Unit-II Electricity Generation and Measuring instruments

Construction and principle of 3 – phase Alternator, Transformer principle, Major sources of electricity generation: schematics of conventional power plants (Thermal and Hydro), Non-conventional sources (solar and wind).

Measuring Instruments: Types, Construction and working principle of Permanent Magnet Moving Coil (PMMC), Moving Iron (MI) Instruments and Single-phase Energy meter- Power rating of different household appliances and Electricity bill.

3 – PHASE ALTERNATOR

Alternators (or AC generator) is a synchronous machine used to convert mechanical power to AC electric power.

Construction

- *There are two main parts of an alternator – stator (stationary part) and rotor (rotating part).*
- *Alternator consists of two windings. i) field winding & ii) armature winding.*
- *Field winding windings produce the magnetic field in a machine.*
- *Armature windings are those windings where the voltage is induced.*
- *For synchronous machines, the field windings are on the rotor and the armature windings are placed on stator.*

Stator:

· *The core of the stator is made of CRGO (cold rolled grain oriented) sheet steel or silicon steel.*

· *A 3-phase winding is put in the slots cut on the inner periphery of the stator.*

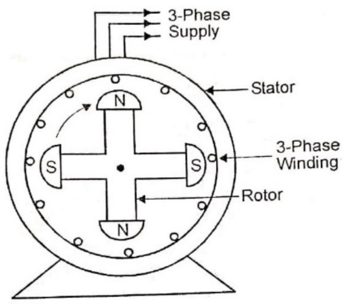


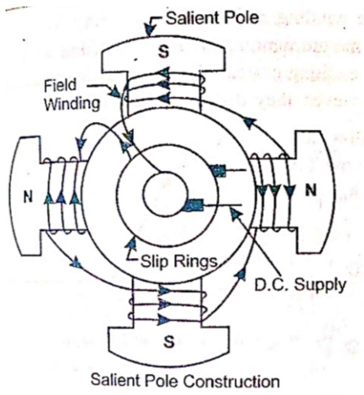
Fig. 3 – Phase, 4-pole salient pole alternator

Rotor:

There are two types of rotors

1. Salient or projected-pole type

2. Cylindrical or non-salient type



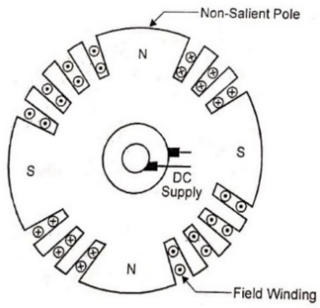
1. Salient pole rotor

A salient-pole rotor consists of poles which project out from the surface of the rotor core.

Salient pole rotors have concentrated winding on the poles.

This type of machine has a non-uniform air gap.

They have a large number of poles and are mainly used for low-speed turbine such as in hydroelectric power plant.



2. Cylindrical Rotor

Fig. Four-pole cylindrical rotor

It is a cylindrical structure which can rotate inside the stator leaving a very small air gap.

It houses the windings to produce dc magnetic field. This winding is excited by a separate dc generator, called exciter. The exciting current is supplied to the rotor windings through two
slip rings and carbon brushes. **Fig. Four-pole**

Cylindrical rotor

The brush is pressed against the slip-ring., there are no physical poles to be seen. Field winding is placed in these slots. The rotor has a small diameter with comparatively long axial length.

It is used for steam turbine driven alternator. The rotor of this generator rotates at very high speed. It has 2 or 4 poles on the rotor.

Principle of Operation

Operating principle of alternators is based upon Faraday's law of electromagnetic induction, when there is a relative motion between the conductors and the flux, e.m.f. gets induced in the conductors.

The rotor winding is energized from the d.c. exciter and alternate N and S poles are developed an the rotor. When the rotor is rotated in anticlockwise direction by a prime mover, the stator or armature conductors are cut by the magnetic flux of rotor poles. Consequently, e.m.f. is induced in the armature conductors due to electromagnetic induction. The induced e.m.f. is alternating since N and S poles of rotor alternatively pass the armature conductors.

The rotor of the alternator is rotated at synchronous speed.

Synchronous Speed (Ns):

The frequency of the generated voltage depends on the number of field poles and the speed at which the field poles are rotated.

P = *Number of field poles*

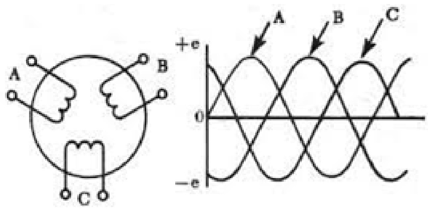
N_s = *Speed in r.p.m (revolutions per minute)*

f = *Frequency/number of cycles per second*

Synchronous Speed, $N_s = \dfrac{120F}{P}$

A machine which runs on synchronous speed is called synchronous machine.

Example:



Above figure shows the three phase emf induced in the alternator A, B and C – three phase windings.

Problem:

A 3- phase, 6-pole star connected alternator rotor rotates at 1000 rpm. Calculate frequency of generated emf.,

Ans: **50Hz**

TRANSFORMER

Transformer is a Static device, which transfers the electrical power or energy from one alternating current circuit to another with the desired change in voltage or current and without any change in the frequency.

