R. C. Patel College of Engineering & Polytechnic, Shirpur

Department of Electrical Engineering

Name of Subject: **- Electrical & Electronic Measurement (EEM)**

Course Code: **- 313334**

Scheme:- **EE-3K**

Semester**:- Third**

Unit No. 02- Measurement of Power and Energy.

CO2 - Measure precisely electrical power and energy using appropriate meters.

Unit	Title	COs	Learning hours	R Level	U Level	A Level	Total Marks
2	Measurement of Power and Energy.	CO2	9	4	6	4	14

THEORY SYLLABUS CONTENT

Fundamentals of Measurement

2.1 Construction and working of dynamometer wattmeter, Multiplying factor.
2.2 Active and reactive power measurement: One, two and three wattmeter methods.
2.3 Effect of Power factor on wattmeter reading in two wattmeter method.
2.4 Construction and working of maximum Demand indicator (MDI), four quadrant meters.
2.5 Construction and working of Induction type single phase energy meter, types of errors and compensation.
2.6 Single and three phase digital energy meter: Block diagram, constructional features and working principle.
2.7 Smart energy meter: Basic concept, block diagram, operation and working principle.

Subject Incharge
Mr. N. S. Borse

Unit - II

Measurement of Power and Energy.

* Dynamometer Wattmeter:

Working principle: Magnetic flux betn two coils produces a force on moving coil.

Construction: 1) The construction of dynamometer type wattmeter is same as dynamometer type ammeter & voltmeter, only difference is that it consist two coils. (Fixed & Moving)

2) It consist of two fixed coil & one moving coil which is placed in betn two fixed coil.

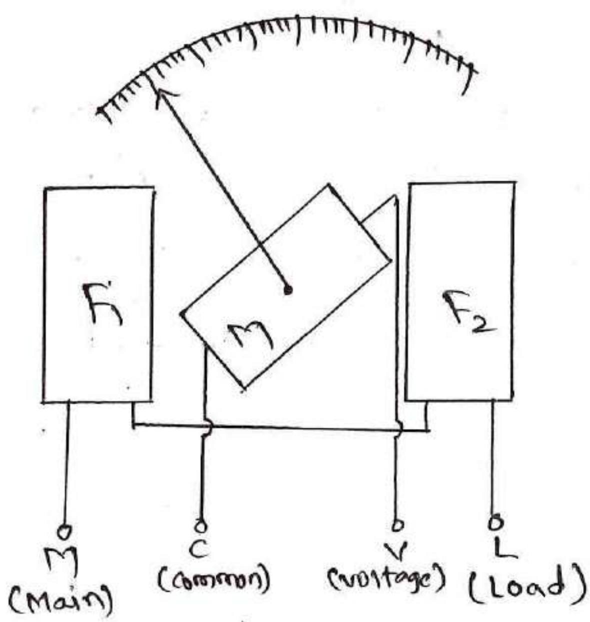
3) Fixed coil are connected in series with the load hence known as current coil

4) The moving coil having high resistance and known as pressure coil connected in parallel with the load.

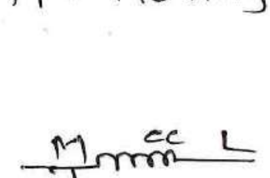
5) All the load c/n passing thro fixed coil

6) Moving coil supported by the spindle.

7) Spring control method is used to produced controlling torque.



F_1, F_2 - Fixed coil
M - Moving coil



Working: 1) Both current coil (CC) & pressure coil (PC)
(Fixed) (Moving)

carries current and produce their own mag flux

2) moving coil is placed in magnetic field of fixed coil.

3) Force is exerted on moving coil, which is

$$F = BIL$$

where, F = Force on moving coil
B = flux density
I = current in fixed coil
L = length of fixed coil.

4) The deflecting torque (Td) is directly proportional to product of current through current coil (CC), current through pressure coil (PC) & cosine of angle betn them (θ)

$$T_d \propto (i_{cc}) \times (i_{pc}) \times \cos\theta$$

5) current through pressure coil is proportional to voltage i.e. $i_{pc} \propto V$

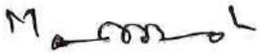
$$\therefore T_d \propto I.V.\cos\theta$$

$$\text{i.e. } \boxed{T_d \propto P}$$

6) Hence, the scale of dynamometer type wattmeter is non-uniform.

7) It can measure both AC & DC power.

* Comparison betn current coil & pressure coil

Parameter	current coil (cc)	pressure coil (pc)
1) symbol		
2) Resistance	low	Medium
3) connection	in series	in parallel
4) size or gauge	less	More
5) Number of turns	Less	More
6) status	stationary	Moving

* Multiplying factor : 1) wattmeter having different current & voltage ranges.

2) Depending upon selection of range of c/n & vltg, a reading of wattmeter is to be multiplied by the factor known as multiplying factor.

or

3) The reading of wattmeter is multiplied by factor known as multiplying factor, we get actual power in watt.

(Power Factor)

$$\text{Multiplying factor} = \frac{\text{current range} \times \text{voltage range} \times \text{p.f.}}{\text{Full scale deflection}}$$

4) generally, it's value is 1, 2 or 4.

* problems on multiplying factor.

* Active and Reactive Power measurement :-

for 1-ϕ Active power = $V \cdot I \cdot \cos\theta$

Reactive power = $V \cdot I \sin\theta$

for 3-ϕ Active power (P) = $\sqrt{3} \cdot V_L I_L \cos\theta$

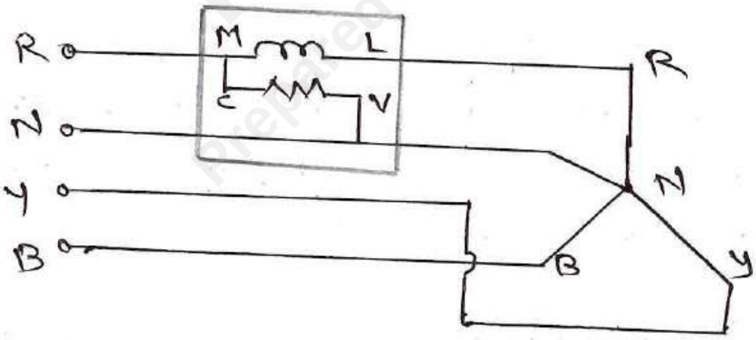
Reactive power (Q) = $\sqrt{3} \cdot V_L I_L \sin\theta$

There are three methods to measure three phase power, such as :

1) one wattmeter method
2) Two wattmeter method
3) Three wattmeter method

1) one wattmeter method :-

- The following fig. shows connection diagram for power measurement in 3-ϕ load using single wattmeter



- The c/n coil carries phase c/n & vltg coil connected across phase vltg.
- The wattmeter reading is

$$W = V_{pc} \cdot I_c \cdot \cos(V_{pc} \angle I_c)$$

where, V_{pc} = vltg thro pressure coil

I_c = c/n thro current coil

- suppose angle betn V_{PC} & I_C is ϕ, then

$$W = V_{ph} \cdot I_{ph} \cdot \cos\phi$$

where, V_{ph} = Phase vltg
I_{ph} = Phase c/n

- The wattmeter reading W indicate the active power per phase.

