NOTES

Subject

r. No:	Date	Topic

ELECTRICAL POWER GENERATION AND UTILIZATION.

Sir Faheem Ali

→ Principles of Power Generation By DeshPaande.

⇛ Principles of Power Systems By V.K Mehta and R. Mehta.

⇛ Power Generation By Naeem Arbab.

19/02/2020.

Chapter 1

Introduction And Electrical Energy

Many advantages of electrical energy;

eg Shorter working day.
Agricultural products.
Better transportation and facilties.

The development of a country depends on per capita consumption of electrical energy.

1.1 Importance of Electrical energy

The industrial growth depends on two factors in electrical energy.

UPS → uninterupted power supply.

Electrical energy is important b/c it is

(i) Convenient → can be easily converted to other forms of energy.

(ii) Easily controlled.
(iii) Flexibility → transport it easily from one place to another.
eg Turbela to Faislabad lines (400-500 km)
(iv) Cheap
(v) Cleanliness.
(vi) High transmission efficiency.

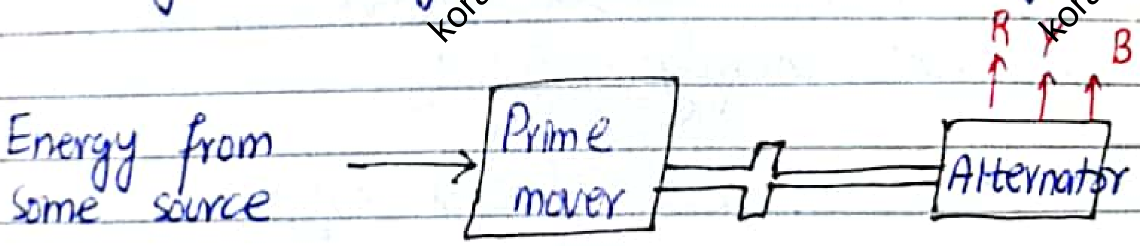
Mostly generation from dams in Pakistan is at 11 KV.
Then through transformer it is stepped up and generated at 220KV or 500 KV.

1.2 Generation of Electrical energy.

↳ It is basically a conversion.

The problem with E.E is that it should be generated, transmitted only when needed to utilize.
It cannot be stored.

Battery → storage but there is decay.



Prime mover converts raw form of energy into mechanical energy.

Sources of Electrical Energy
↓
Water power, Fuel, Nuclear power.

Comparison of Energy sources

We have some parameters

	Water	Fuel	Nuclear
1. Initial cost	High	Low	Very high.
2. Running cost	Low	High	Least
3. Reserves	Permanent	Exhaustable	Inexhaustable
4. Cleanliness	Cleanest	Dirtiest	Clean
5. Simplicity	Simplest	Complex	Most complex
6. Reliability	Reliable	Not	Reliable

Units of Electrical Energy

$1\,KW\,hr = 1\,KW \times 1\,hr = 1000\,W \times 3600\,s = 36 \times 10^5\,W s$

Energy ← J

1 Calorie = 4.18 J

1.7 Efficiency

$$\text{Efficiency} = \eta = \frac{E_{out}}{E_{inp}} = \frac{P_{out}}{P_{inp}}$$

$$P_{in} = P_{o/p} + P_{loss}$$

Ex 1.1 Rate of 4200 J/s. Generator delivers 32.2 A at 120 V.

$P_{in} = 4200\,W \qquad P_{out} = 32.2 \times 120 = 3864$

$$\eta = \frac{3864}{4200} = 92\%$$

$$P_{loss} = P_{i/p} - P_{o/p} = 336$$

$E(\text{minute}) = Pt = 336 \times 60 = 20160\ J$

Calorific Value

The amont of heat produced by complete combustion of unit ~~gain~~ weight of fuel is known as calorific value.

Usually represented in calories per gram or K cal /Kg. for solids.

For fluids in cal/lit or K cal/lit.

Advantages and disadvantages

↓

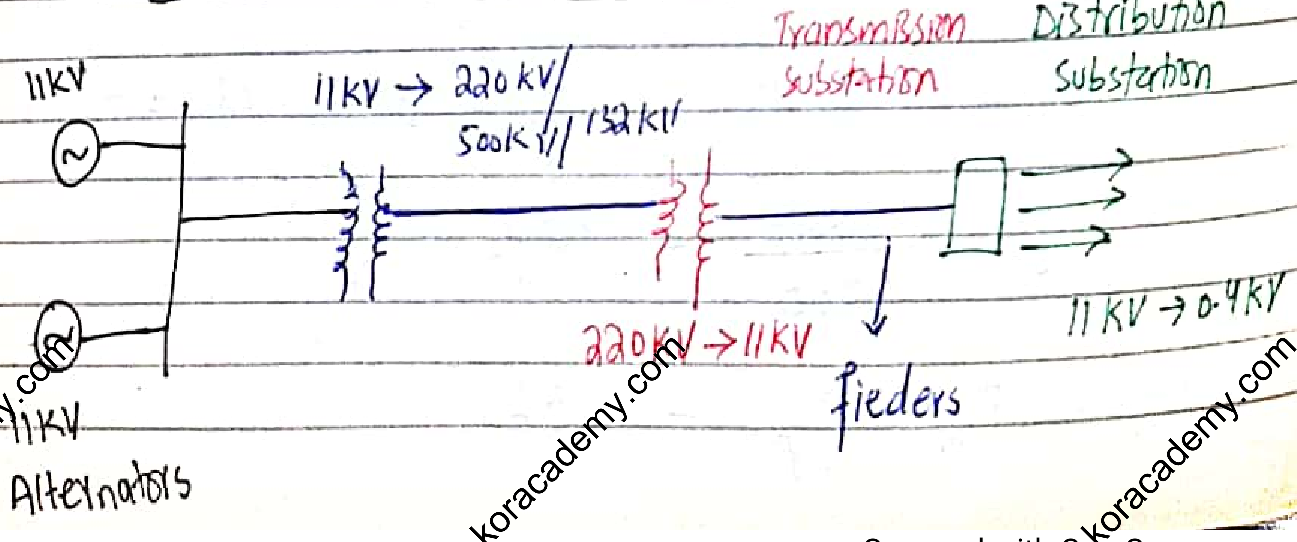
Polution more in solids.
Liquids are more explosive.
Solids can easily be stored

Lecture 2

27/02/20

Chapter 3

Variable Load on Power Station



Whenever you couple generators (connect them in parallel) There voltages must be the same.

