If the neutrals of the primary and secondary are both brought out, then a phase-to-ground fault on the secondary circuit causes neutral fault current to flow in the primary circuit.
- **Trip the T/C in Line-Ground Fault:** All harmonics will propagate through the transformer, zero-sequence current path is continuous through the transformer, one line-to-ground fault will trip the transformer.
- **Suitable for Core Type Transformer:** The third harmonic voltage and current is absent in such type of connection with three phase wire system. or shell type of three phase units, the third harmonic phase voltage may be high. This type of connection is more suitable for core type transformers.

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