Transformer is a Static device which step up or step down the voltage without any change in the frequency. Transformer used to increase the voltage is called "STEP UP" Transformer and decrease the voltage is called "STEP DOWN" Transformer.

Working Principle of a Transformer:

Transformer works on the principle of electromagnetic induction and mutual induction between the two coils.Transformer mainly consists of two windings wounded on a core as shown in below figure.

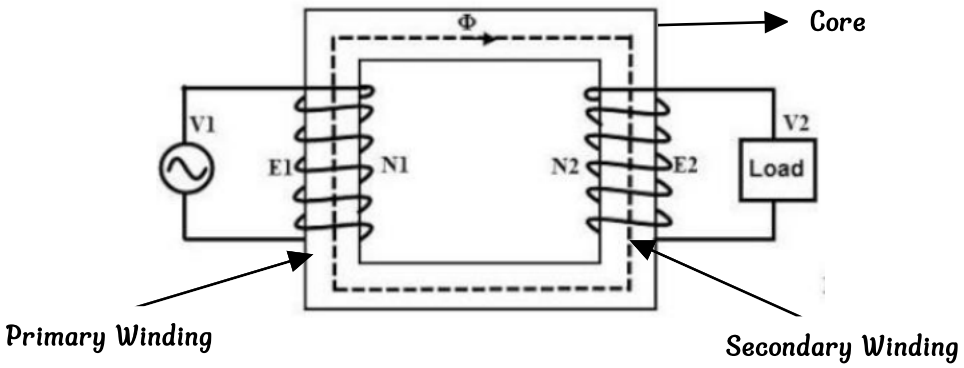


Fig. 1-Phase Transformer

It consists of two windings electrically separated but linked by a common magnetic circuit of low reluctance formed by a laminated core.

The winding which is connected to the supply is known as "Primary Winding" and the other winding on which the load is connected is called "Secondary Winding".

When the 1-phase AC Supply is given to the Primary Winding an alternating current flow through it and produces alternating flux (Ø) in core as shown in figure.

The flux produced at primary links with both primary and secondary winding following the path of low Reluctance core.

The flux linking with primary winding induces an emf known as self-induced emf (E_1) and flux linking with secondary winding induces emf known as mutually induced emf (E_2) according to Faraday's laws of Electromagnetic induction.

If the Secondary winding connected across the load, the mutually induced emf circulates a current to the load. Thus, the electrical energy is transferred from primary to secondary without any change in frequency.

Primary induced e.m.f , $E_1 = -N_1 \frac{d\varnothing}{dt}$

Secondary induced e.m.f , $E_2 = -N_2 \frac{d\varnothing}{dt}$

Voltage transformation ratio:

Since for a transformer, the voltage per turn being equal in both primary and secondary windings, therefore,

$$\frac{E_1}{N_1} = \frac{E_2}{N_2}$$

The ratio of secondary induced e.m.f to primary induced e.m.f is known as voltage transformation ratio.

$$\frac{E_2}{E_1} = \frac{N_2}{N_1} = K$$

H.V and L.V Winding:

The winding connected to High voltage side called High voltage or H.V Winding while that connected to Low voltage called Low voltage or L.V Winding.

In Step up Transformer: L.V Winding is primary; (H.V) Secondary

In Step down Transformer: H.V winding is primary; (L.V) Secondary

Problem:

A 40 KVA, single phase transformer has 400 turns on the primary and 100 turns on the secondary.The primary is connected to 2000 V, 50Hz supply. Determine the secondary voltage.

Sol.

Given data :

Rated power = 40 KVA

Number of primary turns, N_1 = 400

Primary voltage, E_1 = 2000V

Number of secondary turns, N_2= 100

Supply frequency = 50Hz

To find :

Secondary voltage, E_2= ?

Voltage transformation ratio.

$$\frac{E_2}{E_1} = \frac{N_2}{N_1}$$

Secondary voltage, $E_2 = E_1 \times \frac{N_2}{N_1}$

$$= 2000 \times \frac{100}{400} = 500\ V$$

Secondary voltage, E_2= 500 V

Exercise problem: A single-phase 600/6600V, 50Hz transformer has 34 turns in primary winding. Calculate secondary winding turns.

Types of Energy Sources:

1. Conventional (non-renewable) sources
2. Non-conventional (renewable) sources

Conventional Energy Sources

The sources of energy which are exhaustible in nature are called conventional energy sources.
The energy sources which once used cannot be recovered any more. They are depleting in nature.
The sources of energy which are used for the mass generation of power are called conventional energy sources.

Ex: Diesel, Gas, Coal, Nuclear etc.