NPCC → National power control centre.

Power generated is transmitted to load stations which are generally far away.
And if we transmit directly at 11 kV, there will be very high power losses.
as $P = I^2 R$
$\hookrightarrow R \propto l$

So we step up voltage to decrease the value of current

Transmission line is the connecting link between power station and distribution system.

Distribution system connects all the individual loads in a locality to the transmission line through feeder of distributor

For simplicity we represent a Three phase system by single phase.
We do not show neutral because the system is balanced and no unbalanced current flows.

Stray capacitances are not shown.

← Single Line diagram → using symbols.

Supply power should change with change in demand / load.

3.2 Variable load.

Effects of variable load:

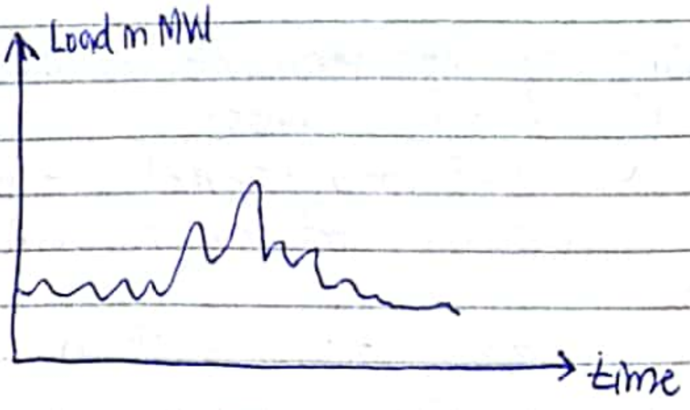
(i) Need additional equipment.
↓
basically results in increased capital cost.

(ii) Increase in production cost.

At lower loads it operates at lowest efficiency.

We can run plant at highest efficiency if we install multiple units - So cost increased as well we require more space so combinely production cost increases.

Load Curve



→ Load variation curve shows actual variation.

→ Diversity is good → different consumers have maximum load at different times.

→ Curve gives maximum demand (daily / monthly etc)

Area under the load curve gives the energy consumed. $E = Pt$ (kW hr)

$$\text{Average load (daily)} = \frac{\text{Energy}}{24}$$

$$\text{Load factor} = \frac{\text{Avg Power} \times T}{\text{Max demand} \times T} = \frac{E\ (\text{kW hr})}{P_m \times T}$$

It helps in selecting size and number of generating units.

let peak load = 1.5
base load = 0.25

Variation 1.5, 1, 0.5, 0.25

So two units of 0.25 and 2 units of 0.5 are needed.

Load curve helps in operation schedule.

Connected load

Sum of continuous ratings of the equipment connected to supply system.

Maximum Demand

The greatest load demand on power stations during a defined period.
↓
daily / monthly / yearly

Demand Factor

It is the ratio of maximum demand to connected load.

$$DF = \frac{P_m}{CL} < 1$$

Average load

day $\frac{kWhr\ (24)}{24}$

month $\frac{kWhr\ (24 \times 30)}{24 \times 30}$

year $\frac{kWhr\ (8760)}{8760}$

Load Factor $= \frac{kWhr}{P_m \times T} = \frac{P_{avg}}{P_m}$

Always less than 1

$$\uparrow F_{LD} = \frac{kWhr \rightarrow fix}{\downarrow P_m \times T}$$

So per unit cost decreases.

Diversity Factor

$$D.F = \frac{\Sigma \text{ Individual maximum demands}}{\text{System max demand}}$$

Always greater than 1.

Plant Capacity Factor

Ratio of actual energy produced to the maximum energy that could have been produced.

$$PCF = \frac{\text{Avg } P \times T}{PC \times T} = \frac{E\,(\text{kWhr})}{PC \times T}$$

PC → plant capacity   RC → Reserve capacity.