- Hence, total Active power

$$P = 3 \cdot V_{ph} \cdot I_{ph} \cdot \cos\phi$$

$$\boxed{P = 3W}$$

Advantages: 1) only one wattmeter required

Disadvantages: 1) It applicable only for balance load

2) For star connected load, if neutral point is available then V terminal is connected

3) For delta connected load, c/n coil is connected in series with any one phase but practically it is not possible to open the delta load.

4) Hence, it's rarely used for 3-φ power measurement.

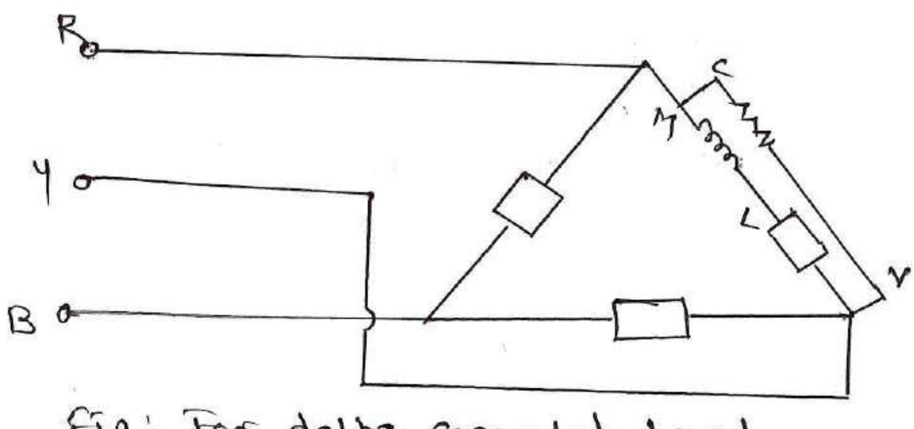
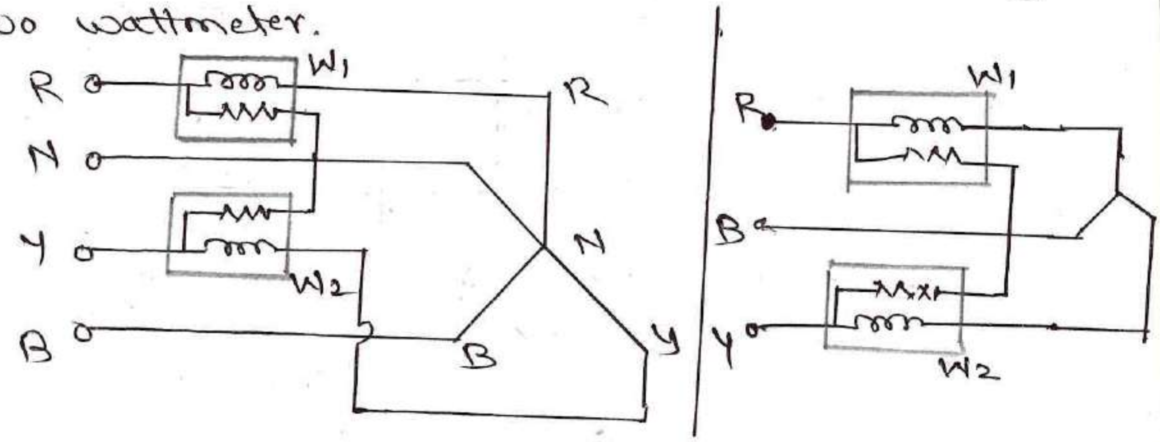


fig: For delta connected load.

2) Two wattmeter Method:

- The following fig. shows connection diagram for power measurement in 3-ϕ load using two wattmeter.



- The current coil of 2 wattmeter are connected in any two lines (here R & Y) and voltage coil are connected bet^n the same of current coil and line without any current coil or neutral.

- The wattmer connection remain same for any type of load (i.e. star or delta)

- Total power in circuit is equal to the algebric sum of two wattmeter readings.

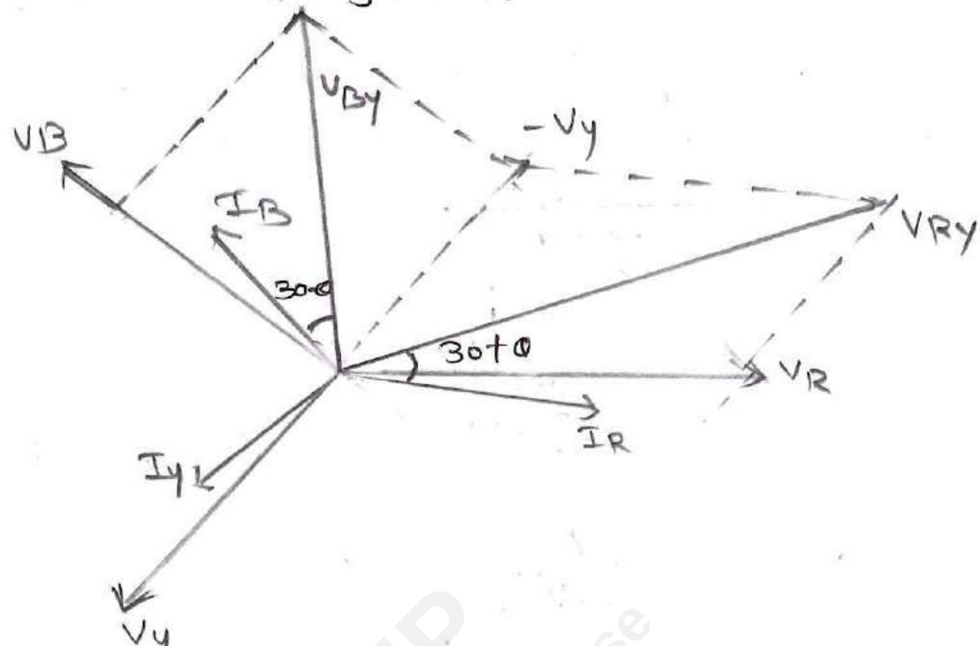
$$P_T = W_1 + W_2$$

- The reading of wattmeter is

$$W_1 = I_R \cdot V_{RY} \cdot \cos(I_R \cdot V_{RY}) \quad \text{--- (1)}$$

$$W_2 = I_B \cdot V_{BY} \cdot \cos(I_B \cdot V_{BY}) \quad \text{--- (2)}$$

Extra pt - To find the angle betn $(I_R . V_{RY})$ & $(I_B . V_{BY})$ we prefer phasor diagram.



