RESEARCH ARTICLE OPEN ACCESS

Harmonics Effects in Power System

Eng. Osamah Saleh Al-duaij
Public Authority for Applied Education and Training Electricity and Water Training Institute Electrical Power Department

Abstract
The summary of the research, first is to introduce the harmonics in power system, by explains the meanings of the harmonic, causes and sources. Then the effects of the harmonics in power system.
Second to analysis the harmonics during the fourier analysis, how we can calculate and analysis the harmonics.
Third, the experiment part which is the results form lab work to inform the harmonics effects in power system.
Fourth, which is explain how to eliminate the harmonics in power system, then the finally the conculation which is try to concluote the all parts of the research.
Objective:-
To study and search on the causes and effects, of harmonics in the public electric supply system.
To achieve the objective the following library search and experimentation has been concluoted.

I. Introduction

1.1 Background:-

In an ideal electrical power, system energy is supplied at a single and constant frequency, and at specified voltage levels of constant magnitudes and sine wave in shape. However, none of those conditions are fulfilled in practice. The problems of voltage and frequency deviations, and the means of keeping them under control, are the subject matter of conventional power system analysis. The problem of waveform distortion, so far neglected in power system.

Power system distortion is not a new phenomenon, and containing it to acceptable proportion has been a concern of power engineers from the early days of alternating current. The recent growing concern for these problem results form the increasing numbers and power rating of the highly non-linear power electronic devices used in the control of power apparatus and system.

The deviation from perfect sinusoids is generally expressed in terms of harmonic components. In this introductory there are briefly defining the meant of harmonics, causes and, effects.

To put the subject in historical perspective, it is necessary to go back to the 18th and 19th century when various mathematicians, and in particular J.B.J. Fourier (1768-1830), set up the basis for harmonic calculation.

The problem of power system harmonics is not new. Utilities recognized the important of harmonics in the 1920s and early 1930s when distorted voltage and current wave forms were observed on transmission lines. At that time, the major concerns were the affects of harmonics on synchronous and induction machines, telephone interference, and power capacitor failures.

1.2 What is meant by 'harmonics':-

The word 'harmonic' was originally used in relation to sound and signified a vibration of a string or column of air at a multiple of the fundamental frequency. The same idea has taken over into electrical engineering where a distorted current or voltage wave form is represented, by the well-known method of fourier analysis, as the sum of a fundamental and a series of harmonic components. For this to be valid, the distorted wave form has to have the same wave shape for an indefinite number of cycles.

Many power system loads cause distortion that changes as the operating condition change. This presents no difficulty provided that the condition to be studied persists for a reasonable length of time. However, it is necessary to distinguish between a harmonic and a transient and some care has to be taken when speaking of harmonic distortion in relation to waveforms that differ markedly form one cycle to the next.

One big advantage of the method of representing a distorted wave as made up to a fundamental and a series of harmonics is that in a linear system, each harmonic component may be considered separately and the final distortion found by superposition of the various components.

In acoustics the additions of harmonics to the fundamental changes the equality of the sound but is generally considered that the audible effect is not effected by phase relationship between the harmonic components and the fundamental.

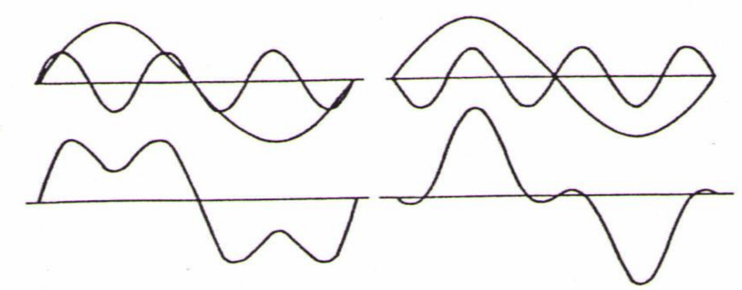


FIG. 1 Effect of harmonic phase angle on waveshape.

In electrical engineering, however, the phase relationship between the fundamental and the harmonic components may be of the greatest importance. (Fig 1) shows the addition of third harmonic component to a fundamental with two different phase relationships.

One increases the crest value of the wave and the other reduces it. When several different sources combine together, the phase angle of the harmonic components may differ considerably and the resulting distortion may be emphasized or reduced.

In power systems the distortion of the voltage wave often needs to be kept small. Under such conditions the shapes of the current wave drawn by a distorting load is little affected by the exact wage form of the voltage supply. It is permissible to represent the distorting equipment as a source of harmonic current that are independent of the impedance of the supplying of the system. The effect of superposing a number of sources on a system can then be found by representing each of them by an equivalent current source at its point of connection. As with any method of calculation, this representation must not be used when the assumptions upon which it is based are no longer valid, for instance in circuit where there is a non-linear relationship between voltage current.

1.3 Causes of harmonics:-

If a power system is to supply a good sinusoidal Voltage the generators themselves must generate a sinusoidal waveform. The design of alternators for power is, in fact such that for practical purposes regard that wave form at the point of generation as a pure sine wage. All the distortion of importance occurs in the transmission and distribution of electricity between the generators and the load point.

Using the ideas of an equivalent current source and the superposition of individual harmonic components, one sees that the distortion of the voltage at a particular point on the network can be as being caused by the flow of harmonic currents through the impedance provided by the supply system. Starting form the generator terminal, the first components to effect the waveforms are the transformers. Partial saturation of the iron causes the magnetizing current to differ significantly from a sin wave, which is to say that it contains harmonic components. These harmonics of the magnetizing current contribute to the distortion of supply voltage to an extent that depends on the source impedance of the supply and the magnitude of the harmonic current.

The larger amounts of harmonic distortion are more usually cussed by various types of rectifying load. For a rectifier of a given size, the harmonic currents are effected by the pulse number and the possible application of phase angle control. In addition, however, one must not over look the effects of overlap as current is transferred from one branch of the rectifier to another, or the influence of the amount of smoothing on the dc. side. AC. Regulators are another potent source of harmonic current distortion. Loads containing saturated iron cores also draw distorted current. This is clearly evident in the distortion of current from fluorescent and other discharge lighting. The currents from discharge lamps have large component, the third harmonic current S from discharge lamps on a 3-phase supply adds together in the neutral conductor, it is important to ensure that the neutral conductor has a sufficient cross-section on low voltage systems supplying large discharge lighting installations.

Significant amounts of harmonic distortion may arise, not only from large installation but from the combined effect of large numbers of small installation. This became particularly apparent when the design of television receivers was changed. A circuit for supplying the dc to television receivers that became popular with receiver manufactures drew a large pulse of current over a short part of one half wave of the supply voltage. This was equivalent to injecting into the supply a substantial amount of harmonic current and, indeed, direct current. Because the current was drawn on only the half-wave, the distorted voltage contained a large second and fourth harmonic component as shown in Fig 2.

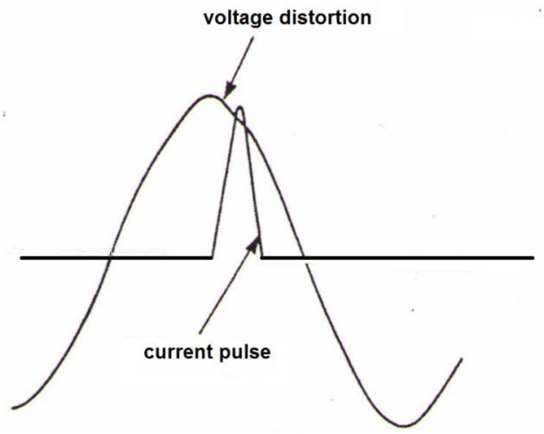


FIG.2 Current pulse from television reciever with thyristor power supply and consequent voltage distortion

Since the number of television receivers on each phase of the supply is approximately equal, the, second and fourth harmonics form balanced systems of negative and positive sequence currents respectively. These pass through the supply transformers cause second and fourth harmonic distortion which can be found even on 400kv. The effects is pronounced in same of the countries where housing wiring uses almost all exclusively polarized 13-amp plug and sockets, which phase relationship. In another country which use two pin plugs the television receivers are connected in either sense at random and so the even harmonic effect was not noticed. The protests of the electricity distributors, assisted by developments in semi-conductor technology, led to receiver manufactures adopting full-wave power supplies and experience now shows that even harmonic distortion will gradually decrease.

