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Refresher Course on Electrical Fundamentals

1.0 DC Current v/s AC Current

- Direct current (**DC**) flows in one direction in the circuit.
- Alternating current (**AC**) flows first in one direction then in the opposite direction.

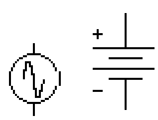
The same definitions apply to alternating voltage (AC voltage):

- DC voltage has a fixed polarity.
- AC voltage switches polarity back and forth.

There are numerous sources of DC and AC current and voltage. However:

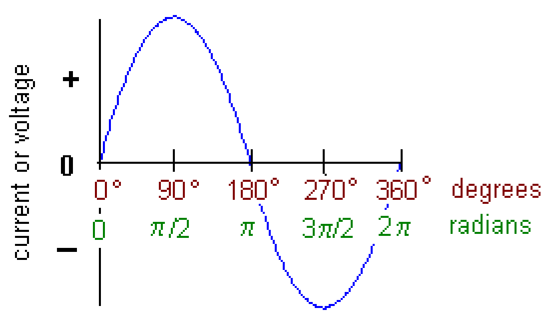
Sources of DC are commonly shown as a cell or battery:

Sources of AC are commonly shown as an AC generator:



2.0 The Sinusoidal AC Waveform

The most common AC waveform is a ***sine*** (or ***sinusoidal***) waveform.



The **vertical axis** represents the **amplitude** of the AC current or voltage, in amperes or volts.

The **horizontal axis** represents the **angular displacement** of the waveform. The units can be degrees or radians. The sine waveform is accurately represented by the **sine function** of plane trigonometry:

$$y = r\ sin\theta$$

Where:

y = the instantaneous amplitude

r = the maximum amplitude

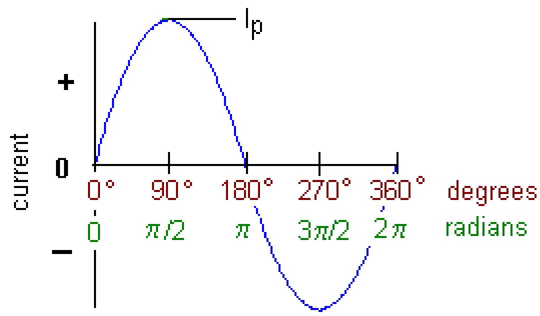
θ = the horizontal displacement

3.0 Instantaneous Current and Voltage

$i = I_p sin\theta$

where

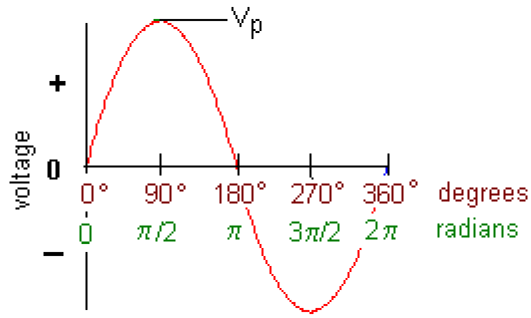
i = **instantaneous current** in amperes
I_p = the maximum, or peak, current in amperes
θ = the angular displacement in degrees or radians



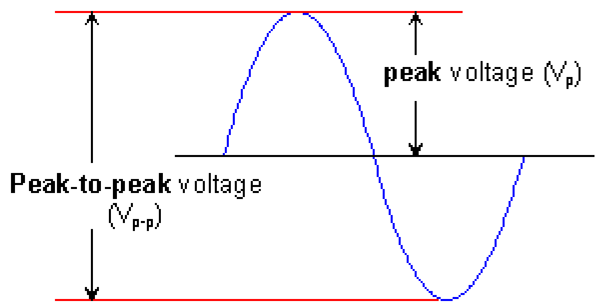
$v = V_p sin\theta$

where

v = **instantaneous voltage** in volts
V_p = the maximum, or peak, voltage in volts
θ = the angular displacement in degrees or radians



Peak and Peak-to-Peak Voltage



Peak and peak-to-peak values are most often used when measuring the amplitude of ac waveforms directly from an oscilloscope display.

Peak voltage is the voltage measured from the baseline of an ac waveform to its maximum, or peak, level.

Unit: Volts peak (V_p)
Symbol: $\mathbf{V_p}$

For a typical sinusoidal waveform, the positive peak voltage is equal to the negative peak voltage.

Peak voltages are expressed without a + or - sign.

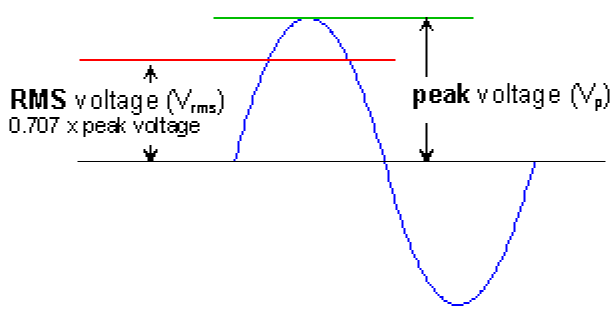
Peak-to-peak voltage is the voltage measured from the maximum positive level to the maximum negative level.

Unit: Volts peak-to-peak (V_{p-p})
Symbol: $\mathbf{V_{p-p}}$

For a typical sinusoidal waveform, the peak-to-peak voltage is equal to 2 times the peak voltage.

Peak-to-peak voltages are expressed without a + or - sign .

Root-Mean-Square (RMS) Voltage



AC levels are assumed to be expressed as RMS values unless clearly specified otherwise.

RMS voltage is the amount of dc voltage that is required for producing the same amount of power as the ac waveform.

Unit: Volts (V)
Symbol: $\mathbf{V_{rms}}$

The RMS voltage of a sinusoidal waveform is equal to 0.707 times its peak value.

$V_{rms} = 0.707V_p$

In a dc circuit, applying 2 V to a 1 Ω resistance produces 4 W of power.

In an ac circuit, applying 2 Vrms to a 1 Ω resistance produces 4 W of power.

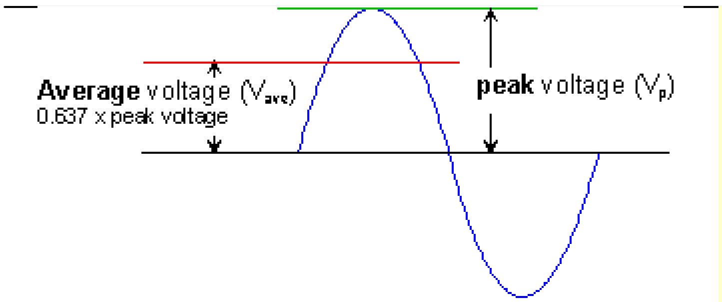
RMS voltages are expressed without a + or - sign.

Average Voltage

Average voltage is the average value of all the values for one half-cycle of the waveform.

The average voltage is determined from just one half-cycle of the waveform because the average value of a full cycle is zero.

Average voltages are expressed



Unit: Volts average (Vave)

without a + or - sign

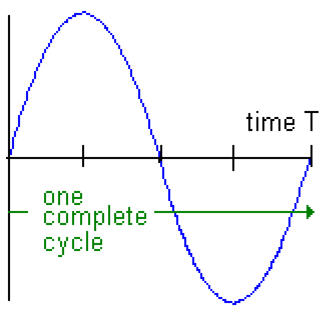
Symbol: V_{ave}

The average voltage of a sinusoidal waveform is equal to 0.637 times its peak value.

$V_{ave} = 0.637V_p$

Period of a Waveform

The **period** of a waveform is the time required for completing one full cycle.



Math symbol: T
Unit of measure: seconds (s)

One period occupies exactly 360º of a sine waveform.

The usual units of measure are:

seconds (s)
milliseconds (ms)
microseconds (us)

Frequency of a Waveform

The usual units of measure are:

hertz (Hz)

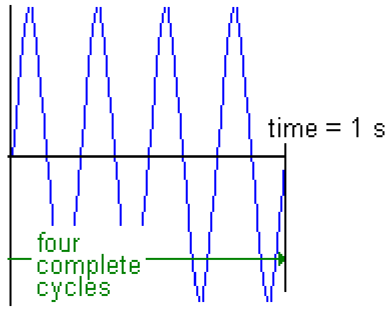
kilohertz (kHz), 10^3 Hz

megahertz (MHz), 10^6 Hz

gigahertz (GHz), 10^9 Hz

The **frequency** of a waveform is the number of cycles that is completed each second.

Math symbol: f
Unit of measure: hertz (Hz)



This example shows four cycles per second, or a waveform that has a frequency of **4 Hz**.

Period to Frequency $f = 1/T$

Frequency to Period $T = 1/f$

Frequency (f) is in hertz (Hz)
Period (T) is in seconds (s)

Phase Angle

The **phase angle** of a waveform is angular difference between two waveforms of the same frequency.

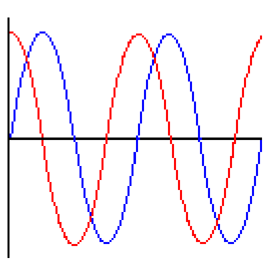
- Math symbol: θ (theta)
- Unit of measure: degrees or radians

Two waveforms are said to be **in phase** when they have the same frequency and there is **no phase difference** between them.

Two waveforms are said to be **out of phase** when they have the same frequency and there is some amount of **phase shift** between them.

Leading and Lagging Phase Angles

A **leading** waveform is one that is **ahead** of a reference waveform of the same frequency.



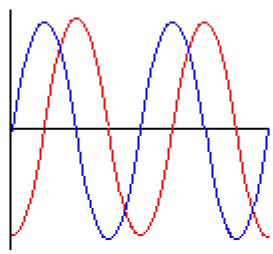
In this example, the blue waveform is taken as the **reference** because it begins at 0 degrees on the horizontal axis.

The red waveform is said to be **leading** because it is

Keeping straight whether one waveform is leading or lagging another is commonly a confusing point for students of AC electricity (and no small number of practicing technicians as well). So it pays to keep in mind whatever pictures or gimmicks that are required for helping you specify which of two out-of-phase waveforms is leading and which is lagging.

already at about 90 degrees when the reference waveform begins at 0 degrees.

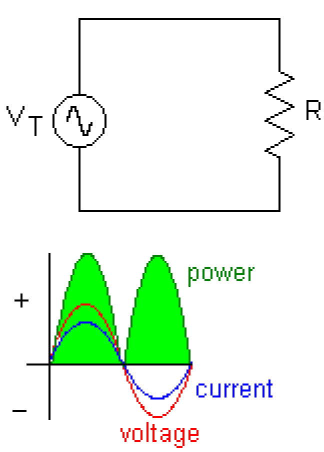
A **lagging** waveform is one that is **behind** a reference waveform of the same frequency.



In this example, the blue waveform is taken as the **reference** because it begins at 0 degrees on the horizontal axis.

The red waveform is said to be **lagging** because it has not yet completed its cycle while the reference waveform is beginning a new one at 0 degrees.

AC Power Waveform



The current and voltage waveforms are shown in phase. This is typical for a resistive load. The shaded green areas represent the corresponding levels of **power**.

Notice that **the power waveform is always positive**.

- A positive value of power indicates that the source is giving power to the load.
- A negative value of power would indicate that the circuit is returning power to the source (which will not happen in a resistor circuit).

The power waveform is always positive because the values of current and voltage always have the same sign--both negative or both positive. In algebra, this means that the product of the two values is always a positive value.

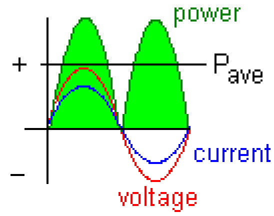
The instantaneous value of power is equal to the instantaneous current times the instantaneous voltage.

$p = ie$ where:

p = instantaneous value of power in watts
i = instantaneous value of current in amperes
v = instantaneous value of voltage in volts

Average AC Power

When the current and voltage waveforms are in phase, the average power is equal to the RMS voltage times the RMS current: $P_{ave} = I_{RMS} \times E_{RMS}$



Conventional use allows us to write this equation more simply as: P = IE

It is then assumed that P is an average value and the other two terms are RMS values.

It would seem more natural to say that the average power dissipation of a circuit is the product of the average values of current and voltage. But some simple math can show that it is not.

Variations of the AC power equation include:

I = P/E	$P = I^2R$
E = P/I	$P = E^2/R$

4.0 Inductive circuits and Reactance

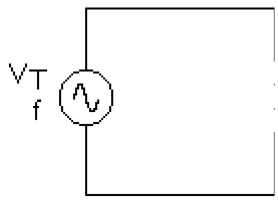
Inductive Reactance

The amount of inductive reactance in a circuit is proportional to:

- Applied frequency, f
- Value of the inductor, L

Inductive reactance is an **AC version of resistance**. In fact, you can use Ohm's Law by substituting X_L for R:

Inductive reactance is the **opposition to AC current flow** that is caused by the presence of an inductor in the circuit.



- The symbol for inductive reactance is X_L.
- The units of measure for inductive reactance is ohms, W.

$V_L = I_L X_L$ where:

VL is the voltage across the inductor in volts
IL is the current through the inductor in amperes
XL is the amount of inductive reactance in ohms

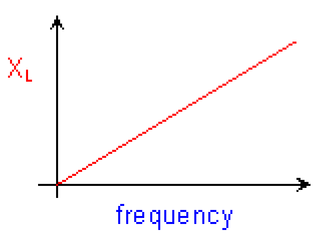
The equation for calculating the amount of inductive reactance in an ac circuit is given by:

$X_L = 2pfL$

where:

X_L = inductive reactance ohms (W)
f = frequency in hertz (Hz)
L = inductance in henries (H)

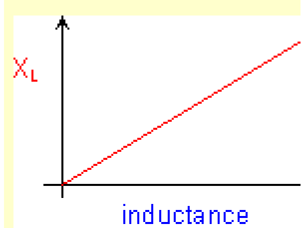
The amount of inductive reactance (X_L) changes proportionally with the applied frequency (f):



- Increasing the value of f causes X_L to increase.
- Decreasing the value of f causes X_L to decrease.

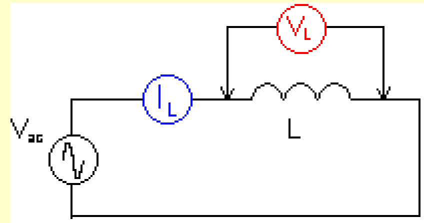
The equation, $X_L = 2\pi fL$, demonstrates the relationship between inductive reactance (X_L), the frequency (f) of the waveform applied to the circuit, and the value of the inductance (L).

The amount of inductive reactance (X_L) changes proportionally with the value of inductance (L):



- Increasing the value of L causes X_L to increase.
- Decreasing the value of L causes X_L to decrease.

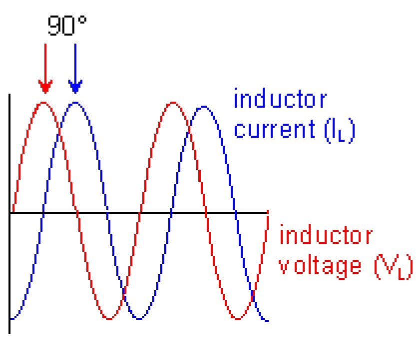
- Changing the amount of voltage applied to an inductor causes a corresponding change in current through the inductor.
- Due to the property of self-inductance, however, changes in inductor current always lag behind the changes in applied voltage.
- When the applied voltage is a sinusoidal waveform, the voltage is changing constantly and the current is constantly lagging behind.



Note:

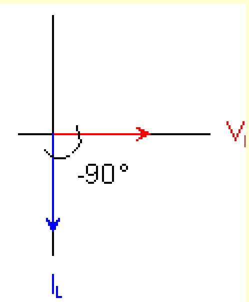
Unless stated otherwise, discussions of inductive reactance in AC circuits assume a sinusoidal voltage source.

The current through an inductor lags the voltage applied to the inductor by 90° It is also correct to say that the voltage applied to an inductor leads the current through the inductor by 90°



The 90° phase difference between current and voltage of an inductor applies only to ideal inductors—inductors that have no internal resistance. The **internal resistance** of real-world inductors causes the phase difference to be something **less than 90°**.

The phase difference between inductor current and voltage can also be shown with a vector diagram:



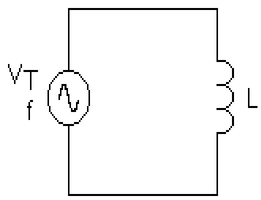
In an AC circuit, **an inductor alternately absorbs and returns power to the circuit**. AC power that is used for building up the magnetic lines of force is subsequently returned to the circuit as the magnetic lines of force collapse.

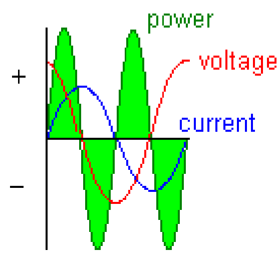
In a purely inductive circuit, **the amount of power absorbed** by building up the inductor's magnet field **is**

The average power dissipation in a purely inductive circuit is zero.

The inductor absorbs power for **one-quarter of the applied AC cycle** and returns it to the circuit during the next quarter cycle

exactly equal to the amount of power returned to the circuit when the field collapses.





The shaded green areas in this diagram show how **power** is absorbed and returned to the circuit.

- The green areas above the baseline (+ levels) represent **power that is absorbed** by the inductor.
- The green areas below the baseline (- levels) represent **power that is returned** to the circuit.

APPARENT POWER

Power in a **purely resistive circuit** is found by multiplying the RMS voltage times the RMS current:

$$P = VI$$

Apparent power in a purely inductive circuit is found the same way, but the name, symbol, and units of measure are slightly different.

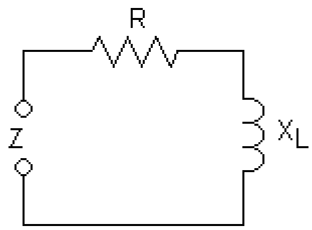
$$S = VI$$

where

S = apparent power in volt-ampere reactive, VAR
V = voltage across the inductor
I = current through the inductor

5.0 Series RL Circuit

The **impedance** of an RL circuit is the total opposition to AC current flow caused by the resistor (R) and the reactance of the inductor (X_L).



The equation for the impedance of an RL circuit is:

Impedance, a complex number by,

$$Z\angle\phi = R + j\omega L$$

where

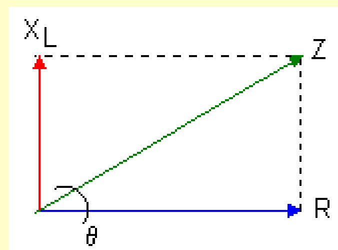
$$Z = \sqrt{X_L^2 + R^2}$$

where:

Z = the total impedance in ohms
X_L = the inductive reactance in ohms
R = the resistance in ohms

It is no accident that the equation for impedance looks like the equation for calculating the hypotenuse of a right triangle.

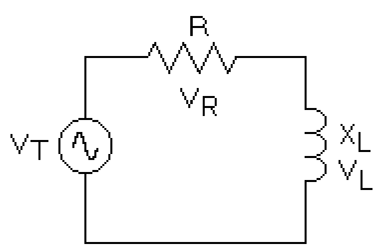
Impedance in series circuit is, in fact, often portrayed as a vector diagram where the horizontal side is the resistance, the vertical side is the reactance, and the hypotenuse is the resulting impedance.



Voltages in a Series RL Circuit

The total voltage in a series RL circuit is given by this equation:

$$V_T = \sqrt{V_L^2 + V_R^2}$$



where:

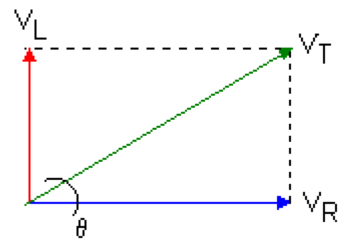
V_T = total voltage

It is very important to notice that the total voltage for a series RL circuit is **NOT** equal to the sum of the voltages across the resistor and inductor.

The sum of voltages in a series RL circuit

V_R = voltage across resistor R

V_L = voltage across inductor L



is always greater than the sum of the voltages across the resistive and inductive components

Phase Angles of Series RL Circuits

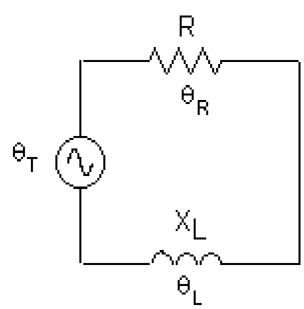
Phase Angles in Series RL Circuits

It is a basic property of resistors and inductors that their phase angles in a series circuit are always give by:

$\theta_R = 0^o \quad \theta_L = 90^o$

However, there are two equations you can use for defining the total phase angle for a series RL circuit.

The **total phase angle** can be determined by the equation: $\theta_T = \tan^{-1}(X_L / R)$

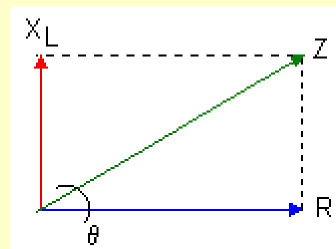


where:

θ_T = total phase angle in degrees or radians
X_L= inductive reactance in ohms
R = resistance in ohms

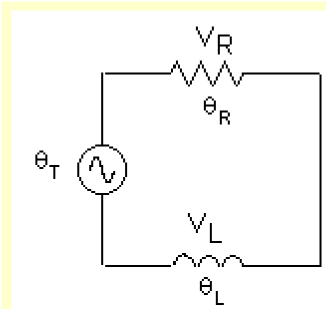
The total phase angle of a series RL circuit is always somewhere between 0º (purely resistive circuit) and 90º (purely inductive circuit).

The **tan**$^{-1}$ expression is the inverse tangent which is used for calculating angle θ for a right triangle, given the lengths of the two sides.



The **total phase angle** is also determined by the equation:

$\theta_T = -\tan^{-1}(V_L / V_R)$



where:

	θ_T = total phase angle in degrees or radians V_L= AC voltage drop across the inductor in volts V_R = AC voltage drop across the resistor in volts

In an RL circuit, **the inductor alternately absorbs and returns power to the circuit--the resistor does not.** The resistor absorbs power from the circuit, but never returns any. The waveforms shown here represent total power, voltage and current.

APPARENT POWER

Apparent power is the 'total' power of an AC circuit that does not take into account the amount of phase shift.

$$S = V_T I_T$$

where

S = apparent power in volt-ampere reactive, VAR
V_T = total voltage in volts
I_T = total current in amperes

Now the *power factor* in the circuit is defined as: $\cos\phi$; a factor by which *V.I* should be multiplied to get the real power. In fact, in a.c circuits, three types of power are commonly in use. They are:

(i) *Apparent Power* (*S*) = *VI* (unit volt-ampere or VA)
(ii) *Active Power* (*P*) = $VI\cos\phi$ (unit watt or W)

(iii) *Reactive Power* (*Q*) = $VI\sin\phi$ (unit reactive volt-ampere or VAR)

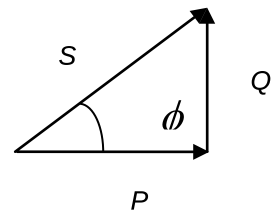


Fig. 6 Power triangle

TRUE POWER

True power takes into account the power absorbed by the resistor and inductor as well as the power that the inductor returns to the circuit. There are two ways to determine true power in an RL circuit.

(1) True power can be found by multiplying the voltage across the resistor by the current through the resistor.

$$P = V_R I_R$$

or

$$P = I^2 R$$

where

P = true power in watts
V_R = voltage across the resistor
I_R = current through the resistor
R = value of the resistor

(2) True power can also be found by

$P = VI \cos \theta$

6.0 Capacitor and capacitive reactance

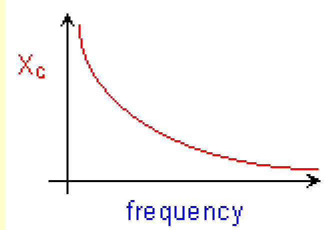
The equation for calculating the amount of capacitive reactance in an ac circuit is given by:

$$X_c = \frac{1}{2\pi fC}$$

where:

X_C = capacitive reactance in ohms
f = frequency in hertz
C = capacitance in farads

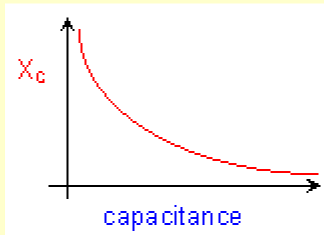
The amount of capacitive reactance (X_C) changes inversely with the applied frequency (f):



Increasing frequency causes X_C to decrease.

Decreasing frequency causes X_C to increase.

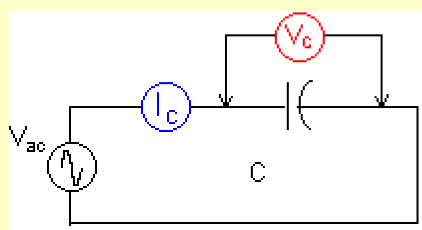
The amount of capacitive reactance (X_C) changes inversely with the value of capacitance (C):



Increasing capacitance causes X_C to decrease.

Decreasing capacitance causes X_C to increase.

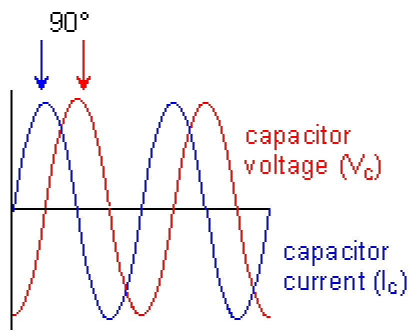
- Attempting to change the amount of voltage applied to a capacitor instantaly causes a corresponding change in current.
- Due to the basic properties of capacitance, however, the voltage across a capacitor cannot change instantly. Therefore, changes in capacitor current always lead the corresponding changes in capacitor voltage.



Notes:

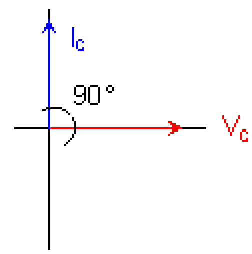
When the applied voltage is a sinusoidal waveform, the current waveform is also a sinusoidal waveform. Unless stated otherwise, discussions of capacitive reactance in AC circuits assume a sinusoidal voltage source.

The current of a capacitor leads the voltage applied to the capacitor by 90°

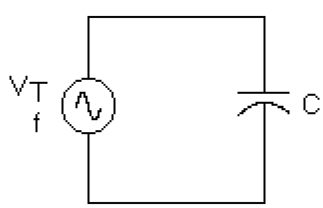


It is also correct to say that the voltage applied to a capacitor lags the current by 90°

The phase difference between capacitor current and voltage can also be shown with a vector diagram:



In an AC circuit, **a capacitor alternately absorbs and returns power to the circuit**. AC power that is stored as electrostatic force in the dielectric material is subsequently returned to the circuit as that energy is released.