$$RC = PC - P_m$$

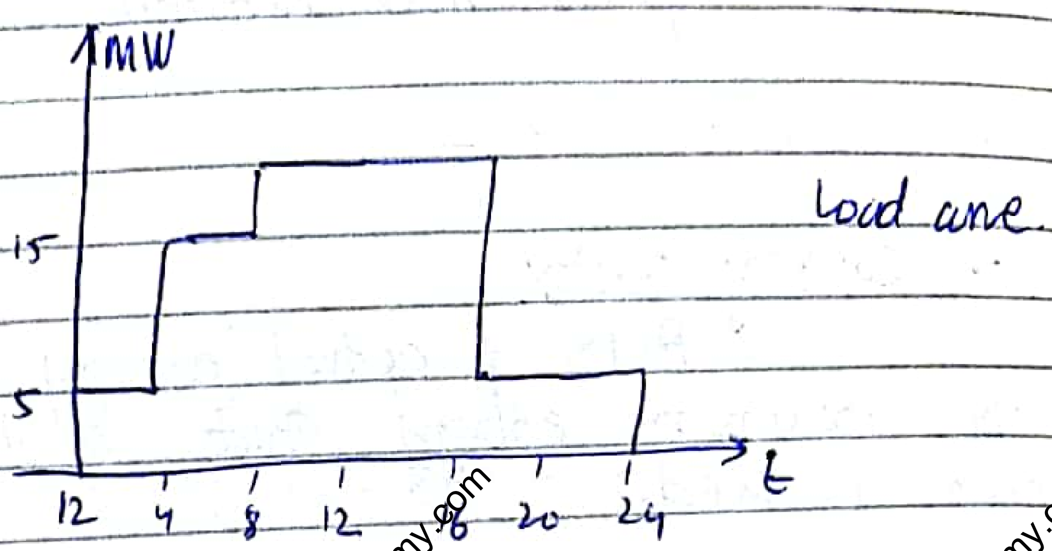
Plant Use Factor

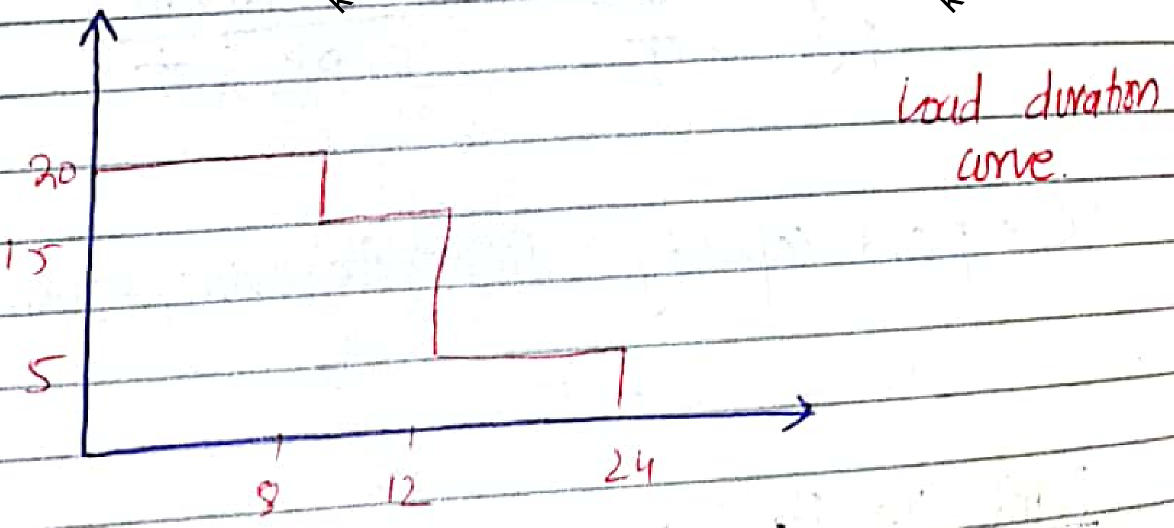
$$PUF = \frac{E\,(\text{kWhr})}{PC \times T'}$$

T' is the time for which the plant is in use.

Load Duration Curve

The load curve gives instantaneous value of load.
Whereas the load duration curve arranges this data in a descending order.





Types of Loads

1. **Domestic loads**

Lights, fans, referigerators, AC, motor etc.

Load factor is 10 to 20%.

ii. Commercial loads.

iii. Industrial loads

iv. Municipal loads street lights etc.

v. Irrigation loads

vi. Traction loads

Typical Demand and Diversity Factor

↓

Ex 3.1 $E = ?$ $F_{LD} = 0.4$ $P_m = 100\,MW$

$$F_{LD} = \frac{E(kWhr)}{P_m \times T}$$

$$E(kWhr) = F_{LD} \times P_m \times T = 0.4 \times 100000 \times 8760$$

$$= 3504 \times 10^5\ kWhr.$$

Ex 3.2 $CL = 43\,MW$ $P_m = 20\,mW$ $DF = ?$ $FLD = ?$

$E = 61.5 \times 10^6$ P/A

$$DF = \frac{P_m}{CL} = \frac{20mW}{43mW} = 0.465$$

$$F_{LD} = \frac{E}{P_m \times T} = \frac{61.5 \times 10^6}{20 \times 10^3 \times 8760} = 35.1\%$$

3.5

3.6 $P_m = 1500\,kW$ $F_{LD} = 0.5$ $PCF = 40\%$

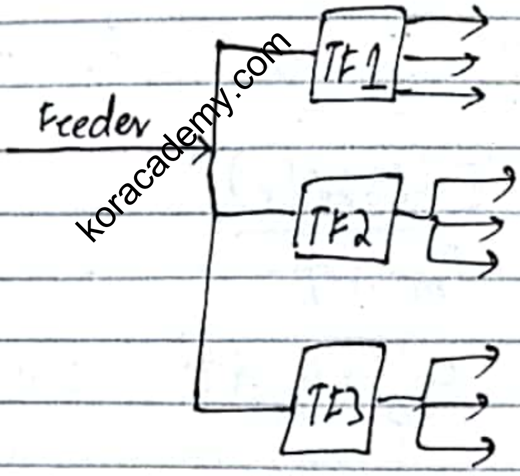
$RC = ?$

$$PCF = \frac{E}{PC \times T} = \frac{F_{LD} \times P_m \times T}{PC \times T}$$

$$PC = \underline{\qquad}.$$

$$RC = PC - P_m$$

* 3.8



	CL	Demand Factor	Diversity of Consumer.
TF 1	10 kW	0.65	1.5
TF 2	12 kW	0.6	3.5
TF 3	15 kW	0.7	1.5

Diversity factor of transformer is 1.3.