1.4 Harmonic sources:-

(1) Tooth ripple or ripples in the voltage waveform of rotating machines.
(2) Variation in air-gap reluctance over synchronous machine pole pitch.
(3) Flux distortion in the synchronous machine form sudden load changes.
(4) No sinusoidal distribution of the flux in the air gap of synchronous machines.
(5) Transformer magnetizing currents.
(6) Network nonlinearilities from loads such as rectifiers, inverters, welders, arc furnaces, voltage controllers, frequency converters.

There are new harmonics sources,

(1) Energy conservation measures, such as those for improved motor efficiency and load mashing, which employ power semiconductor devices and switching for their operation. These devise often produce irregular voltage and current waveforms that are rich in harmonics.
(2) Motor control devices such as speed controls for traction.
(3) High-voltage direct-current power conversion and transmission.
(4) Interconnection of wind and solar power converters with distribution system.
(5) Static-var compensators which have largely replaced synchronous condensers as consciously variable-var sources.
(6) The development and potentially wide use of electric vehicles that require a significant amount of power rectification for battery charging.
(7) The potential use of direct energy conversion devices, such as magneto-hydrodynamics, storage batteries, and fuel cells that require dc/ac power converters.
(8) Pulse-burst-modulated heating elements for large furnaces.

1.5 Analysis of harmonics sources:-

Prior to the development of static converter plant power system harmonic distortion was primarily associated with the design and operation of electric machines and transformers.

Modem transformers and rotating machines under normal steady state operating conditions do not of themselves cause significant distortion in the network, during transient disturbances and when operating outside their normal state range they can considerably increase their harmonic contribution.

Besides the static converter there are other non-linear loads that need to be considered because of their harmonic contribution; these are arc-furnaces and fluorescent lighting.

1.6 Transformer magnetization non-linearities:-

At non-load the primary voltage of a transformer is practically balanced by the back e.m.f. because the effect of winding resistance and leakage reactance is negligible at low current. At any instant, therefore, the impressed voltage v1 for a sinusoidal supply is

$$V_1 = e_1 = -E_m \sin \omega t = N_1 d\phi/dt \quad (1)$$

From equation (1) the following expression is obtained for the main flux:

$$\phi = -\int e_1 / N_1 dt = E_m, / N_1 w \cos \omega t = \phi_m \cos \omega t \quad (2)$$

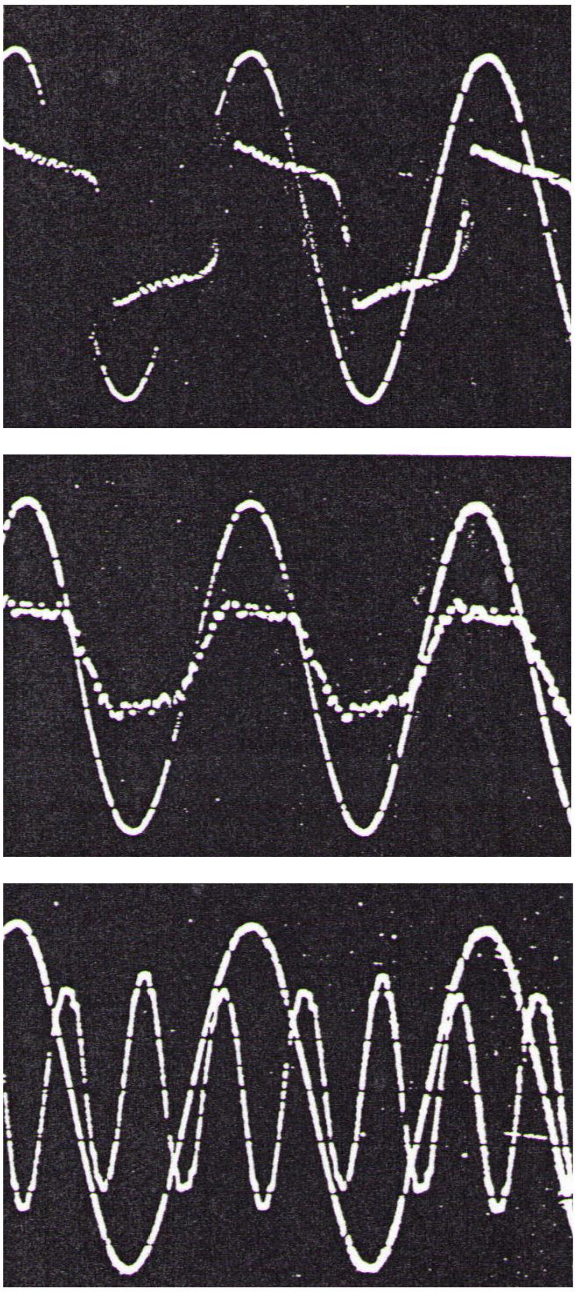
i. a sinusoidal primary voltage produce a sinusoidal flux at no-load. The primary current, however, will not be purely sinusoidal, because the flux is not linearly proportional to the magnetizing current.

1.7 Distortion caused by arc-furnaces:-

A combination of arc ignition delay and the highly non-linear arc voltage-current characteristics introduces harmonics of the fundamental frequency.

1.8 Fluorescent lighting harmonics:-

Luminous discharge lighting and in particular fluorescent tube appliances are highly non-linear and give rise to considered odd-ordered harmonic currents.



(a) (b) (c)

Figure 3 (a) Tube voltage;(b) phase current with capacitor one lamp, 240 mA/division;(c)neutral current, three banks of three lamps in star,240mA/division

In a three-phase, four-wire load the triples are basically additive in neutral and the third is the most dominant.

With reference to the basic fluorescent circuit of Fig (4), a set of voltage and current oscillograms is displayed Fig (3). These waveforms are shown with reference to the sinusoidal phase voltage supply. The voltage across the tube itself fig (3, a) illustrates clearly the non-linearity. The waveform in Fig (3, b) shows the phase current and the waveform in Fig (3, c) the neutral current for a case of three banks of three lamps connected in star. The latter consist almost exclusively of the third harmonic.

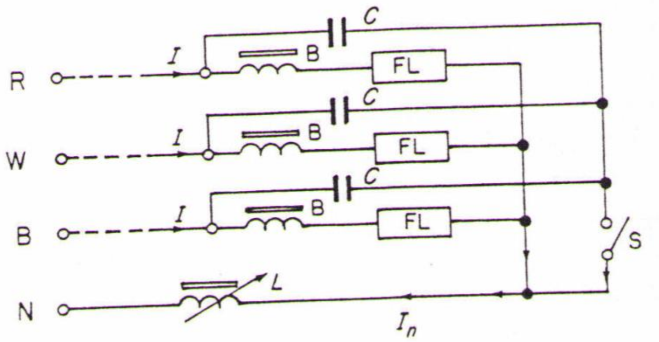


Figure 5 Three-phase fluorescent lighting test circuit. FL, fluorescent lamp; B, ballast; C, power factor correction capacitor; L, variable inductor; S, switch to isolate capacitor star point.