From phasor diagram,

Angle betn I_R & $V_{RY} = 30+\phi$

angle betn I_B & $V_{BY} = 30-\phi$

Putting this angle in eqn ① & ②

$W_1 = I_R . V_{RY} . \cos(30+\phi)$ —③

$W_2 = I_B . V_{BY} . \cos(30-\phi)$ —④

where, V_{RY} & V_{BY} - line vltg

I_R & I_B - line c/n

for two wattmeter method,

$$P_T = W_1 + W_2$$

$$= V_L I_L [\cos(30+\phi) + \cos(30-\phi)]$$

$$= V_L I_L [(\cos 30 . \cos\phi - \sin 30 . \sin\phi) + (\cos 30 . \cos\phi + \sin 30 . \sin\phi)]$$

$$= V_L I_L [2(\cos 30 . \cos\phi)]$$

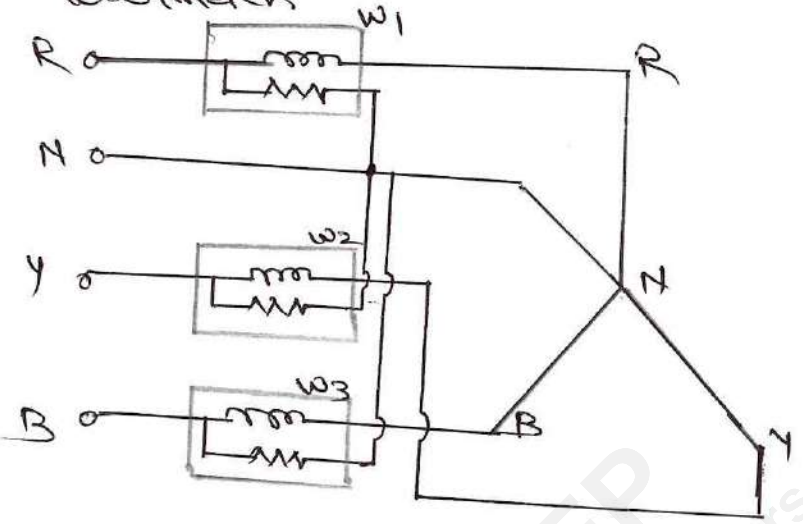
$$= V_L I_L \left[2 \times \frac{\sqrt{3}}{2} \times \cos\phi\right]$$

$$= V_L I_L [\sqrt{3} . \cos\phi]$$

$$\therefore P_T = \sqrt{3} . V_L I_L \cos\phi$$

* Three wattmeter Method:

- The following fig. shows connection diagram for 3-φ power measurement using three wattmeter



- For balanced load, wattmeter readings are equal i.e. $W_1 = W_2 = W_3 = W$

  hence total power $(P_T) = W_1 + W_2 + W_3$

  or $P_T = 3W$

- For unbalance load, wattmeter reading are different i.e. $W_1 \neq W_2 \neq W_3$

  Hence total power

$$P_T = W_1 + W_2 + W_3$$

* Effect of Power factor on two wattmeter Method:

We know, $W_1 = V_L I_L \cos(30-\phi)$ &

$W_2 = V_L I_L \cos(30+\phi)$

1) case I, $\phi = 0$, i.e. $\cos\phi = 1$

$\therefore W_1 = V_L I_L \cos(30)$

$W_2 = V_L I_L \cos(30)$

i.e. when $\phi = 0$ or p.f = 1, wattmeter gives equal and positive deflection.

2) case II, $\phi = 60$, $\cos 60 = 0.5$

$\therefore W_1 = V_L I_L \cos(-30)$

$W_2 = V_L I_L \cos(90) = 0$

i.e. when $\phi = 60$ or p.f = 0.5, one wattmeter gives zero deflection and other one shows positive reading.

3) case III, $\phi = 90$, $\cos 90 = 0$ | $\cos 60 = \frac{1}{2}$

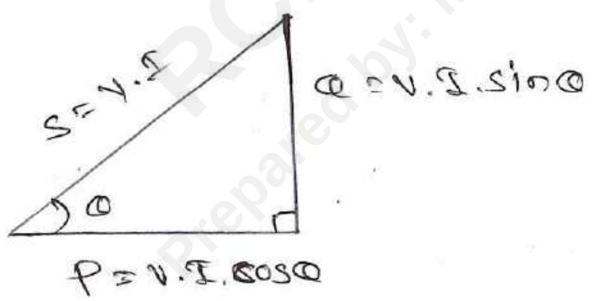
$\therefore W_1 = V_L I_L \cos(-60) = \frac{V_L I_L}{2}$

$W_2 = V_L I_L \cos(120) = -\frac{V_L I_L}{2}$

i.e. when $\phi = 90$ or p.f = 0, one wattmeter shows negative deflection but it is not possible, then interchange their connection. both wattmeter shows equal but opposite reading.

P.F.	Wattmeter Reading
$\cos\phi = 1$	$W_1 = W_2$ equal reading $P_T = W_1 + W_2$
$\cos\phi = 0.5$	$W_1 = 0$ W_2 = total power
$\cos\phi = 0$	W_1 = Positive reading W_2 = Negative reading equal but opposite readings.

* power Triangle:

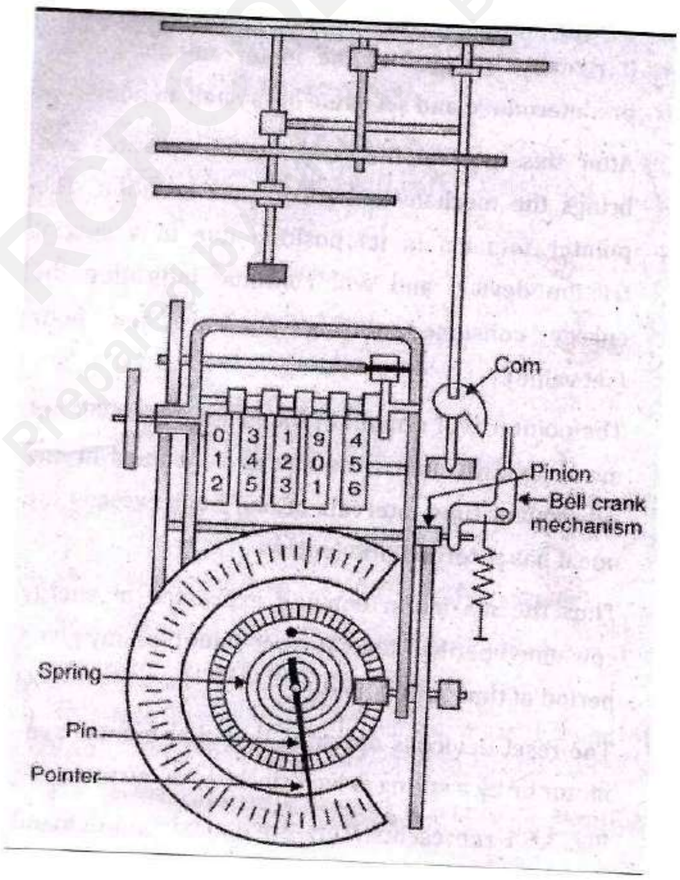


* Errors in wattmeter:

1) Error due to method of connection
2) Error due to pressure coil inductance
3) Error due to pressure coil capacitance
4) Error due to mutual inductance effect
5) Temperature error
6) Error due to stray magnetic field.

* Maximum Demand Indicator (MDI)

- The maximum demand indicator are of following four types.
  1) Recording demand indicator
  2) Average demand indicator (Merz price)
  3) Thermal Type Maximum indicator
  4) Digital maximum demand indicator
- Generally Average demand indicator is used.
- This type of indicator is coupled to the energy meter spindle. It always connected to energy meter.



- It connect at set value of time.
- After this interval, the reset device operate & pointer back to zero position. Meter indicates the energy consumed during set value of time.

- pointer will remain in it's position & will not move forward unless the enegy consume not exceed the one it has recorded priviously.
- Thus, the maximum demand is express in enegy consumed per hour.
- The reset device is operated by either a small synchronous motor or by spring driven clock mechanism.
- The fig. shows Merz price maximum demand indicator. A pin drives the pointer forward for a set period.
- Enegy consumed during this period is indicated on dial.
- The average maximum demand in KW is then calculated as

$$\text{Average M.D. in KW} = \frac{\text{Maximum enegy recorded over a time interval}}{\text{Time interval in hours.}}$$

Advantages:

1) Maximum demand, kWh, average demand can be obtained from single meter
2) Meter has good accuracy
3) Low maintenance.

Disadvantages:

1) Construction is complicated
2) cost is more
3) If max^m demand occurs in time interval then max^m demand devided into two different time inteval, then not give accurate maximum demand.

* Four quadrant Meter:

- The four quadrant meter needed to accurately measure active & reactive power in different import / export condition.
- It can also measure both consumption and generation of energy (forward & reverse dir^n)
- This is an electrostatic meter. It is very accurate and precise meter.
- This meter used for to measure di-electric loss of cable. also used for calibrations of wattmeter or energy meter to find error. It uses as standard meter.
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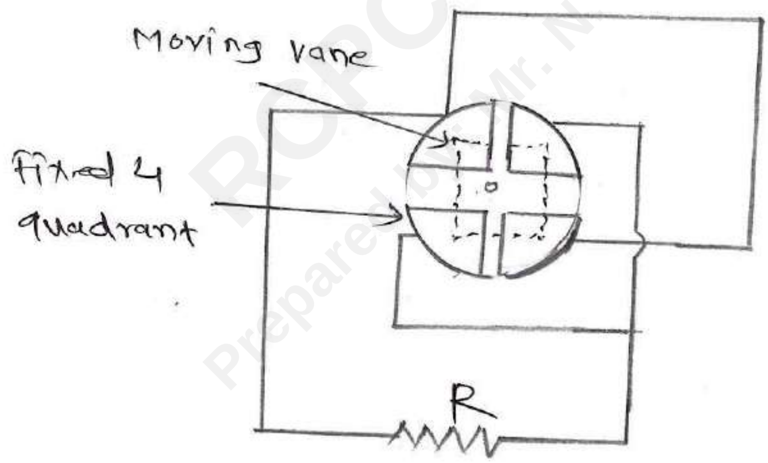
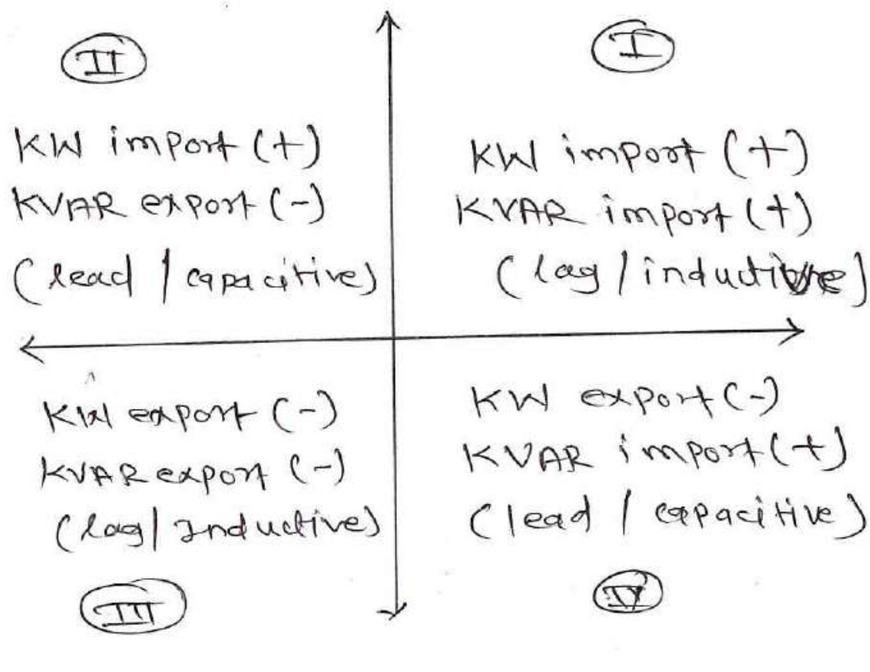


- It has suspended moving element which is fitted with reflecting mirror which is used with a lamp instead of pointer.



- In quadrant I, both active & reactive power are import (inductive load), the power factor of this type of load is lagging.
- In quadrant II, Active power is import but reactive power is export. the power factor of this type of load is leadding & load is capacitive.
- In quadrant III, both active & reactive power are export (inductive load), the power factor of this type of load is lagging.
- In quadrant IV, the active power is export but reactive power is import, the power factor of this type of load is leading & load is capacitive.