Non-conventional Energy Sources or Renewable Energy Sources

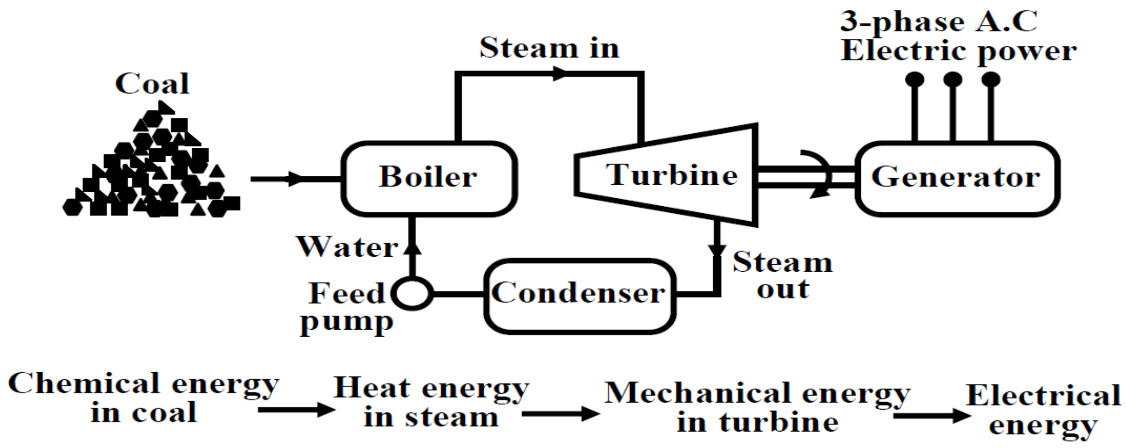
These energy sources are available abundantly in nature and they can be reused again. The energy sources which are non-exhaustible in nature are called non-conventional sources.

Ex: Solar energy, Wind energy, Tidal energy, Geo-thermal energy, Biomass energy, Ocean thermal energy, Biogas energy, Fuel cells etc.

1. Thermal power station

A generating station which converts heat energy of coal combustion into electrical energy is known as a **Thermal power station.**

A Thermal power station basically works on the Rankine cycle. Steam is produced in the boiler by utilizing the heat of coal combustion. The steam is then expanded in the prime mover (*i.e.*, steam turbine) and is condensed in a condenser to be fed into the boiler again. The steam turbine drives the alternator which converts mechanical energy of the turbine



into electrical energy.

Fig. Block diagram of Thermal Power Station

Boiler: The heat of combustion of coal in the boiler is utilised to convert water into steam at high temperature and pressure.

Turbine. The dry and superheated steam from boiler is fed to the steam turbine. The heat energy of steam when passing over the blades of turbine is converted into mechanical energy.

Condenser: After giving heat energy to the turbine, the steam is exhausted to the condenser which condenses the exhausted steam by means of cold water circulation.

Generator: The turbine is coupled to a Generator. The generator converts mechanical energy of turbine into electrical energy.

This type of power station is suitable where coal and water are available in abundance and a large amount of electric power is to be generated.

Advantages

(*i*) The fuel (*i.e.*, coal) used is quite cheap.

(*ii*) Less initial cost as compared to other generating stations.

(*iii*) It can be installed at any place irrespective of the existence of coal. The coal can be transported to the site of the plant by rail or road.

(*iv*) It requires less space as compared to the hydroelectric power station.

Disadvantages

(*i*) It pollutes the atmosphere due to the production of large amount of smoke and fumes.

(ii) It is costlier in running cost as compared to hydroelectric plant.

2. Hydro-Electric Power Station

- *A generating station which utilizes the potential energy of water at a high level for the generation of electrical energy is known as a* **hydro-electric power station.**
- *Hydro-electric power stations are generally located in hilly areas where dams can be built conveniently and large water reservoirs can be obtained.*
- *In a hydro-electric power station, water head is created by constructing a dam across a river or lake. From the dam, water is led to a water turbine. The water turbine captures the energy in the falling water and changes the hydraulic energy (i.e., product of head and flow of water) into mechanical energy at the turbine shaft.*
- *The turbine drives the alternator which converts mechanical energy into electrical energy. Hydro-electric power stations are becoming very popular because the reserves of fuels (i.e., coal and oil) are depleting day by day.*