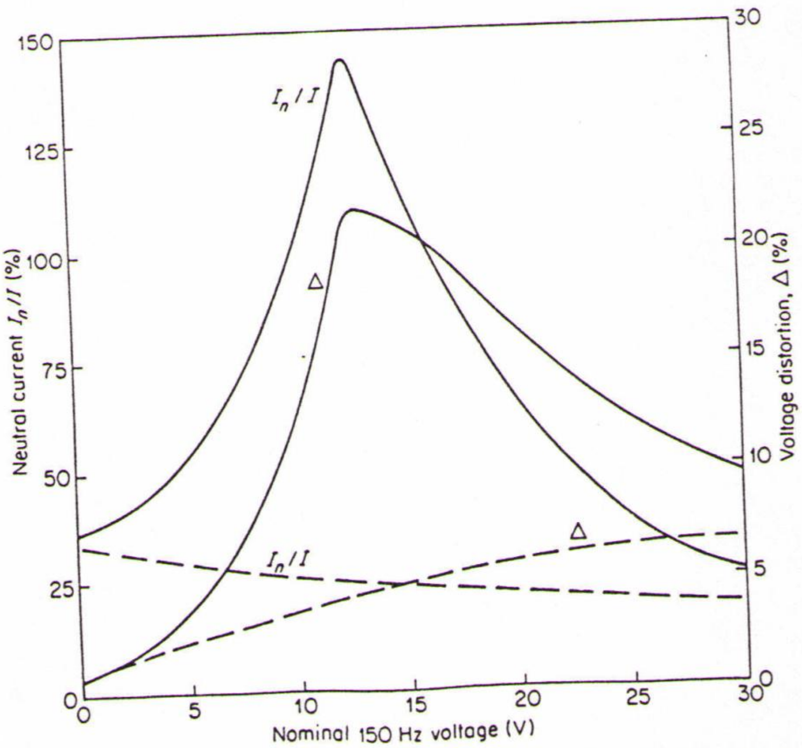


Figure 6 Characteristics of the fluorescent lighting test circuit. The nominal 150 Hz voltage is the calculated product of the 150 Hz lamp current per phase and the circuit zero-sequence impedance (150 Hz). ——, Switch S closed (star point to neutral); -----, switch S open (star point floating)

Lighting circuits often involve long distances and have very little load diversity. With individual power factor corrections capacitors the complex LC circuit can approach a condition of resonance at third harmonic.

In the graph of Fig(5) the abscissa used is the nominal third harmonic voltage, i.e. the product of the lamp third harmonic current per phase and the corresponding circuit third harmonic zero-sequence impedance. It is seen with the capacitor star point connected of neutral; the third harmonic neutral current can by far exceed the nominal lamp current. With the star point disconnected the neutral current is less than the nominal value.

1.9 Effects of harmonics in the p
1.10ower system:-

For more than 50 years, have been researched to cause operational problems.

1- Capacitor bank failure from dielectric breakdown or reactive power overload.

2- Interference with ripple control and power line carrier system, causing misoperatrion of system which accomplish remote switching load control, and metering.

3- Excessive losses in and heating of induction and synchronous machines.
4- Over voltage and excessive currents on the system form resonance to harmonic voltage or currents on the network.
5- Dielectric break down of insulated cables resulting from harmonic over voltage on the system.
6- Inductive interference with telecommunications system.
7- Effects on communication circuits (for example telephone).
8- Errors in induction kW meters.
9- Signal interference and relay malfunction, particularly in solid-state and microprocessor-controlled systems.
10- Interference with large motor controllers and power plant excitation system.
11- Mechanical oscillations of induction and synchronous machines.
12- Unstable operation of firing circuit based on zero voltage crossing detection or latching.
13- Effects of harmonics on consumer equipment.
14- Effects of harmonics on transformers.
15- Harmonic interference with power system protection.

These effects depend, of course, on the harmonic source, its location on power system, and the network characteristics that promote propagation of harmonics.

(In brief I, will talking about each of the last points).

1- Capacitor bank:-

The presence of voltage distortion produces an extra power loss in capacitors. Series and parallel resonances between the capacitors and the rest of the system can cause over voltages and high currents thus increasing dramatically the losses and overheating of capacitors and often lead to their destruction.

2-Harmonic interference with ripple control systems:-

Ripple control is often used for the remote of street lighting circuits and for load reduction (such as domestic hot water heaters) during peak times of the day.

Since ripple relays are essentially voltage operated (high impedance) devices, harmonic interference can cause signal blocking or relay maloperation if present in sufficient amplitude. The exact amplitude at which the voltage harmonic will affect he relay is a function of the relay detection circuit (sensitivity and selectivity) and the proximity of the ripple injection frequency to frequency of the interfering harmonic.

Signal blocking is the presence of sufficient interfering voltage to render the relay unable to detect the presence of the signal. Capacitors can produce the same effect by virtue of their capability to absorb the ripple signal. Relay maloperation is the presence of the harmonic voltage (usually in the absence of the signal) causing the relay to change state. The latter problem has effectively been solved by the use of suitably encoded switching signals in present generation of ripple relay.

3- Effect of harmonics on rotating machines:-

When considering the harmonic heating losses in the rotor of synchronous machines it must be remembered that Paris of stator harmonics produce the same rotor frequency.

4- Interference with telecommunication systems:-

Noise on communication circuits degrades the transmission quality and can interfere with signaling. At low levels noise causes annoyance; at higher levels the transmission quality is degraded and results in loss of information; in extreme cases noise can render a communication circuit unusable.

5- Effect of harmonic on power measurements:-

Measuring instruments initially calibrated on pure sinusoidal alternating current and subsequently used on a distorted electricity supply can be prone to error. The magnitude and direction of the harmonic power flow are important for revenue considerations as the sign of the meter errors is decided by the direction of flow. The main energy measuring instrument is the Ferraris motor type kilowatt-hour meter. Its inherent design is electromagnetic, producing driving and breaking fluxes which impinge on its rotor developing a torque.

6- Effects of harmonics on consumer equipment:-

(1) Television receivers harmonic which affect the peak voltage can cause changes in TV picture size and brightens.
(2) Fluorescent and mercury arc lighting, ballast sometimes have capacitors which, with the inductance of the ballast's circuit, have a resonant frequency. If this corresponds to a generated harmonic, excessive heating and failure may result.
(3) Computers there are designer-imposed limits as to acceptable harmonic distortion in computer and data processing system supply circuit.
(4) Converter equipment notches in the voltage wave resulting form current commutation may effect the synchronizing of other converter equipment or any other apparatus controlled by voltage zeros.

1.1- Effects of harmonics on static power plant:-

1.1 (a) Transmission system

The flow of harmonic currents in a network produces two main effects. One is the additional transmission loss caused by the increased r.m.s value of the current waveform, i.e.

$$\pounds I_n^{2} R_n \quad n=2$$

Where In is the nth harmonic current and Rn the system resistance at that harmonic frequency.

This means in effect that a 'weak' system (with a large amount of impedance and thus low fault level) will result grater voltage disturbance than a 'stiff' system, with a high fault level and low impedance.

In the case of transmission by cable, harmonic voltage increase the dielectric stress in proportion to their crest voltage. This effect shortens the useful life of the cable. It also increases the number of faults and therefore the cost of repairs.

The effects of harmonics on corona starting and extinction levels are a function of peak to peak voltage. The peak depends on the phase relationship between the harmonics and the fundamental. It is possible for the peak voltage to be above the rating while the r.m.s voltage is well within this limit.

1.1 (b) Transformers

The presence of harmonic voltages increases the hysteresis and eddy current losses and stresses the insulation. The flow of harmonic currents increases the copper losses; this effect is more important in the case of converter transformers because they do not benefit from the presence of filters, which are normally connected on the ac. System side. Apart form the extra rating required; converter transformers often develop unexpected hot spots in the tank.

An important effect particularly relevant to power transformer is the circulation of triplen zero sequence currents in the delta windings. The extra circulating currents can overrate the winding unless these are taken into account in the design.

Another important consideration exists for a transformer supplying an asymmetrical load. If the load current contains a dc. Components the resulting saturation of the transformer magnetic circuit greatly increase the level of all harmonic components of the ac. Excitation current.

1.2-Harmonic interference with power system protection:-

Harmonics can distort or degrade the operating characteristics of protective relay depending on the design features and principles of operation. Digital relays and algorithms that on sampled or zero crossing is particularly prone to error when harmonic distortion is present.

1.2(a) Harmonic problems during fault conditions:-

Protective functions are usually developed in terms of fundamental voltages or current and any harmonics present in the fault waveforms are either filtered out or ignored altogether.

The effect of harmonic frequencies on impedance measurement. Distance relay setting are based on fundamental impedance transmission lines and the presence of harmonic current (particularly third harmonic) in a fault situation could cause.