Advantages:
1) It is used to increase the stability of interconnected power system.
2) It also enables the state grid to plan their power consumption & plan load shadding
3) It is used to measure frequency, active & reactive power based on the values & sign of these quantities.

* Induction type Energy Meter:

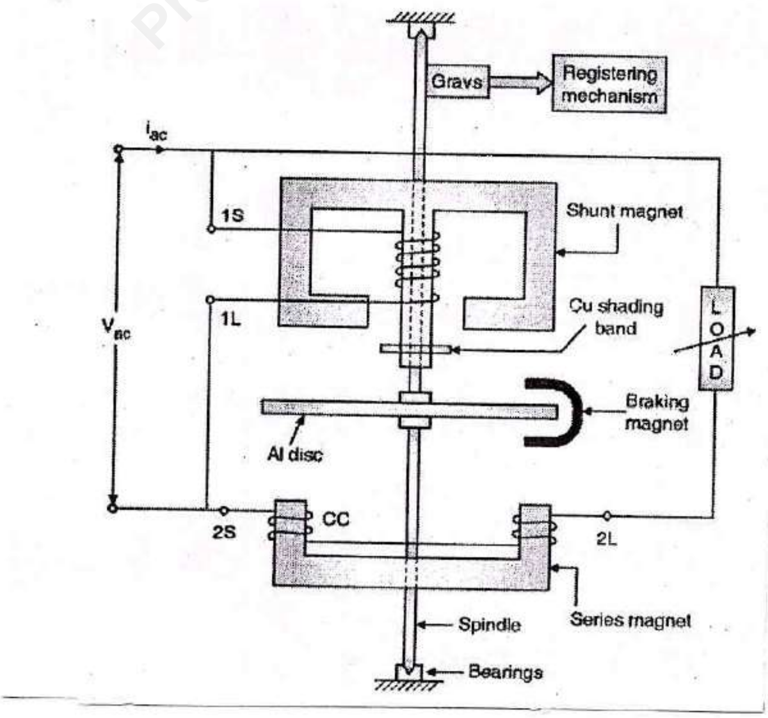
- Energy meter widely used for the purpose of measuring electrical energy in AC circuit.

Working Principle:

- An alternating c/n is passing thro coil of two electromagnet (shunt & series). These two electromagnet produce their own magnetic flux.
- The flux of shunt magnet is proportional to vltg (V) & flux of series magnet is proportional to load c/n (I). These two fluxes are alternating in nature.
- An aluminium disc is suspended betn shunt & series magnet.

Construction & Working:

1) Following fig. shows construction diagram of induction type energy meter



2) The Pressure coil is wound on central limb of E-shaped electromagnet, while c/n coil is wound on lower U-shaped electromagnet.

3) The lower end on E type electromagnet is fixed with copper shading band, which produces phase difference of 90° betn applied vltg & flux.

4) Press coil connected in ||el where c/n coil connected in series with load.

5) The Aluminium disc is placed betn two electromagnet eddy c/n will be induced on the disc by two fluxes i.e. flux due to press & c/n coil, which set up torque on the disc. This torque is proportional to Power i.e. V.I. cosΦ

6) The vertical spindle is supported betn bearings & carries gear arrangement, which drives the counting gear.

7) Breaking torque is provided by means of a permanent magnet used for braking.

8) As disc rotating, spindle also rotates, spindle connected to registering mechanism, which counts the rotation of disc over a period of time.

9) The speed of the disc will be proportional to torque, Hence in a given time, Number of revolutions will be proportional to torque X time.

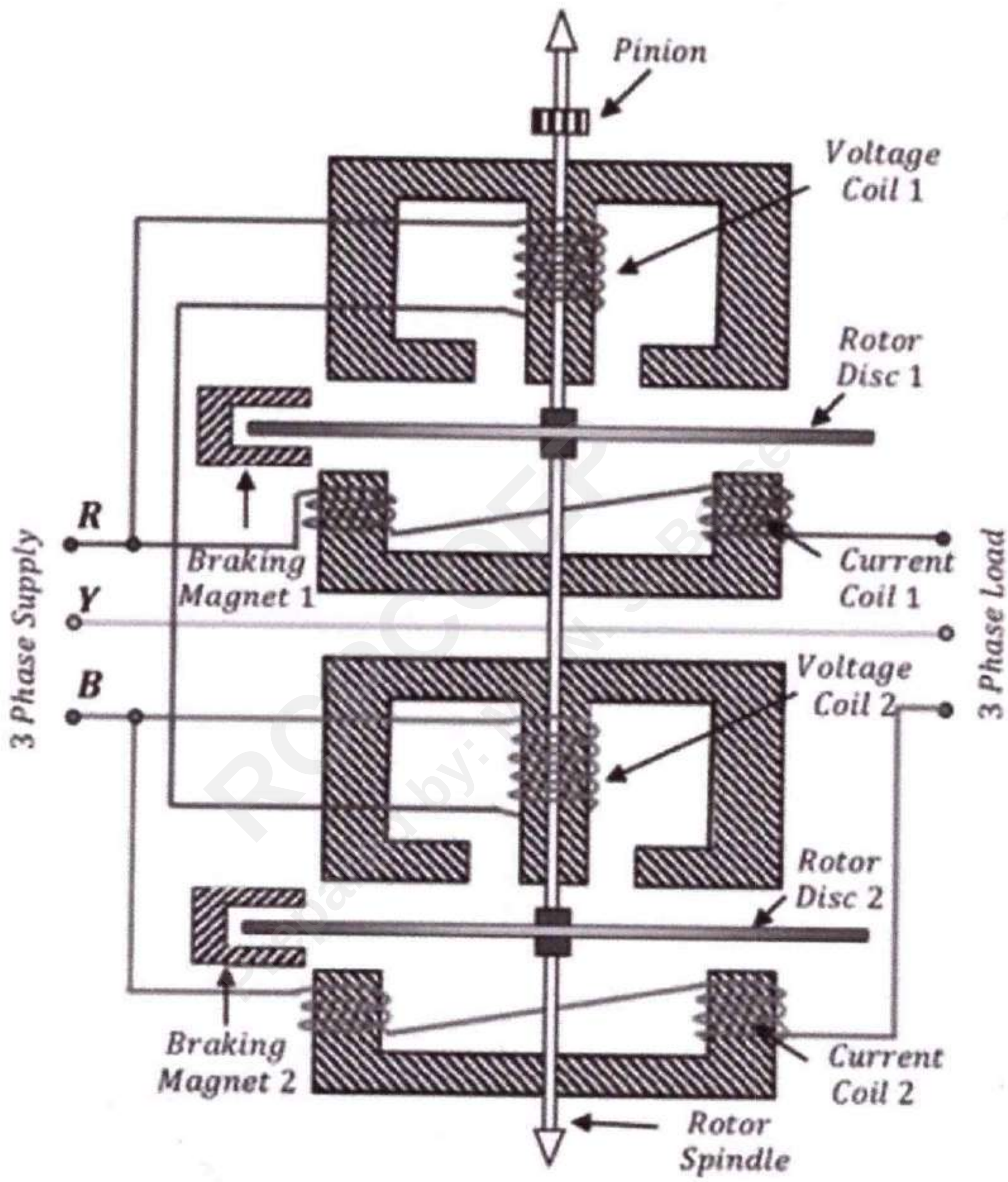
Energy = Power in Watt X Time.