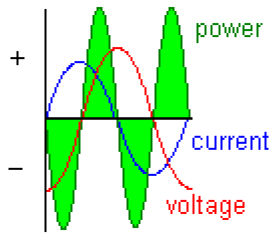
In a purely capacitive circuit, **the amount of power absorbed** by the dielectric field **is exactly equal to the amount of power returned** to the circuit when the field collapses.

The average power dissipation in a purely capacitive circuit is zero.

The capacitor absorbs power for **one-quarter of the applied AC cycle** and returns it to the circuit during the next quarter cycle.

The shaded green areas in this diagram show how **power** is absorbed and returned to the circuit.

- The green areas above the baseline (+ levels) represent **power that is absorbed** by the



capacitor.

- The green areas below the baseline (- levels) represent **power that is returned** to the circuit.

APPARENT POWER

Power in a **purely resistive circuit** is found by multiplying the RMS voltage times the RMS current, P = VI.

Apparent power in a purely capacitive circuit is found the same way, but the name, symbol, and units of measure are slightly different.

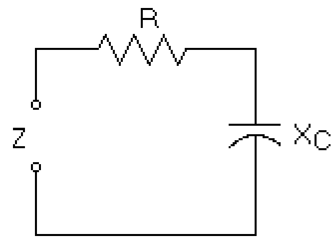
S = VI

It is important to remain aware of the differences in terminology, symbols, and units for power in purely resistive and purely inductive circuits.

Resistor Circuit	Capacitor Circuit
Name: power Symbol: P Unit: watt, W Equation: P = VI	Name: apparent power Symbol: S Unit: volt-ampere reactive, VAR Equation: S = VI

7 Series RC Circuit.

The **impedance** of an RC circuit is the total opposition to AC current flow caused by the resistor (R) and the reactance of the capacitor (X_C).



The equation for the impedance of a series RC circuit is:

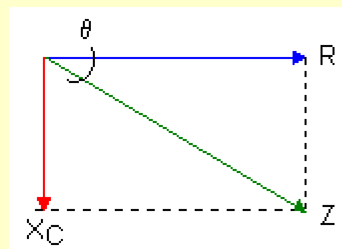
$$Z = \sqrt{X_C^2 + R^2}$$

where:

- Z = the total impedance in ohms
- X_C = the capacitive reactance in ohms
- R = the resistance in ohms

The **impedance** of a series RC circuit is **always less than** the sum of the values of resistance and reactance.

It is no accident that the equation for impedance looks like the equation for calculating the hypotenuse of a right triangle. Impedance in series circuit is, in fact, often portrayed as a vector diagram where the horizontal leg is the resistance, the vertical leg is the reactance, and the hypotenuse is the resulting impedance.



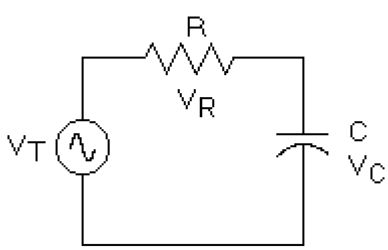
Voltages in a Series RC Circuit

The total voltage in a series RC circuit is given by this equation:

$$V_T = \sqrt{V_C^2 + V_R^2}$$

where:

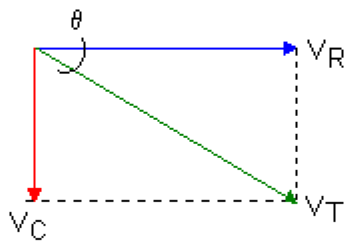
- V_T = total voltage
- V_R = voltage across



It is very important to notice that the total voltage for a series RC circuit is **NOT** equal to the sum of the voltages across the resistor and capacitor.

The sum of voltages in a series RC circuit is always greater than the sum of the voltages across the resistive and capacitive components.

resistor R
V_C = voltage across capacitor C



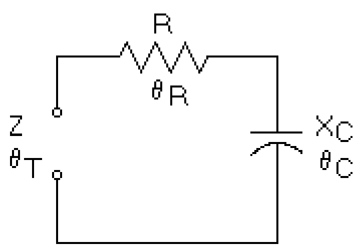
Phase Angles in a Series RC Circuit

It is a basic property of resistors and capacitors that their phase angles are always give by: $\theta_R = 0^o$ $\theta_C = -90^o$

However, there are two equations you can use for defining the total phase angle for a series RC circuit.

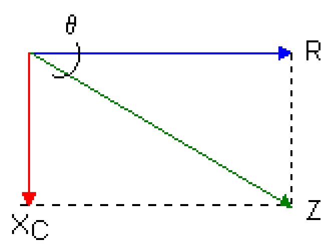
The **total phase angle** can be determined by the equation:

$\theta_T = -\tan^{-1}(X_C / R)$



where:

θ_T = total phase angle in degrees or radians
X_C= capacitive reactance in ohms
R = resistance in ohms



The total phase angle of a series RC circuit is always somewhere between 0º (purely resistive circuit) and -90º (purely capacitive circuit).

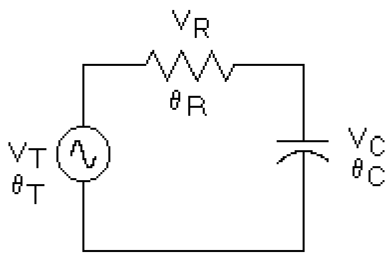
The **tan^{-1}** expression is the inverse tangent function which is used for calculating angle θ for a right triangle, given the lengths of the two sides.

So there are **two different equations** for calculating the total phase angle of a series RC circuit. **Which should you use?** Use the one that is simpler with the information you have at hand:

- If know R and X_C, use the reactance version.
- If you know V_R and V_C, use the voltage version

The **total phase angle** is also determined by the equation: $\theta_T = -\tan^{-1}(V_C / V_R)$ where:

θ_T = total phase angle in degrees or radians
V_C= AC voltage drop across the capacitor in volts
V_R = AC voltage drop across the resistor in volts



8.0 Series RLC Circuit

If an AC emf given by $\mathcal{E} = V_o \sin(\omega t)$ is used to drive current through a resistor, a capacitor, and an inductor connected in series, then the current through each element must be the same. The voltages across the various elements obey the rules given above, and the sum of these voltages must, by the loop theorem, be equal to the applied emf. This sum must be taken at a particular instant of time, which is complicated because each voltage difference will be at a different part of its cycle. Solving this complicated problem gives the following solution for the current *I*(*t*) that flows in the circuit:

$$I(t) = \frac{V_o}{Z} \sin(\omega t - \phi)$$

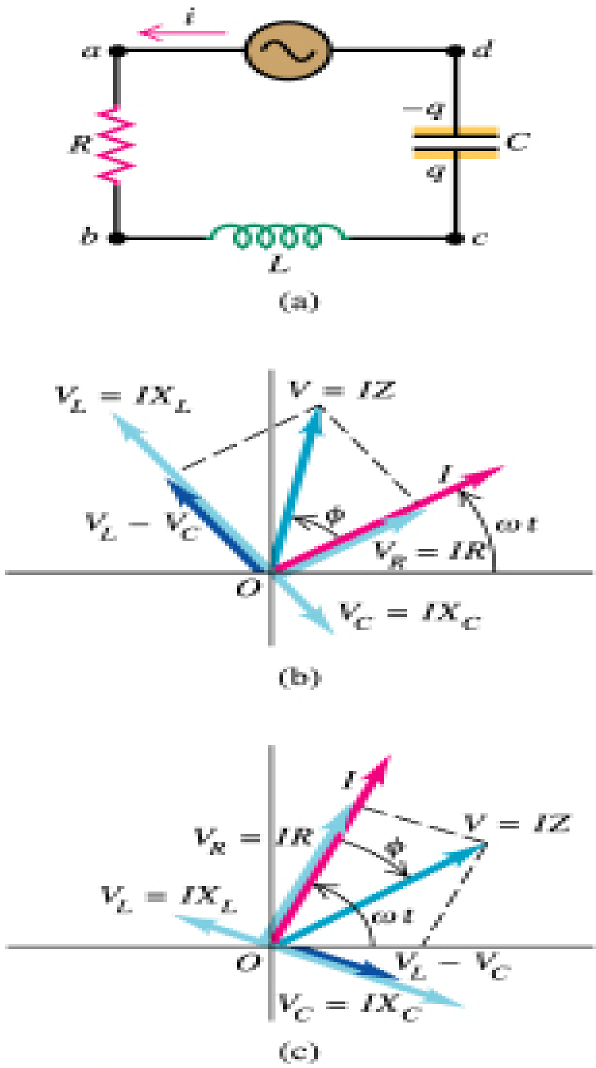
where

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

and where

$$\tan \phi = \frac{X_L - X_C}{R} \quad .$$

Note that the amplitude of *I* is given by V_o/Z, which looks about like the DC relation *I* = *V* / *R*. The quantity *Z* is called the **impedance**, it has units of ohms, and it plays the same role in AC circuits as resistance does in DC circuits. Unlike the resistance, however, it depends on the driving frequency, so the current that flows in the circuit depends sensitively on the driving frequency. Be careful, however; this formula for the impedance only applies to the **series** RLC circuit. Each different circuit has its own impedance formula.


i
a
d
−q
C
q
R
b
L
c
(a)
V_L = IX_L
V = IZ
I
φ
ωt
V_L − V_C
V_R = IR
O
V_C = IX_C
(b)
I
V = IZ
V_R = IR
φ
V_L = IX_L
ωt
O
V_L − V_C
V_C = IX_C
(c)

Resonance: Consider the series RLC circuit discussed above. The formula for the current makes it easy to see how things should be adjusted to get as much current as possible from a given driving emf V_o : simply make *Z* as small as possible. If the circuit value of *R* is fixed (as is usually the case) then the only way to get more current is by fiddling with X_L and X_C. And it is clear that the smallest value of *Z* will be obtained when $X_L = X_C$, which a little algebra shows is equivalent to $\omega = \frac{1}{\sqrt{LC}}$. But this simply says that things should be adjusted so that the driving frequency is equal to the natural frequency of the circuit (without the correction due to resistance). So, if the driving frequency is near the natural frequency, very large currents can result. When a circuit is driven near its natural frequency, we say that it is being driven at **resonance**. And the formula for *Z* shows that the smaller the resistance of the circuit, the larger the response at resonance will be. This is what makes the radio tuner work. The antenna of the radio picks up radio signals from every station in the area, but only the station whose frequency matches the natural frequency of the tuning circuit will cause large currents to flow in the circuit. These currents, when amplified, are the ones that produce the sound you hear. If the circuit is not properly tuned, then it may pick up two stations equally well, an effect you have probably heard many times.

9.0 Some discussion on series R,L,C circuits

By convention, it is assumed that if the circuit is inductive, the reactive power is positive, and for capacitive circuit, the reactive power is negative.

In a series RLC circuit, if the inductive reactance predominates the current will lag the applied voltage, while if the capacitive reactance predominates, the current will lead the applied voltage.

(i) Power considerations:
Consider a load drawing a current I lagging the applied voltage V by an angle Φ as shown in the vector diagram in Fig. The current can be resolved into two components it right – angles, one in phase with V and the other in quadrature lagging V. The two components are

Active component = in-phase component

= I cos Φ

Reactive component = quadrature component

= I sin Φ

The product of volts and amperes in an a.c. circuit gives the apparent power in volt-amperes, i.e. VA.

Thus, Apparent power, S = VI volt-amperes or VA

= VI /1000 kilovolt-amperes or kVA

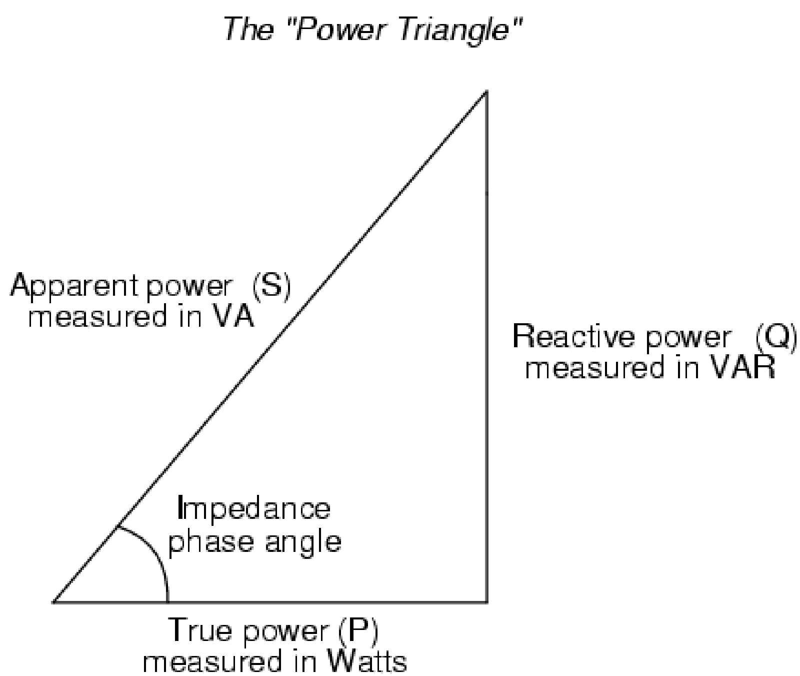
Active power, P = VI cos Φ watts or W

= VI/1000cos Φ kilowatts or kW

Reactive power, Q = VI sin Φ reactive volt-amperes or VAR

= VI/1000 sin Φ reactive kilovolt-amperes or kVAR

The apparent power in kVA can therefore be resolved into two components as shown in the power triangle in Fig. below.



We have

kW = kVA cos Φ

and kVAR = kVA sin Φ

Also, $kVA = \sqrt{(kW^2 + kVAR^2)}$

And p.f. = P/S = (Active power)/ (Apparent power)

The active power is consumed in a circuit whereas the reactive power travels back and forth between the supply and the circuit due to the presence of reactive elements (inductance and capacitance).

By convention, it is assumed that if the circuit is inductive, the reactive power is positive, and for capacitive circuit, the reactive power is negative.

(ii) The practical importance of power factor:
The power factor is given by

$$\text{Cos } \Phi = \frac{kW}{kVA}$$

or $$kVA = \frac{kW}{\cos \Phi}$$

In the case of single-phase supply

kVA = VI/1000

or $$I = \frac{kVA \times 1000}{V}$$

Therefore I ∞ kVA

In the case of 3-phase supply,

$$kVA = \frac{\sqrt{3}\, V_L\, I_L}{1000},$$ V_L = Line Voltage and I_L = Line Current

or I_L = kVA x 1000

$\sqrt{3} \times V_L$

Therefore $I_L \propto kVA$

Thus, in each case, the kVA is directly proportional to current.

The value of the power factor is decided by the nature of the load, i.e. by the consumers. **When the power factor is low, the kVA capacity as well as the current-carrying capacity of a station, to deliver a given amount of true power, increases**. Now the size and the cost of a given plant are decided by the kVA, not by the kW. Thus, the consequences of low power factor are as follows:

(i) Large kVA for a given amount of power:

All electric machinery like alternators, transformers, switchgears and cables are limited in current carrying capacity by the permissible temperature rise which is proportional to I^2. Hence, they may be fully loaded with respect to their rated kVA without delivering their full power. Obviously, it is possible for an existing plant of a given kVA rating to increase its earning capacity (which is proportional to the power supplied in kW) if the overall power factor is improved.

(ii) Poor voltage regulation:

When a load having a low lagging power factor is switched on, there is a large voltage drop in the supply voltage because of the increased voltage drop in the supply lines and transformers. This drop in voltage adversely effects the starting torques of motors and necessitates expensive voltage stabilizing equipment for keeping the consumer's voltage fluctuations within the statutory limits.

Thus from the point of view of the supply company a low power factor is a very serious matter. Hence, all supply undertakings should encourage the consumers to have a high power factor. The usual method is to frame the tariff on a kVA basis by imposing a high charge for the kVA and a low charge for the kW of energy consumed.

It may be mentioned that the active power in a circuit is measured by a watt meter which is an indicating type instrument.

Now the energy consumed over a given time t is the integral of the average power consumed, i.e.

$$\textbf{Energy} = \int_{O}^{t} P\,dt$$

Thus the energy consumed in a circuit is measured by an energy meter which is an integrating type instrument

MEASUREMENT OF POWER IN 3-PHASE CIRCUITS

(a) **Three-watt Method:** This method is employed for measurement of power in 3-phase, 4-wire circuits, the connections being, as shown in Fig 1a). As the neutral wire is common to the three phases, each watt-meter reads power in its own phase, and the total power of the load circuit is given by the sum of the readings of the three watt-meters.

i.e. Total power of load circuit, P = W1 + W2 + W3

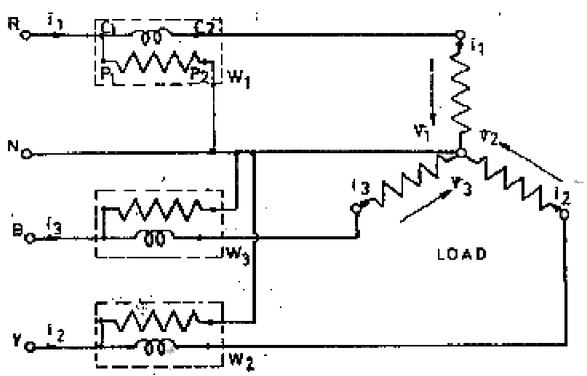


Fig. 1(a) Three Watt-Meter Method of Measuring 3-Phase Power

The above method is only useful for measuring power in 3-phase, 4-wire load circuits. In case of 3-phase 3-wire star connected circuits difficulty is experienced in getting neutral. In special cases

when it is necessary to employ this method for measurement of power in 3-phase, 3-wire circuits an "artificial star" can be formed by connecting three equal high resistances in star to the three line conductors, as shown in Fig.1(b).

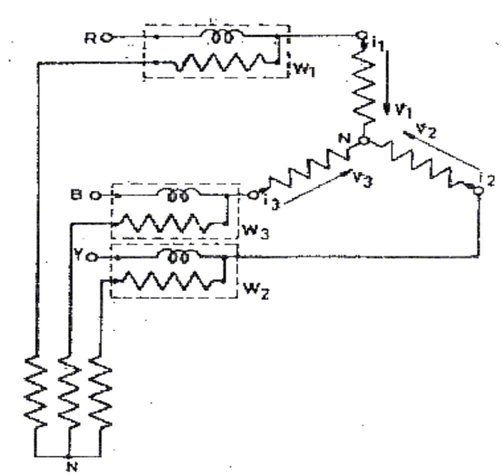


Fig. 1 (b) Three Watt-Meter Method of Measuring 3-Phase Power

In case of delta-connected circuits the difficulty in adopting the above mentioned method for measurement of power is due to the fact that the phase coils are required to be broken for inserting current coils of wattmeters as shown in Fig. 1(c).

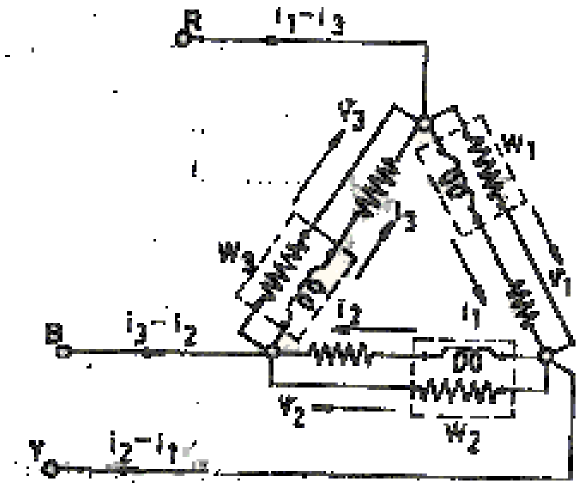


Fig. 1(c) Three Watt-Meter Method of Measuring 3-Phase Power

One-wattmeter Method: In balanced 3-wire, 3-phase load circuit the power in each phase is equal and, therefore, total power of the circuit can be determined by multiplying the power measured in any one phase by three.

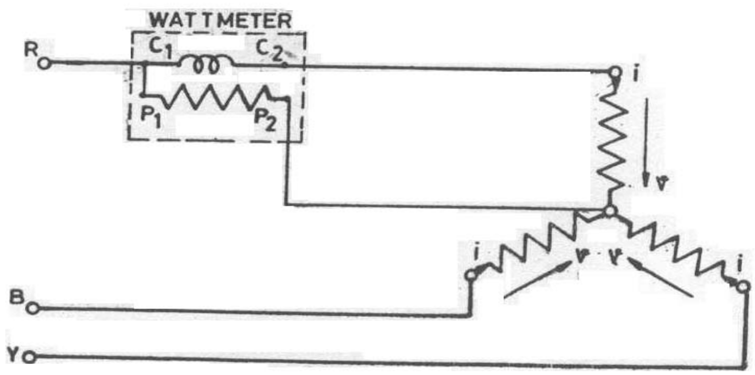


Fig. 2(a) One Watt-Meter Method of Measuring Power in 3-Phase 3- Wire Balance Load

Fig. 2(a) Shows connections for measurement of power in one phase of the 3-phase, 3-wire star connected balanced load circuits. Total power of the load circuit will be 3 times the reading of wattmeter.

Fig. 2 (b) Shows connections for measurement of power in 3-phase, 3-wire delta-connected balanced load circuits by one wattmeter method. In this method of measurement of power resistance coils of resistance of that of pressure coils is connected in each of remaining two phases, as shown in Fig. 2 (b). The pressure coil and resistance coils form a balanced star connection.

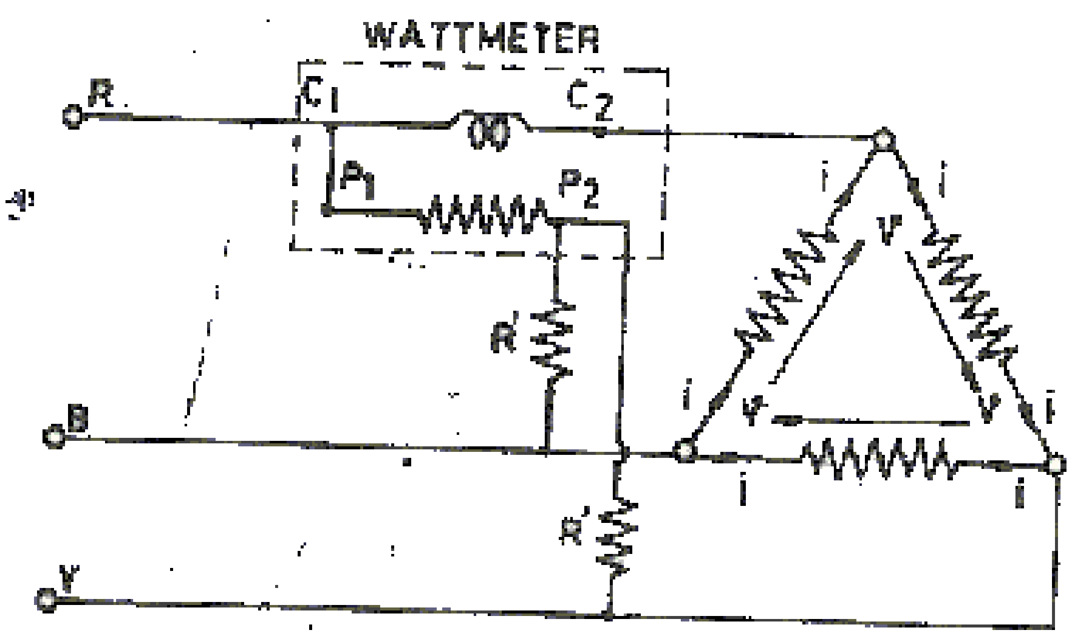


Fig. 2 (b) One Watt-Meter Method of Measuring Power in 3-Phase 3- Wire Balance Load Circuits

It should be noted that the one watt-meter method had the disadvantage that even a slight degree of unbalanced in the loading produces a large error in the measurement.

(c) **Two–Wattmeter Method**: This is the generally used method for measurement of power in 3-phase, 3 –wire, load circuits. The current coils of two wattmeters are inserted in any two lines and pressure coil is connected from its own current coil to the line without a current coil. The connections are shown in Fig. 3(a).

Let v1, v2, v3, and i1, i2, i3 be the voltages and currents of the three loads connected across three different phases at any particular instant. These being instantaneous values, the power at the instant under consideration are equal to the sum of their products, regardless of power factor.

i.e. Instantaneous power, p = v1 i1 + v2 i2 + v3 i3 watts …………(i)

Star –Connected System: Since all the three phases meet at a star point so according to Kirchhoff's first law, the algebraic sum of three instantaneous current is zero

i.e. i1+ i2 + i3 = 0

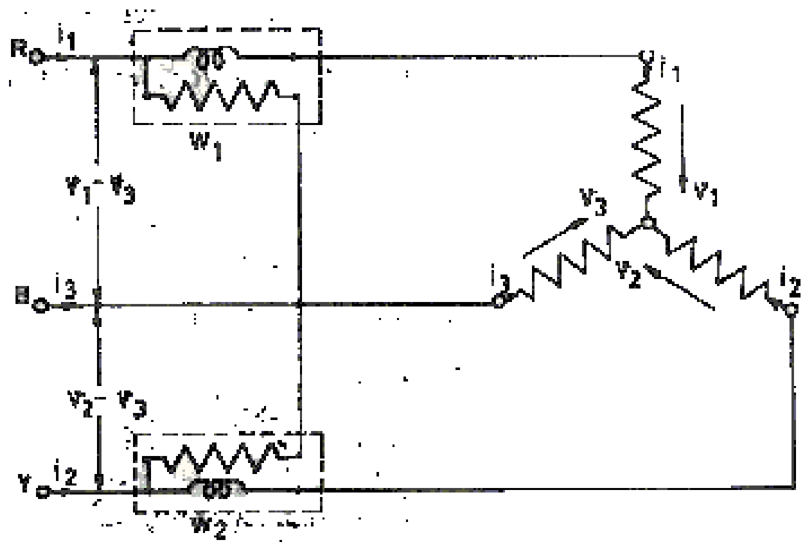
or i3 = - (i1+ i2)

Substituting i3 = - (i1+ i2) in expression (i) we get instantaneous power,

p= v1 i1 + v2 i2 - v3 (i1 +i2) = i1 (v1 – v3) + i2 (v2 - v3)

Since i1 is the instantaneous current flowing through the current coils and (v1 – v3) is the instantaneous potential difference across pressure coil of watt-meter W1, therefore (v1 – v3) i1 = w1, the instantaneous power measured by wattmeter W1.