High harmonic content is common where fault current flow through high receptivity ground – i.e. ground impedance is dominant – so that the possibility of maloperation is great unless only the fundamental waveforms are captured.

In solid fault situation, the fundamental components of current and voltage are much more dominant (not with standing the dc. Asymmetry associated with fault waveforms). However, because of current transformer saturation, secondary induced distortion of current waveforms, particularly with large dc. Offsets in the primary waveforms, occurs. The presence of secondary harmonics in such instances cab be real problem, i.e. whenever current transformer saturation occurs it is very difficult to recover the fundamental current waveform.

When high secondary e.m.f. exists during steady-state conditions, the non-linear current transformer exciting impedance only causes odd-harmonic distortion. During saturation under transient, however, any harmonics can be produced with dominance of second and third harmonic components.

1.2(b) Harmonic problems outside fault conditions:-

The effective of protective apparatus to normal system load conditions implies that, generally, the harmonic content of power system waveforms is not a problem during non-fault conditions.

The most notable exception is probably the problem encountered in energization of power transformer. In practice, constructive use of the high harmonic content of magnetizing inrush current prevents (most of the time!) tripping of the high voltage circuit breaker by the transformer protection due to the excessively high peaks experienced during energization.

The actual peak magnitude of inrush current depends on the air-core inductance of the transformer and the winding resistance plus the point on the voltage wave at which switching occurs. Residual flux in the core prior to switching also increases the problem or alleviates it slightly depending on the polarity of flux with regard to the initial instantaneous voltages.

Since the secondary current is zero during energization, the heavy inrush current would inevitably cause the differential protection to operate unless it is rendered inoperative.

The simple approach is to use a time-delved differential scheme, but this could result in serious damage to the transformer should a fault be present at energization.

In practice, the uncharacteristic second harmonic component present during inrush is used to restrain the protection, but protection is still active should an internal fault develop during energization.

II. Harmonic analysis:-

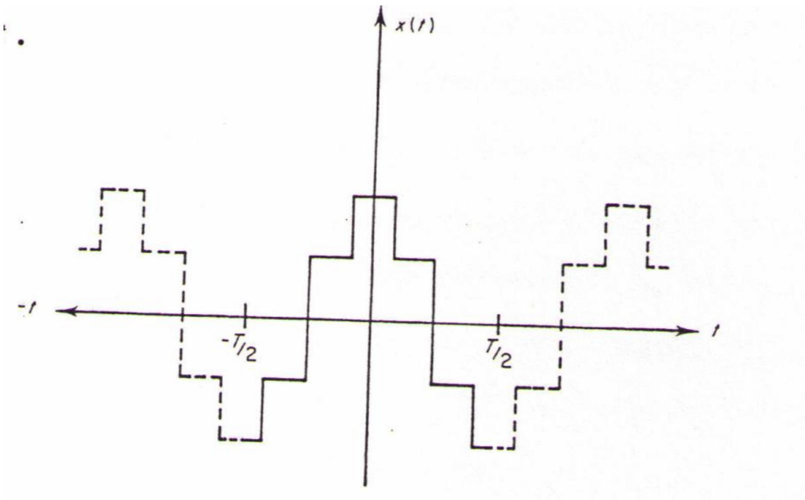
2.1 Introduction

Harmonic analysis is the process of calculating the magnitudes and phase of the fundamental and higher order harmonics of periodic waveform. The resulting series is known as the fourier series and establishes a relationship between a time domain function and that function in the frequency domain.

2.2 Periodic functions:-

A function χ (t) is be periodic if it is defined for all real t and if there is some positive number T such that

$$\chi(t+T) = \chi(t) \text{ for all t.}$$



(Fig 6)

T is called the period of the function. Such a function can be represented by the periodic repetition of the waveform at intervals of T, as depicted in Fig (6).

2.3 Harmonics
Odd and even harmonics

Sin 2ø, sin 4ϕ, sin 6ϕ, ……., are even harmonics of sin ϕ.

Sin 3ø, sin 5ϕ, sin 7ϕ, ……, are odd harmonics of sin ϕ

So, with *n* an even integer, y = A_n sin nϕ indicate even harmonics and with *n* an odd integer, y = A_n sin nϕ indicates odd harmonics.

2.4 Fourier series

The basis of a fourier series is to represent a function by a trigonometrical series of the form

$f(\chi) = A_o + a_1 \cos\chi + a_2 \cos 2\chi + a_3 \cos 3\chi + \ldots$

$+ b_1 \sin\chi + b_2 \sin 2\chi + b_3 \sin 3\chi + \ldots$

2.5 Two important theorems

1) If f (x) is defined over the interval $-\pi < \chi < \pi$ and $f(\chi)$ is even, then the fouier series has cosine terms only. This includes α_n which may be regarded as $\alpha_n \cos n\chi$ with n = 0

$$a_0 = 2/\pi \int_0^{\pi} f(\chi) d\chi$$

$$a_n = 2/\pi \int_0^{\pi} f(\chi) d\chi$$

For n = 1, 2, 3,….., in each case.

Proof:

(a) Since f(x) is even,

$$\int_{-\pi}^{o} f(X)dx = \int_0^{\pi} f(\chi) d\chi$$

$$a_0 = \frac{1}{\pi}\int_{-\pi}^{\pi} f(x)dx = \frac{2}{\pi}\int_o^{\pi} f(x)dx$$

(b) Now cos n χ is also an even function. Therefore the product f(x) cos n χ is a product of two even functions and therefore itself even.

$$\alpha_n = \frac{1}{\pi}\int_{-\pi}^{\pi} f(x)\cos nxdx = \frac{2}{\pi}\int_{o}^{\pi} f(x)\cos nxdx$$

(c) Also, sin n χ is odd function. Therefore, the product f (χ) sin n χ is the product of an even function and an odd function and is therefore itself odd.

$$b_n = \frac{1}{\pi}\int_{-\pi}^{\pi} f(x)\sin nxdx = 0$$

The Fourier series for an even function contains cosine terms only (including the constant term α_n).

2) If f (χ) is defined overt the interval - $\pi < \chi < \pi$ and f (χ) is odd, the fourier series for f (χ) has sine terms only.
The coefficient are then given by

a_0 = 0'
a_n = 0
$b_n = 2 / \pi\int_{-o}^{\pi} f(x)\sin nxdx$

Proof:

(a)

$$a_0 = \frac{1}{n}\int_{-\pi}^{\pi} f(x)dx$$

Since f(x) is odd,

$$\int_{-\pi}^{o} f(x)d = -\int_{o}^{\pi} f(x)dx \qquad a_0 = 0$$

(b) $a_n = \frac{1}{\pi}\int_{-\pi}^{\pi} f(x)coxsnxdx.$

The product f (χ) cosn χ = (odd)×(even),i.e. (odd)

$$\int_{-\pi}^{\pi} f(\chi)\cos\chi = \int_{-\pi}^{\pi} (oddfunction)d\chi = 0$$

a_n = 0
(c)

$$b_n = \frac{1}{\pi}\int_{-\pi}^{\pi} f(\chi)\sin \mathbf{n}\chi\, \mathbf{d}\chi$$

The product f(χ) sin n χ = (odd) ×(odd), i.e. (even)

$$\int_{-\pi}^{\pi} f(\chi)\sin n\chi d\chi = \int_{-\pi}^{\pi} \text{(even function) } d\chi = 2\int_{o}^{\pi} f(\chi)\sin n\chi d\chi$$

$$b_n = \frac{2}{\pi}\int_{o}^{\pi} f\text{ (X)} \quad \sin \quad n\chi\, d\chi$$

(n = 1, 2,3,….)

The fourier series for an odd function contains sine terms only

III. Experimentation

3.1 Magnetising current into a small transformer:-

Transformer magnetization non-linearity:-

At non-load the primary voltage of a transformer is practically balanced by the back e.m.f. because the effect of winding resistance and leakage reactance is negligible at low current. At any instant, therefore, the impressed voltage v1 for a sinusoidal supply is

$$V_1 = -e_1 = -E_m \sin \omega t = N_1 d\phi /dt \qquad (1)$$

From equation (1) the following expression is obtained for the main flux:

$$\phi = -\int e_1 / N_1 dt = E_m / N_1 \text{ wcos } \omega t = \phi_m \cos \omega t \qquad (2)$$

i.e. a sinusoidal primary voltage produce a sinusoidal flux at non-load. The primary current, however, will not be purely sinusoidal, because the flux is not linearly proportional to the magnetizing current.