10) The counting arrangement can be so arranged that, it will register the energy directly in kWh.

* Three phase Induction type Energy Meter.

- This meter is used for measurment of energy in three phase loads.

- construction & working:



- It consist of

1. spindle 2 - Shunt Magnet
3. series Magnet 4 - pressure coil
5. current coil 6 - Alluminum disc
7. Braking Magnet 8 - copper shading Band
9 - Registering Mecha. 10 - Bearings
11 - Shading loops.

- This meter consist of two sets of series, shunt magnet, Aluminium disc, brake Magnet, c/n coil & pressure coil.
- Both the disc are attached to the same spindle & having single registering mechanism.
- The connection of c/n & press coil are same as 1-ϕ Energy meter used for ϕ Energy measurement.
- c/n coil of two element are placed in any two phases of 3-ϕ load. one end of both the press coil & second terminal of both press coil are connected to the third line where c/n coil are not connected i.e. in Y-phase.

* Errors in Energy Meter & it's compensation:

Following are the different types of errors occurs in energy meter.

1. phase error
2. friction error
3. speed error
4. creeping error
5. Temp error
6. Frequency error

1) Phase error:

- The meter read correctly only when shunt magnetic flux lags applied vltg by 90°.
- but practically it is not purely inductive.
- Thus error is introduced in energy meter & is known as phase error.

Compensation:

- To increase the inductance of pressure coil, it is placed on central limb of ~~sh~~ shunt magnet.
- further inductance increases by copper shadding band is placed on the central limb.
- The inductance is adjusted to such that the circuit becomes purely inductive.

2) Friction error:

- when aluminum disc rotates, there is friction at spindle bearing & registering mechanism.
- Due to this frictional torque, which opposes the driving torque.
- These error are serious, particularly in light load

compensation:

- some additional torque, which is equal to frictional torque is produced by small shading loop placed betn central limb & aluminum disc on one side of the central limb of the shunt magnet.

- loop e/n are induced in the aluminium disc which produce small driving torque.
- The value of this torque is adjusted equal to the frictional torque.

3) speed error :
- Some times the speed of the disc is more or less than the rated speed, which causes error in recorded value.

compensation :
- This error can be reduced by help of brake magnet.
- If speed of disc is less than required value, the brake magnet is moved towards the spindle.
- This reduces the braking torque value, increases the speed
- If speed of disc is greater than rated value, brake magnet is moved away from spindle.
- This increases the braking torque value, reduces the speed.

4) creeping error :
- Due to excess vltg across press. coil & incorrect frictional compensation, disc makes slow but continuous rotation when no current flowing through load, this is known as creeping of EM
- Due to this error, the meter record some energy consumption when load is "off".

compensation:
- To avoid creeping, two holes are cut in the disc. Due to this, rotation of aluminium disc is limited to half a revolution.
- The disc stops rotating when one of the holes comes under any one pole of shunt magnet.
- It can also be stopped by iron piece on aluminium disc. The brake magnet attract the piece.

5) Temperature Error:

- An increase in temp, causes rise in resistance of metallic parts, which result small decrease in pressure coil flux, thus resi of coil increases.
- This affects angle betn vltg across pressure coil & pressure coil current.

Compensation:

- These error are small, since the various effect produced intended to neutralise each other.

6) Frequency error:

- If the supply frequency changes, the reactance of the coil changes. Small error may be introduced in the meter reading.

Compensation:

- Generally, frequency must be constant, hence no need to provide compensation.

* Errors in Electronic Energy Meter:

- 1) C.T. Error
  2) Overload Error
  3) Connection Error
  4) P.T. Error
  5) Error due to wrong sensor operation
  6) Error due to wrong operation of scaling network.
  7) Error due to wrong display.

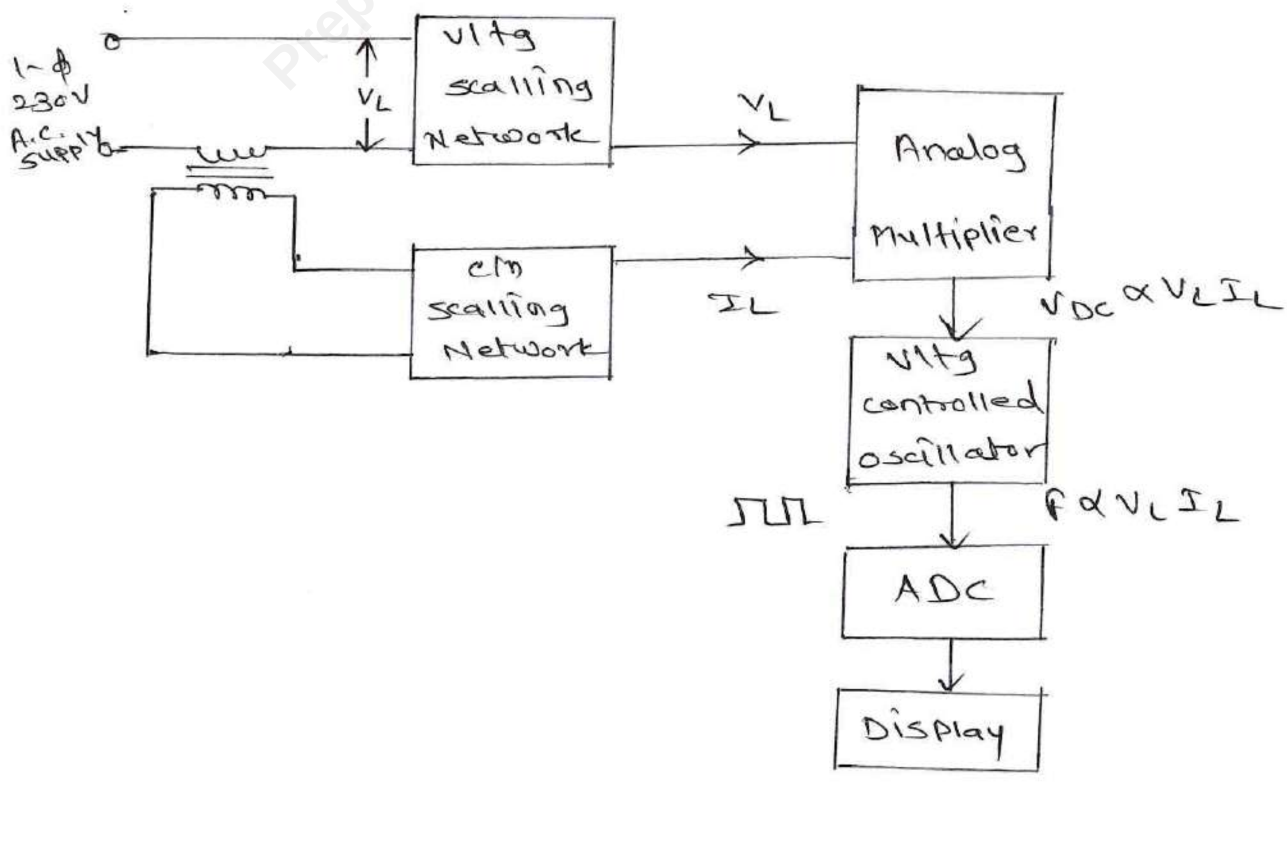
* Electronic Energy Meter.