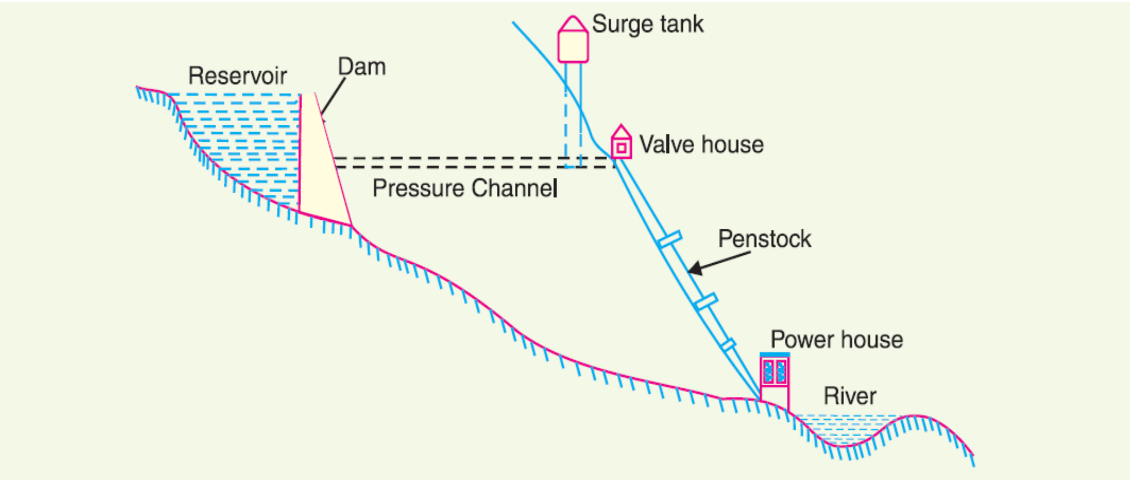


Fig. Schematic arrangement of a modern hydro-electric plant

- *They have the added importance for flood control, storage of water for irrigation and water for drinking purposes.*
- *The dam is constructed across a river or lake and water from the catchment area collects at the back of the dam to form a reservoir.*
- *A pressure tunnel is taken off from the reservoir and water brought to the valve house at the start of the penstock. The valve house contains main sluice valves and automatic isolating valves. The former controls the water flow to the power house and the latter cuts off supply of water when the penstock bursts. From the valve house, water is taken to water turbine through a huge steel pipe known as penstock.*

- *The water turbine converts hydraulic energy into mechanical energy. The turbine drives the alternator which converts mechanical energy into electrical energy.*
- *A surge tank is built just before the valve house and protects the penstock from bursting in case the turbine gates suddenly close due to electrical load being thrown off. When the gates close, there is a sudden stopping of water at the lower end of the penstock and consequently the penstock can burst like a paper log. The surge tank absorbs this pressure swing by increase in its level of water.*

Advantages:

(i) It requires no fuel as water is used for the generation of electrical energy.

(ii) It is quite neat and clean as no smoke or ash is produced.

(iii) It requires very small running charges because water is the source of energy which is available free of cost.

(iv) It is comparatively simple in construction and requires less maintenance.

(v) Such plants serve many purposes. In addition to the generation of electrical energy, they

also help in irrigation and controlling floods.

Disadvantages:

(i) It involves high capital cost due to construction of dam.

(ii) There is uncertainty about the availability of huge amount of water due to dependence on

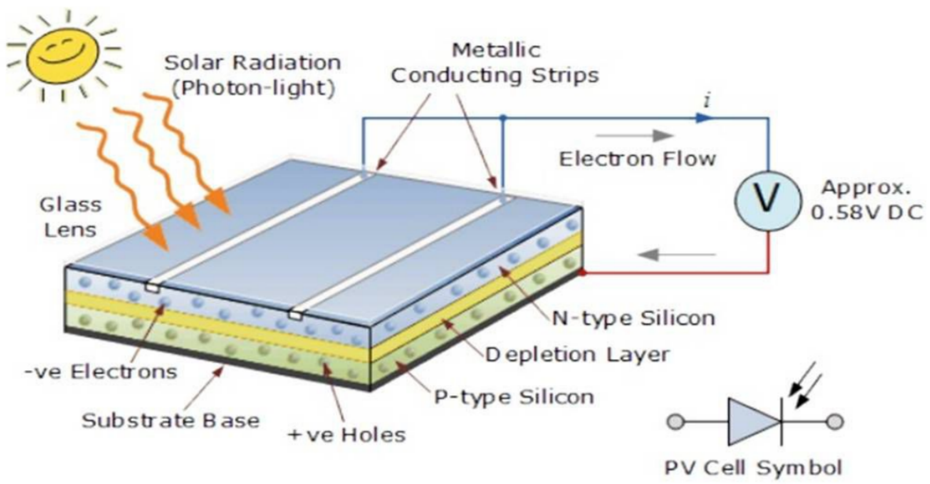
weather conditions.

(iii) It requires high cost of transmission lines as the plant is located in hilly areas which are quite

away from the consumers.

3. Solar Energy

A solar cell or photovoltaic (PV) cell is a device that converts solar energy into electricity by the photovoltaic effect. A material or device that is capable of converting the energy contained in the photons of solar energy into an electrical current is said to be



photovoltaic.

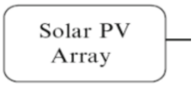
Fig. Solar Cell Operation

Working Principle of Solar Cell:

When light is incident on the surface of a cell, it consists of photons which are absorbed by the
Semi-conductor and electron-hole pairs are liberated to produce an external DC supply.

If the incident energy (ev) is greater than the energy gap of that semiconductor material, these electron-hole pairs are generated at the depletion region of a diode.

When this photon from external radiation hits the diode, these electron-hole pairs disrupt the neutrality of the conductor. If an external current path has been provided then the electrons flowing through the P-side travel towards the N-side, eventually generating a DC current and the magnitude of this electromotive force generated is directly proportional to the intensity of the incident radiation.



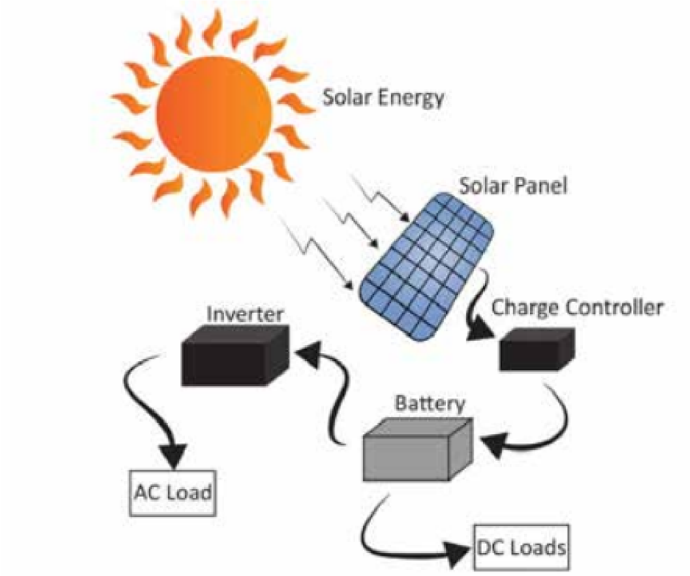


Fig. Block diagram of a typical Solar system.