Sum of P_m of TF1 = CL x Demand factor = 6.5 kW

" TF2 = 12 x 0.6 = 7.2 kW

" TF3 = 15 x 0.7 = 10.5 kW.

$$D.F = \frac{\Sigma MD}{MD_s}$$

$$MD \text{ on } TF\ 1 = \frac{6.5}{1.5} = 4.33\ KW$$

$$\text{''}\quad TF2 = \frac{7.2}{3.5} = 2.057\ KW$$

$$\text{''}\quad TF3 = \frac{10.5}{1.5} = 7\ KW$$

$$\text{Div factor} = \frac{\Sigma\ mD\ (TF)}{MD\ (\text{feeder})}$$

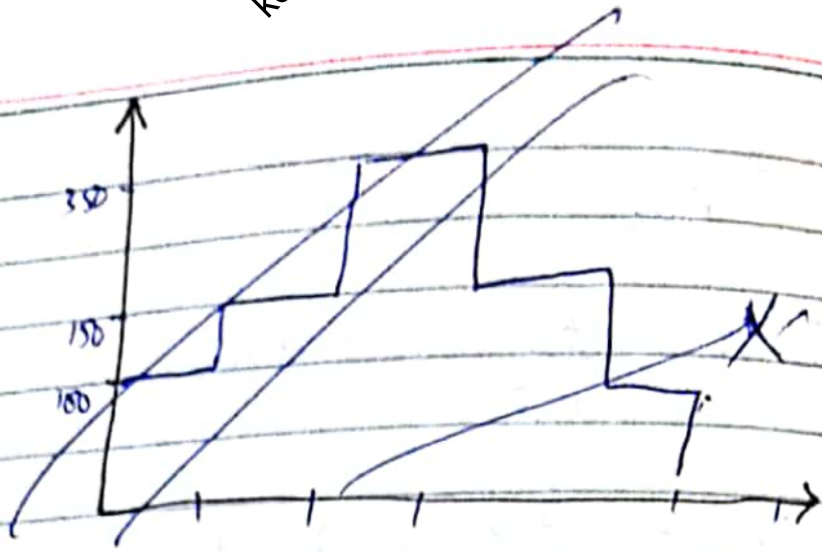
$$MD \text{ on feeder} = \frac{4.3 + 2.057 + 7}{1.3}$$

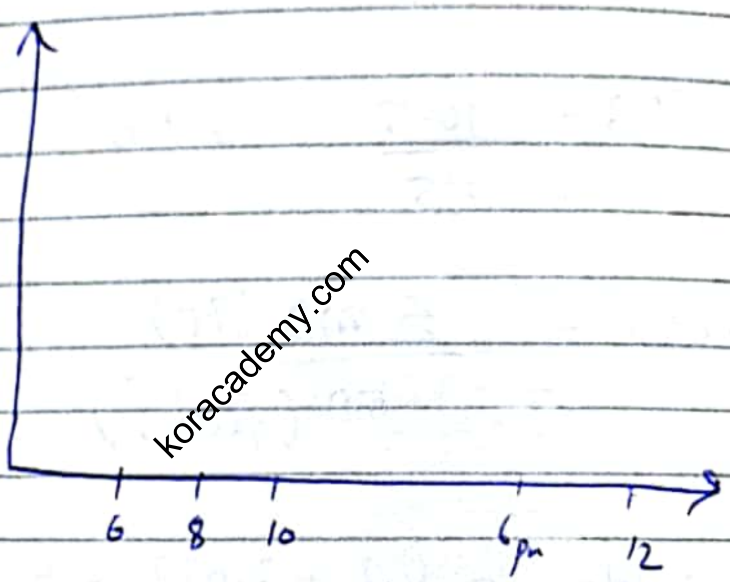
$$= 10.3\ KW.$$

Ex 11

A: 200KW 8am to 6pm
B: 100 KW 6am to 10 am
C: 50 KW 6am to 10 am
D: 100 KW 10 am to 6pm 6pm to 6m

Time	0-6	6-8	8-10	10-6	6-12
A	0	0	200KW	200KW	0
B	0	100KW	100KW	0	0
C	0	50KW	50KW	0	0
D	100KW	0	0	100KW	100KW





DN Factor $= \frac{\sum MD_{grp}}{MD_s} = \frac{200+100+50+100}{350} = \frac{450}{350}$