Fig. 3 (a)Two Watt-Meter Method of Measuring Power in 3-Phase 3- Wire



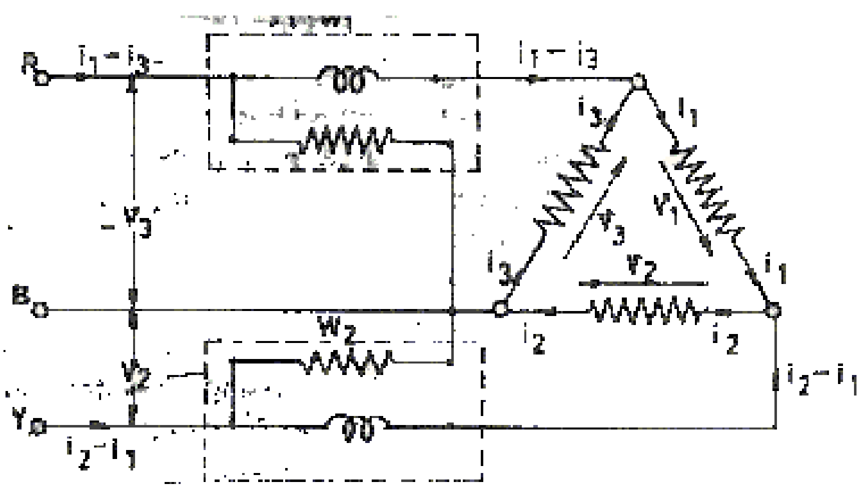


Fig. 3 (b) Two Watt-Meter Method of Measuring Power in 3-Phase 3- Wire

Similarly i2 is the instantaneous current flowing through the current coil and (v2-v3) is the instantaneous potential difference across pressure coil of wattmeter W2, therefore (v2-v3) i2 = w2, the instantaneous power measured by wattmeter W2

Hence total instantaneous power, p = w1+ w2

Or Total average power P = W1+ W2

Hence the algebraic sum of two wattmeter readings gives the total power in the 3-phase, 3-wire star connected load circuits whether the load is balanced or unbalanced.

Delta- Connected System: In delta- connected system the three phases form a closed loop and according to Kirchhoff's second law.

v1+ v2 + v3 = 0

or v1 = - (v2+v3)

Instantaneous power, p = v1i1 + v2i2 + v3i3

= - (v2 + v3) i1+ v2i2 + v3i3

= -v3 (i1-i3) + v2 (i2-i1)

Since –v3 is the instantaneous pd across pressure coil and (i1 – i3) is the instantaneous current flowing through current coil of wattmeter W1, so wattmeter W1 reads average of –v3 (i1- i3) and similarly wattmeter W2 reads average of v2(i2-i1)

Hence total power, P = W1+ W2

Hence the algebraic sum of two wattmeter readings gives total power of the circuit irrespective of the fact that the circuit is balanced or unbalanced and star connected or delta-connected.

Determination of Power Factor from Wattmeter Readings. If load is balanced, then pf of the load can also be determined from the wattmeter readings.

The vector diagram for a balanced star-connected inductive load is shown in Fig. 4 (a). Let V1,V2, and V3 be the rms values of phase voltages and I1, I2 and I3 be the rms values of phase currents.

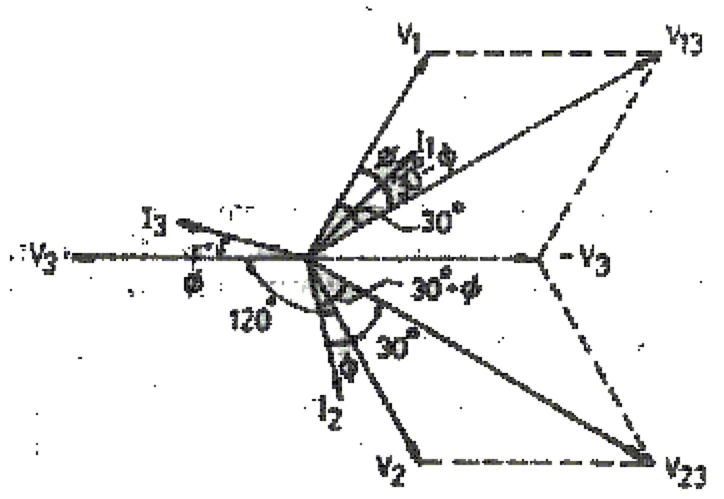


Fig. 4 (a) Vector Diagram of Balanced Star Connected Inductive Load

Since load is balanced therefore

Phase voltages V1, V2 and V3 will be equal (say, equal to Vp)

Phase currents I1, I2 and I3 will be equal (say, equal to Ip or I_L)

Phase angles between respective phase voltages and phase currents will be equal, say Φ

The current in current coil of wattmeter W1 = I1 = I_L lagging behind V1 by Φ

The pd across pressure coil of wattmeter W1 = V13 = $\sqrt{3}$ Vp = V_L lagging behind V1 by 30°

Therefore phase angle between voltage across potential coil and current through current coil of wattmeter W1 is (30°- Φ) and reading of wattmeter

$$W1 = V_L I_L \cos (30° - \Phi)$$

The current in current coil of wattmeter W2 = I2 = IL lagging behind V2 by Φ

The pd across pressure coil of wattmeter W2 = V23 = $\sqrt{3}$ Vp = VL leading V2 by 30°

Therefore phase angle between p d across potential coil and current through current coil of wattmeter W2 is (30° + Φ)

Hence reading of wattmeter W2 = VL IL cos (30° + Φ)

The sum of two watt meter readings

W1 + W2 = VL IL cos (30° - Φ) + VL IL cos (30° + Φ)

= VL IL×2 cos 30° cos Φ

= $\sqrt{3}$ VLIL cos Φ = True power of load ……. (i)

and W1 - W2 = VL IL cos(30° - Φ) -VL IL cos (30° + Φ)

= VL IL×2 sin 30° sin Φ = VL IL sin Φ …….. (ii)

Dividing the expression (ii) by expression (i) we get

$$\frac{W_1 - W_2}{W_1 + W_2} = \frac{Tan\Phi}{\sqrt{3}}$$

or Φ = Tan-1 $\left(\frac{W_1 - W_2}{W_1 + W_2}\right) \times \sqrt{3}$

and pf of load circuit, cos Φ = cos tan-1 $\frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}$

Hence phase angle Φ and pf cos Φ can be determined from readings of two wattmeters.

Alternative Method of Determination of Power Factor from Wattmeter Readings: This is convenient method for determining the power factor from watt-meter readings for a balanced load. In this method of determination of power factor from the watt-meter readings, for various values of phase angles the ratio of two wattmeter readings

cos $\frac{30^\circ + \Phi}{30^\circ - \Phi}$ i.e. $\frac{\text{smaller reading}}{\text{larger reading}}$

and the corresponding power factor values are determined and plotted.

Now by using the watt-ratio curve (Fig. 5(a)) the power factor is read directly, the ratio $\frac{W_2}{W_1}$ being known.

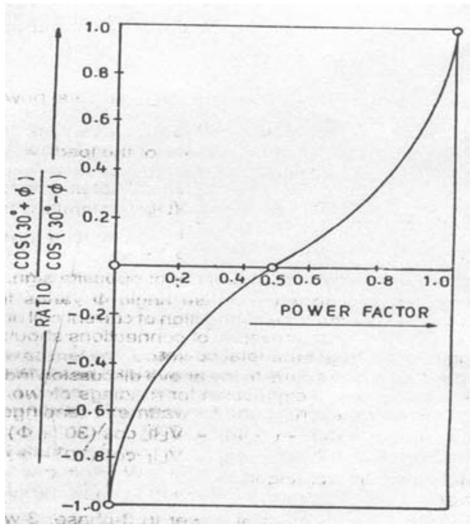


Fig. 5(a) The Watt – ratio Curve

It is seen that $\frac{W_2}{W_1}$ = 1.0, the power factor is unity; when $\frac{W_2}{W_1}$ = 0, the power factor is 0.5; when $\frac{W_2}{W_1}$ is negative i.e when it becomes necessary to reserve W2, the power factor is less than 0.5

Variation in Wattmeter Readings Wattmeter readings for inductive loads

$$W1 = VL\ IL \cos(30° - \Phi)$$

$$W2 = VL\ IL \cos(30° + \Phi)$$

When pf of load is unity i.e $\Phi = 0$ then

$$W1 = VL\ IL \cos 30° = \frac{\sqrt{3}}{2}\ VL\ IL = \text{Half of total power}$$

$$W2 = VL\ IL \cos 30° = \frac{\sqrt{3}}{2}\ VL\ IL = \text{Half of total power}$$

~~Therefore readings of both the wattmeters are same, positive and equal to half the total power circuit~~

when pf of load is 0.5 i.e. Φ = 60° then

$$W1 = VL\ IL \cos(30° - 60°) = \frac{\sqrt{3}}{2}\ VL\ IL = \text{Total power}$$

$$W2 = VL\ IL \cos(30° + 60°) = 0$$

Hence reading of wattmeter W1, will give total power of the load

When the pf of load is zero i.e Φ = 90° then

$$W1 = VL\ IL \cos(30° - 90°) = \frac{1}{2}\ VL\ IL = \text{Total power}$$

$$W2 = VL\ IL \cos(30° + 90°) = \frac{1}{2}\ VL\ IL$$

Hence the reading of two wattmeters are equal but of opposite sign.

So wattmeter W2 gives –ve reading when phase angle Φ varies from 60° to 90°. For obtaining the reading of wattmeter W2 either the connection of current coil or pressure coil should be changed and

readings obtained after the reversal of connections should be subtracted from the other wattmeter reading in order to get the total power.

Wattmeter Readings for Capacitive Loads. In the above discussion inductive load has been considered. If the circuit is capacitive, the expression for readings of two meters is obtained by substituting Φ by (-Φ) in the above expressions for wattmeter readings.

$$W1 = VL\ IL \cos[30° - (-\Phi)] = VL\ IL \cos(30° + \Phi)$$

$$W1 = VL\ IL \cos[30° + (-\Phi)] = VL\ IL \cos(30° - \Phi)$$

i.e readings of wattmeters are interchanged.

7.6 **BLONDEL'S THEOREM**

Two wattmeter methods of measurement of power in 3-phase, 3 wire load circuits and 3-wattmeter method of measurement of power in 3-phase -4 wire load circuits are the most common applications of a general theorem known as BLONDEL'S THEOREM

In an N- wire circuit, the total power supplied is given by the algebraic sum of the readings of N wattmeters, so arranged that a current coil of a wattmeter is in each wire and the corresponding potential coil is connected between that wire and a common point on the system.

If the common point is located on one of the wires, the pd across the potential coil circuit of the wattmeter whose current coil is in the wire zero, and the wattmeter has a zero reading. Thus then only N-1 wattmeters are required e.g. two wattmeters for a 3-wire circuit and three wattmeters for a 4 wire circuit.

CALIBRATION, TESTING METROLOGY &

GOOD LABORATORY PRACTICES

Introduction

Metrology is "science of measurements". We do make lot of measurements in our day to day life. Modern business and trade is impossible without metrology.

Metering is basically a measurement activity. Hence understanding of metrology is fundamental requirement for understanding of metering.

As every other science the metrology also has its own defined terms. Following are important terms which must be understood properly.

Important terms

Metrology

The Science of Measurement.

Note: The word "metrology" is different from the word "meteorology", which is related to climates and weather.

Measurement

The operations having the object of determining the value of a quantity.

When we are measuring a voltage, we want to assign a quantity to the voltage between two points. So this is a measurement process and voltage is a measurand.

Accuracy

The quality (of measurement) which characterizes the ability of a measuring instrument to give indication equivalent to the true value of the quantity measured.

Note: The quantified expression of this concept should be in terms of uncertainty.

Accuracy is a very loosely used term in general and has different quantitative meaning in different situation. For example when we say an energy meter of accuracy class 0.5, it shall be related to accuracy

limits specified in a particular standard for different loads and power factors. The error limits specified by these standards are more than 0.5% for some of the loads and power factors!!!! These error limits are

valid only in reference conditions specified in standard. So if we have installed a class 0.5 meter in field, it does not guarantee that we are measuring energy with +/-0.5% accuracy.

Note: Here the objective is to make meaning of accuracy clear and not to criticize standards. Standards are required to specify reference conditions to make sure that measurements are made in reasonably repeatable and reproducible environment.

Repeatability

A quantitative expression of the closeness of the agreement between the results of successive measurements; of the same value, of the same quantity, carried out by the same method, by the same observer, with the same measuring instrument, at the same location at appropriately short interval of time.

Reproducibility

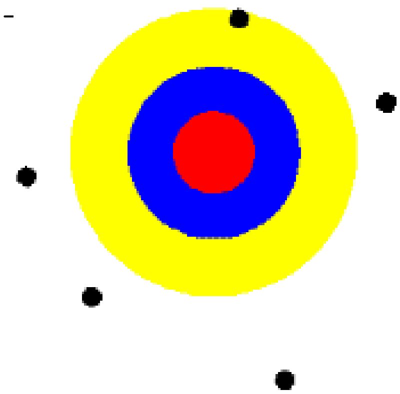
A quantitative expression of the closeness of the agreement between the results of successive measurements of the same value of the same quantity, where individual measurements are made under different defined conditions, e.g.: by different methods or, by different observers, at different locations, after long duration etc.

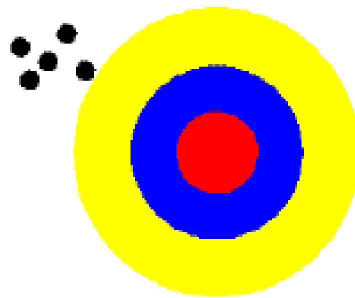
Precision

Precision is a measure of repeatability.

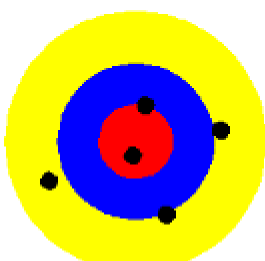
It is important to understand that the terms accuracy and precision has got different meanings though they are used as synonym in common use. A measurement can be more accurate but less precise and vice-versa.

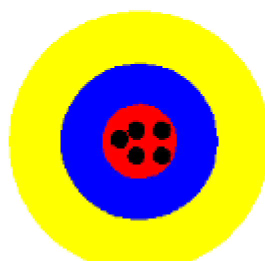
We'll use some graphics to illustrate. Firstly, there is some archery or shooting targets. Four marksmen were aiming for the center "bulls-eye". This is analogous to making a perfect measurement with the "bull" being the conventional, "true value". So, take aim and fire five rounds........





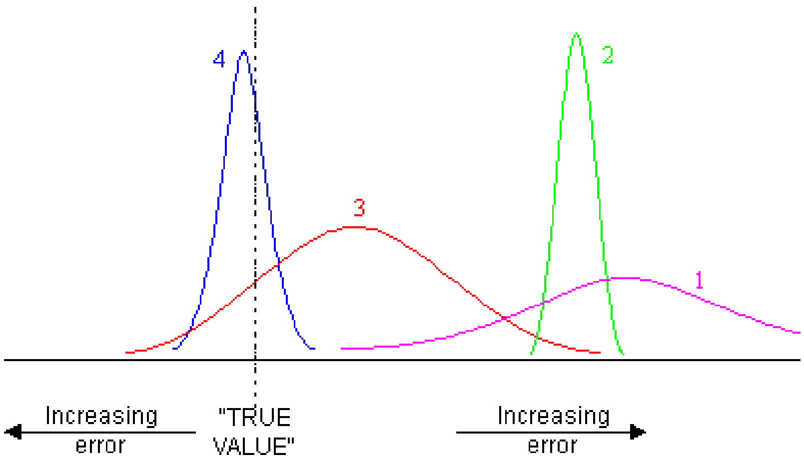
Looking at the first target (above left), the shots are widely distributed and mostly off-target -- this guy's obviously a beginner, both inaccurate and unrepeatable. However, is the second marksman (above right) much better? These shots are closely grouped but they've all missed the target completely! He's precise but inaccurate. On to the third (below left) and our man has reliably hit the target but the shots are dispersed -- so we have accuracy (two in the "bull") but imprecision. Of course, the final target shows the way it should be done -- an Olympic champion's performance perhaps -- little deviation from "true" every time, showing both accuracy and precision.





As far as calibration is concerned, the attribute accurate often also implies precise but it's worth remembering it may not be the case. Conversely, the supplier that claims his product is precise may not be making any claim at all for its correctness (relationship to national standards) -- be warned!

The degree of accuracy and precision results from the combined effect of measuring equipment, technique, environmental conditions and the characteristics of the item being tested. If a series of repeated measurements were made and the data plotted as a histogram (bar graph), the shape described by the bar-heights represents the distribution.



The plots show the performance of our marksmen when given machine guns (lots of data), where their aiming-point (bulls-eye) is the "true value". The distance of each peak from "true" is their average error and the width of the curve shows the dispersion. Whose performance is represented by each plot, do you think?

The "beginner" is purple (inaccurate/imprecise).

The second marksman is green (repeatable but poor accuracy).

Red is the intermediate marksman (accuracy but not good precision).

The "expert" is blue (accurate and precise).

Since they all had the same number of shots, the area under the curve must be equal (the total length of the histogram bars is the same) and so the plots have different "amplitudes". The curve shape depends upon each individual's performance and the amount of data analyzed, but we've assumed normal or Gaussian distribution. In calibration, of course, we don't know the "true value" and an uncertainty is

effectively a figure of merit for the reported measurement -- the limit of potential inaccuracy which should encompass the measured value's deviation from true.

Let us take example of error test results of different meters:

Meter No.	Results (% error)					Average	Conclusion
1	0.00	0.01	-0.01	0.02	0.00	0.00	Accurate and precise
2	0.00	0.05	-0.07	0.03	-0.02	0.00	Accurate but not precise
3	0.20	0.19	0.21	0.18	0.20	0.20	Not accurate but precise
4	0.50	0.23	0.65	0.55	0.30	0.45	Neither accurate nor precise

Calibration

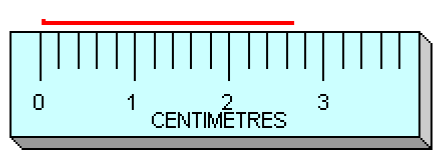
All the operations for the purpose of determining the values of the errors of a measuring instrument (and if necessary, to determine other metrological properties)

Note: may include adjustment

With upcoming of electronics equipments which has got software adjustments the word calibration is more used as determination of errors against reference standards only, rather than including adjustment. It is due to the fact that equipments with software adjustments can be calibrated only by manufacturers and not the calibration laboratories unless there is agreement between manufacturer and the laboratory. For example it is possible to do adjustment of errors of an electromechanical meter in a laboratory but it not possible to do so in case of electronic meters.

Resolution and Sensitivity

Sometimes resolution is mistaken to be the same as accuracy. This misconception often relates to instruments with digital read-outs where a similar assumption is that, for example, a frequency counter with 11 digits must be 100 times more accurate than one with 9 digit resolution. Resolution is just the discrimination that the instrument can show.



Look at this metric ruler; its resolution is 2 millimeters (one fifth of a centimeter) even though it can readily be used to measure the length of the red line with better estimated resolution (certainly to 1mm and possibly 0.1mm with magnification). However, our ability to visually subdivide between the marked graduations contributes to the uncertainty of the measurement. From inspection the evidence is that the line is between 2.6 and 2.8cm and, considering only the resolution, it would be reported as 2.6±0.2cm. If some form of magnification were available, the measured value might be stated as 2.65±0.05cm.

But what about sensitivity and resolution? Whereas resolution is a measure of the smallest change in output (indication) that is possible, sensitivity relates to the smallest change in the input (stimulus) that causes a discernible change in the output. So there is an association between these two terms.

How this concept is important for an energy meter? For an electromechanical display, the resolution is minimum amount of an energy we can read from its display. This may be say 0.1Wh or 0.01Wh.

For electronic display, this is equal to the significance of the right most digits.

It is important to understand that in energy meters the actual measurement resolution and display resolution may be different. The measurement resolution is decided by equivalent amount of energy which is assigned to one revolution of disc or one LED pulse. In modern electronic meters with electronics memory registers the actual measurement resolution is far better than what is being displayed. Lot of digits will be required on the meter to show all this resolution, but as energy is an accumulated quantity over time, the user is benefited by this fine resolution.

True value (of a quantity)

The value which characterizes a quantity perfectly defined.

Note: The true value of quantity is an ideal concept and, in general it cannot be known. No measurement can be 100% perfect and there will always be some uncertainty associated with all measurements. This is true even for a most precise measurement done in any of the best internationally recognized laboratory.

Conventional true value (of a quantity)

A value approximating to the true value of a quantity such that, for the purpose for which that value is used, the difference between these two values can be neglected.

Note: The conventional true value of a quantity is generally determined by means of methods and by the use of instruments of accuracy suitable for each particular case.

SI Units

The 11th General Conference on Weights and Measures (1960) adopted the name Système International d'Unités (International System of Units, international abbreviation SI), for the recommended practical system of units of measurement.

The 11th CGPM laid down rules for the prefixes, the derived units, and other matters. The base units are a choice of seven well-defined units which by convention are regarded as dimensionally independent: the meter, the kilogram, the second, the ampere, the kelvin, the mole, and the candela. Derived units are those formed by combining base units according to the algebraic relations linking the corresponding quantities. The names and symbols of some of the units thus formed can be replaced by special names and symbols which can themselves be used to form expressions and symbols of other derived units.

Primary Standard.

A standard of a particular quantity which has the highest class of metrological qualities in a given field.

NOTE: The concept of a primary standard is equally valid for base units and for derived units.

National standard (of measurement)

A standard recognized by a national decision as the basis for fixing the value, in a country, of all other standards of the given quantity.

NOTE: In general, the national standard in a country is also the primary standard to which the other standards are traceable. In India National Physical Laboratory, New Delhi is authorized to maintain national measurement standards by parliamentary law.

Transfer Standard

A measuring device used to compare measurement standards, or to compare a measuring instrument with a measurement standard by sequential comparison. This is basically a standard which is used to transfer traceability of two standards for example an ac-dc transfer standard.

Working Standard.

A measurement standard, not specifically reserved as a reference standard, which is intended to verify measuring instruments of lower accuracy.

So in a meter manufacturing company, the energy standard against which all meters being manufactured are calibrated is a working standard. The DMM which we use for generic measurement is a working standard.

Reference Standard

The measurement standard of best accuracy level at a particular location for the particular quantity is called reference standard. Reference standards are generally reserved for calibration of working standards against them.

Error of Measurement.

The discrepancy between the result of measurement and the true value of the quality measured.

NOTE1. In general, 'true value' may be replaced by 'conventional true value'.

NOTE2: The discrepancy can be expressed as either:

The algebraic difference between these two values, i.e. (error of measurement) = (result of measurement) - (true value), or as the quotient of that difference and the value of the quantity measured. These two forms of expression are often identified as 'absolute error' and 'relative error' respectively.

NOTE3: The term 'absolute value of an error of measurement' is used to describe the value of an error without regard to sign, i.e. the modulus of error.

Random Error.

An error which varies in an unpredictable manner, in magnitude and sign, when a large no. of measurements of the same value of a quantity are made under effectively identical conditions.

This error can be due to random temperature variation or white noise in electronic circuits.

Systematic Error.

An error which , in the course of a number of measurements of the same value of a given quantity , remains constant when measurements are made under the same condition and remains constant or varies according to a definite law when conditions change.

A systematic error can be due to inherent error of reference standard, fixed temperature difference from reference condition etc.

NOTE1: The causes of systematic error may be known or unknown. If the cause and quantity is known the systematic error can be corrected for.

Uncertainty of Measurement

That part of expression of the results of a measurement which states the range of values within which the true value or, if appropriate conventional true value is estimated to lie. So the result of a measurement is meaningful only if it contains both the measurement value and uncertainty associated with it.

Despite what the salesman might tell you, no measurement can be guaranteed to be perfect! An uncertainty is a figure of merit associated with the actual measured value; the boundary limits within which the 'true' value lies. Contributors to this "potential for inaccuracy" include the performance of the equipment used to make the measurement, the test process or technique itself and environmental effects. Additional imprecision may result from behavior of the phenomenon or item being measured. A skilled metrologist will assess and combine these various components in an uncertainty budget.

Following are lists of factors which will contribute to errors in accuracy testing of energy meters for laboratory and field conditions; hence these factors shall be considered while estimating uncertainty of measurement for accuracy testing of energy meters.

Sources contributing to uncertainties in Laboratory condition

Repeatability of Meter Under Test:

This is type A uncertainty, which has to be calculated statistically by taking multiple measurements as described above.

Calibration Uncertainty of the Calibrator:

This is mentioned in the calibration certificate of the calibrator.

Error of the Calibrator (if no correction is being applied to the results):

When the error of the calibrator is small as compared to the accuracy specification of the METER UNDER TEST, the errors of the calibrator can directly considered as a factor of uncertainty.

Accuracy Specifications of Calibrator or Aging:

This factor takes into account the change in errors of the calibrator from the time it was calibrated to the time it is being used. If the manufacturer has not specified the time factor in its specifications either the worst case specifications has to be taken or if it is an old instrument, the drift can be calculated from its previous calibration results.

Temperature Coefficient of the Calibrator:

As specified in manufacturer specification taking into consideration the environment in which the calibration is being done and the temperature at which the calibrator was calibrated.

Display Resolution of the Calibrator:

This is due to rounding off of error calculated by calibrator. e.g. if error displayed is 0.13%, the uncertainty contribution due to resolution is +/-0.005%.

Sources contributing to uncertainty in field condition

All sources as applicable to laboratory condition are present for field condition but as there is no control on reference conditions in field, the contribution of these factors is far more.

Repeatability of Meter Under Test:

The variation in errors of MUT may high in field due high variation in temperature, humidity, load, voltage, pf, and distortion.

Calibration Uncertainty of the Calibrator:

This is mentioned in the calibration certificate of the calibrator.

Error of the calibrator (if no correction is being applied to the results)

When the error of the calibrator is small as compared to the accuracy specification of the METER UNDER TEST, the errors of the calibrator can directly considered as a factor of uncertainty.

Accuracy Specifications of Calibrator or Aging:

This factor takes into account the change in errors of the calibrator from the time it was calibrated to the time it is being used. If the manufacturer has not specified the time factor in its specifications either the worst case specifications has to be taken or if it is an old instrument, the drift can be calculated from its previous calibration results.

The accuracy specification must be carefully studied for its applicability in field conditions. Sometimes the manufacturers specify some extra error to be included in specific conditions.

Generally, solid state sources are used in laboratory, which controls the voltage, current and pf within the limits of "reference conditions" as specified in metering standards and IS12346 or IEC60736. But in field, these parameters are not controlled and so variations in voltages, high distortion, variations in current, variation in frequency and pf may affect accuracy of calibrator. Voltage may be +/- 30% of reference value, distortion in V and I may be of the order of 10%, frequency may in the range of 47.5 to 52.5Hz and so on. An estimate of these variations and their effect on accuracy of reference shall be made. If it is not specified in manufacturer specification, an IS or IEC standard can be referred.

Temperature Coefficient of the Calibrator:

As specified in manufacturer specification taking into consideration the environment in which the calibration is being done and the temperature at which the calibrator was calibrated. This variation will be very high in field condition because temperature can not be controlled as against controlled temperature in laboratory.