Solar array: A solar array is a collection of multiple solar panels that generate electricity as a system.

Batteries: For those PV systems which are required to operate at night or during the absence of sunlight, storage of energy is important. Batteries are used to store electricity.

Charge Controller: The PV module output depends on the intensity of sunlight and the temperature of the cell. Charge controllers or regulators are the components which control the DC output and deliver that to the grid, batteries, and/or loads and ensures smooth operation of the PV system.

Inverter: A inverter is a electronic device that changes direct current (DC) to alternating current (AC). For applications that are run by AC power, the DC/AC inverters are required to be installed in PV systems

Load: The household appliances and equipment that require to be powered by the PV solar system are called load.

Advantages:

- It is clean and non-polluting.
- It is renewable energy.
- Solar cells do not produce noise and are totally silent.
- They require very little maintenance.

- They are long lasting sources of energy which can be used almost anywhere.
- They have long life time.
- There is no fuel cost or fuel supply problems.

Disadvantages:

- Solar power cannot be obtained in night time.
- Solar cells (or) solar panels are very expensive.
- Energy has to be stored in batteries.
- They need large area of land to produce efficient power supply.

Irradiance (w/m^2): Irradiance (or power density) is defined as the solar energy received by earth's surface per unit area.

4. Wind energy

Wind flow is created as an effect of solar energy which creates low- pressure and high-pressure regions on the earth due to heating. Wind energy is inexhaustible, plentiful and pollution free source of energy.

Wind possesses energy by virtue of its motion. Any device capable of slowing down the motion of air can convert its energy into useful work. Windmills or wind energy converters converts wind power into electrical power.