- Induction EM is replaced by electronic Energy Meter due to - low cost, High accuracy, High sensitivity more flexibility, No frictional losses, data can be stored & recorded power consumption is less.

Advantages ⇒

They can provide protection against theft.

- It also enables automatic meter reading (AMR) whereby energy metering data is transmitted to utility over an radio frequency.
- Improved accuracy & lower power consumption are other benefits of electronic instrument.
- It consist of energy meter IC that drives a stepper motor, display or mechanical counter. To perform energy to pulse conversion required A/D converter, a Vltg reference, clock and some signal processing circuitry.
- The below fig. shows block diagram of electronic E.M.



Operation/Working:

1. The load vltg & cln are sensed & down scaled using the vltg & cln scalling Network.
2. The scaled down vltg & cln are applied to an analog multiplier
3. The analog multiplier Produces a dc vltg proportional to product of it's two inputs
   i.e. $V_{DC} \propto V_L \times I_L$
4. The vltg controlled oscillator (Vco) is basically a vltg to frequency converter. The o/p of Vco is square wave, the frequency is proportional to dc input vltg.
   i.e. $f \propto V_L \times I_L$
5. The analog signal at the o/p of Vco is converted into digital signal by ADC.
6. The ADC o/p is a digital o/p which is applied to the display unit.
7. If we measure the freq i.e. $V_L I_L$ over a unit time period, then power gets converted into energy.
8. The display unit then displays the energy in watt-hour.

Advantages:

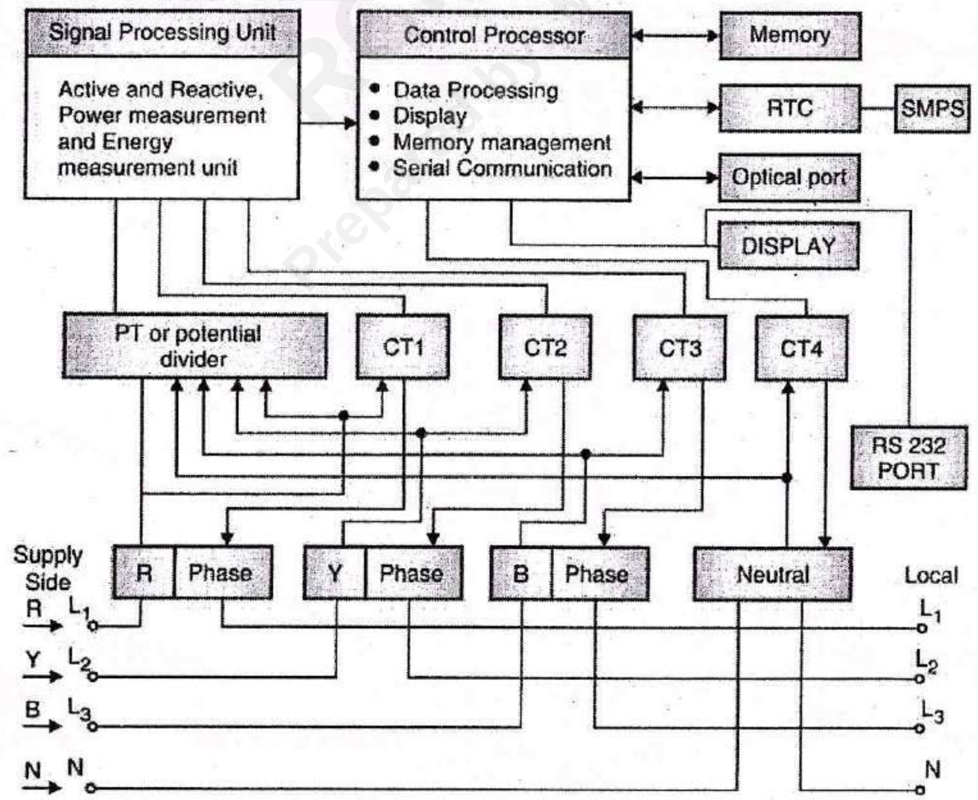
1) No frictional losses as there are no moving parts.
2) High accuracy
3) High resolution
4) No external adjustment

* Three phase Electronic Energy Meter:

- Working principle:
  - The vltg & crn signal from PT & CT are sampled & converted to digital form. These are compared with programmed reference data and finally a vltg rate is given at output.
  - The o/p is available in terms of pulses indicated by LED. This diode blinks. The pulses or blinks are equal to average kwh.

Construction:

- The following fig. shows block diagram of 3-φ Electronic E.M.



- CT_1, CT_2 & CT_3 are connected in R, Y, B phase. These step down the c/n to suitable value & it is given to signal processing unit.
- P.T. is used to step down the line vltg to suitable value & it is given to signal processing unit.
- CT_4 is connected in neutral. The neutral c/n is monitored to check balanced load condition.

