UNIT-2 ELECTRICAL SYSTEMS

Electricity Billing - HT Supply:

The electricity billing by utilities for medium & large enterprises, in High Tension (HT) category, is often done on two-part tariff structure, i.e. one part for capacity (or demand) drawn and the second part for actual energy drawn during the billing cycle. Capacity or demand is in kVA (apparent power) or kW terms. The reactive energy (i.e.) kVArh drawn by the service is also recorded and billed for in some utilities, because this would affect the load on the utility.
Accordingly, utility charges for maximum demand, active energy and reactive power drawn (as reflected by the power factor) in its billing structure.

ELECTRICITY TARIFF

Definition: The amount of money frame by the supplier for the supply of electrical energy to various types of consumers in known as an electricity tariff. In other words, the tariff is the methods of charging a consumer for consuming electric power. The tariff covers the total cost of producing and supplying electric energy plus a reasonable cost.

The actual tariffs that the customer pay depends on the consumption of the electricity. The consumer bill varies according to their requirements. The industrial consumers pay more tariffs because they use more power for long times than the domestic consumers. The electricity tariffs depends on the following factors

- Type of load
- Time at which load is required.
- The power factor of the load.
- The amount of energy used.
- The total bill of the consumer has three parts, namely, fixed charge D, semi-fixed charge Ax and running charge By.

$$C = Ax + By + D$$

where,

C–total charge for a period (say one month)
x – maximum demand during the period (kW or kVA)
y – Total energy consumed during the period (kW or kVA)
A – cost per kW or kVA of maximum demand.

B – cost per kWh of energy consumed.
D – fixed charge during each billing period.

Factors Affecting the Electricity Tariffs

The following factors are taken into accounts to decide the electricity tariff:

Types of Load – The load is mainly classified into three types, i.e., domestic, commercial, or industrial. The industrial consumers use more energy for a longer time than domestic consumers, and hence the tariff for the industrial consumers is more than the domestic consumers. The tariff of the electric energy varies according to their requirement.

Maximum demand – The cost of the electrical energy supplied by a generating station depends on the installed capacity of the plant and kWh generated. Increased in maximum capacity increased the installed capacity of the generating station.

The time at which load is required – The time at which the maximum load required is also essential for the electricity tariff. If the maximum demand coincides with the maximum demand of the consumer, then the additional plant is required. And if the maximum demand of the consumers occurs during off-peak hours, the load factor is improved, and no extra plant capacity is needed. Thus, the overall cost per kWh generated is reduced.

The power factor of the load – The power factor plays a major role in the plant economics. The low power factor increases the load current which increases the losses in the system. Thus, the regulation becomes poor. For improving the power factor, the power factor correction equipment is installed at the generating station. Thus, the cost of the generation increases.

The amount of energy used – The cost of electrical energy is reduced by using large amounts of energy for longer periods.

Types of Electricity Tariff

Some of the most important types of tariff are as follows;

1. Flat Demand Rate tariff
2. Straight-line Meter rate tariff
3. Block meter Rate tariff
4. Two-part tariff
5. Power factor tariff

6. Seasonal rate tariff
7. Peak load tariff
8. Three-part tariff

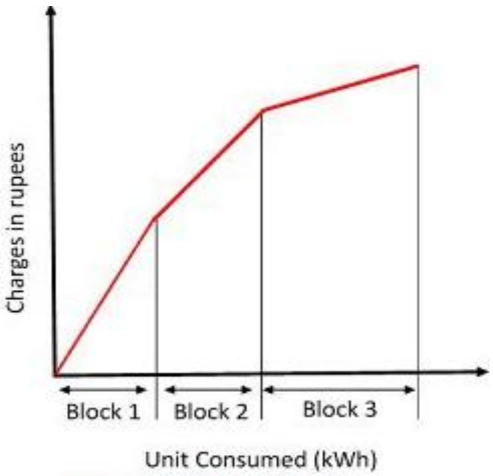
The different types of tariffs are explained below in details

1. Flat demand rate tariff – The flat demand rate tariff is expressed by the equation C = Ax. In this type of tariff, the bill of the power consumption depends only on the maximum demand of the load. The generation of the bill is independent of the normal energy consumption. This type of tariff is used on the street light, sign lighting, irrigation, etc., where the working hours of the equipment are unknown. The metering system is not used for calculating such type of tariffs.