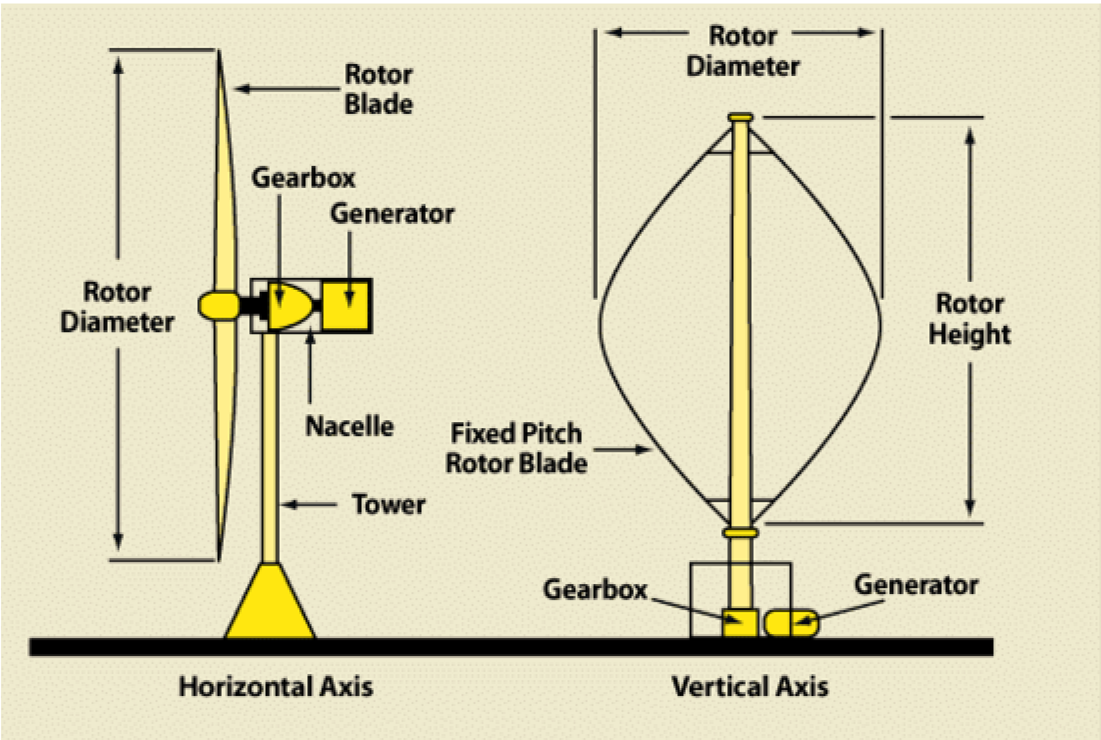


Fig: Horizontal Axis Wind Turbine

Fig: Vertical Axis Wind Turbine

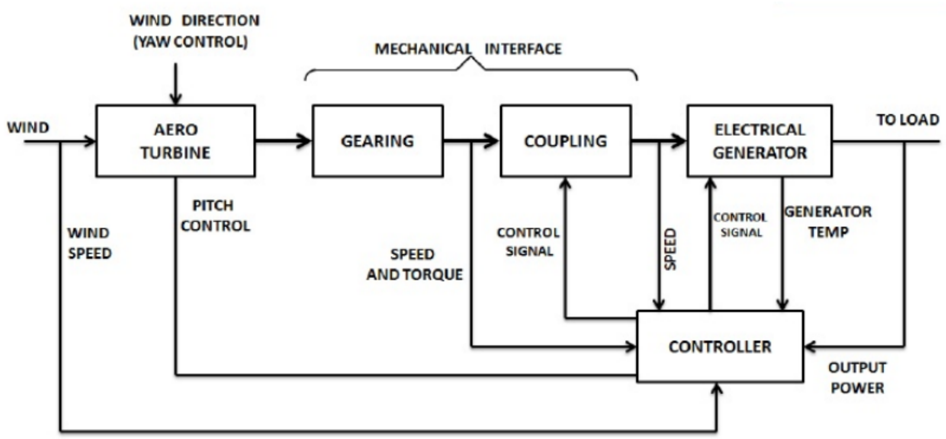


Fig. Block diagram of Wind Power Plant

Aero turbine converts wind energy into rotary mechanical energy.

This aero turbine requires pitch control and yaw control for proper operation.

Mechanical interface consisting of a step-up gear and suitable coupling to transmit the rotary mechanical energy into electrical generator.

The generator converts mechanical energy into electrical energy.

The output of the generator is connected to the load or power station.

The controller senses the wind direction, wind speed, generator output and other necessary performance quantities & generates a control signal to take proper corrective actions.

Advantages

- It is renewable source of energy.
- It can be installed any locations where topographical conditions are suitable.
- It is non-polluting in nature, so it has no adverse influence on the environment.
- These plants avoid fuel provision and transport.
- Cost of generation is low.

Disadvantages

- Wind energy available in fluctuating in nature.
- It requires large area to collect the energy.
- Noisy in operation.
- Wind energy requires storage capacity because of its irregularity.
- Power generated is quite small.

MEASURING INSTRUMENT

The device or instrument used for comparing the unknown quantity with the unit of measurement or a standard quantity is called a measuring instrument.

Deflecting, Controlling and Damping Torques:

1. Deflecting Torque:

The deflecting torque or operating force is required for moving the pointer from its zero position. Thus, the deflecting system of an instrument converts the electric current or potential into a mechanical force called deflecting torque.

2. Controlling Torque:

The deflection of the pointer will be indefinite, and pointer will go on moving, if there is no controlling or restoring torque. This controlling torque opposes the deflecting torque. Pointer will be at rest when controlling torque becomes equal to deflecting torque. Controlling torque acts in the opposite direction to the deflecting torque.

3. Damping Torque:

A damping torque is produced by a damping or stopping force which acts on the moving system only when it is moving and always opposes its motion. Such a torque is necessary to bring the pointer to rest quickly.

Permanent Magnet Moving Coil (PMMC) Instrument:

The instruments which use the permanent magnet for creating the stationary magnetic field between which the coil moves, is known as the permanent magnet moving coil or PMMC instrument. It operates on the principle that the torque is exerted on the moving coil placed in the field of the permanent magnet.

Construction: The moving coil and permanent magnet are the main part of the PMMC instrument.

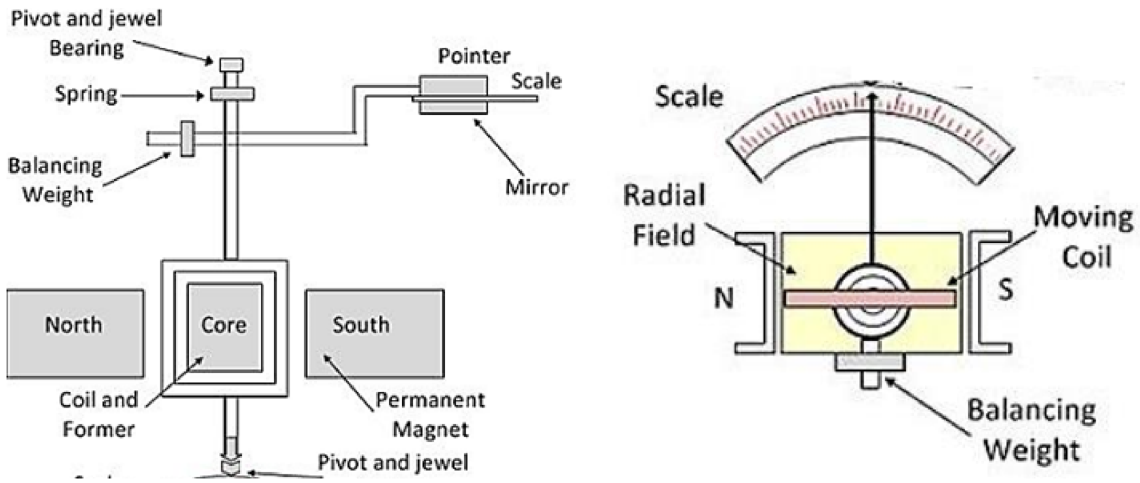


Fig. PMMC Instrument

Moving Coil – *The coil is the current carrying part of the instruments which is freely moved between the stationary field of the permanent magnet. The current passes through the coil deflects it due to which the magnitude of the current or voltage is determined. The coil is mounted on the rectangular former which is made up of aluminium. The former increases the radial and uniform magnetic field between the air gap of the poles. The coil is wound with the silk cover copper wire between the poles of a magnet.*