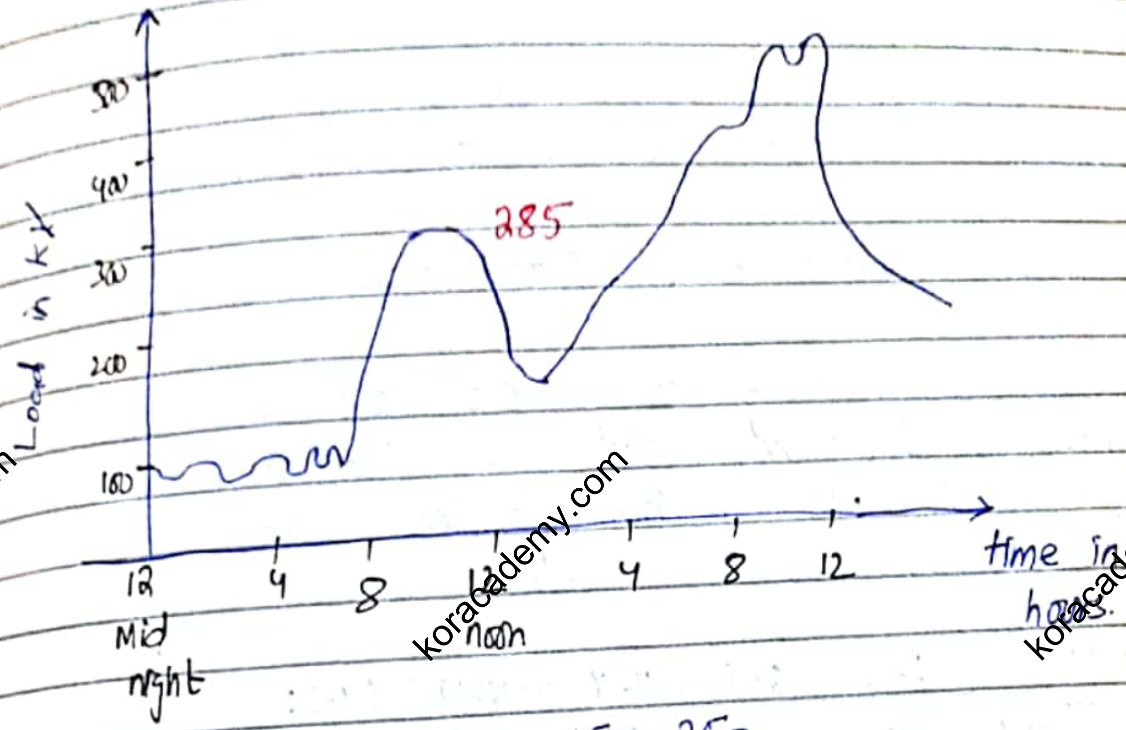
$E = 100(6) + 150(2) + 350(2) + 300(4)$
$+ 100(6) = 4600$ KW

$F_{LD} = \frac{E}{P_m \times T} = \frac{4600}{350 \times 24}$

Lecture 3

05/03/20

3.9 Load curves and selection of generating stations



Three units 150, 150, 250.

12 MN → 7am ⇒ unit 1 ie 150 is operating.
From 7am → 12 N ⇒ unit 1 and 2 → 150 + 150 ≅ 300.
feeding 285 and also has. ↵
some reserve capacity.

12 N → 2pm ⇒ unit 1.
2 → 4pm ⇒ unit 1 + 2 ~~pm~~
5 → 10:30 ⇒ unit 1 + 2 + 3.

3.10 Important points in selection of units

1- Number and size of units should be such that it fits the load curve.

2. The units selected should be preferably of different capacities. Although units of same capacity will ensure savings but it will not fit into the load curve in a better way.

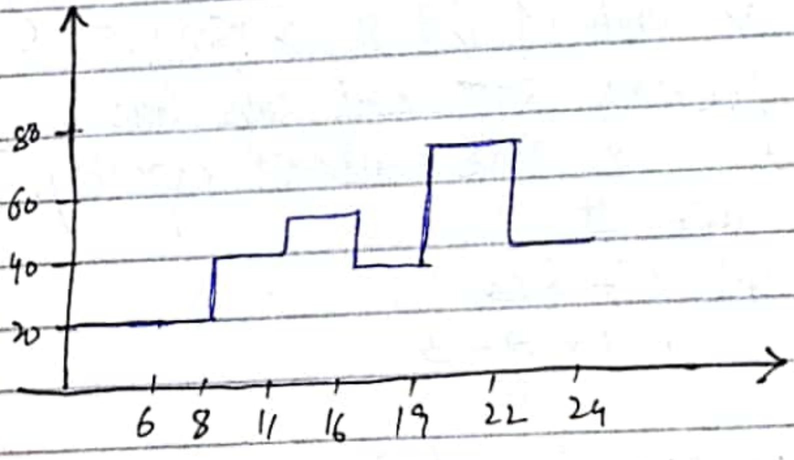
3. The capacity of unit should carry 15 to 20 percent reserve capacity or for future growth.

4. There should be a spare generating unit.

5. The tendency ~~of~~ to select more smaller units to fit the load curve perfectly should be avoided b/c in this way the cost will increase.

Ex 3.18

	6-8	8-11	11-16	16-19	19-22	22-24	24-6
KW	20	40	50	35	70	40	20



$\downarrow F_{LD} =$

3.11 Base load and Peak load on Power station

3.12 Method of meeting the load.

low efficiency → peak

high " → base

Efficiency of steam power plant is 29 to 30%. whereas for hydropower it is about 90%.

3.13 Interconnected Grid system

In Pakistan we have interconnected grid system has many advantages.

1- Exchange of peak loads.
2- Use of older plants.
3- Ensures economical operation.
4. Increases diversity factor.
5- Reduces plant reserve capacity.

Chapter 2

Generating Stations

A generating station / power plant is basically a combination of a prime mover and alternator.

Prime mover converts raw form of energy into mechanical energy.

Depending upon the form of energy converted into electrical energy, we have;
(i) Steam power stations
(ii) Hydroelectric power stations.
(iii) Diesel.
(iv) Nuclear