3.2 Determination of the current wave shape:-

In an ideal core without hysteresis loss flux ϕ and the magnetizing current im needed produce it are related to each other by the magnetization curve of the steel used in the laminations as shown in fig(7,a). In fig(7,b) where ϕ represents the sinusoidal flux necessary to balance the primary voltage, the magnetizing current is plotted against time for each value of ϕ and the resulting waveform is far from sinusoidal.

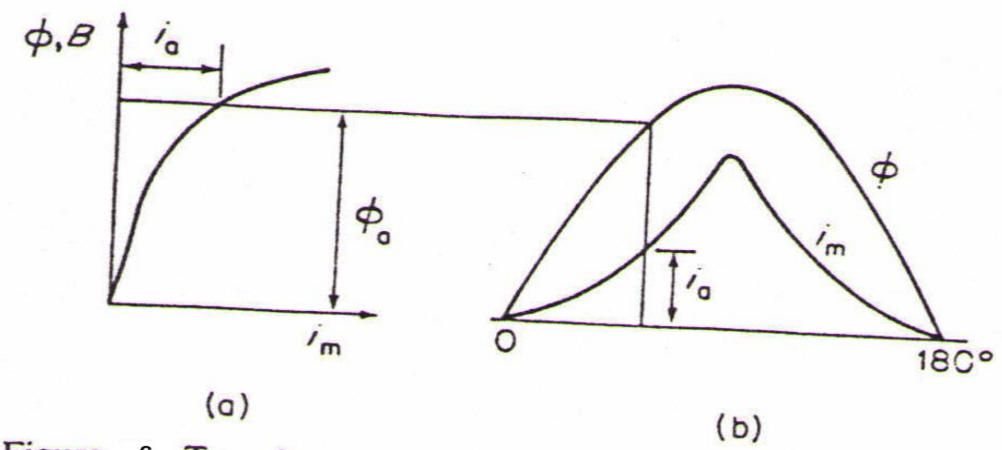


Figure 6 Transformer magnetization (without hysteresis): (a) magnetization curve; (b) flux and magnetization current waveforms

When the hysteresis effect is included, as in the case of fig (7), the non-sinusoidal magnetizing current wave is no longer symmetrical about its maximum value. In this case the current corresponding to any point on the flux density wave of fig (7,b) is determined from fig (7,a), the ascending portion of the hysteresis being used for the ascending portion of the flux density wave.

The distortion illustrated in fig (6) and (7) is mainly caused by triplen harmonics and particularly the third. Thus on order to maintain a reasonably sinusoidal voltage supply it is necessary to provide a path for the triple harmonics and this normally achieved by the delta-connected windings.

With three-limb transformers the triplen harmonic m.m.fs are all in phase and they act in each limb in the same direction. Hence the path of triplen harmonic flux must return through the air (or rather through the oil and transformer tank) and the higher reluctance of such path reduces the triplen harmonic flux to a very small value (about 10% of the appearing in independent core phases). Thus flux density and e.m.f waveforms remain sinusoidal under all conditions in this case. The fifth and seven harmonic components of the magnetizing current may also be large enough (5-10%) to produce visible distortion and cannot be ignored.

The magnetizing current harmonics often rise to their maximum levels in the early hours of the morning, i.e. when the system is lightly loaded and the voltage high.

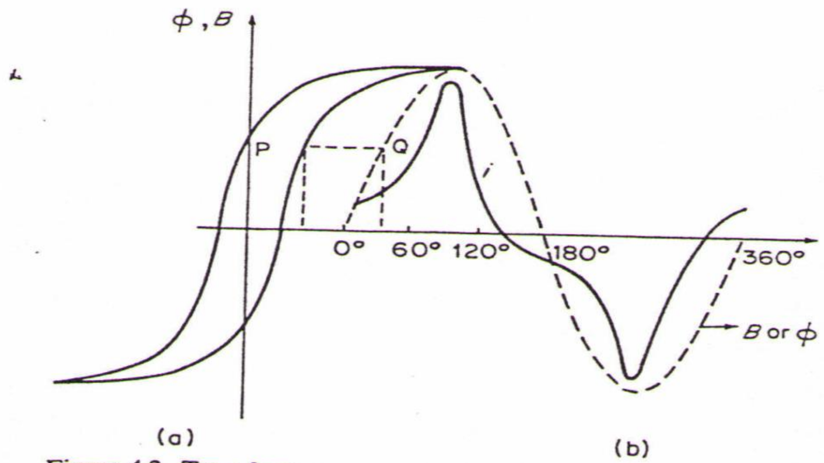
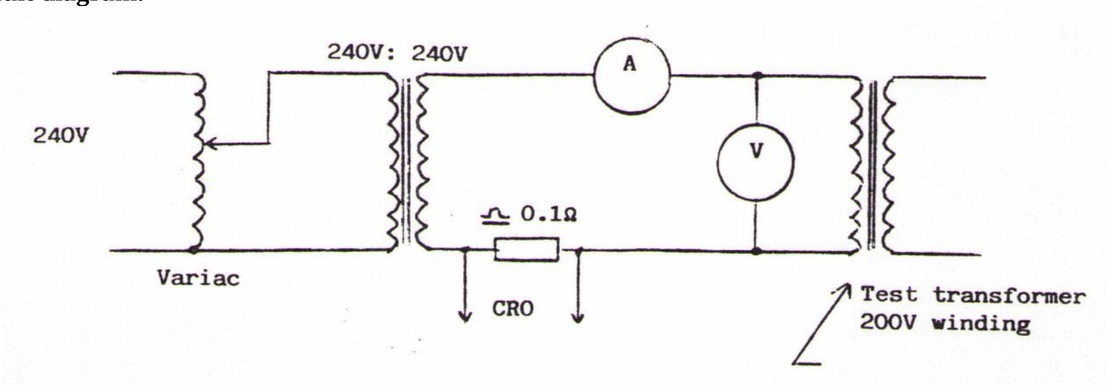


Figure 4.2. Transformer magnetization (including hysteresis): (a) magnetization curve; (b) flux and magnetization current waveforms

Harmonic	**Rated voltage**	**105% voltage**	**110%voltage**
	200V	210V	220V
Irms	0.0490A	0.0689A	0.1005A
1st	0.0452A	0.0622A	0.0872A
2nd	0.20%	0.22%	0.40%
3rd	36.86%	45.25%	52.45%
5th	14.87%	20.83%	26.44%
7th	6.15%	9.31%	11.72%
9th	2.96%	4.02%	4.49%
11th	1.34%	1.51%	1.51%
13th	0.50%	0.41%	0.39%
Watts	2.04W	2.46	3.03
VA	9.83VA	14.64	22.87
P.F	0.207Lag	0166	0.132

Table (1), Harmonic measurements during the test of small transformer 240V/240 isolating transformer.

Circuit diagram:-



The principles of third harmonics in three phase system, there are two general forms of connections of three phase systems to consider:-
(a) Star connection. (b) Delta connection.
In any star connected system of conductors it is a basic law that the instantaneous sum of the currents flowing to and form common junction or star point is zero.
In a three phase, three wire stars connected system the current and voltages of each phase at fundamental frequency are spaced 120o apart.