Magnet System – *The PMMC instrument using the permanent magnet for creating the stationary magnets. The Alcomax and Alnico material are used for creating the permanent magnet because this magnet has the high coercive force. (The coercive force changes the magnetisation property of the magnet). Also, the magnet has high field intensities.*

Control – *In PMMC instrument the controlling torque is because of the springs. The springs are made up of phosphorous bronze and placed between the two jewel bearings. The spring also provides the path to the lead current to flow in and out of the moving coil.*

Damping – *The damping torque is used for keeping the movement of the coil in rest. This damping torque is induced because of the movement of the aluminium core which is moving between the poles of the permanent magnet.*

Pointer & Scale – *The pointer is linked with the moving coil. The pointer notices the deflection of the coil, and the magnitude of their deviation is shown on the scale. The pointer is made of the lightweight material, and hence it is easily deflected with the movement of the coil.*

Torque Equation for PMMC Instruments:
The deflecting torque equation for Permanent Magnet Moving Coil or PMMC Instruments is given as

Deflecting Torque $(T)_d = N\ B\ L\ d\ I = G\ I$

Where, G = *a constant*
N = *Number of turns in the moving coil*
B = *magnetic flux density between the magnetic poles*
L = *Length of moving coil*
d = *Breadth of moving coil*

As the Controlling Torque (T_C) *is provided by the spring, therefore*

$$T_c = K\theta$$

Where K = *Spring constant*
θ = *Angular movement of coil*

At steady state condition, deflecting and controlling torque shall be equal,

$$T_d = T_c$$
$$GI = K\theta$$
$$\theta = (G/K)\ I$$
$$\theta \propto I$$

Thus, from the above equation, the deflection in Permanent Magnet Moving Coil or PMMC

Instruments is directly proportional to the current flowing in the moving coil. Because of this the meter scale of such instrument for the measurement of current / voltage is linear.

Moving Iron (MI) Instruments:

The attraction type of MI instrument depends on the attraction of an iron vane into a coil carrying current to be measured.

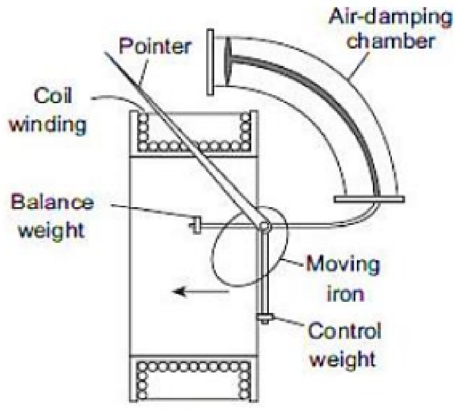


Fig. MI Instrument

A soft iron vane is attached to the moving system.

When the current to be measured is passed through the coil C, a magnetic field is produced. This field attracts the eccentrically mounted vane on the spindle towards it. The spindle is supported at the two ends on a pair of jewel bearings.

Thus, the pointer , which is attached to the spindle of the moving system is deflected. The pointer moves over a calibrated scale. The control torque is provided by two hair springs S_1 and S_2 in the same way as for a PMMC instrument, but in such instrument's springs are not used to carry any current. Gravity control can also be used for vertically mounted panel type MI meters.

Air friction damping used for MI instruments. Eddy current damping can distort the otherwise weak operating magnetic field produced by the coil. If the current in the fixed coil is reversed, the field produced by it also reverses. So the polarity induced on the vane reverses. Hence such instrument can be used for both direct current as well as alternating current.

$$\text{deflecting torque } T_d = \frac{1}{2} I^2 \frac{dL}{d\theta}$$

Hence the deflecting torque is proportional to square of the rms value of the operating current

($T_d \propto I^2$). The deflection torque is, therefore unidirectional whatever may be the polarity of the current.

Digital Energy Meter:

Energy meters for measurement of energy in domestic and industrial ac circuits.