Display Resolution of the Calibrator:

This is due to rounding off of error calculated by calibrator. e.g. if error displayed is 0.13%, the uncertainty contribution due to resolution is +/-0.005%.

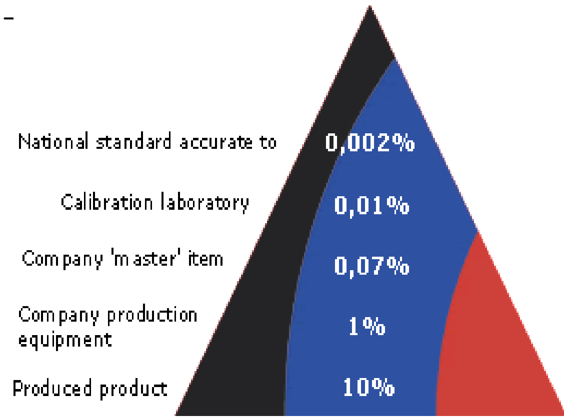
Clearly the measurement uncertainty in field condition will be higher than that in laboratory condition.

Traceability:

The simple concept behind calibration is that measuring equipment should be tested against a standard of higher accuracy.

Traceability has been defined as "the property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties." Clearly the accuracy of measurement

deteriorates as we go downwards from international or national standard which can be depicted by following figure.



For any parameter/range we should be able to illustrate this type of hierarchical relationship:-

National Standard Accurate to………………..0.002%
Calibration Laboratory.....................................0.01 %
Company "Master" Item...................................0.02%
Company Production Equipment.....................0.02%
Produced Product..0.2 %
Of course, these calibrations need to be done on a planned, periodic basis with evidence of the comparison results maintained. This record must include identification of the specific standards used (which must be within their assigned calibration interval) and some means of knowing the method used and other test conditions. By examining these records, it should be possible to demonstrate an unbroken chain of comparisons that ends at the agency responsible for maintaining and developing a country's measurement standards (now generically known as a national metrology institute). This demonstrable linkage to national standards, with known accuracy, represents 'traceability'. In fact, it doesn't stop there because these laboratories routinely undertake international comparisons which help to establish worldwide consensus on the accepted value of the fundamental measurement units, without which, there would be little confidence in, for instance, successfully mating a 10 mm screw manufactured in one country with a 10 mm nut produced in another!

Electrical power/energy is a derived quantity. The traceability for it is derived from traceability of ac voltage, ac current, power factor and time. Time is parameter which can be measured with very high accuracy and generally have negligible contribution in uncertainty of energy measurement.

At international level, there are mutual recognition agreements between various countries. As a part of these agreements, inter-comparisons of measurements are conducted among these laboratories to ensure harmonization of measurements. One such inter-comparison was started in 1995 with NIST, USA as nodal agency. 15 national measurements institutes participated in this comparison. It took five years to complete the program and results were published in 2000. It is found that most of the premiere institutes are in harmonization with each other.

Periodicity

This refers to the calibration interval assigned to an item of equipment -- examples could be 3 months or perhaps 2 years. An alternative way of expressing this is the calibration cycle, usually how many calibrations are required per year. Equipment used in any metrological situation must have known accuracy; that is, a specification assigned by the manufacturer or by the user. Since the performance of pretty much everything on the earth degrades with time, or use (or potential abuse), the expected accuracy must relate to a given period.

How and who should a calibration interval be decided? It is common misunderstanding that calibration laboratory should mention calibration due date in calibration certificate, but this is not a correct practice. The IEC17025:1999 (General requirements for competence of testing and calibration laboratories), prohibits calibration laboratories from mentioning calibration due date in calibration certificates. Than who should decide calibration interval?

It has to be decided by user, because only user knows his accuracy requirement, conditions of use. Though it true that user must take into consideration a recommendation by manufacturer, recommendation by any national or international standard, history of equipments etc.

Test Accuracy Ratio or Test Uncertainty Ratio

It's generally considered good practice to use test equipment and techniques whose combined uncertainty is 3 to 10 times smaller than the specification of the unit under test -- see concept of traceability -- which represents the test accuracy ratio: i.e. TAR = Spec/Unc.

Of course, the higher the TAR the better, but higher performance test gear or extended test times for averaging, for instance, costs more and the pursuit of an excessively high TAR is cautioned against.

It is important to note that for higher accuracies which are close to measurement capabilities of national standards, it is difficult to maintain higher TUR. Sometime a TUR of 1:1 or 1:2 is only possible.

Accreditation of Laboratories

Introduction

Laboratory accreditation is a system to evaluate competence of laboratories and give recognition to these laboratories in the form of accreditation certificate. To ensure that laboratory once accredited is maintaining its competent continuously, surveillance assessment are done by accreditation bodies. The frequency of these assessments is generally once every year.

These assessments are different from assessments done for ISO9001 certification of various organizations because the assessment team also consists of technical experts from the areas in which the laboratory is working. Equal importance is given to quality system assessment and technical competence assessment of laboratories. The technical assessment involves assessment of personnel,

equipments, traceability, measurement uncertainty evaluations, environmental conditions and methods. The assessment is done as per criteria specified in ISO/IEC 17025 standard.

The laboratory is also required to participate in relevant inter-comparisons and proficiency testing programs periodically, as a further demonstration of technical competence. Accredited laboratories usually issue test or calibration reports bearing the accreditation body's logo or endorsement, as an indication of their accreditation.

The laboratories are accredited for specific parameters or tests including ranges thereof. This information is unambiguously mentions in laboratory's scope of accreditation along with uncertainty of measurements. The description in the scope of accreditation also has advantages for the customers of laboratories in enabling them to find the appropriate laboratory or testing service.

National and International Accreditation System

All countries have their own accreditation bodies, generally one but some countries have more than one body also. Most of these accreditation bodies have adopted ISO/IEC 17025:1999 (general requirements for competence of calibration and testing laboratories) standard for accreditation of laboratories, which means that there is common system through out the world. This has also helped in development of MRAs (Mutual Recognition Agreements) among various accreditation bodies. The signing of MRA between two accreditation bodies means that a calibration of test certificate issued by a laboratory accredited by one accreditation body is considered acceptable and recognized by another accreditation body. This eliminates requirements of multiple testing for manufacturers involved in export of goods.

International Laboratory Accreditation Co-operation (ILAC) is one organization which is working to develop various MRAs.

In India, National accreditation Board for Testing and Calibration Laboratories (NABL), Department of Science and Technology, Government of India is responsible of accreditation of laboratories. The NABL is also one of the ILAC signatories and hence calibration and test certificates issued with NABL logo are acceptable worldwide.

IMPORT & EXPORT OF ELECTRICAL ENERGY

1. INTRODUCTION

Electricity is generated by generating stations and transmitted to load centers from where it is distributed to end consumers. These load centers are controlled by distribution utilities, and there is an inter-change of energy between different utilities connected to the grid.

Consumers connected to the distribution utilities, though consuming active energy may or may not consume reactive energy. There may be consumers whose loads are predominantly inductive and other consumers whose loads are predominantly capacitive. There may be bulk consumers who have their own generators who operate their generators in synchronism with the grid, drawing active energy from the system or even exporting active energy into the system.

The exchange of electricity is complex in such situations, and four quadrant energy measurements are needed to accurately measure the active and reactive energy under different export/import conditions for both active & reactive energy.

Energy measurement under such situations will depend on applicable tariff structures, and hence to cater for different tariff structures in the environment of import/export of active/reactive energy special data logging/measuring features are required in meters.

In this regards there are three forms of measurements to deal with (in metering) and these are active energy, reactive energy & apparent energy. The definitions and inter-relations are explained for import/export are explained below.

2. POWER FLOW

We need to understand the definition of power flow. Power flow is always measured with respect to the Voltage, and the Voltage at the point of measurement is taken as reference vector for defining the

direction of power flow. The angular position of the current vector with reference to this reference Voltage vector defines the direction of the flow for active, reactive and apparent energy.

When we consider vectors, and we assume that the voltage vector is a reference vector (with the current vector as a variable vector based on the load), the current vector may assume any position within 360^0 of the voltage vector. Suppose we now divide the 360^0 into four equal quadrants of 90^0 each, we shall have four quadrants, and for import/export of active/reactive power, the current vector can lie in any of the four quadrants. Let us call these quadrants as Quadrant 1, 2, 3 & 4.

When the current vector is placed in any of these quadrants, it forms an angle with respect to the voltage vector. The in-phase component of the current arrived at by considering the Cosine of the angle between the voltage & current vectors is known as the active current. Multiplication of this active component of the current with the voltage gives us the active power. The integration of the active power with time gives us the active energy.

The quadrature component of the current, arrived at by considering the Sine of the angle between the voltage & current vectors is known as the reactive current. Multiplication of this reactive component of the current with the voltage gives us the reactive power. The integration of the reactive power with time gives us the reactive energy.

The point to emphasize is that the reference point or point of measurement is critical in defining whether the power (both active or reactive) is “imported” or “exported”, and it is with respect to the Voltage vector at this reference point that the definitions are made.

The diagram shown below illustrates two positions of measurement and defines the import and export of electricity in accordance to the above definition.

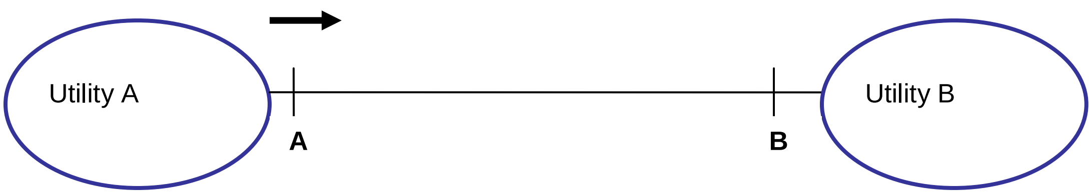


Figure 1

Shown in the above example is a condition where power (in general) is flowing from utility A to B.

At point "A" the power is being exported and at point "B" the power is being imported. These import/export definitions are always with respect to the voltage vectors at the respective points. Hence, to be able to measure the import & export correctly, we have to see these with relation to the polarity of current connections of the meter. Incorrect current connections at the meter end will result in an "export energy" to be recorded as an "import energy" and vice versa. There is therefore a need to check connections of meters carefully in the field.

3. POWER FLOW QUADRANTS

It is now explained how the angle of 360^0 can be divided into 4 quadrants of 90^0 each. The active/reactive power flow is defined as per these 4 quadrants by IEC 62053-23, with the voltage at the measuring point taken as the reference vector at vertical position shown as the 0^0 position.

The 4 quadrants are illustrated in Figure 2 below. Illustrated in the diagram are the vectorial position of the current with respect to the voltage to show what is meant by import and export for active and reactive power (or energy).

Voltage vector

Quadrant 2 **Quadrant 1**

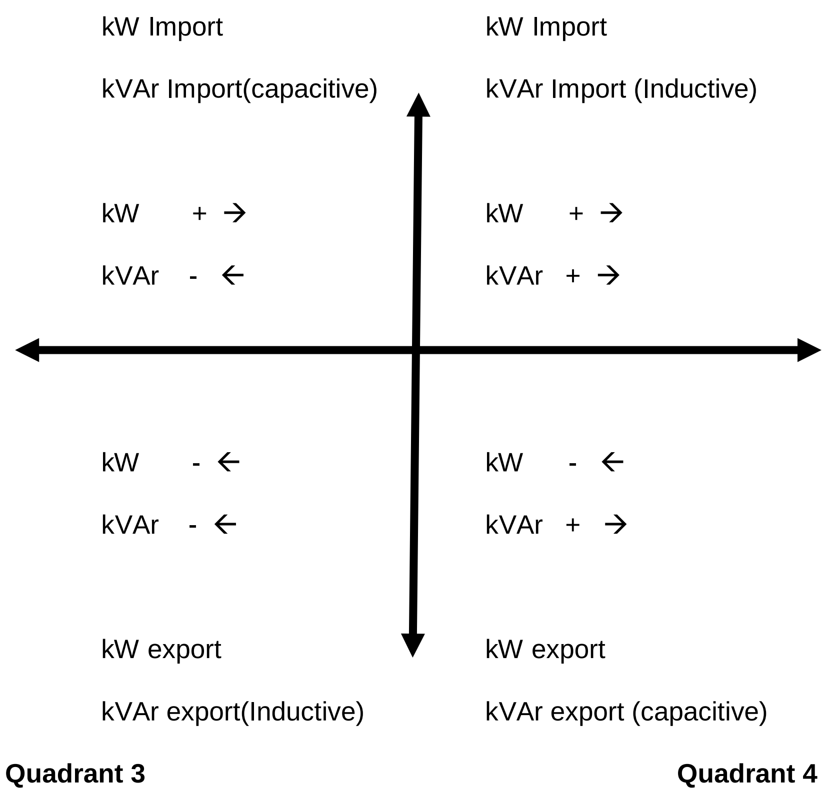


Figure 2

The power flow quadrants as per IEC 62053-23 are shown in the figure 3.

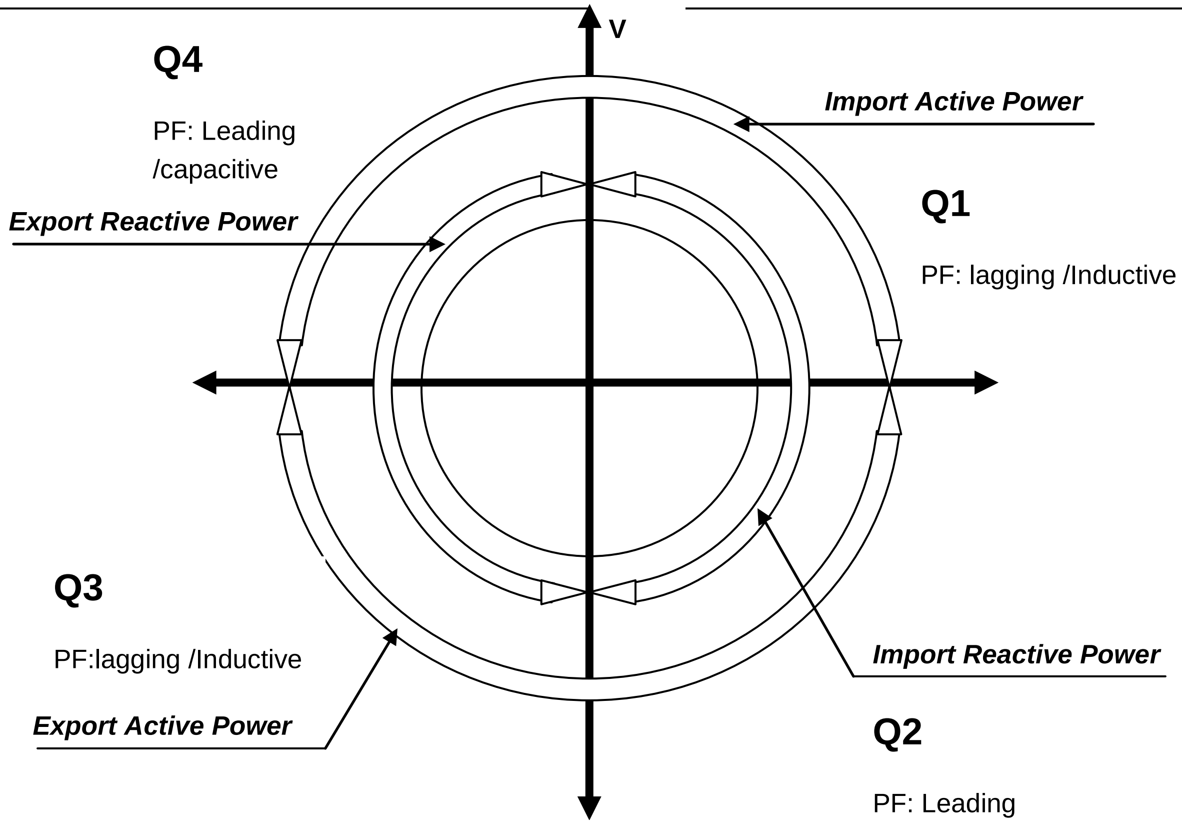


Figure 3

4. ACTIVE ENERGY

The loads are comprised of a combination of inductive load, resistive load and capacitive load. The current vector can be maximum 90° away from the voltage vector when the load is either inductive or capacitive. It is in-phase with voltage when load is resistive.

When the angle between the voltage and **active component of current** is **0^0 degrees**, the power flow is considered as **" active import"**. All energy recorded by the energy meter for this type of power flow is recorded as "import energy". The current vector lies in either quadrant 1 or 2, active energy is being consumed**..** The quadrants defined in IEC for active energy import are 1 & 4 as shown in figure 3.

When the angle between the voltage and **active component of current** is **180^0 degrees**, the power flow is considered as **"active export"**. All energy recorded by the energy meter for this type of power flow is recorded as "active export energy". The current vector lies in either quadrant 3 or 4 active energy is being generated. The quadrants defined in IEC for active energy export are 2&3 as shown in figure 3.

5. REACTIVE ENERGY

There can be two types of reactive power (or energy), namely (i) capacitive power and (ii) inductive power.

When the angle between the voltage and **reactive component of current** is **90^0 degrees**, the power flow is considered as **" reactive import"**. All energy recorded by the energy meter for this type of power flow is recorded as "import of reactive energy".

When the load (or power) is capacitive, the current vector leads the voltage vector. The current vector therefore lies in Quadrant 2 (or 3) depending on whether the capacitive load is import or export, and the quadrature component of the load current (capacitive current) is either at a 90^0 angle or 270^0 with respect to the voltage vector, as shown in figure 2. This reactive energy is called Reactive energy *capacitive* or simply reactive energy *lead*.

When the angle between the voltage and **reactive component of current** is **270^0 degrees**, the power flow is considered as **"reactive export"**. All energy recorded by the energy meter for this type of power flow is recorded as "active export energy". When the load (or power) is inductive, the current vector is leads the voltage vector. The current vector lies in Quadrant 1 (or 4) depending on whether the inductive load is import or export, and the quadrature component of the load current (reactive current) is either at 270^0 angle or 90^0 angle with respect to the voltage vector as shown in figure2. This reactive energy is called Reactive energy Inductive energy or simply Reactive energy *lag*.

Reactive energy is always defined in association with active energy. Thus reactive energy is defined for each quadrant separately. Based on the quadrant, reactive energy is either an import reactive energy or an export reactive energy. The forms of reactive energies are defined as: Reference Figure 2.

1. In Quadrant 1, active energy is considered as "**import**", reactive energy is also considered as "**import**". This is called **reactive import. (inductive)** The power factor of this type of load is a lagging power factor.

2. In Quadrant 2 active energy is considered as "**import**", but reactive energy is considered as "**export**". This is called **reactive import (capacitive**) The power factor of this type of load is a leading power factor.
3. In Quadrant 3 active energy is considered as "**export**", reactive energy is also considered as "**export**". This is called **reactive export (inductive)** because this is a mirror image of inductive import (of quadrant 1). The power factor of this type of load is a lagging power factor.

4. In Quadrant 4 active energy is considered as "**export**", but reactive energy is considered as "**import**". This is called **reactive export (capacitive)** because this is a mirror image of reactive import (capacitive) (of quadrant 2). The power factor of this type of load is a leading power factor.

The quadrant definitions are as per IEC62053-23 is shown in figure 3, and the energy definition is as illustrated in Figure 2.

6. APPARENT ENERGY

Apparent energy is essential the product of the scalar values of the voltage and current. Because the current vectors can lie in any of the four quadrants, it is not sufficient to define the apparent energy as the product of voltage and current. For every type of energy we need to define a direction to state whether

the energy is being imported or exported, and the same is also needed for apparent energy. Hence defining apparent energy is not as simple as stating that it is the product of voltage & current.

Apparent energy is the product of voltage & current (scalar quantities) and is considered as "apparent import" in case the current vector lies in Quadrant 1 or 2, and "apparent export" in case the current vector lies in Quadrant 3 or 4.

The quantities measured by meters are the active and reactive components of the current (with angle). Hence, using these values the apparent energy can be defined in two different ways, and it is important to recognize that for each of these definitions we shall get a different value for the apparent power (or energy).

In the first definition, the apparent power can either be defined as the ***Pythagoras Sum*** of ***"sum of inductive plus capacitive"*** and the ***"corresponding active power"*** .

In the second definition, the apparent can be defined as the ***Pythagoras Sum*** of ***"sum of inductive component only"*** and the ***"corresponding active power"*** .

As both the definitions do not give the same "value" for apparent power, the concept of having apparent energy tariffs can be fraught with misunderstanding. *(There are of course many other technical & commercial reasons why tariffs based on apparent energy is illogical)*

The Apparent power is called as ***"import apparent power"*** when current vector lies in ***quadrants 1 or 2*** as shown in figure 1. Apparent power in ***quadrant 3 and 4*** is called as **"export apparent power"**, in these quadrants active power is exported.

7. ENERGY REGISTERS

As we have seen, different energies can be defined as "Active", "Reactive" and "Apparent" based on the direction of active energy and in relation to the position of the voltage vector at the point of measurement. The following energy registers are required to record them accordingly

(i) Active import
(ii) Active export
(iii) Reactive import (inductive)
(iv) Reactive import (Capacitive)
(v) Reactive export (Inductive)
(vi) Reactive export (Capacitive)
(vii) Apparent import (based on definition of apparent energy)
(viii) Apparent export (based on definition of apparent energy)

8. METERING POINT AND ENERGY FLOW

An example of a single tie line with generators and loads are shown in the fig 2.

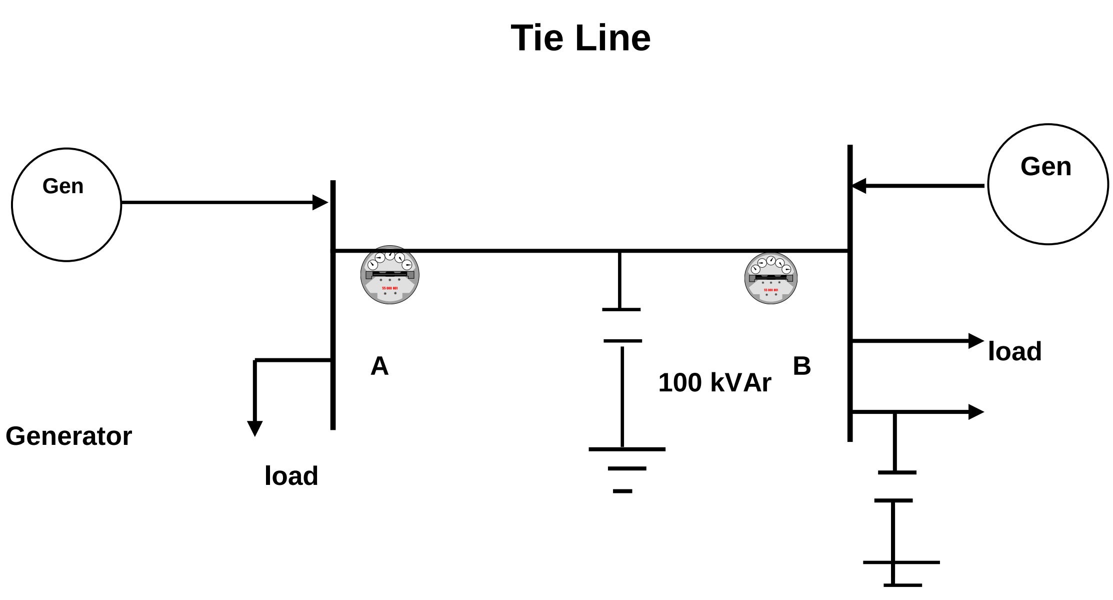


FIG. 4

As shown above, various loads are connected to the system. These loads can be inductive, capacitive, resistive or mixed. *(Generally the loads are mixed with some active & some reactive component, but in the reactive component they may be either predominantly inductive or predominantly capacitive)*.

The lines (shown above as a tie-line) are generally long HT lines that have a significant capacitance. The tie line capacitance for the above example is assumed as 100 kVAr. The points marked as "X" are the locations where meters are installed.

Lets consider point B as metering point and examine the different load conditions. As meters are installed, the increment of the energy registers will depend on the vectorial position of currents at metering point with respect to their respective voltages.

Case -1 (The load at metering point "B" is predominantly inductive, but <u>more than</u> the VARs generated by the tie-line)

When the load is inductive, it draws reactive power from the system (i.e. grid). This reactive power requirement is met by capacitances in the system *(synchronous condensers, fixed/switched capacitors, generators supplying VARs, capacitance of the lines etc.)*

If the reactive requirement of the inductive load is more than the reactive VARs generated by the tie-line capacitance, the generator will start supplying reactive energy to meet the reactive demand of the load. Under these conditions the load and meter (at point B) will operate in quadrant 1 but the generator (and the meter at point A in generator end) will operate in quadrant 3.

Suppose the capacitance of the tie-line (i.e. the 100 kVAr generated by the tie-line) meets the reactive requirements of the load reactive power will flow from the tie line to the load to meet the reactive demand and this will be measured by the meter located at point "B". It may be noted that there will be no reactive flow towards the metering point located at "A".

At Point B, active & reactive power is sensed as being "imported" and the current vector will lie in Quadrant 1.

Case -2 (The load at metering point "B" is predominantly capacitive)

If the reactive requirement of the load is capacitive, the reactive VARs generated by the tie-line and the capacitive reactive energy of the load will flow towards the generator side. The meter connected at the generator end will operate in quadrant 4 and the meter at metering point B will operate in quadrant 2.

When the load is predominantly capacitive, reactive energy will flow from the load into the system (grid). The tie line capacitance and load capacitance will add up and flow towards the generator and become a reactive energy reserve for the grid. This will lead to two conditions

(i) Either the generator absorbs the VARs by operating at a leading power factor (i.e. endangering the stability of generator, as leading PF operation is close to the stability limits)
(ii) Or, the voltage at the generator terminals (at Bus A) will rise sharply.

Under these conditions, at point B reactive power will flow from the tie line, and sum of both load-end reactive power and tie line's reactive power will flow towards the meter located at point A near the generator. The point B (load end meter) will operate in Quadrant 2, and the point A meter will operate in Quadrant 4.

The different conditions can be explained in the way stated above for other quadrants as well.

METER INSTALLATION PRACTICES AND FIELD TESTING

1.0 INTRODUCTION

Energy Meters form an integral part of electricity revenue generation system. The necessity of complete metering and energy accountability is justified by the steps taken by APDRP in prioritizing the need of providing 100% metering as an important step to create accountability for the sale of energy and to reduce Aggregate Technical & Commercial Losses (ATC losses). The Electricity Act 2003 also stipulates that every point of energy exchange needs to be metered. It is worthwhile to remember that at no other stage in the history of the Indian Power Sector, has the need for metering been so much emphasized.