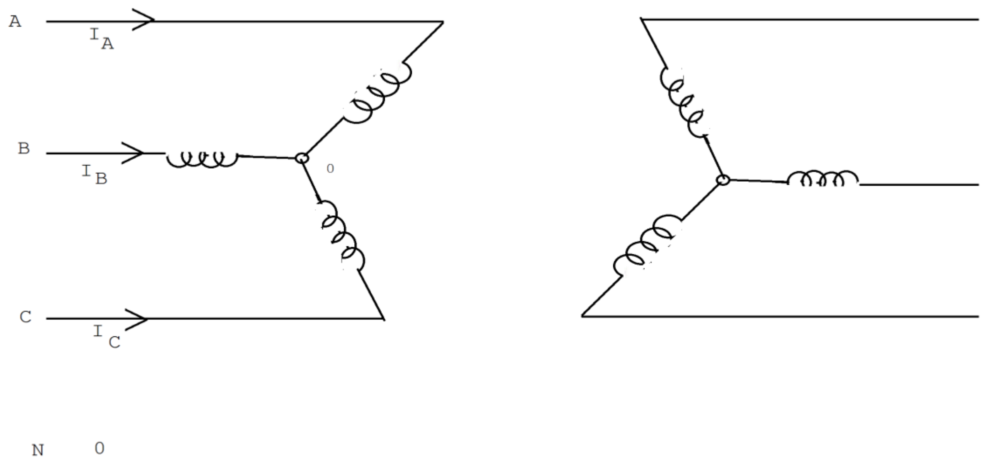
3-wire star/star:-

	A phase	B phase	C phase
Irms A	1.2623	1.0050	1.3954
I1rms A	1.2362	0.9611	1.3553
2nd	1.30	0.63	0.80
3rd	2.57	19.22	11.26
5th	20.14	21.99	18.44
7th	2.51	4.01	2.21
9th	0.11	0.55	0.55
11th	1.95	2.11	1.68
13th	0.12	0.48	0.33

Table (2)

Voltage, star point 0 to neutral N

Circuit diagram:-



3-Wire star/delta:-

	A phase	B phase	C phase
Irms A	1.2623	1.0233	1.3962
I1rms A	1.2395	0.9860	1.3514
2nd	1.14	0.57	0.91
3rd	2.16	17.70	11.42
5th	20.73	22.38	18.41
7th	2.86	4.22	2.11
9th	0.09	0.57	0.59
11th	2.31	2.35	1.60
13th	0.06	0.48	0.37

Table (3)

Voltage, star point 0 to neutral N

In discussing the third harmonic aspect of combination of star and delta connections for three phase transformer operation I therefore have the following bases to work upon:-

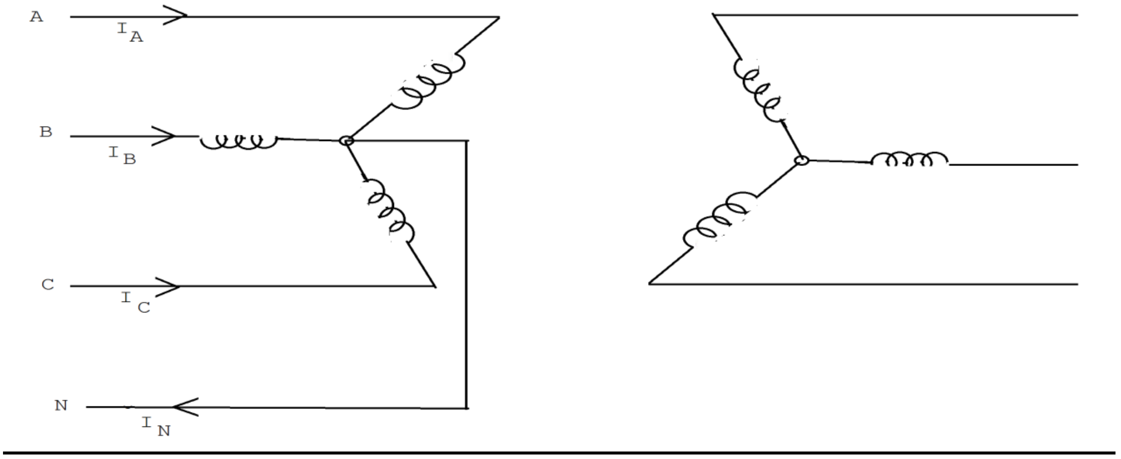
1- With a three wire star connection, third harmonic voltages may exist between lines and neutral or ground, but not between lines.
2- With a three wire connection, third harmonic current cannot exist.
3- With four wire star connections, third harmonic voltage form lines to neutral or ground is suppressed partially or completely according to the impedance of the third harmonic circuit.
4- With a four wire star connection, third harmonic currents may flow through the phases and through the line wires and fourth lead form the neutral.
5- With a three wire delta connection, third harmonic voltages in the phases and hence between the lines are suppressed.
6- With a three wire delta connection, a third harmonic current may flow round the closed delta, but not in the lines.

4-Wire star/star:-

	A phase	B phase	C phase	Neutral
Irms current A	1.2203	1.0637	1.4476	0.7818
Fundamental (1st) rms A	1.1638	1.0325	1.3529	0.1887
2nd	1.45	1.02	0.44	10.16
3rd	23.96	7.07	29.52	39.72
5th	20.68	22.81	18.29	26.19
7th	2.83	4.33	1.93	8.45
9th	1.06	1.12	1.55	23.92
11th	2.61	2.35	1.67	3.26
13th	0.26	0.27	0.29	0.85

Table (4) Note: - {Harmonics %}

Circuit diagram:-

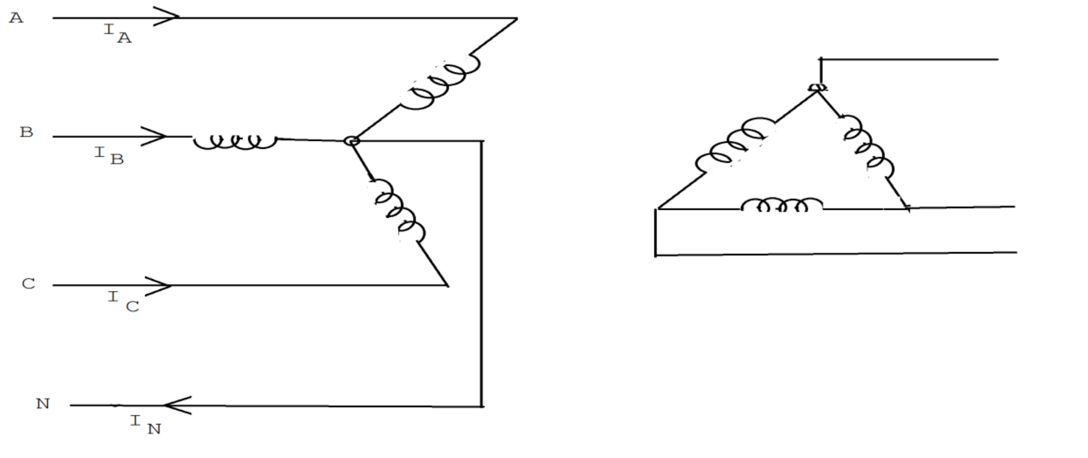


4-Wire star/delta:-

	A phase	B phase	C phase	Neutral
Irms A	1.1860	1.0295	1.4116	0.1255
I1 rms A	1.1532	0.9917	1.3774	0.1056
2nd	1.31	0.64	0.88	2.57
3rd	3.61	16.71	11.47	62.56
5th	21.60	22.34	18.33	8.18
7th	2.83	4.28	2.38	5.36
9th	0.23	0.66	0.42	5.39
11th	2.11	2.32	1.77	2.54
13th	0.09	0.50	0.22	0.90

Table (5)

Circuit diagram:-



In the end of the experiment of transformer I mighty be summarized the features of the third harmonics:-

1- Due to third harmonic currents.

(a) Overheating of transformer windings and of load.

(b) Telephone and discriminative protective gear magnetic disturbances.

(c) Increased iron loss in transformers.

2- Due to third harmonic voltages.

(a) Increased transformer insulation stresses.

(b) Electrostatic charging of adjacent lines and telephone cables.

(c) Possible resonance at third harmonic frequency of transformer windings and line capacitance.

3.3 Rectifiers:-

With the increasing of using the convectors and other thyristor-controlled devices, the problem of harmonics is achieving increasing importance. Of particular interest are the harmonics produced by rail traction loads, since these loads are large and are often accompanied by phase unbalance.