2. Straight-line meter rate tariff – This type of tariff is given by the equation C = By. The eneration of the bills depends on the energy consumption of the load. Thus, different types of bills are generated by the consumers.

The charges for different types of consumption depends on the load and diversity factors of the load. For example, the tariff for small devices is less as compared to the power loads. Hence different meters are used for measuring the power consumption

3. Block meter rate tariff – In this type of tariff, the energy consumption is distinguished into blocks. The per unit tariff of the individual block is fixed. The price of the block is arranged in the decreasing order. The first block has the highest cost, and it goes on decreasing accordingly.



Block Meter Rate Tariff

The price and the energy consumption are divided into three blocks. The first few units of energy at a certain rate, the next at a slightly lower rate and the remaining unit at a very lower rate.

4. Two-part tariff – In such type of tariff, the total bill is divided into two parts. The first one is the fixed charge and the second is the running charge. The fixed charge is because of the maximum demand and the second charge depends on the energy consumption by the load

$$C = Ax + By$$

$$C = A(kW) + B(kWh)$$

5.Three-part tariff – The three-part tariff is in the form of, and it is applied to the big consumer.

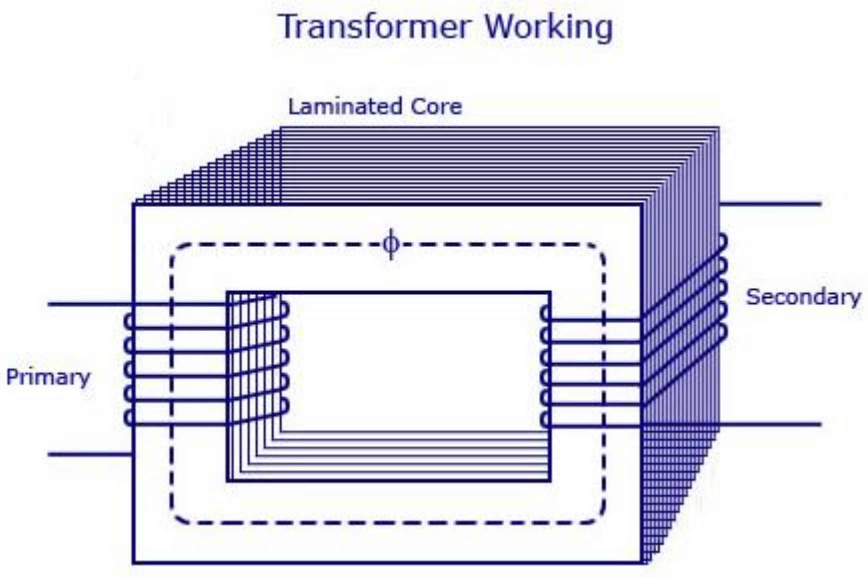
$$C = Ax + By + D$$

TRANSFORMER:

Definition-A transformer can be defined as a static device which helps in the transformation of electric power in one circuit to electric power of the same frequency in another circuit. The voltage can be raised or lowered in a circuit.

Working Principle of Transformer:

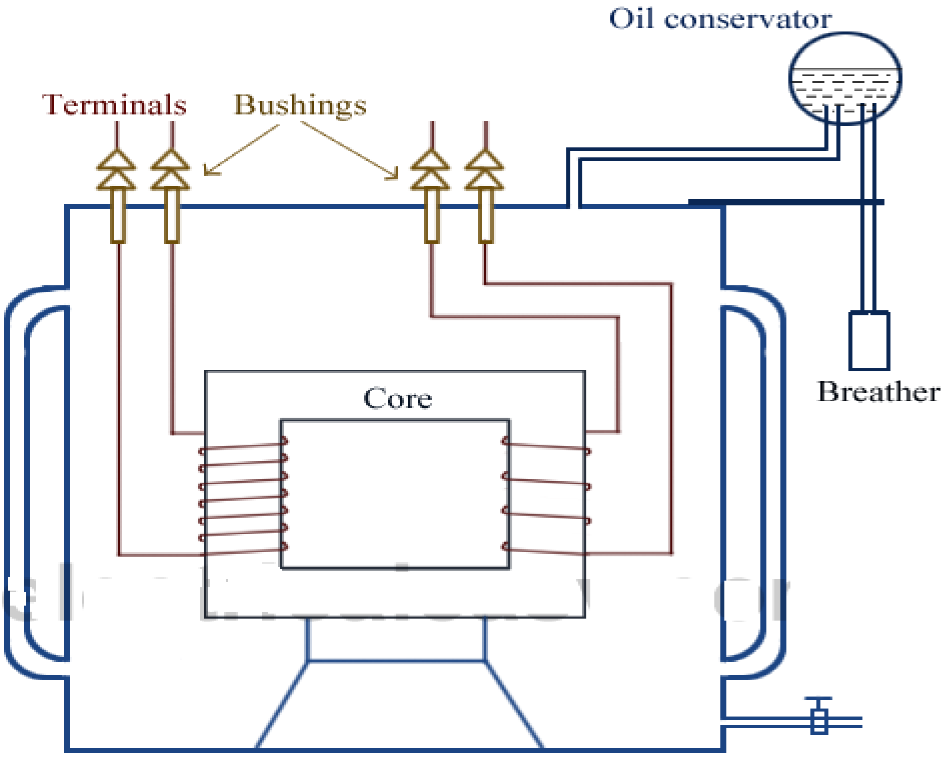
The main principle of operation of a transformer is mutual inductance between two circuits which is linked by a common magnetic flux. A basic transformer consists of two coils that are electrically separate and inductive, but are magnetically linked through a path of reluctance



As shown above the electrical transformer has primary and secondary windings. The core laminations are joined in the form of strips in between the strips you can see that there are some narrow gaps right through the cross-section of the core.

A mutual electro-motive force is induced in the transformer from the alternating flux that is set up in the laminated core, due to the coil that is connected to a source of alternating voltage. Most of the alternating flux developed by this coil is linked with the other coil and thus produces the mutual induced electro-motive force. The so produced electro-motive force can be explained with the help of Faradayâs laws of Electromagnetic Induction.

Basically a transformer consists of two inductive windings and a laminated steel core. The coils are insulated from each other as well as from the steel core.



basic construction of a transformer. In all types of transformers, core is constructed by assembling (stacking) laminated sheets of steel, with minimum air-gap between them.Laminated sheets of steel are used to reduce eddy current loss. The sheets are cut in the shape as E,I and L.

Types of transformer:

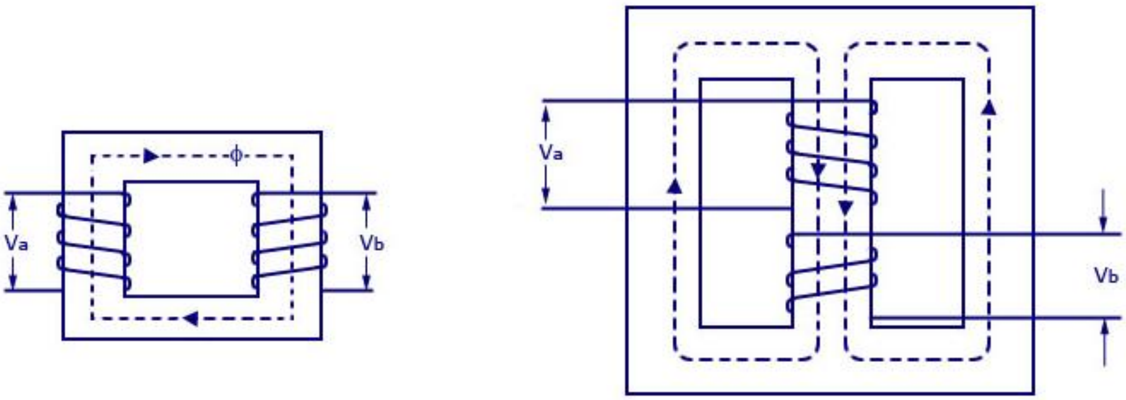
(i)Core Type Transformer

In core type transformer, windings are cylindrical former wound, mounted on the core limbs as shown in the figure above. The cylindrical coils have different layers and each layer is insulated from each other. Materials like paper, cloth or mica can be used for insulation. Low voltage windings are placed nearer to the core, as they are easier to insulate.

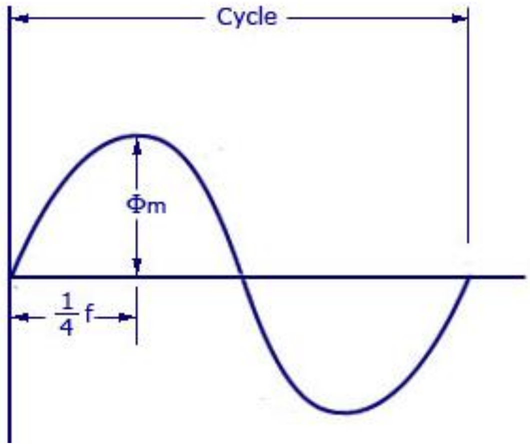
(Ii) Shell Type Transformer

The coils are former wound and mounted in layers stacked with insulation between them. A shell type transformer may have simple rectangular form , or it may have a distributed form.

Core Type and Shell Type Transformer Winding



EMF EQUATION OF A TRANSFORMER



Let,

N_A =Number of turns in primary Windings

N_B = Number of turns in secondaryWindings

ø = Maximum flux in the core in webers

F = Frequency of alternating current input in hertz (H_Z)

As shown in figure above, the core flux increases from its zero value to maximum value in one quarter of the cycle , that is in ¼ frequency second.

average electro-motive force induced/turn = 4f ø

Form Factor = r.m.s. value/average value = 1.11

Therefore, r.m.s value of e.m.f/turn = 1.11 X 4fø = 4.44f ø

Now, r.m.s value of induced e.m.f in the whole of primary winding

= (induced e.m.f./turn) X Number of primary turns

Therefore,

E1 = 4.44øf N1 (Volts)

E2 = 4.44 ø f N2 (Volts)

Applications of a transformer

Transformers are used in most electronic circuits. A transformer has only 3 applications;

- To step up voltage and current.
- To Step down voltage and current
- To prevent DC – transformers can pass only Alternating Currents so they totally prevent DC from passing to the next circuit.

Power Factor Improvement and Benefits

Power factor Basics

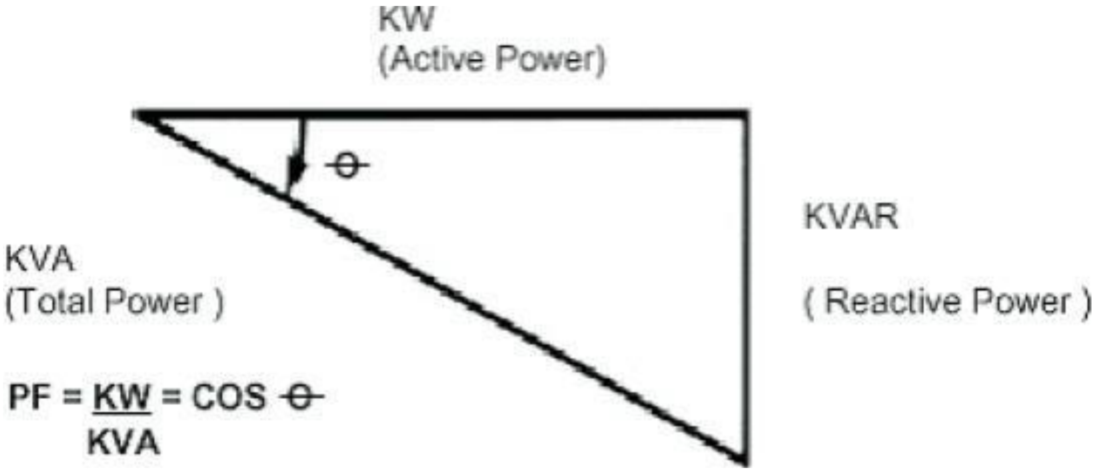
In all industrial electrical distribution systems, the major loads are resistive and inductive. Resistive loads are incandescent lighting and resistance heating. In case of pure resistive loads, the voltage (V), current (I), resistance (R) relations are linearly related