To achieve this, procurement and installation of energy meters will be the key focus area for all power utilities in the country. Drafting appropriate technical and functional specifications of the meters is the important first step, requiring sufficient vision to ensure that the new meters do not get obsolete within their desired life-period, and to differentiate their application requirements vis-à-vis a broader roadmap for comprehensive revenue management. This is an involved subject by itself and can be covered in a separate paper.

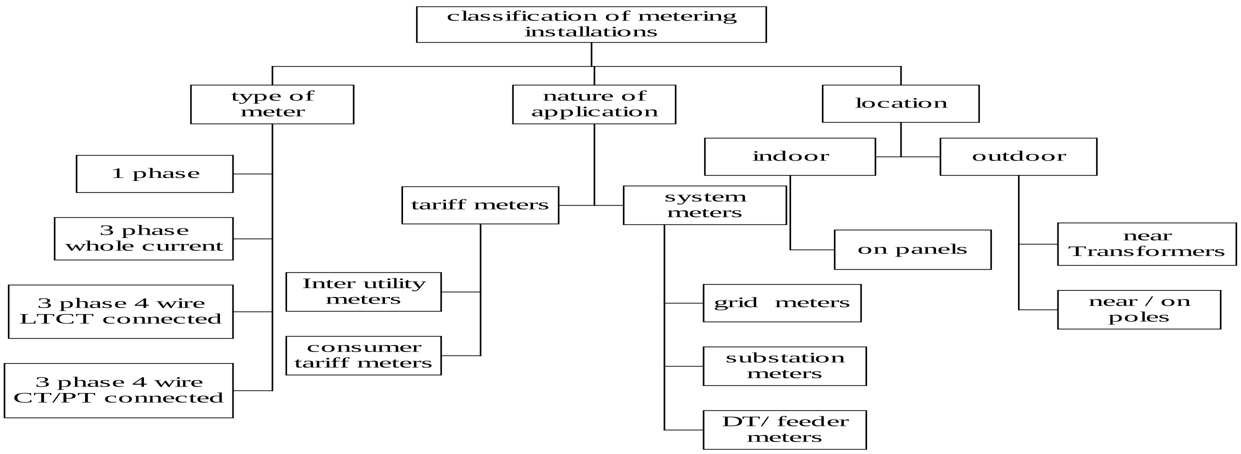
Preparing the functional and other specifications for meters, though an intellectual and knowledge based activity, is nevertheless far easier than installing the meters.

Meter installation has often been considered as a low skill labour oriented activity. What is being overlooked is the fact that there is something far beyond hanging/fixing a meter at the consumer premises, connecting the wires and putting a seal. Installation activity must follow quality installation practices, in the absence of which, even the best of the meters would not be able to guard the system against the revenue loss that may be caused by a shortsighted approach. This is an area where most utilities have gone wrong, trying to save their pennies by looking for cheaper installation methods. Specifying quality installation practices and catering for the right budget to ensure installation quality is an art, which not only needs awareness, but also compliance of the same. A few fundamentals about meter installation practices are covered in this paper as shown hereunder.

2.0 METER INSTALLATION CLASSIFICATION

While laying down or defining meter installation practices, it is important to recognize that installation practices need to be differentiated based on the following factors which influence the systems in the long run. They are,

(i) type of meter
(ii) nature of application
(iii) location of the meter, i.e. the type of site where meters are to be installed.



Classification of installations

Let us discuss the above classifications in detail.

2.1 Meter type

Meters of different accuracy classes (ex. 0.2, 0.5, 1.0, 2.0, 3.0 etc) are used for different purposes (ex. domestic, commercial and industrial etc.) based on the requirement of accuracy. Different types of meters are as follows.

(i) 1 phase meters
(ii) 3 phase 4 wire Whole Current meters
(iii) 3 phase 4 wire CT connected meters
(iv) 3 phase CT/PT connected meters for HT supplies

It is important to note that 3-phase 3 wire meters (whether Whole Current or CT operated) are unsuitable for 4 wire systems. Nearly all of our LT systems are 4 wire systems with the neutral grounded at the

transformer end. Utilities have now recognized this aspect, but there are still a number of such sites equipped with 3 phase 3 wire meters. It is worth replacing these meters on priority, as they are a potential cause for loss of revenue especially for measurement in severely unbalanced applications.

Most of the meters in the field are those meters that cater to household/low energy requirements of customers. Single phase meters have been correctly used for this purpose. However, recent years have seen trends of single phase meters being used for higher loads, by the utilities using a single phase meter with larger current range. This is preferred to avoid frequent replacements. For higher loads, it is always better to have three phase meters either as whole current or CT operated meters depending on the current, as the higher single phase loads contribute for larger unbalance on the distribution transformer.

Balance has to be kept in mind between single phase and three phase while allowing single phase loads of higher capacities. It is evident that severe unbalance is one of the causes for high failure rates of DTs. Catering for a large current in single phase meters requires suitable downstream isolation (like a number of MCBs) inside the customer premises. Hence, this needs to be engineered suitably.

2.2 Metering application

Metering applications can be broadly categorized under two types viz.

(i) Tariff metering
(ii) System metering

Tariff metering covers

a) Inter-utility tariff metering
b) Consumer tariff metering

System metering covers

a) Meters at Grid Substations with two way power flow
b) Metering at distribution substations on incomers, radial feeders and substation transformers
c) Metering on outdoor/indoor distribution transformer

It is important to recognize that different applications need different installation practices vis-à-vis different functional specifications for the meters. Taking care of the installation practice alone without heed to the functional specifications will not serve the overall purpose. For example, with the advent of introducing ABT tariffs, the need for boundary meters to support frequency linked rates is highlighted, in the absence of which the basic function is not achieved.

2.3 Location of the meter

The location of the meter, i.e. the type or nature of site where meters are to be installed is important and must be known in advance. Each different type of site needs a different installation practice.

Different types of locations are,

(i) Indoor installation
(ii) Outdoor installation at/near transformers
(iii) Outdoor installation on poles

In case of indoor installation at consumer premises, the focus of installation practices for tariff meters are directed at

a) Preventing misuse and deterring tampering / bypassing of meter by the customer by having a "visually traceable" and "joint-free" incoming cable, or shrink-wrapped sealed joints

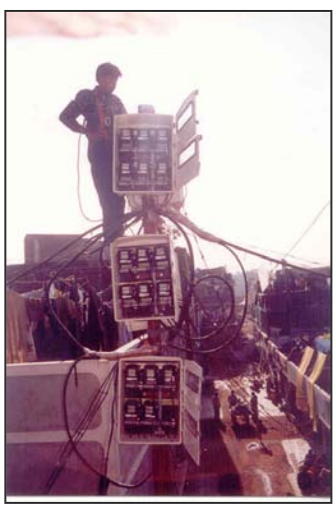
    (i) having clearly visible and accessible seals that can be subjected to easy inspection

b) Mounting the meter and CTs inside a box with a clear window, where the internals cannot be accessed without breaking through a seal.

c) Ensuring height and location of the installation for easy readability of meters (i.e. noting or downloading the meter readings)

The major cause of revenue loss has been due to lacunae in installation practices that allowed tampers by customers, and role of a few unscrupulous employees of utilities training their customers on different methods of tampering the metering system cannot be ruled out. Implementation of sound installation practices can certainly deter this.

Internationally, certain countries, particularly a few developing countries have recognized this need and follow a practice of installing the meter in public domain, as this acts as a deterrent. In India, customers do not prefer this, even though the Utilities are gaining awareness on this. The alternative is to spend a little more on meter installations, if sociological compulsions force the utilities to install the meters inside the customer premises.



Meters Arranged on a Pole

A typical place to install the meters can be on the poles from where the service cables are drawn to the houses. When meters are installed on a pole, they remain at a height in full public view, and direct connection by unscrupulous customers (bypassing the meter), is difficult.

Installing meters on poles at a height has its associated disadvantages, and it becomes more difficult for meter readers to note the readings and in-situ accuracy tests require greater efforts. In an experimental theft prone area at one of the utility, meters were installed on a tall pole; several of them together in clusters, and the supply to consumer premises were given through these meters. There was one meter on the pole for every customer end meter.

Observations from the experiment were interesting. Reading these meters on a regular basis and comparing their reading with the customer end meter readings was difficult. But even before these logistics were worked out, it was found that revenue from these customers has increased drastically. Installation of meters on the poles proved to be a psychological deterrent. Infact, these were dummy meters when the experiment was started. Simple calculation shows that the additional investment for working meters including the cost for reading the meters is paid back to the utility within a few months.

3.0 FACTORS AFFECTING MEASUREMENTS

There are a number of factors concerned with installation, which unless taken care of might affect the overall measurement system.

These factors, particularly for 3 phase CT or PT connected meters are covered below. Factors affecting single phase meters and the philosophy to deal with them is a different subject.

The factors pertaining to the CT/PT connected meters are :-

(i) Influence of CT & PT wires
(ii) Influence of VA burden
(iii) Influence of errors in wiring & nameplate
(iv) Substation panel metering
(v) Location of meters at substations
(vi) Distribution transformer metering
(vii) Industrial and Commercial metering
(viii) Metering of Agricultural connections
(ix) Mounting and meter enclosure
(x) The need for aesthetics

3.1 Influence of CT & PT wires

(xi) In CT connected meters and CT & PT connected HT meter installations, the size and length of the CT & PT wires play a major role in measurement accuracy.

(xii) Large voltage drops in undersized PT wires cause lower energy to be registered by the meter, and hence this is a loss of revenue. Voltage drops in PT wires causes an error which can be as large as

(xiii) 1% or more in energy recording, and all the “extra” investment for high accuracy meters and PTs is undone by the PT cables.
(xiv) This problem is perceptible at substations with large switchyards where a common bus PT is used for metering. This is the reason why in HV and EHV lines, the energy recorded at the receiving end is at times more than the energy sent from the sending end. All CT/PT meter installations deal with large amounts of energy, and a small error of even 1% is a significant loss in terms of revenue. It is best to specify a maximum voltage drop criteria while specifying the installation requirements.

(xv) PT leads do not constitute so serious a problem for HT consumer meter installations, as the PT is located in the close vicinity of the meters, at times inside the metering cubicle itself. Here the focus is to ensure contact tightness and to ensure that tampering/opening the PT wires is prevented through a sealing system and restriction of access to the metering system.
(xvi) Influence of VA burden
(xvii) VA burden of both CTs and PTs need to be carefully examined prior to installation. In case of CTs, the loop burden by considering the CT leads needs a quick calculation or test at site. The operating burden must be such that the instrument transformers are not over-burdened or under-burdened, as that affects accuracy of the measurement system. Normally the distance from the CTs/PTs to the metering unit shall be minimized to the extent possible as the length of the secondary conductors contribute additional burden. In case, longer secondary wires are unavoidable, for an easy assessment of the size of the secondary wires to be used, Nomograph charts may be used for the same.
(xviii) In addition, joints in CT & PT wires must be avoided. The terminations have to be carefully examined and in case lugs are used, special care during crimping is needed.
(xix) Influence of errors in wiring & nameplate
(xx) In case of CTs, special caution is needed to ensure
(xxi) correct polarity of wires
(xxii) correct phase association
(xxiii) use of low loss core
(xxiv) use of metering core and not protection core.

(xxv) The latter is very important as meters wired to protection cores of CTs or protection CTs have a large error in the normal operating range and do not saturate fast on faults leading to the meter damages as well.

(xxvi) Sometimes, for procuring accessories, utilities go wrong by selecting bidders who do not adhere to the specifications and the material supplied does not match with the specifications and hence quality of the same may not be acceptable; which in turn affects the energy recorded and there by the revenue realization from these installations.

(xxvii) In a typical case, utility conducted a check on the metering system accuracy for newly installed systems and found that majority of the errors found were out of prescribed limits. An in-depth examination showed that low quality instrument transformers were the cause for errors.

(xxviii) One common sources of error (or manipulation) is the nameplate for CTs. Mismatch in what is written in the nameplate and the actual CT ratio can cause revenue loss (very rarely one may gain revenue). Hence a ratio test prior to installation is needed.

(xxix) In case of multi-tap CT cores, where wiring the CT to different CT ratios is possible, the adopted tap position needs to be correctly noted, and the multiplication factor needs to be documented together with each installation.

(xxx) Most utilities specify (and use) primary reading meters where the multiplication factor of the CTs and PTs used in conjunction with meters is inbuilt into the meter display. It is recommended that all meters record and display the secondary quantities only. This recommendation has wide ranging

benefits and also helps in preventing revenue loss, but it is beyond the scope of this paper to go into these aspects.

(xxxi) Substation panel metering

(xxxii) Substation metering covers meters installed on panels at the substations, for the outgoing lines, feeders, and substation transformers.

(xxxiii) The precautions to be taken here are more directed towards measurement accuracy and reliability, and less towards revenue protection. There is a little reason why a substation operator will tamper a meter installed at a substation, unless the feeder is a dedicated feeder for an industry which has another meter at the industry end. Whatever may be the case, the operational practice of carrying out periodic energy balance at every substation busbar will eliminate these kind of possibilities.

(xxxiv) The focus here is on two aspects viz. Accuracy & Reliability

(i) Accuracy aspects

In substation metering the aim is not to arrest the “large errors” as conditions prevailing at a substation eliminate most sources of “large errors” (only consumer end metering needs to be careful about possibility of large errors). The errors that need to be guarded here are the “small errors” caused by systems outside the “meter box”.

The meters connected at a substation are panel meters and invariably connected to a common PT. This PT may be connected on the busbar or on the incomer side of the transformer panel. The long 11KV bus may have a bus section, and a good installation practice here is to check/test & verify whether more than one PT is needed, and the consequent voltage drop in the PT leads. It is always advisable to use a dedicated PT/CT for measurement.

(ii) Reliability aspects

The most important thing at a substation that can affect the reliability of measurements at a substation is the voltage supplied to the meter. Most substations have a fuse in the voltage circuit, backed up by more fuses upstream right up to the outdoor PT terminals. The failure of any of these fuses, in case it goes undetected, will affect the measurement reliability.

Hence, fuse failure relays are a necessary accompaniment wherever there are PT fuses, and too many downstream fuses are of little use and may be avoided as far as practicable.

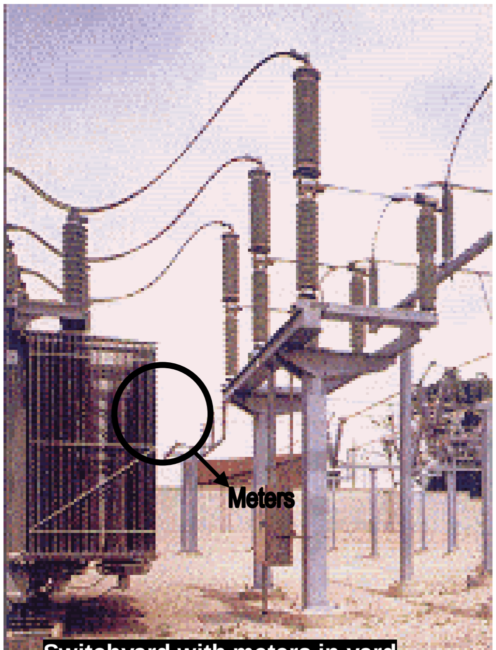
Most switchyards also have a PT selection relay, where the PT supply can be switched to the adjacent bus PT. For these cases, the health of the PT selection scheme including the pressure of the relay contacts needs to be checked at the time of meter installation.

All these aspects must be examined in routine during meter installation. Generally the meter installation groups are not be authorized to carry out testing or to make changes in the PT wiring system of a substation, as protection systems are also wired to the PTs. In such cases, the matter must be formally reported back to concerned authorities for corrective action.

3.2 Location of meters at substations

Locating the meters appropriately at substations has been an aspect often overlooked by designers.

The concept here is to improve the accuracy of the overall measurement system, i.e. the accuracy of the combined effect of CT, PT, PT leads and the meter. The best practice is to avoid installation of meters on the panels; rather they should be installed in the switchyard, preferably on integrated CT/PT units wherever feasible, to eliminate the wire related problems. The meters can be installed in the switchyard in water and dust proof enclosures with relevant IP specification.



Switchyard with meters in yard

3.3 Distribution transformer metering

Installation of meters on distribution transformers is a concept that is gaining popularity. It is the best way to account for energy and contain the AT&C losses.

The first concept about distribution transformer metering is that the metering must be done at the LT side of distribution transformers, and not on the HT side. HT side metering is not only expensive and tedious, but also not serving the purpose of energy accounting and a host of other features like power supply reliability assessment, monitoring of unbalance, technical loss calculations and others. How this is to be done, and what must be the meter's functional specifications is beyond the reach of this paper. It is sufficient to emphasize here that distribution transformer metering must be provided in the LT side only.

The aspect to be taken care of in these installations is that the cable from the transformer terminal should go directly to the CT chamber and from there only, the subsequent distribution should be allowed.

Distribution transformer meters are typically installed near the transformer terminals. But in most of the places, the meter is located at a height. It is obvious that a meter is of no use if they cannot be read on a regular basis. Usage of Low Power Radio for reading these meters is recommended. This may add to the meter cost, but save much of the meter reading cost and inconvenience in reading the meters.

A simple philosophy worth reflecting upon is as follows. If a meter is difficult to read, it will not be read. Ways and means or a justification is somehow created over a period of time as to why the readings should not be taken. So, whenever a meter installation is planned, the feasibility to read the meter in a simple way must be catered to and considered as an important feature for meter installation.

3.4 Industrial and Commercial metering

Metering at Industrial and Commercial establishments are the main and bulk sources of revenue for any utility and installation practices for such installations must be the best.

These meters are ideally located at the gate itself or near the compound wall with easy accessibility, and aesthetically housed.

The practice to allow the meters to be installed far inside the premises must be discouraged. Many cases of meter tampering can be prevented by insisting on this practice. When the meters are located far inside the premises, an unscrupulous customer will have sufficient time to restore a tamper before allowing the inspecting authority or meter reader to visit the meter.

Other key issues to be ensured during meter installation are

(i) Fire and safety considerations
(ii) Easy accessibility and readability of the meter
(iii) Earthing and the neutral wire

The subject of quality installation practices for these types of installations, including the mandatory tests needs to be specified in detail.

Coming to the functional aspects, one of the prime requirements of the meter is that it should support time stamped event logging facility for logging of different events supported by good base computer software.

3.5 Metering of Agriculture supplies

Agriculture supplies have been seen as a burden to the utility because of free-power and highly subsidized tariffs. These might have been appropriate at the time of Independence when barely a small percentage of energy was used in Agriculture, but today with nearly a third of our energy consumed by

the Agriculture sector, there is a need for accounting for it accurately and regulating the consumption. Most Agriculture supplies are as yet unmetered, and both "no metering" and "free agriculture supply" have

been exploited in the past by a few engineers in some utilities to consider a part of commercial loss as "agriculture consumption" to show a "low total loss".

The meters used for Agriculture supplies and their installation practice must aim at addressing these above issues to ensure (i) energy delivered for Agriculture purposes is accounted for reliably (ii) energy consumption beyond the sanctioned load is discouraged.

Addressing these will require specifying the metering system appropriately. The points to keep in view are:

(i) Meters must act as load restrictors based on sanctioned demand (to restrict the low tariff consumption to allowed limits), and hence the practice of having meters with inbuilt switches is recommended.
(ii) They must be located typically on poles where it will be difficult to tap Single phase power
(iii) Earthing and other safety aspects need to be taken care of

3.6 Metering of street lighting installations

In the earlier days there was no practice to account for the consumption of the street lighting installations. Slowly utilities realized the need for metering the consumption of street lighting installations. Now a days, the street lighting metering cubicles are coming with meters which act as a time switch also. In addition to energy recording, these intelligent meters offer the following advantages over conventional timers and contactors type of switching cubicles

~~(i) The meter can be programmed for switching the street lights for different times on a daily basis.~~ This kind of facility is particularly useful in northern parts of India where the day lengths vary from summer to winter seasons; thereby conserving the energy from unwanted switching of street lights at an early time.

(ii) Date of failure of street lights in a particular circuit can be found from the consumption data

(iii) Lesser maintenance as compared to the conventional contactors and timers

3.7 Mounting and meter enclosure

In the earlier days there was a practice to mount meters directly on a wooden board. Experience has shown that this is unadvisable. To have better security and safety, it is advisable to mount the meter inside a steel box or a box made of engineering plastic. For such installations it is wise to keep the incoming and outgoing wires visible for ready inspection.

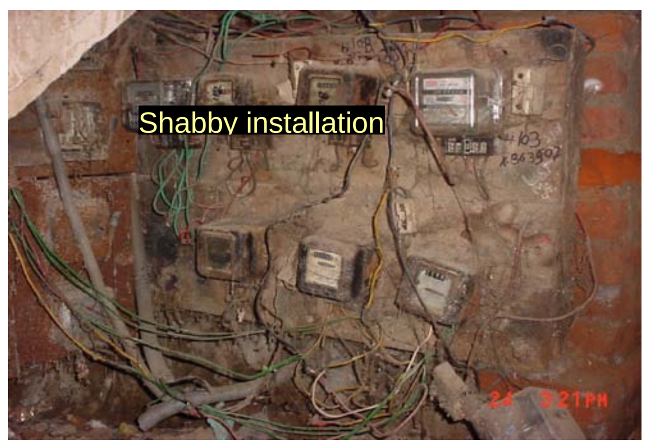
The issues to be addressed here are

(i) Mounting the meter on a wooden board
(ii) Mounting the meter inside a metal or plastic housing
(iii) Incomers must be visible or auditable
(iv) Sealing aspects
(v) Theft deterrent motives

Combination of above while installing the meters is required, and site conditions can vary.

3.8 Need for aesthetics

The need for installation aesthetics is something which the Indian Power Sector is yet to learn from the international sector. The author wonders why our "foreign visiting engineers" fail to bring back home this very important aspect.



When this matter was discussed with a few Utility engineers, it was stated that ours is a poor sector and we must learn to first provide the functional essentials. Little do we realize that poor aesthetics can indirectly lead to revenue loss, and if we can afford a little "extra" towards aesthetics, we can arrest this revenue leakage, which will help in pay back very fast.

In advanced countries, specific installation standard is enforced to be followed by a new consumer to get his connection energized from the utility. This kind of process, if strictly implemented by utilities, can result in enforcing aesthetics and standards, right from the day one.

Installation aesthetics are important aspects of a meter installation. Aesthetics are not meant for visual effects alone, but to assure electrical neatness. Typical meter installations, illustrating showing poor aesthetics is shown below. It is easy to see how such installations can be potential sources of revenue loss, and the wires shown below also give a feel of the large energy that must be passing through these poorly installed meters.

4.0 OTHER RECOMMENDED PRACTICES

The other recommended practices for quality installation cover

(i) Safety aspects
(ii) Aspects that are liable to damage meters
(iii) Tamper immunity aspects
(iv) Sound sealing practices

4.1 Safety Aspects

The guidelines for safety, to be taken of during meter installation are

(i) Proper stripping of cable/wire should be ensured i.e. wires should be stripped to the required length such that the bare wire is not exposed, that could prove to be dangerous

(ii) Lugging of cable/wire with different types of lugs like O-type, U-type, Pin type used for the wires should have proper contact with terminals
(iii) Proper crimping of lugs to be ensured by using inhibiting compound to ensure full contact of wires with meter
(iv) When tightening screws, the threaded portion of terminal screws should be visible from top side and the terminal completely fitting in the slot i.e. after tightening, threaded portion of screw must not be visible, or just one/two threads may be visible from top
(v) During the screw tightening process, the technician must shake or try to rotate the cable for proper seating of conductor strands in the terminals.
(vi) We must ensure that the terminal must completely cover the conductor part of the cable and the bare conductor is not exposed
(vii) The meter should be properly mounted on to the panel (or wooden plate) and firmly fixed with screws to the base and installed at a proper height.
(viii) Correct connections must be ensured with the right polarity, phase association and phase sequence
(ix) When joining two wires use a crimped joint and not a twist joint.
(x) Protection fuses must be used as per practice at appropriate places only.
(xi) Crossing of wire at meter terminal must not be allowed
(xii) All wires must be numbered and ferruled for easy identification. The ferrule numbers shall be as per a standard (and common) nomenclature

4.2 Aspects that are liable to damage meters

There are certain aspects that are liable to cause damage to the meter or metering installation. The recommended practice to guard against them are:

(i) Neutral wire must be properly wired for all 4 wire meters
(ii) The size of neutral wire must be the same as the size of the phase wires. The practice of using 3½ core cables does not permit this, and hence separate neutral wires are needed. Practical experience

shows that 3 phase loads in Indian installations are not adequately balanced and the neutral wire is forced to carry a large neutral current, both fundamental and harmonic current. This causes a large incidence of burning of the neutral wire. Having neutral wires of the same cross section as the phase wires prevents this problem.

(iii) In case of single-phase meters it has been observed that normally the neutral wire does not burn while the phase wires may get damaged frequently. The reason is single earth wire return systems are being adopted by many customers knowingly or unknowingly. It is necessary to keep track of such installations. One method of checking this during installation is to request the customer to switch on loads (as much as he allows) and check the phase and neutral currents

(iv) It is necessary to reconfirm the secondary ratings of a CT (for CT connected meters) at the time of meter installation. Connecting 1 ampere meter to a 5 ampere CT secondary can damage the meter. Revenue will be lost if the reverse happens.

4.3 Tamper immunity aspects

Meters installed at consumer premises are prone to different types of tampers. A good installation practice includes methods that check potentiality for tampers and follow methods to limit or eliminate them

Different tampering methods typically are as follows

(i) Magnetic tampers

Mechanical meters can be tampered very easily even without disturbing the wiring by using an external magnet to slow down the rotating disc.

Electronic meters too are susceptible to magnetic tampers, but modern designs have a high magnetic tamper immunity. Moreover electronic meters can now be designed to "run fast" whenever tampered magnetically as a measure of deterrence.

Use of suitable arrangements like meter boxes create a shield or increase the air gap (or increase reluctance of flux path) to prevent magnet based tampering.

(ii) Chemical tampers

This kind of tamper involves altering the meter performance by using chemicals. Chemicals are often injected inside the meter to hinder its performance.

A neat installation will generally discourage this type of tamper.

(iii) Direct tampers

In case of a single phase meter, a number of ways are being adopted by unscrupulous consumers, by manipulation of external wires to make the meter record less energy.

In case of a 3 phase meter, external wiring can also be manipulated to make the meter slow, and wrong phase association will render the energy readings meaningless.

Methods of tampering are evolving methods, and with each method to arrest tampering, ingenious methods to tamper once again are constantly being developed by crafty minds

There are experts with a complete knowledge of tamper methods and how to prevent most of them, and care that is needed during installation for this. The paper has not covered these aspects consciously, as detailed tampering methods and prevention techniques must not be publicly discussed.

4.4 Sound sealing practices

Sealing is necessary as a guard against tampering of connections and internals of a meter. It is a mechanism to ensure sanctity of the relevant part of a meter installation that is not meant to be accessed by customers.