2.2 Steam Power Station (Thermal)

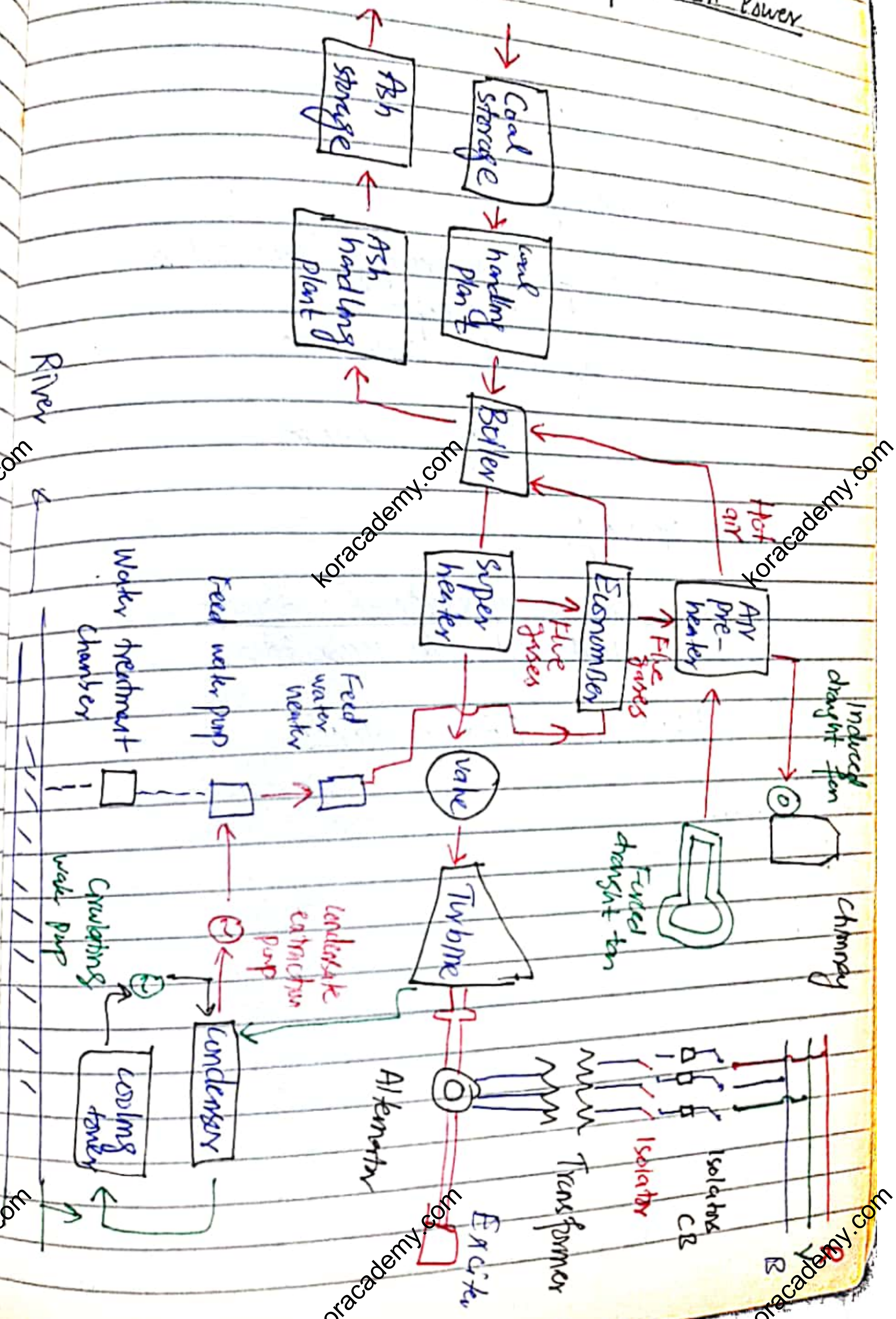
Advantages

i. Coal is quite cheap.
ii. Less initial cost comparatively.
iii. Can be installed anywhere irrespective of existence of coal.
iv. Requires less space as compared to hydroelectric
v. Cost of generation is less than diesel.

Disadvantages.

1. Pollutes the atmosphere.
ii. It is costlier in running cost as compared to hydroelectric plant.

2.3 Schematic Arrangement of Steam Power Station.



2.4 Choice of site

↓

2.6 ↓

2.5 Efficiency

Thermal efficiency;

$$\eta_{Th} = \frac{\text{Heat eq of mech energy transmitted to the shaft}}{\text{Heat of coal combustion.}}$$

$\simeq$ 30% maximum.

Overall efficiency;

$$\eta_{overall} = \frac{\text{Heat eq of electrical output}}{\text{Heat of coal combustion}}$$

1 kW hr = 860 K Calories

Ex 2.1 ……

↓ - - - .

Ex 2.5

Lecture 4

12/03/20

2.7 Hydroelectric Power Station

$PE = mgh$ $K.E = \frac{1}{2}mv^2$

Normally located in hilly areas.

- → sustainability
- → large cathment area
- → Natural resources.
- → Greater storage capacity.

water head. 'h'.