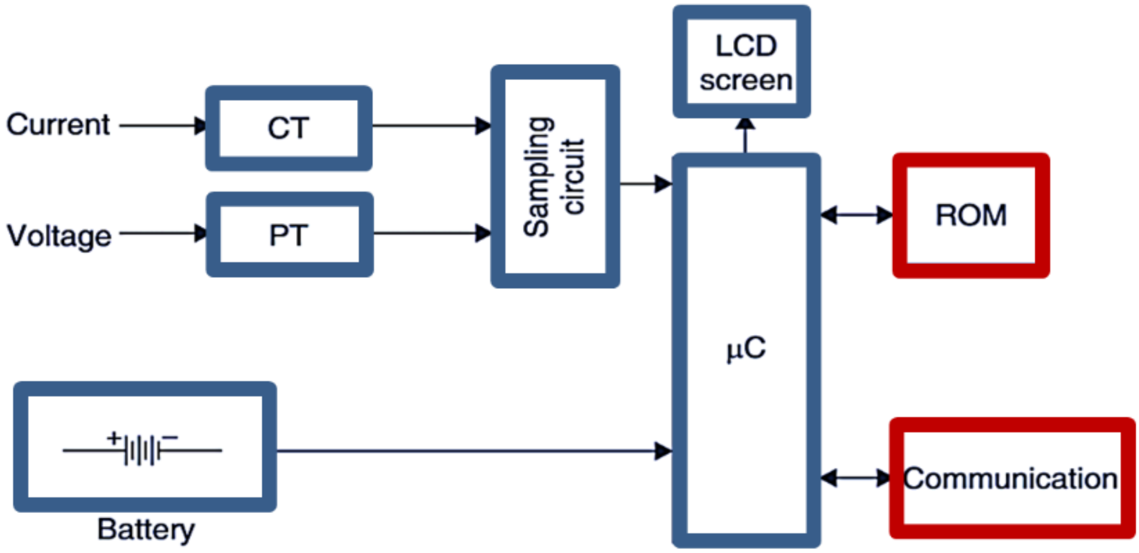


Fig. Block diagram of Digital Energy Meter

Energy meter which can measure Active energy in KWh, Reactive energy in KVArh, Apparent Energy in KVAh, and Maximum demand in KVA. These meters are for domestic, commercial and industrial purposes. These electronic meters use micro controllers with their own programming language.

The figure shows the simple block diagram of digital energy meter. The meter gets input supply to measured through current transformer(CT) and potential transformer(PT).That is it gets current input through a CT and Voltage input through a PT.For showing various measurents ,a LCD display is used.

The current and voltage are sampled through a sampling circuit.For getting accurate results the sampling rate should be high.For data processing a micro controller is used along with a battery .Very reliable ROM(read only memory) is used to retain the data for years.The data from ROM can either displayed on the LCD screen or communicated to a meter.

ELECTRICITY BILL

A bill for money owed for electricity used.

Tariff

The rate at which electrical energy is supplied to a consumer is known as tariff.

Objectives of tariff:

Like other commodities, electrical energy is also sold at such a rate so that it not only returns the cost but also earns reasonable profit. Therefore, a tariff should include the following items

- Recovery of cost of producing electrical energy at the power station.
- Recovery of cost on the capital investment in transmission and distribution systems.
- Recovery of cost of operation and maintenance of supply of electrical energy e.g., metering equipment, billing etc.
- A suitable profit on the capital investment.

Two-part tariff:

When the rate of electrical energy is charged on the basis of maximum demand of the consumer and the units consumed, it is called a **two-part tariff**.

In two-part tariff, the total charge to be made from the consumer is split into two components viz., fixed charges and running charges.

The fixed charges depend upon the maximum demand of the consumer while the running charges depend upon the number of units consumed by the consumer.

Thus, the consumer is charged at a certain amount per kW of maximum demand plus a certain amount per kWh of energy consumed i.e.,

$$\textbf{Total charges} = \text{Rs } (a \times kW + b \times kWh)$$

where, a = charge per kW of maximum demand

b = charge per kWh of energy consumed

Advantages

(i) It is easily understood by the consumers.

(ii) It recovers the fixed charges which depend upon the maximum demand of the consumer but are independent of the units consumed.

Disadvantages

(i) The consumer has to pay the fixed charges irrespective of the fact whether he has consumed

or not consumed the electrical energy.

POWER RATINGS OF HOUSEHOLD ELECTRICAL APPLIANCES

S. No	Appliances	Power ratings
1	Incandescent lamp	40W – 100W
2	CFL	6W – 30W
3	LED Bulb	4W – 25 W
4	Fluorescent tube light	18W – 60W
5	LED tube light	8W – 36W
6	Table fan	30W – 70W
7	Induction motor Ceiling fan	60W – 80W
8	Cooler	100W – 500W
9	AC (1 ton)	3.517KW
10	Refrigerator	150W – 400W
11	Computer	100W – 250W
12	Microwave	600W – 1700W
13	Washing machine	300W – 500W
14	TV	60W – 120W
15	Smartphone charger	4W – 33W

Energy Calculation:

S.No	Number of appliances	Power rating in watt	Daily use in hours	Load Calculation	Energy Consumption
1	4 LED bulbs	9-W each	10	4 x 9W x 10hr =360	360Wh
2	2 fans	60-W each	16	2 x 60W x 16hr = 1920	1920Wh
3	1 TV	100-W	5	1 x 100W x 5hr = 500	500Wh
4	1	200-W	10	1 x 200W x	1000Wh

	Refrigerator		hours	10hr = 1000	
				Total Energy	**3780Wh**

Where, the total energy consumed = 3780 Watt Hour or 3.78KWh or **3.78 units per day.**

Since these appliances will run for the entire month, therefore, the **final units used per month will be 3.78 units x 30 days = 114 units per month.***(approximately)*

If the electricity tariff/unit in your state is ₹5 (approximately), then the electricity bill will be **= ₹570(Energy charges) + Fixed charges.**

Note: Fixed charges depend on Electricity Distribution Corporation.