A seal is not a lock which can be opened and shut again. It is simply to detect unauthorized entry to the meter internals.

Effectiveness of seal depends on the type of seal, and procedures used in tracking its total movement starting from manufacturing, procurement, storage, record keeping, installation, inspection, series of inspection, removal and disposal.

Sealing meters without a mechanism to trace the seals or without a mechanism to ensure that the right seal is there at the right place, are of little meaning.

Unfortunately, most utilities do not have an efficient seal management system. Now a days, seal management is being controlled by using software for better manageability.

The author suggests the concept of a "meter installation life cycle ownership", where a third party provides comprehensive service for

(i) installation of meters
(ii) seal management
(iii) installation audits and preventive vigilance
(iv) Periodic accuracy testing of meters: The money invested by utilities for this activity will be recovered by the reduction in theft/pilferage etc.

5.0 SUGGESTED TENDERING PRACTICES

All factors stated above can be addressed through intelligent installation practices carried out by knowledge based engineers and technicians. The way we generally go about with meter installation by using lesser skilled manpower and techniques cannot deliver us these desired intelligent practices.
To avoid installation problems and have an assured quality, the utilities need to invest wisely on meter installation and choose such contractors (or their own manpower):
(i) Who are knowledgeable on these aspects
(ii) Who can distinguish between protection cores and metering cores
(iii) Who have the necessary testing tools with them like burden tester, wiring & phase association testers
(iv) Who carry with them torque wrenches, crimping tools and high quality lugs
(v) Who are equipped to carry out a "metering system" accuracy test at site after installing the meters.

This costs money, simply because qualified meter installers will have to be deputed for the job, cost of their tool-kit & consumables will be high and the time spent at each site will be more. But this extra cost is saved by many times in terms of revenue protection. A good installation can cost money, but it optimizes on life cycle for the installation.
The low cost approach towards meter installation, which most of us invariably do, is a sure way to loose precious revenue, because meters can be installed from a few Rupees to more than a thousand Rupees.

The suggested method is to select capable meter installation contractors (in case contracting rules of your organization restrict your freedom to select contractors on single tender basis). This method is not new to the Public Sector and has already been used successfully in certain large Public Sector organizations.
The suggested steps are:

a) Draft a 3 part tender, with the three parts as
   (i) Short-listing & preliminary assessment
   (ii) Sample installation
   (ii) Final (bulk) order

b) In part-1 the contractors are short-listed based on their technical proposals, skills and equipment they shall use
c) For part-2, financial bids of all short-listed contractors are opened, and a sample installation is ordered at their respective prices, irrespective of whether the prices are high or low
d) The sample installations are audited & a life cycle cost for each type of installation is worked out. The tamper deterrent features for the sample installation are also examined, together with the associated techniques offered by each contractor

e) The tests carried out by the contractors and effectiveness of methods used for testing each installation needs to be noted and audited. This audit must also check whether the test equipment used by the contractors are duly calibrated together with traceability of standards.
f) The most cost-effective installation (and the contractor capable of doing this) is selected
g) Modifications in the installation can be suggested at this stage (which may imply an additional price)
h) The original price offered by the contractor together with “price for additions/ modifications” is negotiated
i) The sample installation is declared as a model installation (for that meter type)

j) The work is awarded
k) The model installation is used to check the quality of all installations carried out by the contractor

In case these 3 parts are stated at the time of tendering, and there is complete transparency in the process, it is possible for utility engineers to assure quality meter installations.

6.0 INSTALLATION AUDITS

The subject of quality and intelligent installation practices is incomplete in the absence of a complimentary installation audit that must be carried out systematically and periodically. The periodicity of installation audits have to be decided on a scientific basis based on sampled observation from the field and other data generated through energy audits.

An installation audits is a comprehensive periodic inspection of the metering installation to check the correctness, health, proper functioning, conformance to proper installation practices and applicable standards, adaptability to site conditions, suitability of the components used with respect to the application, security and safety aspects, including an examination and assessment of the suitability of the systems and processes put in place by the utility to assure a continued health for the metering installation.

Installation audits are needed because one cannot forget the installation condition after installation. In fact, most problems are post-installation problems caused due to either poor installation practices or due to concerted efforts by unscrupulous consumers.

Installation audits cover not only a physical inspection of the site, but also a detailed testing as was done at the time of first installation and necessary study of processes being adopted for the maintenance of the system.

In addition to the above, installation audits offer the following advantages

a. provide an opportunity to assess the standard of installations with an eye to evolve better practices

b. safety aspects like identifying the conditions that may lead to possible Injuries / accidents or hazards and minimize the same (safety aspects of potential hazards)
c. allow an examination of installation by a third party with a critical eye
d. examine whether sound processes, systems and records are maintained by the utility to assure continued health.
e. identify and address resistance/ non conformance to periodic changes in the installation procedures and practices
f. identify training needs for metering installations and its maintenance by analyzing shortcomings observed during audits

During the installation audits, aspects such as accuracy of the meter, present load on the meter, fuses, ferruling of wires, evidence of tamper, etc. are checked. In addition, the terminals are opened to examine deposits and re-tightened.
That is, installation audits also cover some of the preventive maintenance aspects of a meter installation.

7.0 CONCLUSION
Sound meter installation practices are a must to prevent revenue loss, and deserve adequate investment.

This is not a simple labour oriented activity, but highly skilled activity requiring sufficient domain knowledge, tools and testing equipment and methods.

Different types of meters and applications require different techniques.

Meter installation must be followed up with installation audits to give a life cycle coverage for the installation. Here a comprehensive life cycle responsibility for meter installation and maintenance is useful.

The money invested for a sound meter installation is paid back within a few months and ensure a much higher billing for the utility.

Proper attention to meter installation practice can give the utility, far more benefits than what the meter in isolation can provide.

STANDARDS SPECIALLY ENERGY METERING STANDARDS

Introduction

Standards are starting point for designing of any product. They provide basic minimum requirements for any product to designers. Meeting standard requirements is necessary for any product to be acceptable in market. This note helps reader in understanding standard making process and gives introduction to various standards for energy meters and their requirements.

Why standards?

The man has infinite desire to invent and know new things. In the process to satisfying this desire, lot of developments are made and hence lot of complexities creeps in human life. The management of these complexities requires some basic discipline. Standards are one of these disciplines. The life will become miserable if this discipline is defied even for a common non-technical man (strictly speaking, there is hardly any non-technical man now in this world!!!!). There are ample examples of help provided by standards in our common life. Just think of following few:

a) We buy any make of bulb and it invariably fits in almost any (standard) make bulb holder;

b) No matter where we are, the same TV works and receives programs;

c) The one spanner set is sufficient to open various types of nuts and bolts.

All above happens because of standardization. In brief following are main motives for making standards:

a. Mutual reference (e.g. Standards on time, weights and measures)
b. Interoperability (e.g. PCMCIA, RS232 etc.)
c. Crisply specifying a product or service (e.g. IEC 61036)
d. Fitting (e.g. plug and sockets)
e. Economies of scale (Most industry standards)
f. Performance Quality Control (Agmark, CE mark)
g. Safety (UL standards)

Try to find how these relate to meters…?

There are some counterpoints of standards also. Some of them are as follows:

a) Impedes innovation: Sometimes technology is specified in standard instead of performance specification. This means that a new innovative product with a new technology can not be introduced in market because it will not meet the standard requirement till standard is modified which itself generally is a very lengthy process.

b) Satisfying standards - Not a performance guarantee!!

c) The standards Jungle - The problem of universal acceptability : There are lots of standard making bodies in the world. Almost each country has its own standard making body. Invariably, there are differences in requirements specified in standards made by different bodies for the same product. This makes the life of manufacturer and many others difficult. The manufacturers are required to maintain different designs to supply their products in global market. The laboratories are required keep different instruments for testing and so on.

Making of standards

Almost each country has a legally recognized body for formulation of standards. In India Bureau of Indian standards (BIS) makes standards. Similarly US has American National Standards Institute (ANSI), Australia has “standards Australia” and so on. There are bodies which are formed by members from different countries. These bodies also make standards. For example International Electro-technical commission (IEC) and International Standard Organization (ISO).

All these bodies make various committees for different groups of products or specific area. For example BIS have committee ET13 identified as “Equipment for Electrical energy Measurement and load control committee”. This committee is primarily responsible for making standards for electrical energy meters in India. Annexure-A gives list of standards presently published by this committee. Similarly, IEC has TC 13 for “Equipment for Electrical Energy Measurement and Load Control”. Annexure-B gives list of standards presently published by this committee.

The members of committee are taken from manufacturers, consumers, users, renowned specialists or any other affected party.

The committee discusses various issues and requirements of the standard and makes a draft standard. This draft is circulated widely to affected parties for comments. The comments from various parties are discussed and incorporated appropriately by the committee and finally the standard is published. Clearly, this is a lengthy exercise and generally takes more than one year.

Types of standards (our classification)

Standards are made for different purposes. Following is a classification which has been made to understand different purposes for making standards.

a) Product standard: These are standards for specific product. For example IS 13779 (as static watt-hour meter class 1 and 2)

b) System standard: These are standards for quality assurance system. For example ISO 9001 (quality management systems – requirements), ISO/IEC 17025 (General requirements for the competence of testing and calibration laboratories).

c) Vocabulary standard: There are some standards which only defines specific terms used in a particular area. For example ISO8402 defines terms used in quality management system.

d) Testing standards: These are standards which define the test methods and testing equipments to be used for specific test. For example IEC61000-4-2 defines test method for carrying out ESD test and equipments required for this test.

e) Guideline standards: These standards give guidance on particular subject. Like guidance for application of energy meters.

Contents of a standard

All standards have more or less similar format. The individual contents of the standards are of specific importance and it is necessary to understand this importance.

a) **First page:** The first page of a standard in general provide the number of the standard, year of publication, the title of the standard, amendment or revision number, name and address of publisher, the price group.

b) **Contents:** This is index of the standard.

c) **Foreword:** This provides general information on various administrative procedures followed for the formulation of the standard. This also gives the committee which was responsible for formation of the standard.

d) **Introduction:** This provides information on the necessity of the standard and information about linkage to similar standards.

e) **Scope:** This is very important portion of the standard. This defines to which product, process, system etc the standard is applicable. Sometimes people may apply a standard to a closely similar product or process but the committee might not have intended to apply the particular standard to such type of product. To eliminate such confusion, this portion of standard generally also includes products or processes to which it is not applicable. For example following is scope of IEC62053-11:

"1 Scope

This part of IEC 62052 covers type tests for electricity metering equipment for indoor and outdoor application and applies to newly manufactured equipment designed to measure the electrical energy on 50 Hz or 60 Hz networks, with a voltage up to 600 V.

It applies to electromechanical or static meters for indoor and outdoor application consisting of a measuring element and register(s) enclosed together in a meter case. It also applies to operation indicator(s) and test output(s). If the meter has a measuring element for more than one type of energy (multi-energy meters), or when other functional elements, such as maximum demand indicators, electronic tariff registers, time switches, ripple control receivers, data communication interfaces, etc. are enclosed in the meter case, then the relevant standards for these elements apply.

It does not apply to:

a) Portable meters;

b) Data interfaces to the register of the meter;

c) Reference meters.

For rack-mounted meters, the mechanical properties are not covered in this standard."

a) **References:** This gives list of other standards to which it refers.

b) **Definitions:** Many technical terms may have different meaning for other if left to the interpretation of individuals. Hence it is very necessary that the meaning of these types of terms is defined so that everyone interprets the standard in same way. This portion of standards contains standard definitions of such terms. For example "meter type" may have different meaning for different people. Hence it is defined in IEC62052-11 as follows:

"3.1.8 Meter Type

3.1.8.1 Meter Type (for electromechanical meter) term used to define a particular design

of meter, manufactured by one manufacturer, having:

a) Similar metrological properties;

b) The same uniform construction of parts determining these properties;

c) The same ratio of the maximum current to the reference current;

d) The same number of ampere-turns for the current winding at reference current and the same number of turns per volt for the voltage winding at reference voltage.

The type may have several values of reference current and reference voltage.

Meters are designated by the manufacturer by one or more groups of letters or numbers, or a combination of letters and numbers. Each type has one designation only.

NOTE 1: The type is represented by the sample meter(s) intended for the type tests, whose characteristics (reference current and reference voltage) are chosen from the values given in the tables proposed by the manufacturer.

NOTE 2: Where the number of ampere-turns would lead to a number of turns other than a whole number, the product of the number of turns of the windings by the value of the basic current may differ from that of the sample meter(s) representative of the type.

It is advisable to choose the next number immediately above or below in order to have whole numbers of turns.

For this reason only may the number of turns per volt of the voltage windings differ, but by not more than 20 % from that of the sample meters representative of the type.

NOTE 3: The ratio of the highest to the lowest basic speed of the rotors of each of the meters of the same type shall not exceed 1,5.

3.1.8.2 Meter Type (for static meter) term used to define a particular design of meter, manufactured by one manufacturer, having:

a) Similar metrological properties;

b) The same uniform construction of parts determining these properties;

c) The same ratio of the maximum current to the reference current.

The type may have several values of reference current and reference voltage.

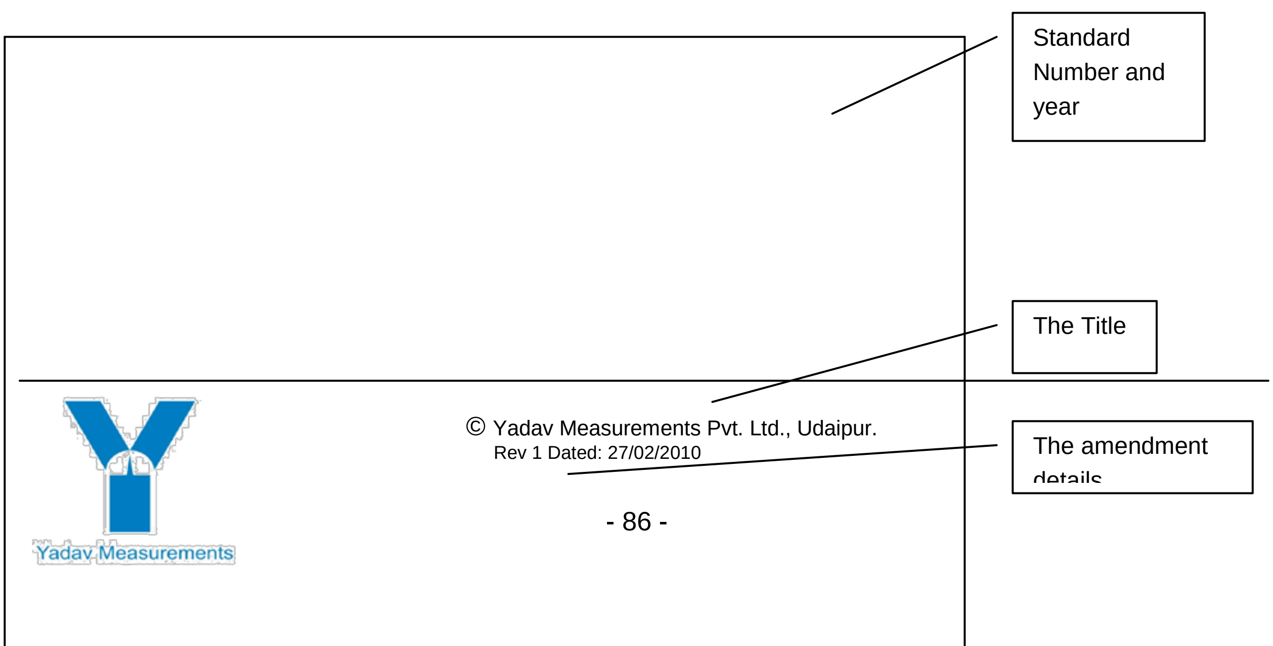
Meters are designated by the manufacturer by one or more groups of letters or numbers, or a combination of letters and numbers. Each type has one designation only.

NOTE: The type is represented by the sample meter(s) intended for the type tests, whose characteristics (reference current and reference voltage) are chosen from the values given in the tables proposed by the manufacturer."

Requirements: This gives complete requirements of the product, process or system for

which the particular standard has been made.

Appendixes: This provides any additional information.



IS 13779 : 1999

भारतीय मानक

ए सी स्थैतिक घंटा मीटर, वर्ग 1 और 2 — विशिष्टि

(पहला पुनरीक्षण)

Indian Standard

ac STATIC WATTHOUR METERS, CLASS 1 AND 2 — SPECIFICATION

(First Revision)

ICS 91.140.50

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

October 1999

Price Group 10

Metering standard

The annexure A and B gives list of all standard published by energy meter technical committees of BIS and IEC respectively and which are active as on 1st December, 2003.

Static energy meter requirements of standards

The following discussion covers requirements for static energy meters in brief.

Note: The emphasis has been given to the understanding the basis of requirements rather than on actual standard values. Special stress has been given on points where special test methods are required. The sequence has been taken from IEC62052-11 which is latest standard from IEC and replaces IEC61036 and IEC60687.

Mechanical requirements and tests

General mechanical requirements

Meters shall be designed and constructed in such a way as to avoid introducing any danger in normal use and under normal conditions, so as to ensure especially:

– Personal safety against electric shock;

– Personal safety against effects of excessive temperature;

– Protection against spread of fire;

– Protection against penetration of solid objects, dust and water.

Case Requirements

The meter shall have a case which can be sealed in such a way that the internal parts of the

meter are accessible only after breaking the seal(s).

The cover shall not be removable without the use of a tool.

The case shall be so constructed and arranged that any non-permanent deformation cannot prevent the satisfactory operation of the meter.

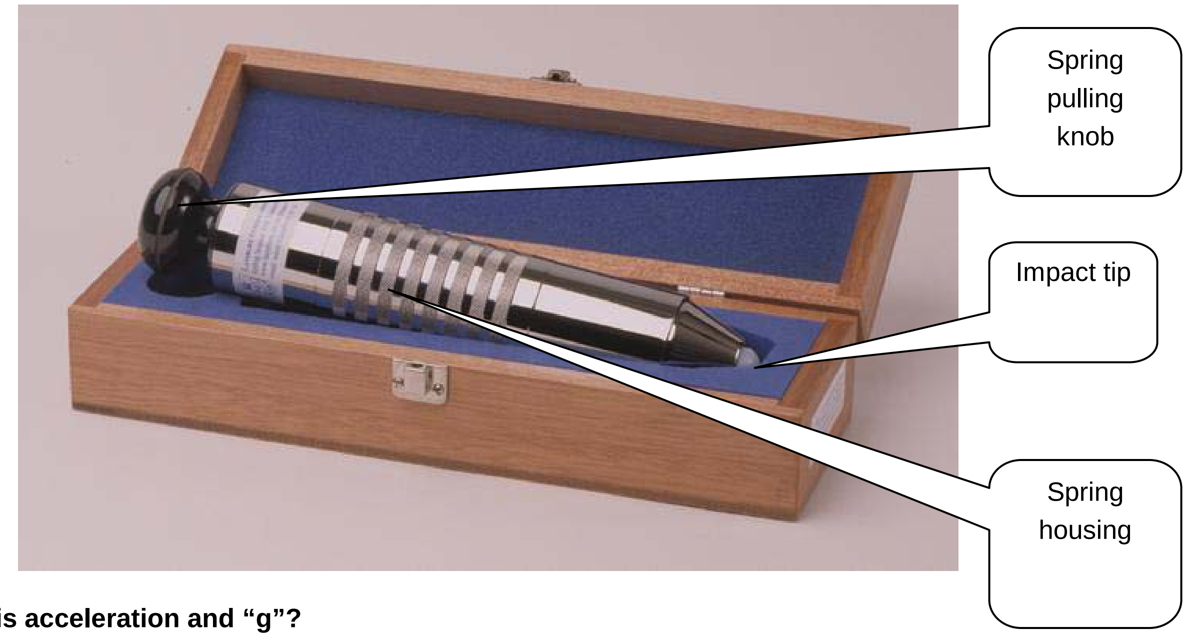
Mechanical tests

Spring hammer test

This test is done to test mechanical strength of meter case. This test simulates condition of striking of some object with some kinetic energy.

The mechanical strength of the meter case shall be tested with a spring hammer (see IEC60068-2-75). The meter shall be mounted in its normal working position and the spring hammer shall act on the outer surfaces of the meter cover (including windows) and on the terminal cover with a kinetic energy of 0.2 J ± 0.02 J.

A Typical Spring hammer test apparatus:



What is acceleration and "g"?

If we are moving at a constant speed, no matter how much is the speed it is not felt. That is why we can sit comfortably in an airplane running at 500km/hour or even higher. It is acceleration which (i.e. change in velocity) we can feel. This is true for all products also.

The acceleration is measured in m/s^2. The acceleration due to gravity can be approximated to 10 m/s^2 which we always feel. It is usual practice to express acceleration in g levels which is acceleration in m/s^2 divided by 10.

So acceleration of 20 m/s^2 is equal to 2g.

A sinusoidal vibration is defined as

X(t) = D * sin (2. pi. f . t)

Above equation when differentiated twice with respect to time gives equation for acceleration which again will be a sinusoidal and hence equation for peak acceleration will be;

~~Peak acceleration = 4 * $(pi)^2$* f^2 * D~~

Peak acceleration in g = {4 * $(pi)^2$* f^2 * D}/10,000

f= frequency in Hz

D= peak displacement in mm (not peak to peak)

Shock test

This test is done to test immunity of meters against mechanical shock which a meter may encounter during transportation or handling.

The test shall be carried out according to IEC 60068-2-27, under the following conditions:

– meter in non-operating condition, without the packing;

– half-sine pulse;

– peak acceleration: 30 gn (300 m/s2); (This value varies from standard to standard)

– duration of the pulse: 18 ms. (This value varies from standard to standard)

After the test, the meter shall show no damage or change of the information and shall operate correctly in accordance with the requirements of the relevant standard.

A Typical Shock Test system

Vibration test

A meter may be subjected to mechanical vibration during transportation and handling. There might be vibrations at installation site also due to operation of heavy machineries.

The test shall be carried out according to IEC 60068-2-6, under the following conditions:

– meter in non-operating condition, without the packing;

– frequency range: 10 Hz to 150 Hz;

– transition frequency: 60 Hz;

– f < 60 Hz, constant amplitude of movement 0,075 mm;

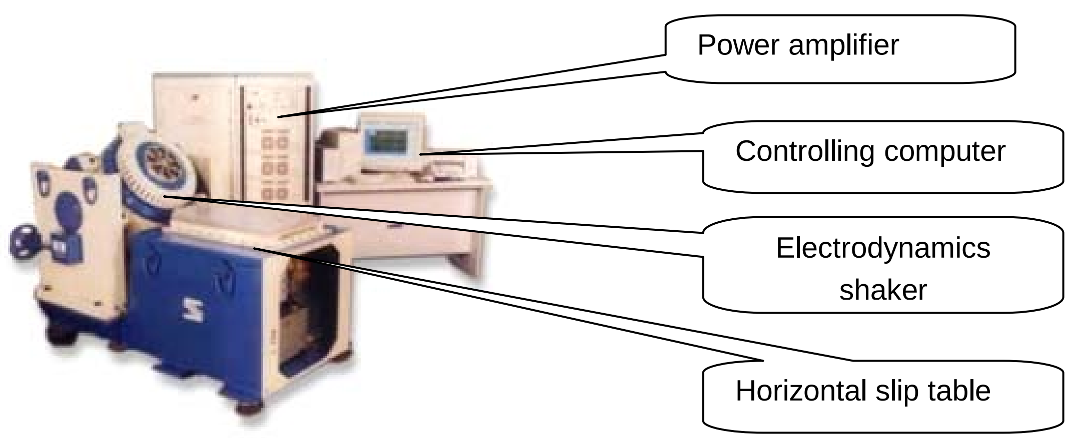
– f > 60 Hz, constant acceleration 9,8 m/s2 (1 g);

– single point control;

– number of sweep cycles per axis: 10.

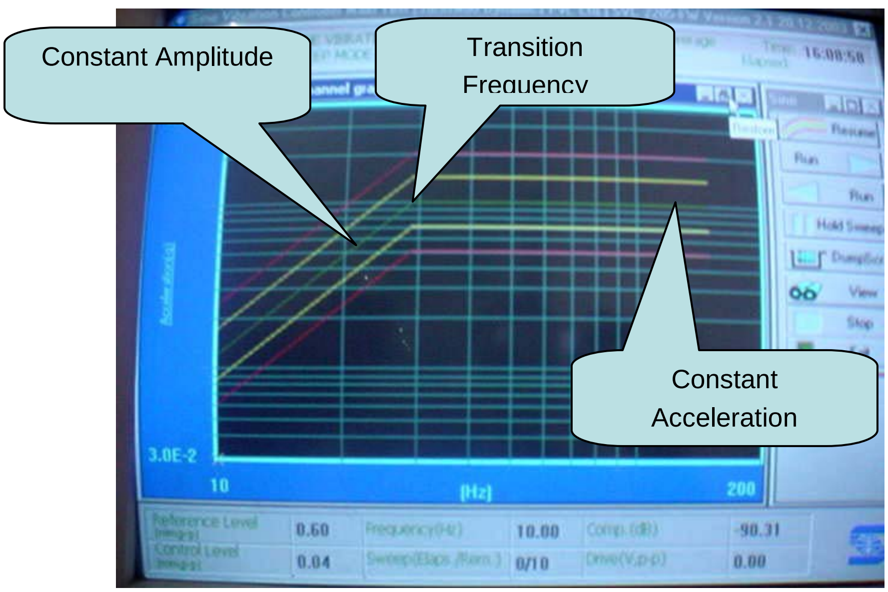
NOTE 10 sweep cycles = 75 min.

After the test, the meter shall show no damage or change of the information and shall operate correctly in accordance with the requirements of the relevant standard.



What is transition frequency?

When we are vibrating an object at constant amplitude (say 4mm) and continuously increase frequency, the acceleration will increase. If we want to limit the g level, a particular frequency will reach beyond which it will not be possible to maintain the constant amplitude. This frequency is called transition frequency. In general a constant amplitude test is specified till transition frequency and a constant acceleration test is specified beyond transition frequency.



Terminals – Terminal block(s) – Protective earth terminal

Terminal and terminal blocks are required to facilitate connections. It should have good thermal, mechanical, insulation and electrical properties. It should be suitable for the type of connections to be made.

The protective earth terminal, if any:

a) shall be electrically bonded to the accessible metal parts;

b) should, if possible, form part of the meter base;

c) should preferably be located adjacent to its terminal block;

d) shall accommodate a conductor having a cross-section at least equivalent to the main current conductors but with a lower limit of 6 mm2 and an upper limit of 16 mm2 (these dimensions apply only when copper conductors are used);

e) shall be clearly identified by the graphical symbol IEC 60417-5019: Protective earth (ground). After installation, it shall not be possible to loosen the protective earth terminal without the use of a tool.