Working:

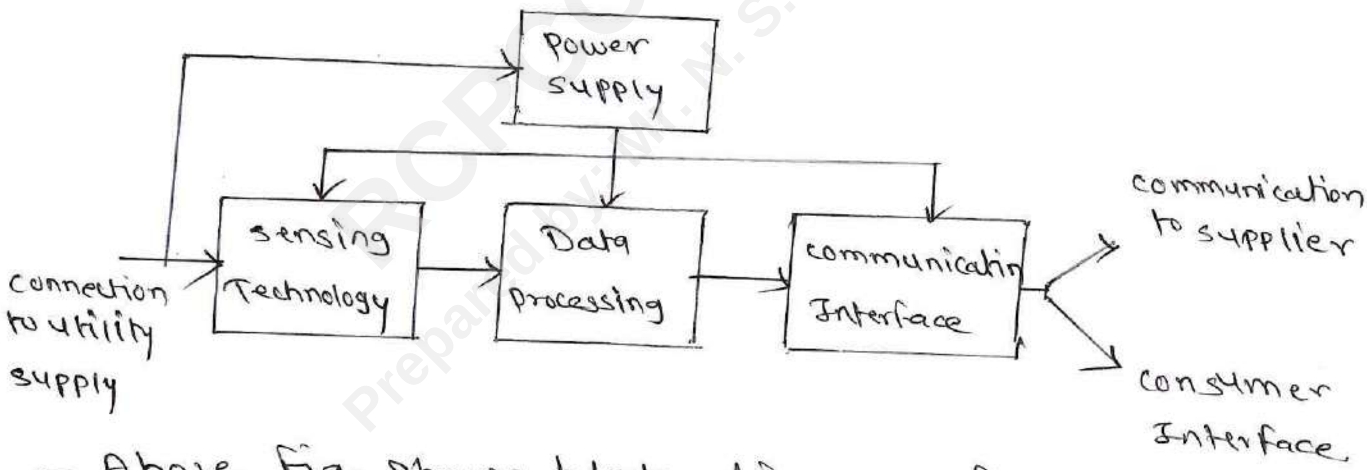
- The signal processing unit measures active, reactive and energy in terms of kWh.
- The control processor, perform necessary data processing work & memory management to monitor diff^n parameter
- RTC (Real time clock) is provided for synchronisation of all data processing work.
- different electrical parameter can be displayed on LCD display. SMPS (switch mode power supply) is provided to give constant D.C. supply.
- The data of energy meter is stored in memory.
- The data can be transferred to external device like AMR through RS232 port or optical port.

* Smart Energy Meter:

Basic concept - Smart EM is an advanced electronic device used to measure energy consumption automatically and send the data to provider and consumer digitally.

Smart meter measure energy in real time, store consumption data, communicate remotely using wireless, helps in automatic billing and energy Management.

Features - Real time monitoring
- Remote Accessibility.
- Two way communication
- Data Analytics
- Billing Accuracy.



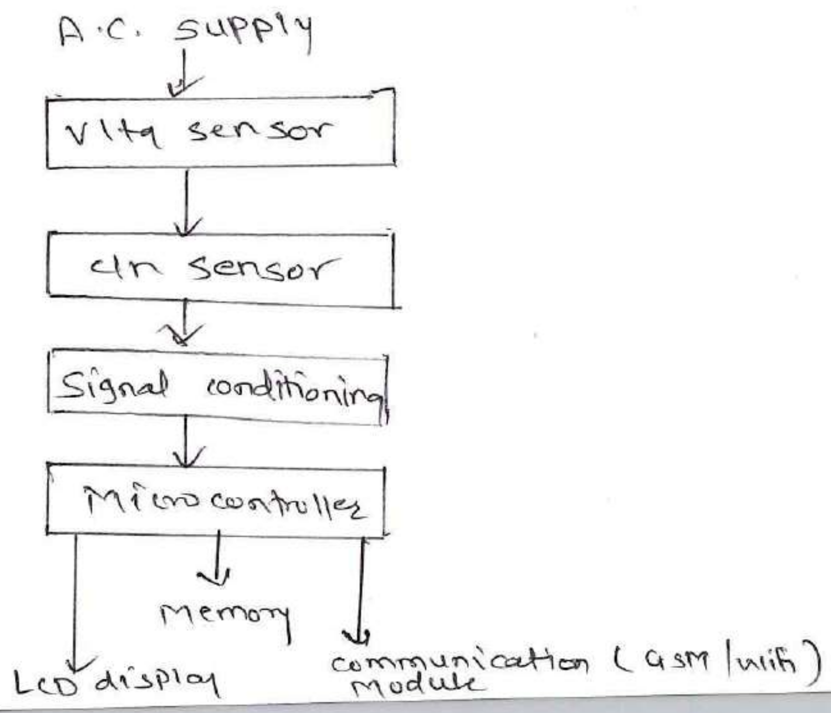
- Above fig. shows block diagram of smart meter.
- Sensing Technology - Smart energy meter consist advanced sensing technologies to measure flow of electricity thro the meter. It consist vltg and c/n sensor to measure supply vltg & load c/n.
- Data processing - The sensed data is processed in data processing unit. It consist of microcontroller and ~~data~~ memory interface circuit.
  The microcontroller calculates vltg, c/n, power and energy consumption.

- Data Transmission – The measured data can be transferred with help of communication protocals such as Zigbee, wifi or fibreoptics to transmit data to utility company.
- Remote Billing & Monitoring – Electricity board can monitor consumption and generate bill remotely.
- consumer interface – Consumer can access their energy usage data thro various interface, such as web portals or mobile applications.

Advantages : Accurate energy measurement
Automatic meter reading
Reduced human error
Remote monitoring
reduce power theft

Applications : Residential Buildings
Industrial plants
commercial complexes
Renewable energy monitoring

or



Unit - 2

Question Bank

1) A single phase wattmeter rated for 500V, 5A is having full scale deflection of 1000 watt, what is multiplying factor of the wattmeter
S-19 | W-19

2) Explain the effect of P.f. on wattmeter reading in two wattmeter method.

3) Explain with block diagram, construction working of single phase electronic energy meter. (W-18 | S-19 | W-19

4) State the various error in single phase electronic energy meter (S-19 | W-19

5) State advantages of electronic energy meter
(S-19 | W-22 | W-19

6) Explain with block diagram, the construction and working of 3-Ø electronic E.M.
(W-18 | W-19

7) Explain with suitable diagram, the constructional details & working of dynamometer type wattmeter
W-18 | S-19 | W-22

8) List various errors occured in dynamometer type wattmeter & describe the way of compensation.
S-19 | W-18

9) list the various errors occured in energy meter & describe the way of compensation.

10) Explain with neat diagram, construction and working of induction type energy meter

W-22

11) Represent the vector representation of power triangle.

W-18 | S-19

12) Explain different methods of three phase power measurement

13) Explain working of maximum demand indicator with a neat sketch.

W-22

14) State the purpose of four quadrant meter

W-19

15) Draw the circuit diagram for-

a) measurement of power in 3-ϕ load using two wattmeter

b) measurement of power in 3-ϕ load using one wattmeter

W-19

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