$$V = I \times R \text{ and Power (kW)} = V \times I$$

Typical inductive loads are A.C. Motors, induction furnaces, transformers and ballast-type lighting. Inductive loads require two kinds of power: a) active (or working) power to perform the work and b) reactive power to create and maintain electro-magnetic fields

Active power is measured in kW (Kilo Watts). Reactive power is measured in kVAr (Kilo Volt-Amperes Reactive).

The vector sum of the active power and reactive power make up the total (or apparent) power used. This is the power generated by the SEBs for the user to perform a given amount of work. Total Power is measured in kVA (Kilo Volts-Amperes)



The active power (shaft power required or true power required) in kW and the reactive power required (kVAr) are 90° apart vectorically in a pure inductive circuit i.e., reactive power kVAr lagging the active kW. The vector sum of the two is called the apparent power or kVA, as illustrated above and the kVA reflects the actual electrical load on distribution system.

The ratio of kW to kVA is called the power factor, which is always less than or equal to unity. Theoretically, when electric utilities supply power, if all loads have unity power factor, maximum power can be transferred for the same distribution system capacity. However, as the loads are inductive in nature, with the power factor ranging from 0.2 to 0.9, the electrical distribution network is stressed for capacity at low power factors.

Improving Power Factor

The solution to improve the power factor is to add power factor correction capacitors to the plant power distribution system. They act as reactive power generators, and provide the needed reactive power to accomplish kW of work. This reduces the amount of reactive power, and thus total power, generated by the utilities.

The advantages of PF improvement by capacitor addition

Reactive component of the network is reduced and so also the total current in the system from the source end.

- I^2R power losses are reduced in the system because of reduction in current.
- Voltage level at the load end is increased.
- kVAloading on the source generators as also on the transformers and lines up to the capacitors reduces giving capacity relief. A high power factor can help in utilizing the full capacity of your electrical system.

Cost benefits of PF improvement

While costs of PF improvement are in terms of investment needs for capacitor addition the benefits to be quantified for feasibility analysis are:

- Reduced kVA (Maximum demand) charges in utility bill
- Reduced distribution losses (KWH) within the plant network
- Better voltage at motor terminals and improved performance of motors
-
- A high power factor eliminates penalty charges imposed when operating with a low power factor
- Investment on system facilities such as transformers, cables, switchgears etc for delivering load is reduced.