Clearance and creepage distances

Proper clearance and creepage distances are to be maintained to prevent arcing or short circuiting. It is important that they are not only maintained on terminal blocks but also inside the meters where ever required.

Resistance to heat and fire test

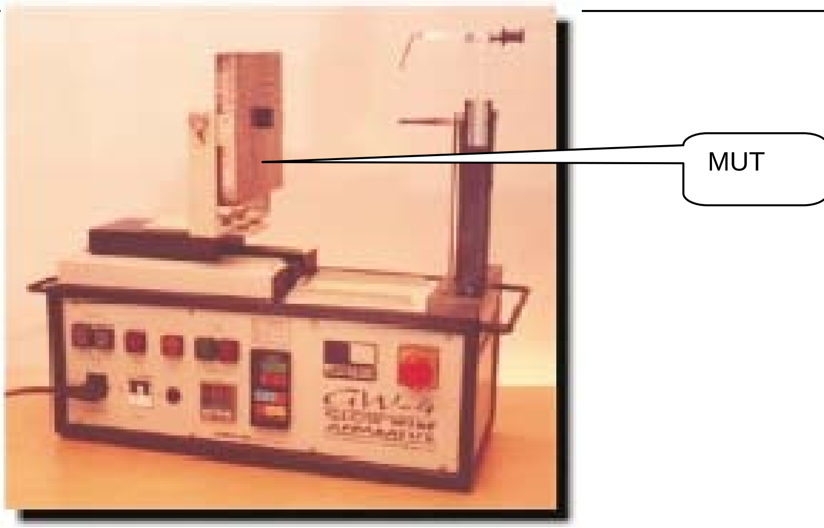
The terminal block, the terminal cover and the meter case shall ensure reasonable safety against spread of fire. They should not be ignited by thermal overload of live parts in contact with them. This test is done to ensure that the meter plastic does not help in spreading fire which may be caused due to fault conditions in or external to the meter.

To comply therewith they shall fulfill the following test.

– terminal block: 960 °C ± 15 °C;

– terminal cover and meter case: 650 °C ± 10 °C;

– duration of application: 30 s ± 1 s.



A typical Glow wire test set up

Protection against penetration of dust and water

The meter casing shall be such that there is no significant ingress of dust and water which can affect any functioning. The meter may be subjected to dust and water in field conditions. Both may be dangerous to the working of meter. The deposition of dust in meter may reduce insulation level between two live points and may cause spark or arcing. This dust may be a conductive dust. Even a non conductive dust after absorption of moisture may reduce effective creepage insulation level.

Ingress protection (IP) test is done to verify this characteristic.

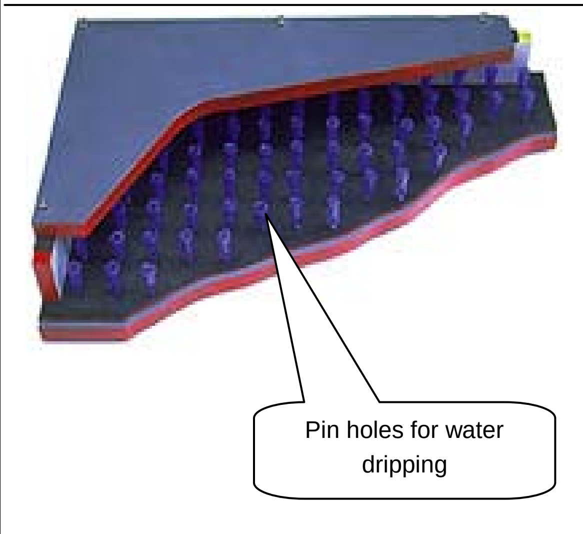
a) Protection against penetration of dust

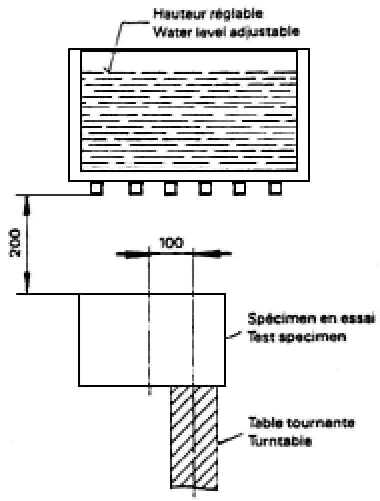
– meter in non-operating condition and mounted on an artificial wall; this test is done in dust chamber.

A Typical Dust chamber

b) Protection against penetration of water

– meter in non-operating condition;





Climatic requirements and tests

The metering installations are generally not protected from climatic changes and hence a meter shall not only withstand but also work properly in these climatic conditions.

Typical temperature values;

	Indoor meter	Outdoor meters
Specified operating range	–10 °C to 45 °C	–25 °C to 55 °C
Limit range of operation	–25 °C to 55 °C	–40 °C to 70 °C
Limit range for storage	–25 °C to 70 °C	–40 °C to 70 °C

Typical Humidity values

- Annual mean <75 %

- For 30 days, these days being spread in a natural manner over one year : 95 %
- Occasionally on other days: 85 %.

The dry test and cold test as described below are conducted to simulate storage conditions during which meter may be subjected to extreme temperatures. The damp heat cyclic test is done to see the effect of variations of climatic conditions under operating conditions.

Dry heat test

The test shall be carried out according to IEC 60068-2-2, under the following conditions:

meter in non-operating condition; temperature: +70 °C ± 2 °C; duration of the test: 72 h.

Cold test

The test shall be carried out according to IEC 60068-2-1, under the following conditions:

meter in non-operating condition; temperature: 25 °C ± 3 °C for indoor meters; 40 °C ± 3 °C for outdoor meters; duration of the test: 72 h for indoor meters;16 h for outdoor meters.

Damp heat cyclic test

The test shall be carried out according to IEC 60068-2-30, under the following conditions:

. voltage and auxiliary circuits energized with reference voltage;

. without any current in the current circuits;

. variant 1;

. upper temperature: +40 °C ± 2 °C for indoor meters;

+55 °C ± 2 °C for outdoor meters;

. no special precautions shall be taken regarding the removal of surface moisture;

. duration of the test: 6 cycles.

24 h after the end of this test, the meter shall be submitted to Insulation tests.

Protection against solar radiation

The meter for outdoor use shall withstand solar radiation.

The test shall be carried out according to IEC 60068-2-5, under the following conditions:

- . for outdoor meters only;
- . meter in non-operating condition;
- . test procedure A (8 h irradiation and 16 h darkness);
- . upper temperature: +55 °C;
- . duration of the test: 3 cycles or 3 days.

Electrical requirements

Voltage range:

The standard voltage range is specified as +/-10%. In practice we see a larger variation in voltages, typically +/-30%. It is important that the meter is tested for its functionality in this voltage range.

Voltage dips and short interruptions

This test is done to check the immunity of the meter to short duration (50ms, 20ms and 1 min) interruptions. When this dips and short interruptions are applied, the meter shall not loose the information recorded and shall work correctly when brought to normal conditions.

Heating

This test is done to ensure that there is no abnormal heating in the meter which raises the temperature of the body to a limit which can create a safety risk for personnel or insulation of the meter itself. It is important to note that in this test the standard ask to measure the maximum rise in temperature at 40 degree centigrade ambient temperature and hence it has to be done in environmental chamber.

Insulation tests

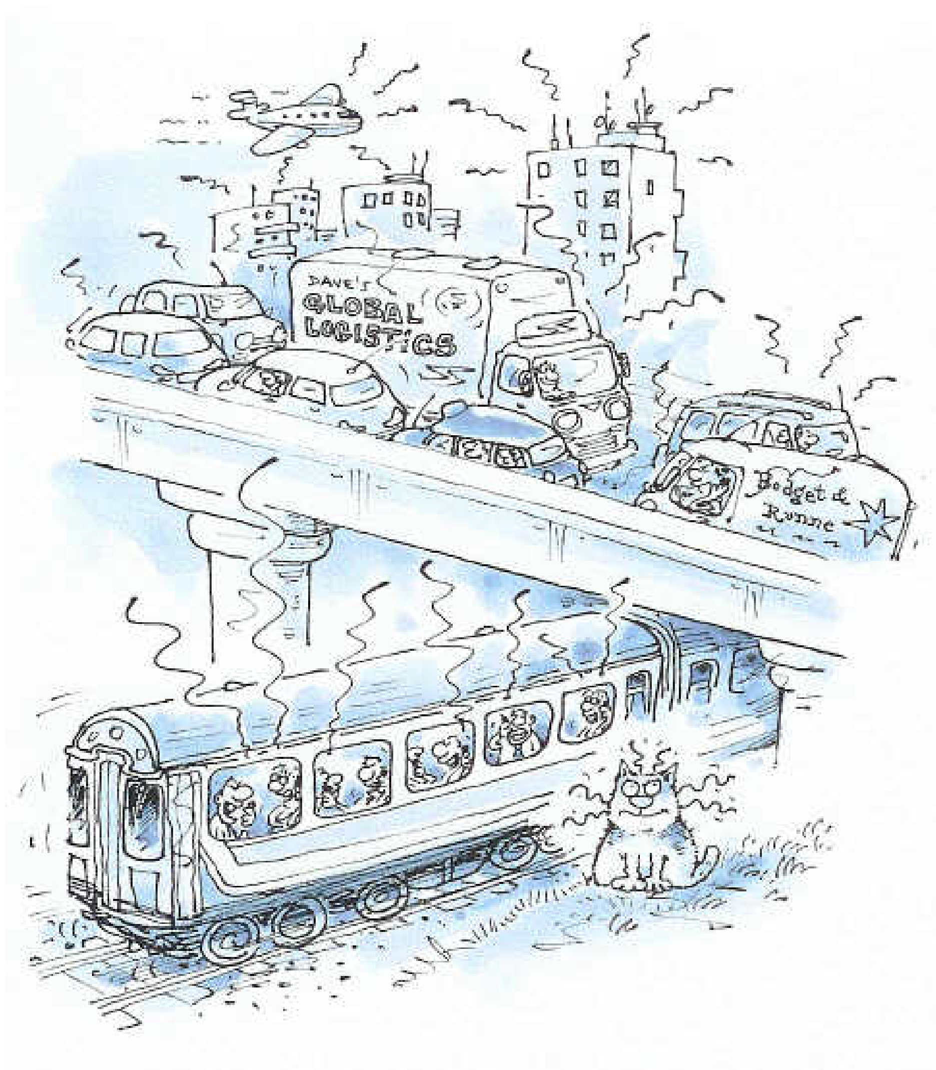
Insulation tests are mainly done for testing safety aspect. Three types of insulation tests are specified generally in different metering standards.

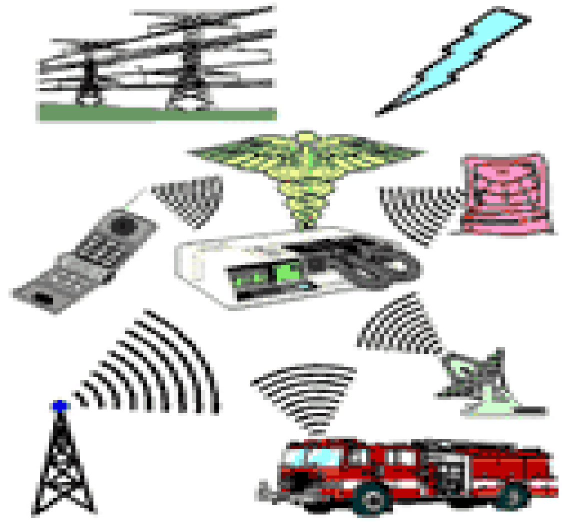
- Insulation resistance test
- Ac voltage test
- Impulse voltage test

Electromagnetic compatibility requirements and testing

What is EMI/EMC?

EMC stands for Electromagnetic Compatibility. It is defined as the ability of a device, unit of equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment. It can be regarded as the absence of effects due to electromagnetic interference. The following pictures depicts usual electromagnetic environment in a typical metropolitan city and its possible sources.

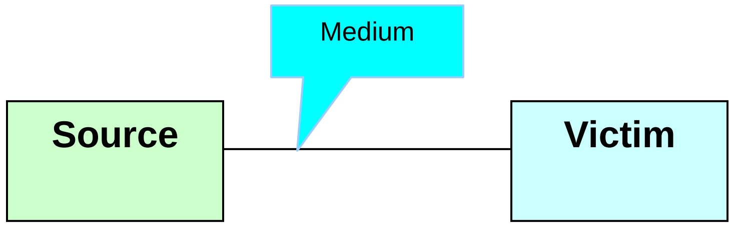


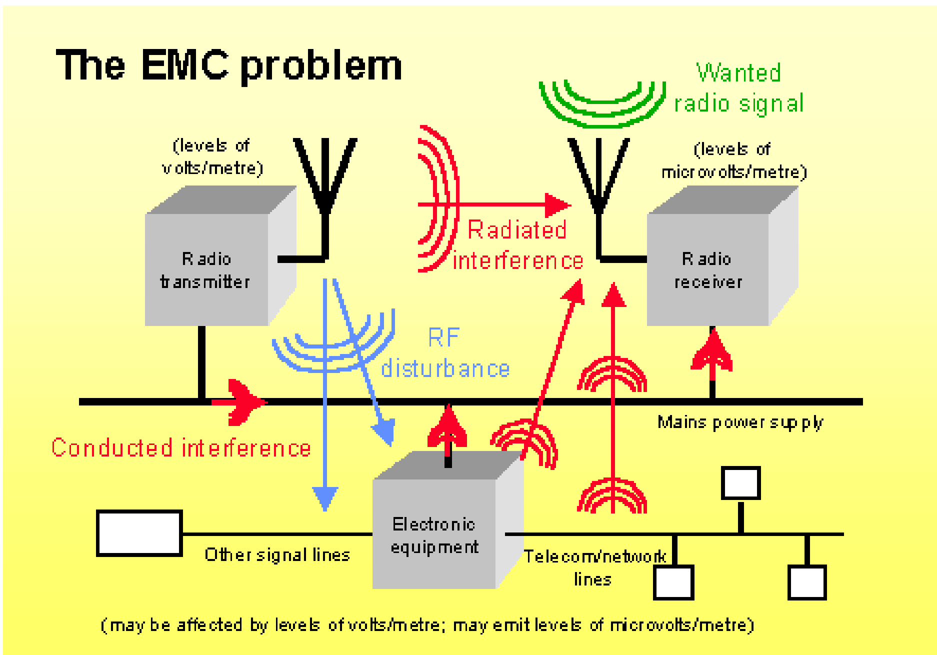


In simple terms, EMC means nothing more than "an electronic or electrical product shall work as intended in its environment". The electronic or electrical product shall not generate electromagnetic disturbances, which may influence other products. In other words, EMC deals with problems of noise emission as well as noise immunity of electronic and electrical products and systems. Electromagnetic disturbances occur as conducted interference as well as radiated emissions and immunity problems.

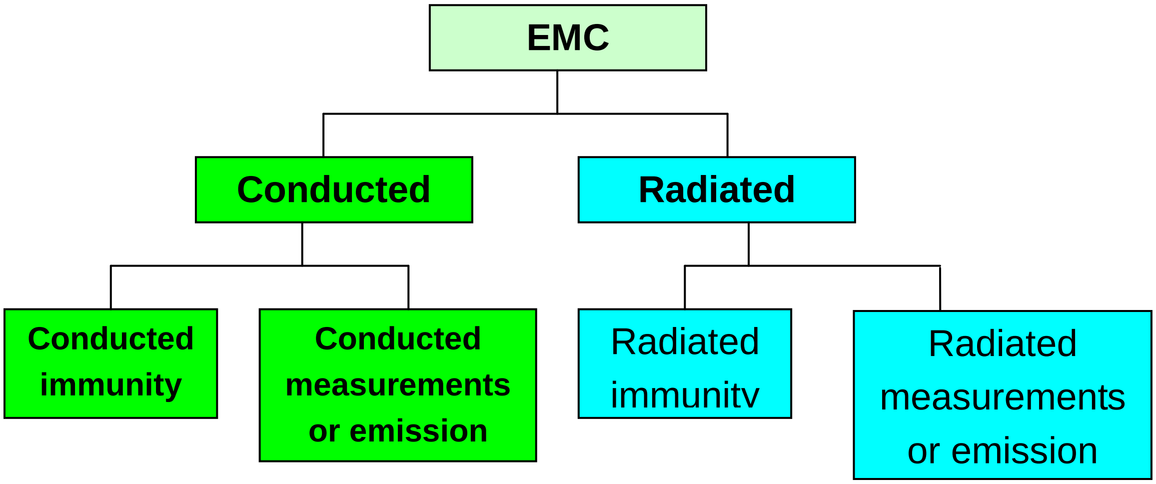
For interference to occur, we need several coincidences:

- a source of interference;
- a victim of that interference;
- a coupling path between them;
- the source must be emitting on a frequency at which the victim is susceptible;
- it must be emitting at a time when the victim is operating;
- the interference must be at a level which is noticeable and significant.





As depicted in above figure the EMC problem of a product can be divided in four categories:



Because of all the efforts made and being made to ensure EMC compatibility, people start to believe that, after a certain time, all products are safe and immune. Sorry, but this has not come true as yet. Each new generation of engineers and technicians are again challenged by the issue of EMC with each new product and within each new installation. Practical solutions to EMC problems are not taught at universities. This can only be achieved with many years of experience in the field and testing.

EMC requirements for energy meters

All energy meter standards specify requirements to cater all four conditions described above. These are listed below. The values specified in different standards for testing and acceptance may vary a little from standard to standard.

Immunity requirements:

- electrostatic discharges;
- electromagnetic RF fields;
- fast transient burst;
- surges;
- oscillatory waves;

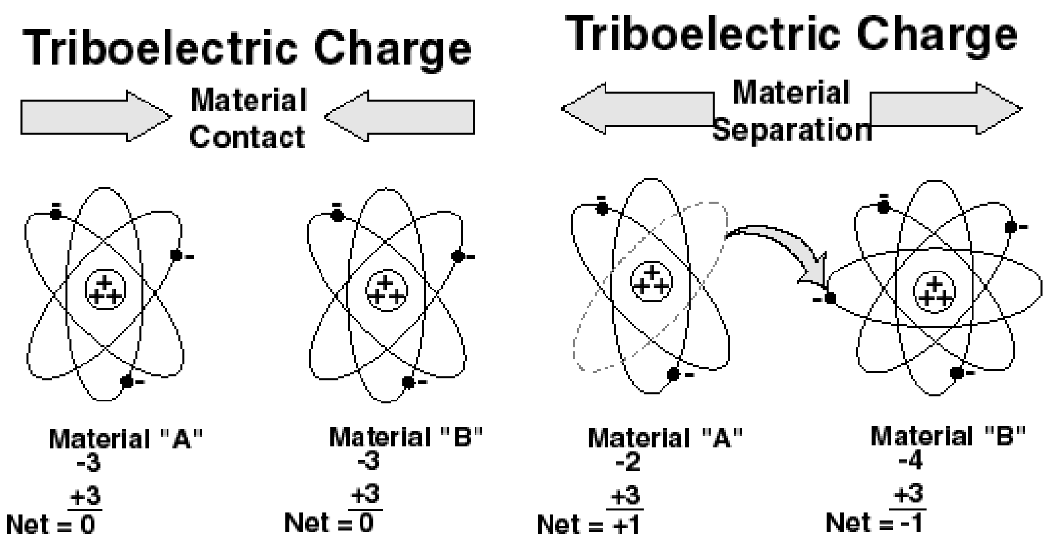
Measurement requirements:

- Radio interference measurements (Both conducted and radiated)

All EMC tests are very complex and require specialized knowledge and skill set for correct performance of test. Even a small change in set up (even wiring arrangements) may change the test results. Following are brief description and set up requirements of above tests.

Electrostatic Discharges (ESD):

Electrostatic discharges are produced when two material are rubbed against each other. Electrostatic voltage is generated due transfer of electrons from one surface to another which makes one surface positive and another negative. Modern microelectronics devices are sensitive to this voltage which can go up to 40kV, though these have very small energy. Human body is one of the major source and carrier of ESD, though there can be other sources. The flow of air can also generate ESD.

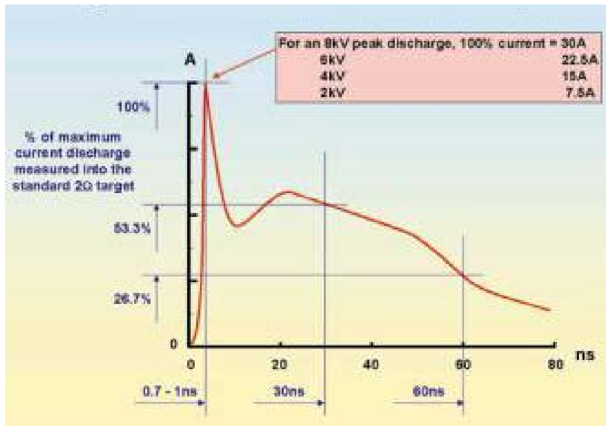


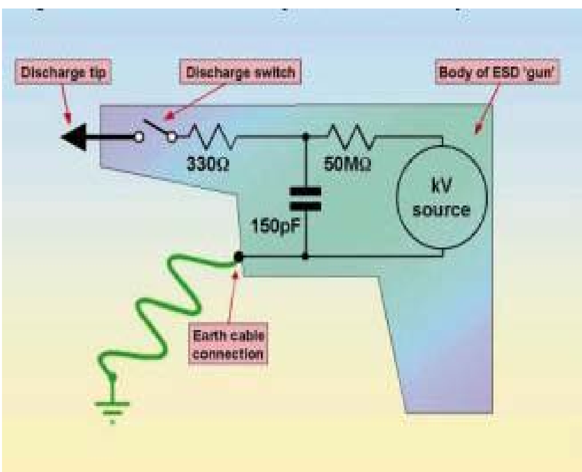
Examples of Static Generation
Typical Voltage Levels

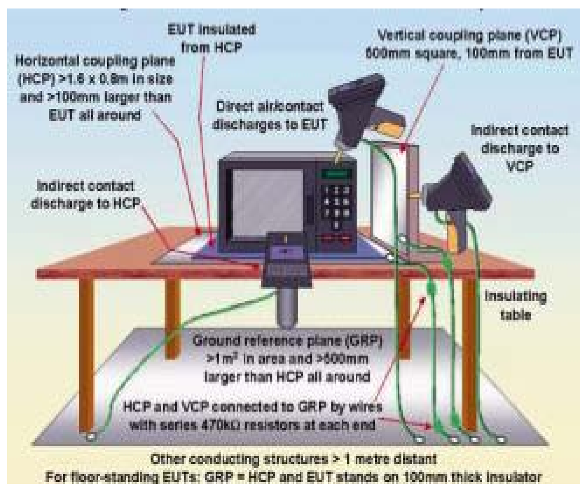
Means of Generation	10-25% RH	65-90% RH
Walking across carpet	35,000V	1,500V
Walking across vinyl tile	12,000V	250V
Worker at bench	6,000V	100V
Poly bag picked up from bench	20,000V	1,200V
Chair with urethane foam	18,000V	1,500V

ESD can damage the electronics in two ways. One due to very high voltage, there can be heavy current flowing in device. This is called direct damage. Second, if there is a discharge in a nearby set up, the heavy current flowing in the adjoining set up will induce a high voltage in the device and can damage it. ESD testing standard (IEC61000-4-2) requires testing for both failure mode.

The ESD waveform is as shown in following figures.







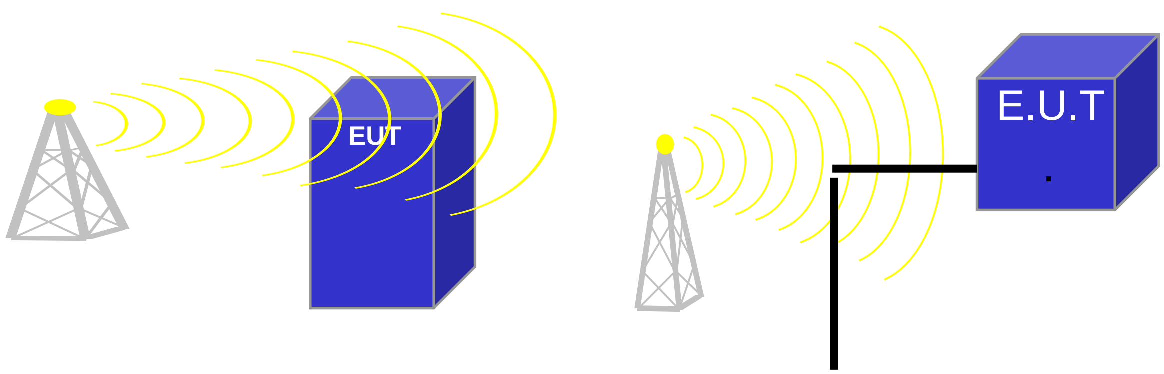
Above figures give a typical design of ESD simulator gun and typical set up for ESD testing respectively.

Typical ESD testing requirements for energy meters is 8kV contact discharge with only voltage applied to the meter.

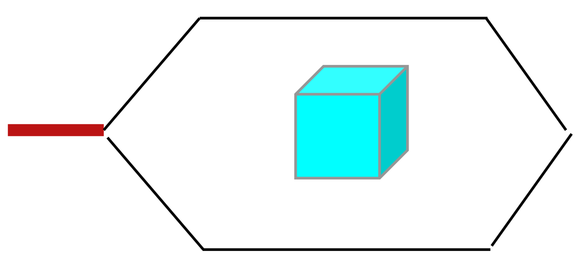
Electromagnetic RF fields:

There is lot of RF field around us. Most of it is intentionally created by man. Typical examples are radio, TV, cellular, navigation transmissions. The RF field is measured in V/m unit. The frequency range of all these transmission is between 80MHz to 2GHz.

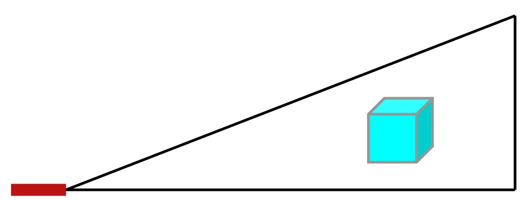
EM field can also affect an equipment in two ways. One direct effect and second is through cables as shown in following figures.