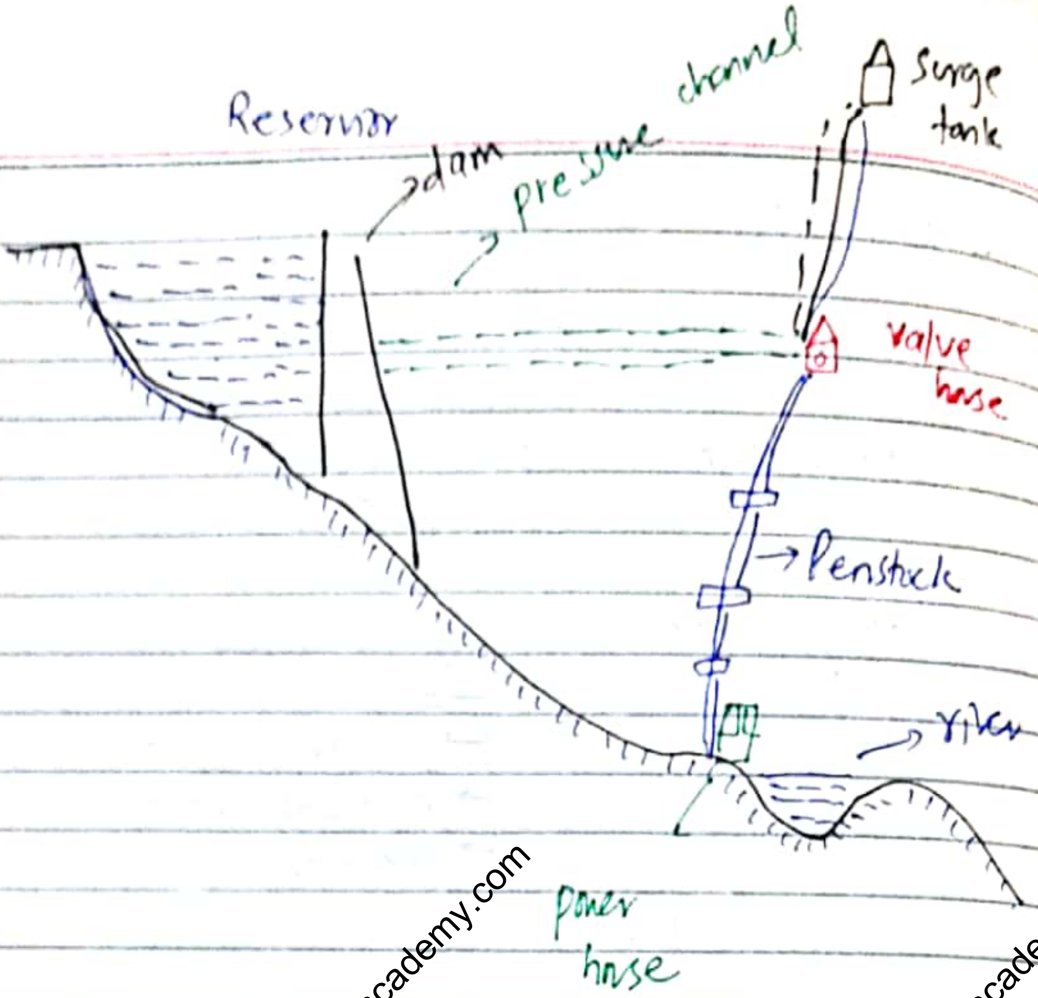
Advantages

- → no fuel.
- → environmental friendly → neat and clean.
- → minimum running charges.
- → simple construction and low maintanance.
- → No/Low starting time.
- → Multipurpose
- → simple operation.

Disadvantage

- → High capital cost due to construction of dams.
- → uncertainty of availability of water.

2.8 Schematic Arrangement



Main sluice valves → controls the flow of water to the power house.

Automatic isolating valve → controls flow from valve house to turbine gate
↓
power house

$N_s = 120 \frac{f}{P}$

→ Synchronous speed of generator.

Power house → turbine gates → Servo motor
Scada ← Governer

→ avoid penstock bursting.

↳ made of steel or concrete.

either open or close.

Steel → high heads   concrete → lower heads.

Surge tank is open at the top.
↳ controls the pressure at penstock.

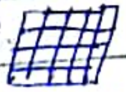
2.9 Choice of site

- Availability of water.
- Storage of water.
- cost and type of land.
- Transpotation facilities.

2.10 Constituents of Hydroelectric Power Plant

1. Hydroelectric structures.
2. Water turbines.
3. Electrical equipment.

1 (i) Dam (ii) Spillways.
(iii) Headworks.



↳ diversion structures at head of intake. booms and racks for diverting floating debris etc.
(iv) Surge tank (v) Penstocks

2 (i) Impulse turbines → used for high heads.
(ii) Reaction turbine
(a) Francis turbine (b) Kaplan
↓
Ghazi barotha
↳ the inclination controls water flow into the runner system.

Water is stored at height ; so

$$PE = mgh = \rho V gh$$

$$\boxed{E = \eta \rho V g h}$$

$$P = \frac{E}{t} = \frac{\eta \rho V g h}{t}$$

$$\boxed{P = \eta \rho Q g h}$$ $Q \to$ discharge of water.

Ex 2.6 $V = 5 \times 10^6 \text{ cm}^3$ $h = 200\text{m}$ $\eta = 0.75$

$E = ?$

$$E = \frac{\eta \rho V g h}{1000 \times 3600} = 2.04 \times 10^6 \text{ KWhr}$$

$\hookrightarrow$ to convert to KW hr.

Ex 2.7 ✗

Ex 2.8 $h = 100\text{m}$ $E = ?$ $(1 \text{ hr}, 1\text{cm}^3)$

$\eta_H = 0.86$ $\eta_e = 0.92$

Overall efficiency, $\eta = \eta_H \times \eta_e = 0.79$

$$P = \frac{\eta \rho Q g h}{1000} = 775 \text{ KW}$$

$$E = P \times t = 775 \text{ KW} \times 1\text{hr} = 775 \text{ KWhr.}$$

Ex 2.9 $P = ?$ $A = 5 \times 10^9 m^2$ $h = 30m$

Annual rainfall, $F = 1.25m$ Yield factor, $K = 0.8$

$\eta = 70\% = 0.7$ $F_{LD} = 0.4$

$$V = A \times ARF \times K$$
$$= 5 \times 10^9 \times 1.25 \times 0.8$$

$$\Rightarrow V = 5 \times 10^9 m^3.$$

$$E = \frac{\eta \rho V g h}{3600000} = 2.86 \times 10^8 KW/hr$$

$$P_{avg} = \frac{E}{t} = \frac{2.86 \times 10^8}{365 \times 24} = 3264.8 KW.$$

↳ annual → b/c in question annual terms are given

$$F_{LD} = \frac{P_{avg}}{P_m} \Rightarrow P_m = \frac{P_{avg}}{F_{LD}} = 81620 KW$$

Assume $pf = 1$

KVA = 81620 KVA

↳ It meets maximum demand and now we take reserve capacity (10–25%)

KVA = 85020 KVA

Ex 2.10 $A = 2.4 \times 10^6 km^2$ $V = 9 \times 10^6 m^3$ $h = 100m$

$\eta = 0.72$

$$E = \frac{\eta \rho V g h}{3600000} = 989175 KW hr$$

(b) load 15000 kW supplied 3 hrs.

$$h = \frac{V}{A} = \frac{5\times10^6}{2.4\times10^6} = 2.083\,m$$

$$E = 15000 \times 3 = 45000\,kW$$

$$989175 \rightarrow 2.083\,m$$

$$1 \rightarrow \frac{2.083}{999175} = 9.47\,cm$$

2.11 $h = 25\,m$ $P_{req} = 400\,kW$ throughout the year.