Generally, electrical equipment, when working normally, produces only odd harmonics. Even harmonics usually occur only during transient conditions, conditions, of malfunction or single-phase rectification (table 6).

Thyristor devices operating on an electrically weak system: here tow 70KVA six-pulse thyristor drives were fed form a 415V system with a fault level of 3MVA. This be regarded as a weak system since the short circuit / load-current ration was about 22:1. As a rule of thumb the system short-circuit/load ration should be at least 1001, otherwise trouble might be expected and remedial measures may be necessary. In fact this system showed gross harmonic distortion and phases unbalance (table 6).

As can be seen presence of 20KVAR power factor correction capacitors exacerbated the situation by causing a resonance at the 5th harmonic.

Harmonic					With 20KVAR Capacitors connected		
Number	Hz	R, A	Y, A	B, A	R, A	Y, A	B, A
1	50	98	127	116	96	129	118
2	100	7.7	6.5	8.0	8.8	9.3	8.3
3	150	3.2	7.8	8.1	3.9	8.1	8.7
4	200	4.5	4.1	5.8	6.3	5.6	6.2
5	250	32.7	36.5	38.7	50.8	56.5	58.7
6	30	1.5	1.0	0.7	2.5	2.1	1.6
7	350	17.1	16.4	17.0	25.5	23.7	23.8
8	400	1.9	1.2	2.6	2.6	1.8	1.6
9	450	1.1	3.5	2.3	1.2	4.0	2.6
10	500	1.8	1.8	2.4	2.0	3.7	2.7
11	550	10.8	11.9	12.0	13.0	15.3	13.8
12	600	1.0	0.5	0.4	1.4	1.3	1.0
13	650	8.9	7.4	7.6	9.7	9.2	11.0

Table (6) example of an abnormal harmonic current spectrum produced by 70 KVA, 415V six-pluse thyristor convector showing phases unbalance and even harmonics.

Harmonics are generated in system non-linearity, i.e. the energy conversion form fundamental to harmonic frequencies takes place in non-linear devices connected to the sinusoidal supply.

This example illustrates a problem that has been encountered on several occasions, i.e. the thyristor drives are designed on the assumption (or faith) that they will be operated on relatively strong systems. Usually or fortuitously this obtains but, on occasions, as indicated here, a drive will be connected to an electrically weak system and trouble results.

Harmonic				
Number	HZ	R, A	Y, A	B, A
1	50	109	116	111
2	100	0.9	0.98	1.2
3	150	3.0	3.6	4.0
4	200	0.2	0.4	0.15
5	250	16.3	16.9	17.7
6	300	0.1	0.1	…
7	350	7.3	7.1	7.0
8	400	0.3	0.35	0.3
9	450	0.25	0.3	0.2
10	500	0.15	0.1	0.1
11	550	0.15	0.1	0.1
12	600	0.09	0.1	0.1
13	650	4.5	4.5	4.7

Table (7) example of harmonic current spectrum produced by a 70 KVA, 415V six-pulse thyristor convector drive after remedial measured.

The harmonics thus generated can be regard as being superposed on the fundamental voltage and current. Because of this superposition and because the three-phase supply can be regarded as linear, the effects of harmonic cab be studied and analyzed separately from the fundamental.

It should be clearly understood that no energy transfer can take place through a voltage and a current of different frequency, i.e. the net power per cycle between a fundamental voltage and a 5th harmonic current is zero.

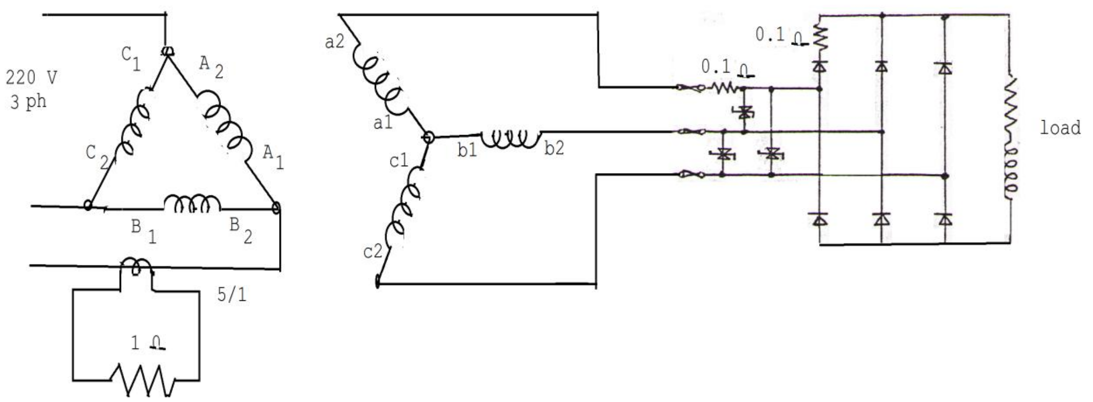
The general expression for harmonic currents in a balanced three-phase system is given by:

Neutral red phase yellow phaseblue phase

In = I sin ( ) n+I sin (+ 240)n + I sin (+ 120)n
Where n is harmonic order.

It is clear form the above why the 3rd and all triple harmonics are zero sequence in nature and must always have a neutral to flow in or a delta in which to circulate. Furthermore, the 5th harmonic is seen to be backward rotating, i.e. negative phase sequence in nature. So the harmonic sequence is as follows:
Harmonic number 1 2 3 4 5 6 7 8 9 10 11
Harmonic sequence + - 0 + - 0 + - 0 + -

Input current to 3 phase diode bridge rectifier:-
Circuit diagram, with inductive load, wave form

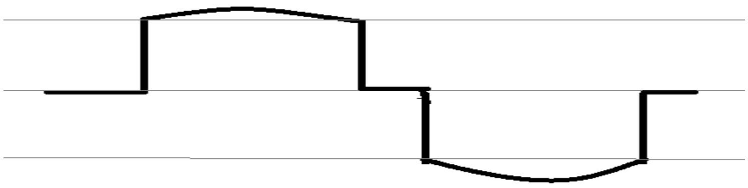


Irms = $\sqrt{I^2 \text{rms} + I^2 \text{rms} + \ldots}$

Irs value = 2.593.

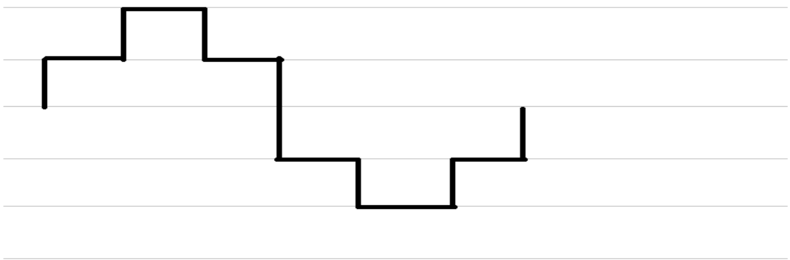
Harmonic		Theory
Fundamental 1st	2.593 A → 100%	
2nd	0.18	0%
3rd	1.04	0%
5th	19.09	$\frac{1}{5}$ → 20%
7th	14.47	$\frac{1}{7}$ → 14.3%
9th	1.23	0%
11th	8.24	$\frac{1}{11}$ → 9.1%
13th	7.70	$\frac{1}{13}$ → 7%

Load resistance only
Wave form



Irms	1st	2nd	3rd	5th	7th	9th	11th	13th
2.972 A	2.851 A	0.014 %	1.05 %	22.39 %	10.66 %	1.17 %	7.87 %	6.50 %

Input current to primary:-
Wave form



Rect load + transformer mag current

Rect load + transformer mag current

Irms	0.1714 A	
1st	0.1665 A	
2nd	0.27%	0%
3rd	1.06%	0%
5th	17.81%	$\frac{1}{5} \rightarrow 20\%$
7th	11.52%	$\frac{1}{7}$
9th	1.22%	0
11th	7.93%	$\frac{1}{11}$
13th	5.61%	$\frac{1}{13}$

Another experiment that shows the effects of harmonics, as I minion before in chapter 2, the effects of harmonics in telecomecations' systems.