Direct relation for capacitor sizing

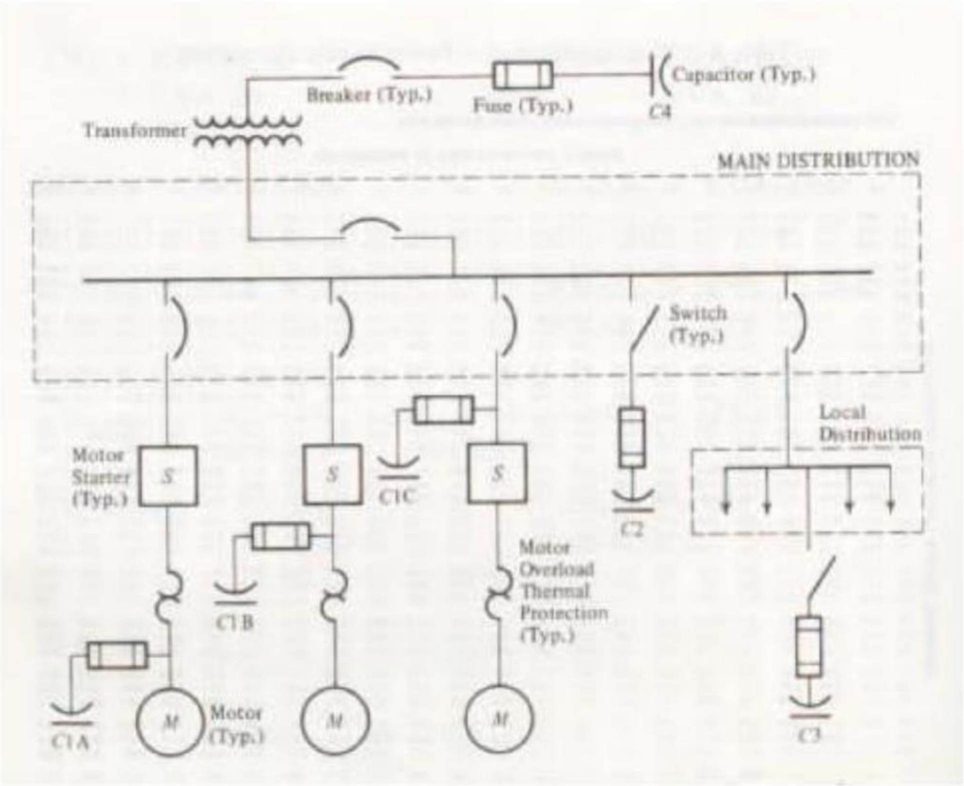
kVAr Rating = kW [tan $\Phi 1$ – tan $\Phi 2$]

Where kVAr rating is the size of the capacitor needed, kW is the average power drawn, tan $\phi 1$ is the trigonometric ratio for the present power factor, and tan $\phi 2$ is the trigonometric ratio for the desired PF.

$\Phi 1$ = Existing (Cos-1 PF1) and $\Phi 2$ = Improved (Cos-1 PF2)

Location of Capacitors

The primary purpose of capacitors is to reduce the maximum demand. Additional benefits are derived by capacitor location. The Figure 2.3 indicates typical capacitor locations. Maximum benefit of capacitors is derived by locating them as close as possible to the load. At this location, its kVAr are confined to the smallest possible segment, decreasing the load current. This, in turn, will reduce power losses of the system substantially. Power losses are proportional to the square of the current. When power losses are reduced, voltage at the motor increases; thus, motor performance also increases.



Locations C1A, C1B and C1C of Figure 1.9 indicate three different arrangements at the load. Note that in all three locations extra switches are not required, since the capacitor is either switched with the motor starter or the breaker before the starter. Case C1A is recommended for new installation, since the maximum benefit is derived and the size of the motor thermal protector is reduced. In Case C1B, as in Case C1A, the capacitor is energized only when the motor is in operation. Case C1B is recommended in cases where the installation already exists and the thermal protector does not need to be re-sized. In position C1C, the capacitor is permanently connected to the circuit but does not require a separate switch, since capacitor can be disconnected by the breaker before the starter.

It should be noted that the rating of the capacitor should not be greater than the no-load magnetizing kVAr of the motor. If this condition exists, damaging over voltage or transient torques can occur. This is why most motor manufacturers specify maximum capacitor ratings to be applied to specific motors.

The next preference for capacitor locations as illustrated by Figure is at locations C2 and C3. In these locations, a breaker or switch will be required. Location C4 requires a high voltage breaker. The advantage of locating capacitors at power centres or feeders is that they can be grouped together. When several motors are running intermittently, the capacitors are permitted to be on line all the time, reducing the total power regardless of load.