(a) 4 months $Q_1 = 10\,m^3/s$

(b) 2 m $Q_2 = 6\,m^3/s$

(c) 6 $Q_3 = 1.5\,m^3/s$

$$P_1 = \frac{\eta \rho Q g h}{1000} = 1962$$

$1962 - 400 = 1562\,kW$
↳ surplus.

$P_2 = \eta \rho Q g h = 1172\,kW$

$1172 - 400 = 777.2\,kW$
↳ surplus

$P_3 = 294\,kW$
↳ we require more 106 kW of power

So require a standby capacity of say 150 kW.

with reservoir

$$Q_{avg} = \frac{10(4) + 6(2) + 1.5(6)}{12} = 5.08\ m^3/s$$

Power $P' = \frac{0.5 \times 1000 \times 5.08 \times 9.81 \times 25}{1000}$

$P' = 996$ kW.

Excess power available, $996 - 400 = 596$ kW.

Ex 2-12 $IC = 10$ MW $h = 20$ m $\eta = 0.8$

$F_{LD} = 0.4$ $Q = ?$

As $P = \frac{\cancel{\rho}\,\eta\,Q\,g\,h}{\cancel{1000}}$

$P = 156.96\,Q$ kW $\rightarrow$ ①

$E = F_{LD} \times P_m \times T$

Assume $P_m = IC$ or little less

Assume $T = 1$ week

$E = 0.4 \times 10 \times 10^6 \times 24 \times 7$ $\rightarrow$ ②

$=$

① ⇒ $E = P \times t = 156.96\,Q \times 24 \times 7$ $\rightarrow$ ③

Compare ② and ③

$Q = 25.48\ m^3/s$

(b) If $Q = 20\,m^3/s$ $F_{LD} = ?$

$$F_{LD} = \frac{E}{P_m \times t} \rightarrow Ⓐ$$

Find E from ②
put in Ⓐ and find F_{LD}.

Lecture 5. 04/06/20

Economics of Power Generation.

Power station to meet consumer demands on large scale.

High economy so as to reduce per unit cost.

Cost of production of electricity is highly complex problem.

The art of determining the per unit (ie one kWh) cost of production of electrical energy is known as economics of power generation.

Usage is dependent on per unit rate.

Economical generation to encourage consumers.

Interest.

The cost of use of money is known as interest.

PS requires huge capital.

Generally this amount is borrowed and therefore the supply company has to pay interest on this amount.

While calculating the cost of electricity, the interest payable on the capital cost must be included.

The rate of interest depends upon market position and other factors (3% to 12%.)

Depreciation

The decrease in the value of equipment / building due to constant use is known as depreciation.

PS life is limited. Constant deterioration with use.

Yearly reduction in plant value is annual depreciation. Therefore plant has to be replaced by a new one after its useful life.

While determining cost of electricity interest and depreciation is kept in mind.

Cost of Electrical Energy

The total cost of electrical energy generated can be divided into three parts, namely;

Fixed cost.
Semi fixed cost.
Running or operating cost.

i. **Fixed cost**

Cost that does not depend on maximum demand and energy units.

It includes;
- Annual cost of central organization.
- interest on capital cost, and
- Salaries of high officials.

ii. **Semi fixed cost.**

Cost that depends on maximum demand and is independent of energy units.

It includes;

- Annual interest and depriciation on capital cost of building / equipment, taxes and
- Salaries of management and clerical staff

iii. Running cost

Cost that only depends on energy units.

It includes;

- Annual cost of fuel, lubricating oil.
- Maintanace, repairs, cost and
- salaries of operating staff.

Expressions for cost of electrical energy.

Three part form; in this method, the overall cost of EE is divided into three parts viz fixed cost, semifixed cost and running cost i.e

Total annual cost of energy = Fixed cost + Semifixed cost + Running cost.

= Constant + Proportional to maximum demand + proportion to

Two part form, Annual cost of energy is divided into two parts viz, fixed cost per kW of MD plus a running charge per kWh.

Total annual cost of energy = Rs (A KW + B KWhr)

Methods of Determining Depreciation.

The following three methods.

i. Straight line method.

ii. Diminishing value method

iii.

i.

A constant depreciation charge is made every year on the basis of total depreciation and the useful life of property.

Suppose initial cost is Rs 100000 and its scrap value is 10000 after 20 years. Then

$$\text{Annual depreciation charge} = \frac{\text{total depreciation}}{\text{useful life}}$$

$$= (100000 - 10000)/_{20} = 4500$$

$$\text{Annual } D/A = (P-S)/_{n}$$

Uniform depreciation from initial cost to the scrap value. However this method suffers two defects;

- Firstly, the assumption of constant depreciation charge every year is not correct
- Secondly it does not account for the interest which must be drawn during accumulation.

Deminishing value method

In this method depreciation charge is made every year at a fixed rate on the diminished value of equipment.

Say initial cost is Rs 10,000 and scrap value is zero.

If annual rate of depreciation is 10%, then the depreciation charge for the first year will be

$0.1 \times 10,000 =$