IV. Harmonic elimination:-

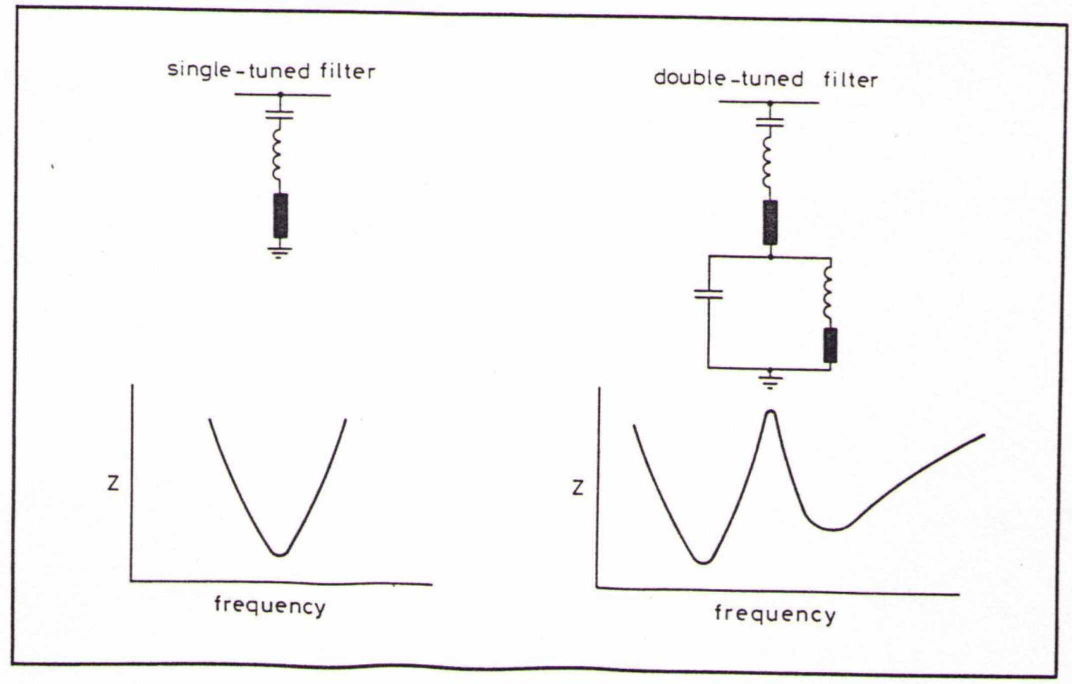
4.1 Purpose of harmonic filters:-

The primary object of harmonic filter is to reduce the amplitude of one or more fixed frequency currents or voltage.

When the only purpose is to prevent a particular frequency form entering selected plant components or parts of a power system (e.g. in the case of ripple control signals) it is possible to use a series filter consisting of a parallel inductor and capacitor which presents a large impedance to the relevant frequency. Such a solution, however, cannot be extended to eliminate the harmonics from arising the source because the production of harmonics by non-linear plant components (like transformers and converters) is essential to their normal operation.

In the case of static converters, the harmonic currents are normally prevented form entering the rest of the system by providing a shunt path of low impedance to the harmonic frequencies. Cobined series and shunt filters could be designed to minimize harmonic currents and voltagein the ac system regardless of its impedance, but they are expensive.

The shunt filters is to be turned to the frequency that makes its inductive and capacitive reactance equal (fig).



4.2 Damped filters:-

4.2a Types of damped filters

There are four types of damped filters are shown in (fig) first order, secand order, third order, and C type.

(a) The first order filter is not normally used, as it requires a large capacitor and has excessive loss at the fundamental frequency.

(b) The second order type provides the best filtering performance, but has higher fundamental frequency losses as compared with the third order filters.

(c) Its main advantages over (b) is a substantial reduction in fundamental frequency loss, owing to the increased impedance at that frequency caused by the presence of the capacitor C2. Moreover, the rating of C2 is very small compared with C1.

(d) The filtering performance of the newly introduced C-type lies in between those of (b) and (c). Its main advantages are a considerable reduction in frequency. This filter is more susceptible to fundamental frequency deviations and component value drifs.

4.3 The damped filter offers several advantages:-

1- Its performance and loading is less sensitive to temperature variation, frequency deviation, components manufacturing tolerance, loss of capacitor elements, etc.

2- It provides a low impedance for a wide spectrum of harmonics without the need for subdivision of parallel branches with increased switching and maintenance problems.

3- The use of tuned filters often results in parallel resonance between the filter and system admittances at a harmonic order below the lower tuned filter frequency, or in between tuned filter frequencies. In such cases the use of one or more damped filters is a more acceptable alternative.

4.4 The main disadvantage of the damped filters:-

1- To achieve a similar level of filtering performance the damped filter needs to be designed for higher fundamental VA ratings, though in most cases a good performance can be met within the limits required for power factor correction.

2- The losses in the resistor and reactor are generally higher.

4.5 Alternative ideas for harmonic elimination:-

Because of the complexity and cost of filters, there have been several attempts to achieve harmonic control by other means.

There are:-

1- Elimination by magnetic flux compensation.

2- Elimination by harmonic injection.

3- Elimination by dc ripple injection.

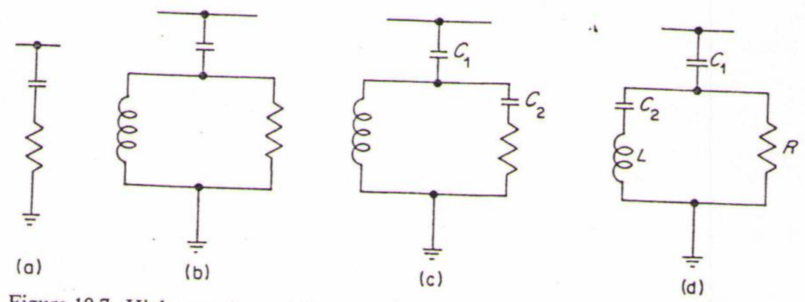


Figure 10.7. High-pass damped filters: (a) first order; (b) second order; (c) third order; (d) C-type

V. Conclusion

Since the nonlinear loads are ever increasing in a power circuit, the voltage and current waveforms usually become no sinusoidal. The conventional definitions for power-component calculation, especially reactive power, become contentious.

Sources of system harmonics have been identified and concern for their proliferation on electric systems has been characterized.

Then the meanings of harmonics, which is give an idea to the reader to understand the mean of it, where the power system engineer got it form which is originally used in relation to sound and a vibration of a string or column of air at a multiple of the fundamental frequency.

Then identified the causes of harmonic, the flow harmonic currents through the impedance provided by the supply system, of course this starting form generator terminal, the first components effects the wave forms are the transformers and as will the larger amounts of harmonic distortion are usually caused by various types of rectifying load.

Once the harmonic sources and their magnitude are clearly defined, they must be interpreted in terms of their effects in power system and equipment operation.

The effects of harmonics or problems affect individual power plant components and system is discussed in parts of the chapter (1)

Then in chapter (2) discussed the harmonic analysis, which is the process of calculating the magnitudes and phase of the fundamental and higher order harmonics of the periodic waveforms.

The experimentation part that discussed clearly in chapter (3), to show the percentage of the harmonics currents or voltage in difference circuits and when it compromised between the results and the theory results, which is show the difference between the poth of it.

Then the solioustion of the harmonics problems or how to eliminate and control the harmonics in power system that is by different ways like filters, magnetic flux compensation, harmonic injection and dc ripple injection.

Finally the occurrence and control of harmonic distortion on power systems although a first sight a simple matter, raises many problems. The causes, investigation and limitation of harmonics are worthy of considerable study and debate.

References

[1] Fourier series and harmonic analysis (by K.A.Stroud).
[2] IEEE transactions on power apparatus and systems.
[3] Power electronics (by Cyril W. lander).
[4] Power engineering journal.
[5] Power system harmonics (by J. arrillaga, D.A.Bradley and P.S.Bodger).
[6] The J & P. transformer book (by S. Austen Stigant, H. Morgan Lacey and A.C. Franklin).