Harmonics

In any alternating current network, flow of current depends upon the voltage applied and the impedance (resistance to AC) provided by elements like resistances, reactances of inductive and capacitive nature. As the value of impedance in above devices is constant, they are called linear whereby the voltage and current relation is of linear nature

However in real life situation, various devices like diodes, silicon controlled rectifiers, PWM systems, thyristors, voltage & current chopping saturated core reactors, induction & arc furnaces are also deployed for various requirements and due to their varying impedance characteristic, these non - linear devices cause distortion in voltage and current waveforms which is of increasing concern in recent times. Harmonics occurs as spikes at intervals which are multiples of the mains (supply) frequency and these distort the pure sine wave form of the supply voltage & current.

Harmonics are multiples of the fundamental frequency of an electrical power system. If, for example, the fundamental frequency is 50 Hz, then the 5th harmonic is five times that frequency, or 250 Hz. Likewise, the 7th harmonic is seven times the fundamental or 350 Hz, and so on for higher order harmonics.

Harmonics can be discussed in terms of current or voltage. A 5th harmonic current is simply a current flowing at 250 Hz on a 50 Hz system. The 5th harmonic current flowing through the system impedance creates a 5th harmonic voltage. Total Harmonic Distortion (THD) expresses the amount of harmonics. The following is the formula for calculating the THD for current

$$THD_{current} = \sqrt{\sum_{n=2}^{n=n} \left(\frac{I_n}{I_1} \right)^2} \times 100$$

Then...

$$I_{THD} = \sqrt{\left[\left(\frac{50}{250} \right)^2 + \left(\frac{35}{250} \right)^2 \right]} x100 = 24\%$$

When harmonic currents flow in a power system, they are known as "poor power quality" or "dirty power". Other causes of poor power quality include transients such as voltage spikes, surges, sags, and ringing. Because they repeat every cycle, harmonics are regarded as a steady-state cause of poor power quality

When expressed as a percentage of fundamental voltage THD is given by,

$$\mathrm{THD}_{\mathrm{voltage}} = \sqrt{\sum_{n=2}^{n=n} \left(\frac{V_n}{V_1} \right)^2} \times 100$$

where,V1 is the fundamental frequency voltage and Vn is nth harmonic voltage component.

Major Causes Of Harmonics

Devices that draw non-sinusoidal currents when a sinusoidal voltage is applied create harmonics. Frequently these are devices that convert AC to DC. Some of these devices are listed below:

- Electronic Switching Power Converters
- Computers, Uninterruptible power supplies (UPS), Solid-state rectifiers
- Electronic process control equipment, PLC's, etc

- Electronic lighting ballasts, including light dimmer &Reduced voltage motor controllers

Arcing Devices

- Discharge lighting, e.g. Fluorescent, Sodium and Mercury vapor
- Arc furnaces, Welding equipment, Electrical traction system

Ferromagnetic Devices

- Transformers operating near saturation level
- Magnetic ballasts (Saturated Iron core)
- Induction heating equipment, Chokes, Motors

Appliances

- TV sets, air conditioners, washing machines, microwave ovens
- Fax machines, photocopiers, printers

These devices use power electronics like SCRs, diodes, and thyristors, which are a growing percentage of the load in industrial power systems. The majority use a 6-pulse converter. Most loads which produce harmonics, do so as a steady-state phenomenon. A snapshot reading of an operating load that is suspected to be non-linear can determine if it is producing harmonics.

Many problems can arise from harmonic currents in a power system. Some problems are easy to detect; others exist and persist because harmonics are not suspected. Higher RMS cur- rent and voltage in the system are caused by harmonic currents, which can result in any of the problems listed below:

Blinking of Incandescent Lights - Transformer Saturation

2. Capacitor Failure - Harmonic Resonance

3. Circuit Breakers Tripping - Inductive Heating and Overload

4. Conductor Failure - Inductive Heating

5. Electronic Equipment Shutting down - Voltage Distortion

6. Flickering of Fluorescent Lights - Transformer Saturation

7. Fuses Blowing for No Apparent Reason - Inductive Heating and Overload

8. Motor Failures (overheating) - Voltage Drop

9. Neutral Conductor and Terminal Failures - Additive Triplen Currents

10. Electromagnetic Load Failures - Inductive Heating

11. Overheating of Metal Enclosures - Inductive Heating