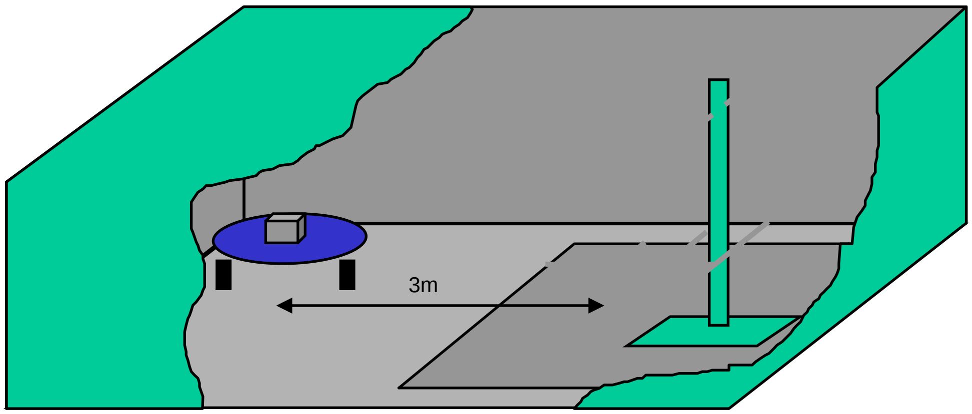
The test method for EMHF field is specified by IEC61000-4-3 standard. This test can not be done in open as it will affect the surroundings and it will be very difficult to control the uniformity of field. Hence it is required that the field is generated in a shielded chamber. There are various methods for doing this.



Strip Line or TEM cell

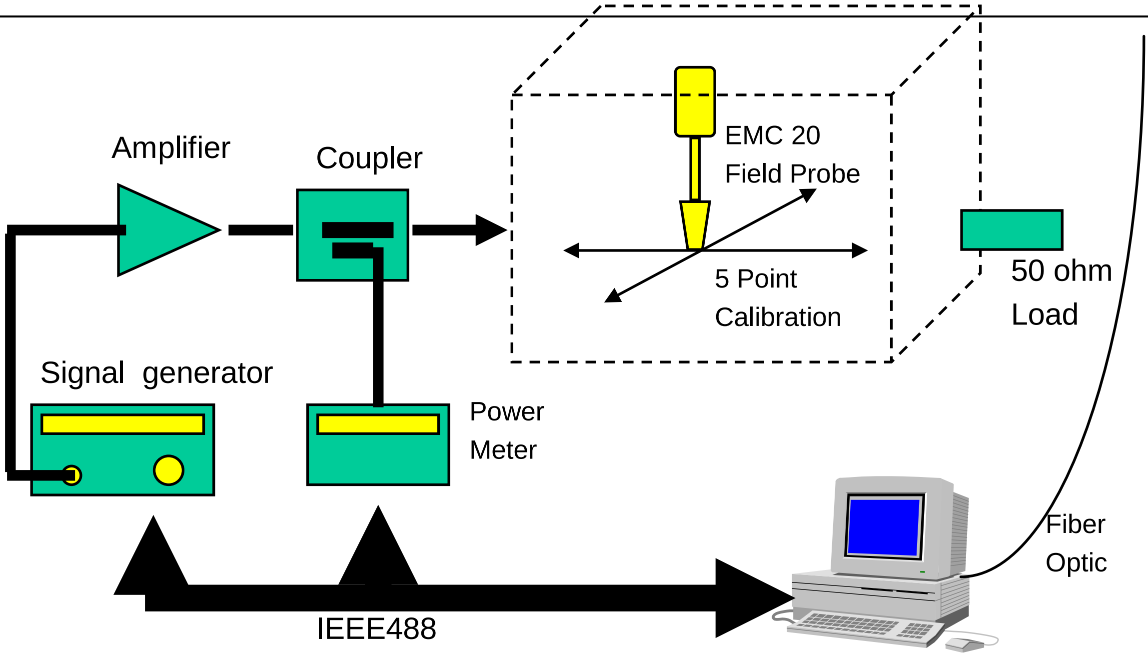


G-TEM



Anechoic or semi anechoic chamber

Calibration and Test set up

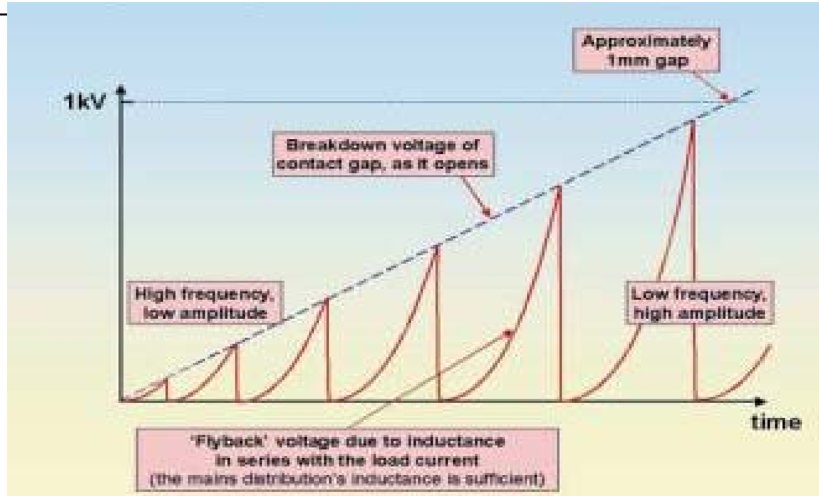


EMHF test requirements for energy meters:

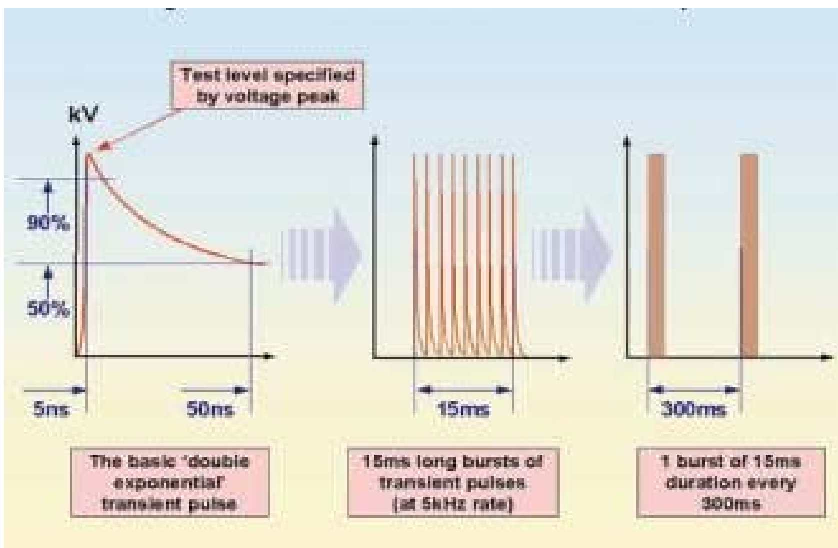
As per IEC62052-11, an energy meter has to be tested in EMHF field in two ways. One, without any current in which the energy meter is checked for any undesired increment in energy register. This test is done at 30V/m. Second test is done with I_{basic} current at 10V/m and here the accuracy of the meter is tested. The variation in error of the meter shall be within specified values.

Electrical Fast Transients burst test:

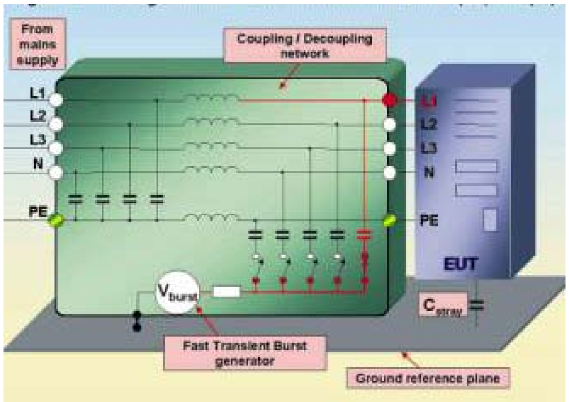
The fast transient burst test aims to simulate the disturbances created by a 'showering arc' at the contacts of an ordinary AC mains switch or relay contacts as it opens. The inductance of the mains cable (plus any in the load) causes a fly back voltage at the instant the current is interrupted, and the fly back voltage rises until it is sufficient to break down the air gap at the contacts and make an arc. When the arc stops the fly back occurs again, this time with the contacts slightly further apart. So during the opening of a switch or relay contact the transients generated can look something like following figure, starting off with low amplitude and a high frequency (could be MHz) and with rising amplitude and falling frequency as the contact gap widens.

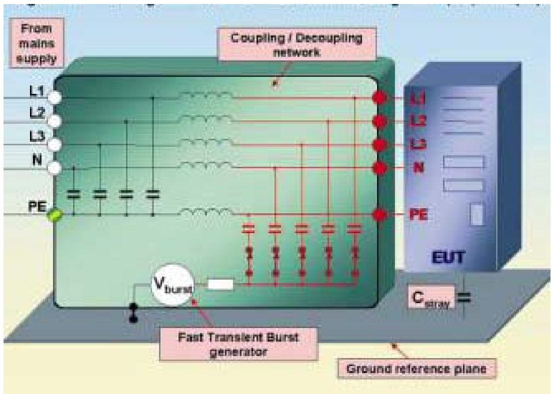


The Electrical fast transient waveform as specified in standards is as shown in following figure



The Test set up of the EFT test is as shown in the following figure respectively for one line at a time and for all lines together. It is required that accuracy test is done during the application of the EFT.





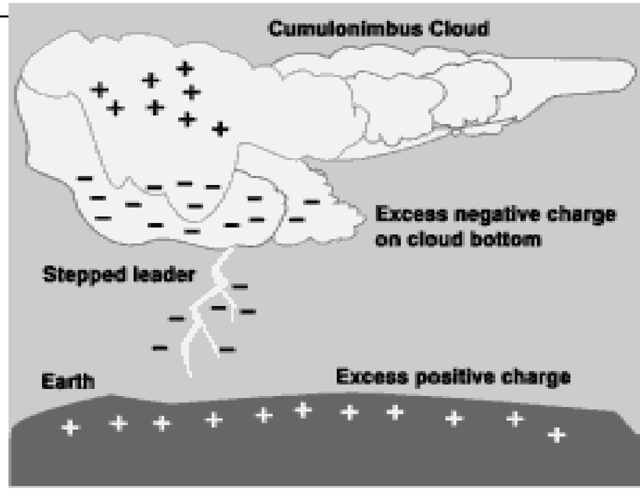
How lightning surges are produced?

Lightening strike is the most common cause of surges. There are many theories behind the reason for accumulation of charge on clouds.

It is most likely that the charge accumulation is a result of a combination of the precipitation and convection mechanisms.

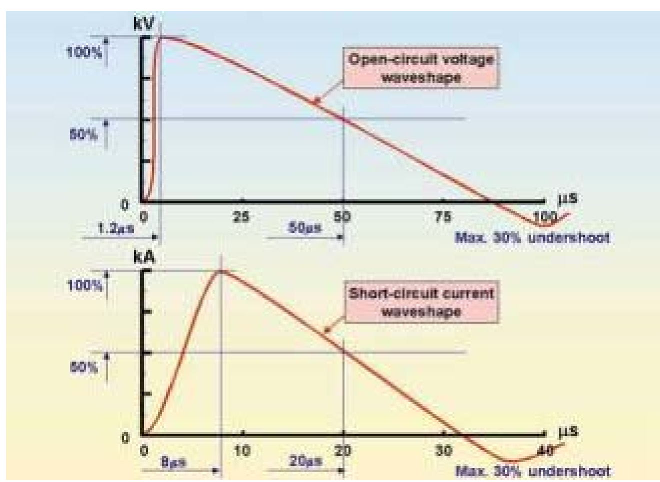
In any case, a result of the charge concentration is a tremendous electric field building between cloud and Earth. When this field becomes large enough then the air corridor between the cloud and earth becomes susceptible to electrical breakdown. This can be viewed as the cloud and the earth constituting the plates of a giant capacitor with an air dielectric. A 'too large' battery is placed across the capacitor and this causes the dielectric to breakdown.

This total discharge is usually referred to as the lightning 'flash.' It has time duration of about 0.5 seconds. The flash is made up of several distinct discharge components. Each component, itself, is composed of three or four high-current pulses called 'strokes.'



Cloud-to Ground Lightning

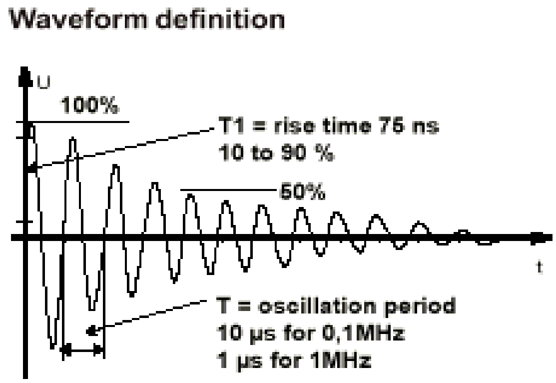
The surge waveform is shown in following figures



Damped Oscillatory waves test

Damped oscillatory wave test is representative of switching actions in HV/MV open air stations, and is particularly related to the switching of HV bus bars. The oscillation ranges from about 100 kHz to a few megahertz, depending on the length of the circuit & on the propagation time. The minimum repetition frequency, in respect to each phase, is twice the power frequency (100/s per phase for 50Hz & 120/s per phase for 60Hz). The repetition rate 40Hz & 400Hz represents a combination of a three phase system.

The damped oscillatory wave test waveform is shown in the following figure



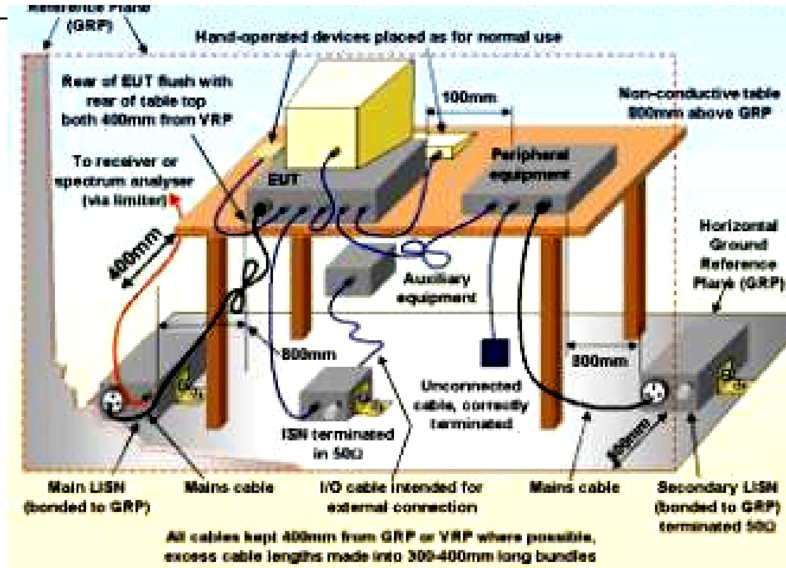
Radio interference measurement

Conducted Emission

The term conducted emission refers to the mechanism that enables electromagnetic energy to be created in an electronic device and coupled to its AC power cord. The primary reason for performing and regulating it is that the conducted emission by a product can find its way to the entire power distribution network in which

it is connected to and these emissions will use the larger network to radiate more efficiently than the product could by itself. Other devices can then receive the electromagnetic interference through a radiated path.

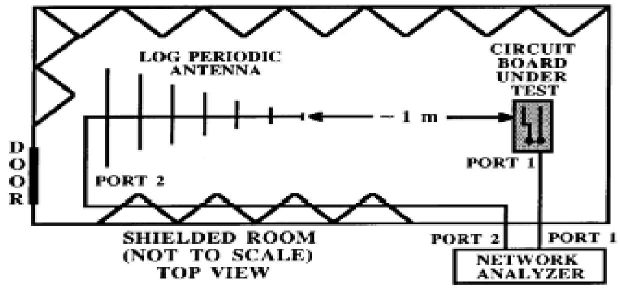
The test set up of conducted emission



Radiated Emission

The term radiated emission refers to the unintentional release of electromagnetic energy from an electronic device. The electronic device generates the electromagnetic fields that unintentionally propagate away from device's structure. In general, radiated emissions are usually associated with non-intentional radiators, but intentional radiators can also have unwanted emission at frequencies

Outside their intended transmission frequency band. Conductors carrying current at frequencies with wavelengths appreciable to the size of the conductors may efficiently radiate electromagnetic energy. The test set up for Radiated Emission test is shown below:



Electrical requirements

Following electrical requirements are specified in metering standards.

a) Power consumption: The power consumption in voltage and current circuit shall be within specified limits. The limits on power consumption are not only important from the point of consumption of power but also from the angle of limited rating of current and voltage transformers used.

b) Short time over current test: All electrical circuits have short circuit protection and so have metering circuits. But whenever short circuits happen, these protections take finite time to act and cut off the circuit. During this time a heavy current will flow. All equipments which are connected in the circuit must withstand the heavy current for that duration. The duration will depend on type of protection used.

   The heavy current can not only cause heating in meter but also can saturate a magnetic device like current transformer. Hence it is required that an accuracy test is performed after application of over current and change in error shall be within the limits specified.

c) Influence of self heating: The load current in the field conditions is always varying. The worst case variation can be from zero to maximum current rating of the meter. The devices in the meter may take some time to stabilise and give correct measurement of energy. This stabilising period shall not be very large as otherwise the meter will be measuring erroneously most of the time.

d) Ac voltage test: This is simple insulation test required for safety of personnel and equipments.

Tests of accuracy requirements

Correct energy measurement is the prime function of energy meters. Energy meter must not only measure correctly under reference conditions but also under various influences as specified in standards. Following are the main influences:

a) Voltage variation
b) Frequency variation
c) Voltage unbalance
d) Reverse phase sequence
e) Temperature
f) Harmonics
g) Dc and ac magnetic fields
h) Conducted disturbances
i) Fast transient burst
j) EMHF field

Tests of starting and No load conditions

a) Initial start up of the meter: The meter shall start doing all desired function within 5 second of applying voltage to it.
b) Test of No load conditions: When only voltage is applied to the meter, it shall not register energy.
c) Starting current test: The meter shall start measuring energy at some minimum current specified in standards.

Meter certification

Most of the meter purchasing is done through tenders. In tenders there is requirement of type test certificates. Generally more than two year old type test certificates are not accepted. This process is neither manufacturer nor purchaser friendly. The purchaser has to go through all type test certificates and decide whether the meter design meets all requirements or not. This requires special skill and knowledge. The manufacturer will have to regularly get type new test certificates even if his design has not been changed. This process can be simplified by following a meter certification process model as being followed in UK which is described below.

Office of Gas and Electricity Markets (OFGEM) is a body responsible for certification of meters. OFGEM has been authorised by parliamentary act of UK. The complete process involves (a) Design certification, (b) manufacturer certification, and (c) continuous surveillance.

Anyone, who wants to supply meters in UK have to get the meter design certified by OFGEM. For this he has to submit few samples of meters along with design and reliability calculations. OFGEM will test the samples as per standard and any other specific requirements and certify the meter for particular life, which is based on reliability calculations.

The manufacturing facilities of the manufacturer are also audited by OFGEM and certified for particular type of meters. The manufacturer is assigned a particular code which is used for sealing of the meter.

Myths of standards and tests

a) "If a meter meets class 1.0 requirements of a standard, it automatically meets class 2.0 requirements".

No, the power consumption requirements are tighter for class 2.0 as compared to that for class 1.0 meters.

b) If a meter passes surge test at 10kV , it automatically meets requirements of lower surge values

It is not guaranteed. The surge and ESD test standards require that lower voltages in defined steps shall also be tested as confirmatory tests.

c) If a design is meeting vibration test requirements, if some of the components are removed from it, example y phase CT from 3 phase 4 wire meter to make it 3 phase 3 wire meter, its performance in vibration will not be affected.

Vibration failures occur due to resonance which occurs at particular frequency. The resonance frequency is a function of weight distribution which will be affected by removal of components.

d) If a particular meter casing design meets ingress protection tests, there is no need to test other types of same manufacturer using same box design

This is true if there is no ingress of dust or water during the test. A meter is considered pass even if there is some ingress of water or dust, but it does not affect the functionality. If there is an ingress in the meter, the decision regarding effect on functionality may vary from type to type.

Annexure- A: List of Standards Published by ET13 of Bureau of Indian Standards

SL.NO.	IS NUMBER / DOC NUMBER	TITLE
1.	IS 11426(Part 0/Sec 0):1985	Alternating current precision kilowatt hour meters of class 0.5 for testing purposes(first revision)
2.	IS 11448(Part 0/Sec 0):2000	Application guide for ac electricity meters(first revision)
3.	IS 12346(Part 0/Sec 0):1999	Testing equipment for ac electrical energy meters (first revision)
4.	IS 13010(Part 0/Sec 0):2002	AC watt-hour meters, Class 0.5, 1 and 2(first revision)

5.	IS 13779(Part 0/Sec 0):1999	AC static watthour meters (Class 1 and 2) rev1)
6.	IS 14372(Part 0/Sec 0):1996	Volt-ampere hour meters for full power factor range [superseding IS:722(Part 7/Sections 1, 2 and 3)-1987]
7.	IS 14390(Part 0/Sec 0):1996	Var-hour meters, Class 3.0 [Superseding IS 722 (Part 6):1980]
8.	IS 14415(Part 0/Sec 0):1997	Volt-Ampere hour meters for restricted power factor range - specification [superseding IS:722 (Part 5):1980
9.	IS 14451(Part 1/Sec 0):1998	Tele metering of consumption and demand: Part 1 Impulse transmitting and receiving devices
10.	IS 14451(Part 2/Sec 0):1999	Tele metering for Consumption and Demands Part 2 Direct digital transfer of meter values
11.	IS 14697:1999	ac static transformer operated watthour and var-hour meters, class 0.2S and 0.5S-Specification
12.	IS 1766(Part 0/Sec 0):1998	Time switches for metering and load control (second revision)
13.	IS 7700(Part 0/Sec 0):1975	Quadrature phase-shifting voltage transformers
14.	IS 8530(Part 0/Sec 0):1977	Maximum demand indicators (class 1)
15.	IS 9792(Part 1/Sec 0):1987	Guide for testing, calibration and maintenance of ac electricity meters: Part 1Single phase whole current watthour meters, Class 2 (first revision)

Annexure- B: List of Standards Published by TC13 of International Electro-technical commission

S.No	Document or standard no.	Title and applicability
1.	IEC 60145 : 1963	Var-hour(reactive energy)meters
2.	IEC 60211 : 1966	Maximum demand indicators, Class 1.0
3.	IEC 60338 : 1970	Tele metering for consumption and demand
4.	IEC 60514 TS: 1975	Acceptance inspection of Class 2 alternating -current watthour meters.
5.	IEC 60736 TR3 : 1982	Testing equipment for electricity energy meters.
6.	IEC 61354 :1995	Electricity meters-Marking of auxiliary terminals for tariff devices
7.	IEC 61358 : 1996	Acceptance inspection for direct connected alternating current static watt-hour meters for active energy(Classes 1 and 2)
8.	IEC 62051:1999	Electricity Metering – Glossary of terms
9.	IEC 62051-1 : 2004	Electricity metering - Data exchange for meter reading, tariff and load control - Glossary of terms - Part 1: Terms related to data exchange with metering equipment using DLMS/COSEM
10.	IEC 62052-11: 2003	Electricity metering equipment (a.c)-General requirements, tests and test conditions Part 11:Metering equipment.
11.	IEC 62052-21 : 2004	Electricity metering equipment (a.c.) - General requirements, tests and test conditions - Part 21: Tariff and load control equipment
12.	IEC 62053-11: 2003	Electricity metering equipment (a.c)-Particular requirements -Part 11: Electromechanical meters for active energy (classes 0.5,1 and 2)

S.No	Document or standard no.	Title and applicability
13.	IEC 62053-21 :2003	Electricity metering equipment (a.c)-Particular requirements -Part 21: Static meters for active energy (classes 1 and 2)
14.	IEC 62053-22 :2003	Electricity metering equipment (a.c)-Particular requirements -Part 22: Static meters for active energy (classes 0.2 S and 0.5 S)
15.	IEC 62053-23 :2003	Electricity metering equipment (a.c)-Particular requirements -Part 23: Static meters for reactive energy (classes 2 and 3)
16.	IEC 62053-31 :1998	Electricity metering equipment (a.c)-Particular requirements -Part 31: Pulse output devices for electromechanical and electronic meters (two wires only)
17.	IEC 62053-52 : 2005	Electricity metering equipment (a. c.) – Particular requirements – Part 52: symbols
18.	IEC 62053-61 : 1998	Electricity metering equipment (a.c)-Particular requirements -Part 61: Power consumption and voltage requirements.
19.	IEC 62054-11 : 2004	Electricity metering (a.c.) - Tariff and load control - Part 11: Particular requirements for electronic ripple control receivers
20.	IEC 62054-21:2004	Electricity metering (a.c.) - Tariff and load control - Part 21: Particular requirements for time switches.
21.	IEC 62055-41 : 2003	Electricity Metering : Payment metering system – Part 41: Standard Transfer Specification
22.	IEC 62055-21 : 2005	Electricity Metering : Payment metering system – Part 21: Framework for standardization
23.	IEC 62055-31: 2005	Electricity Metering : Payment metering system – Part 31: Particular Requirements – static payment meter (classes 1 and 2)
24.	IEC 62056-21:2002	Electricity metering - Data exchange for meter reading , tariff and load control -Part 21 :Direct local data exchange.
25.	IEC 62056-31:1999	Electricity metering - Data exchange for meter reading , tariff and load control -Part 31:Use of local area networks on twisted pair with carrier signaling.

S.No	Document or standard no.	Title and applicability
26.	IEC 62056-41: 1998	Electricity metering - Data exchange for meter reading , tariff and load control -Part 41 :Data exchange using wide area networks: Public switched telephone network(PSTN)with LINK+protocol.
27.	IEC 62056-42:2002	Electricity metering - Data exchange for meter reading , tariff and load control -Part 42 :Physical layer services and procedures for connection -oriented asynchronous data exchange.
28.	IEC 62056-46:2002	Electricity metering - Data exchange for meter reading , tariff and load control -Part 46 :Data link layer using HDLC protocol.
29.	IEC 62056-51:1998	Electricity metering - Data exchange for meter reading, tariff and load control -Part 51: Application layer protocols.
30.	IEC 62056-52: 1998	Electricity metering - Data exchange for meter reading, tariff and load control -Part 52: Communication protocols management distribution line message specification (DLMS) Server.
31.	IEC 62056-53:2002	Electricity metering - Data exchange for meter reading, tariff and load control -Part 53: COSEM application layer.
32.	IEC 62056-61:2002	Electricity metering - Data exchange for meter reading, tariff and load control -Part 61: OBIS object identification system.
33.	IEC 62056-62:2002	Electricity metering - Data exchange for meter reading, tariff and load control -Part 62: Interface classes.
34.	IEC 62059-11:2002	Electricity metering equipment -Dependability-Part 11:General Concepts.
35.	IEC 62059-21:2002	Electricity metering equipment -Dependability-Part 21: Collection of meter dependability data from the field.
36.	IEC62059-41:2006	Electricity Metering equipment – Dependability – Part 41 : Reliability Prediction
37.	IEC/PAS 62055-41:2003	Electricity metering -Payment metering systems-Part 41 : Standard transfer Specification.