IES/GATE

Electrical Engineering

VOLUME-VIII

Power System-I

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POWER SYSTEM

1) Transmission
Basics
voltage / Reactive power control
TL parameters
TL perfomance
Travelling waves
Corona
Cables
Insulators
Distribution

II) Economic Factors
Economic load dispatch
power generation methods
load frequency control

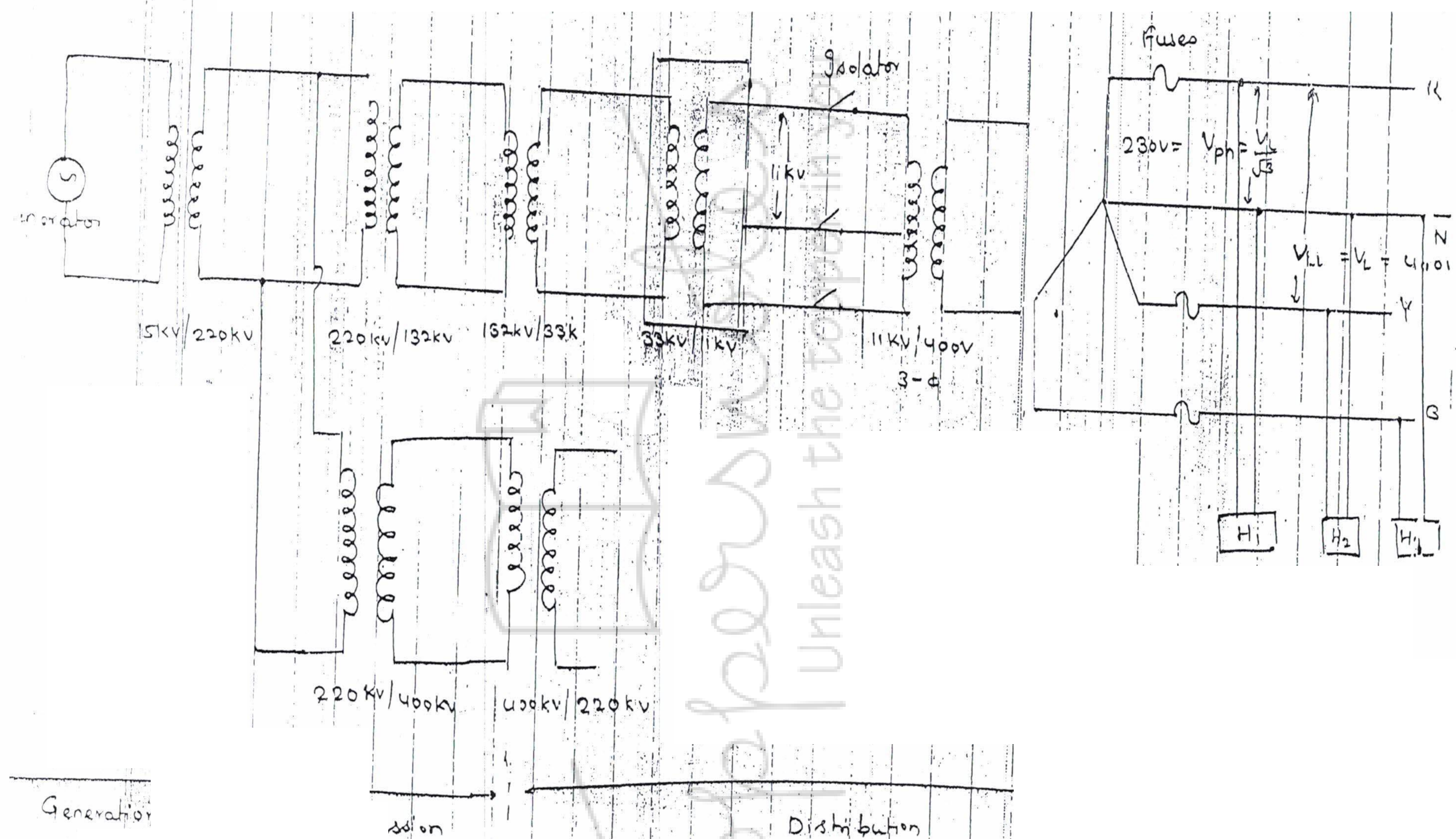
III) Fault analysis

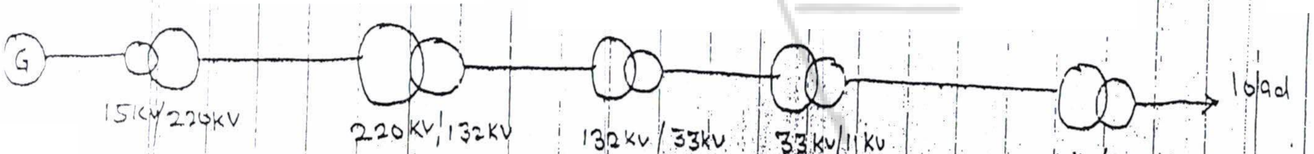
IV) Stability

V) Switch Gear and protection

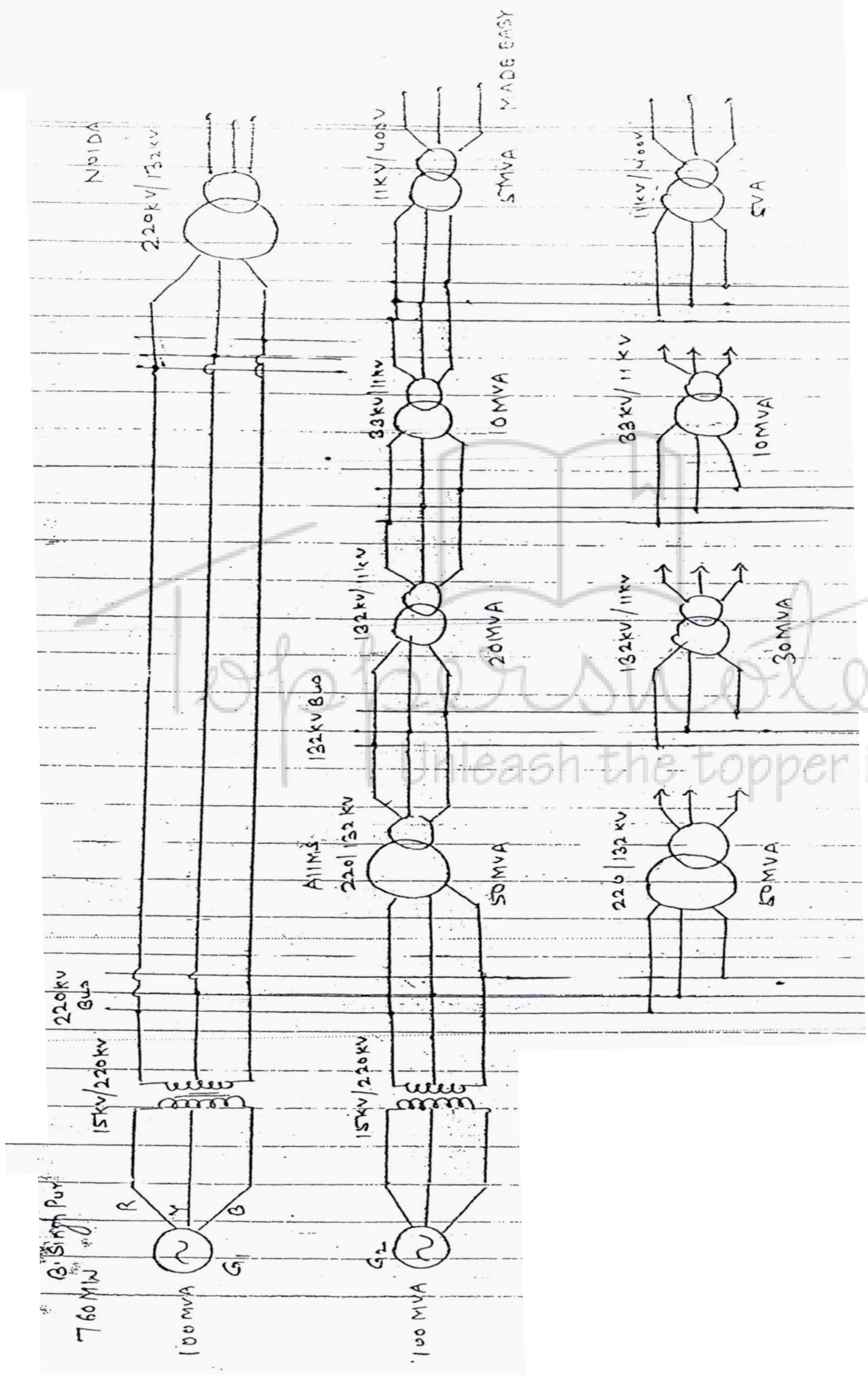
VI) HVDC

Text books
1) CL Wadhwa
2) Nagrath & kothari
3) Stevenson





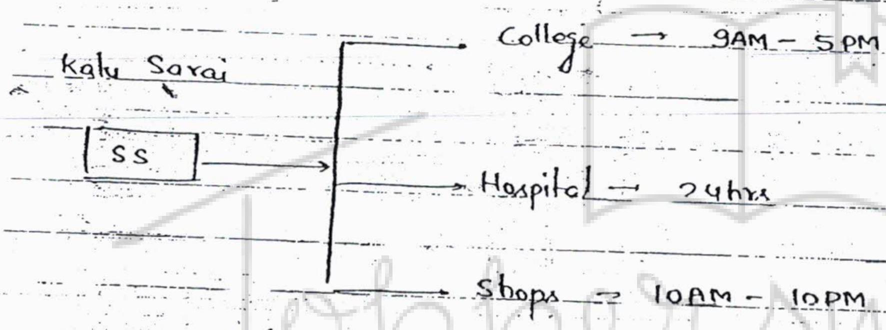
Single line diagram

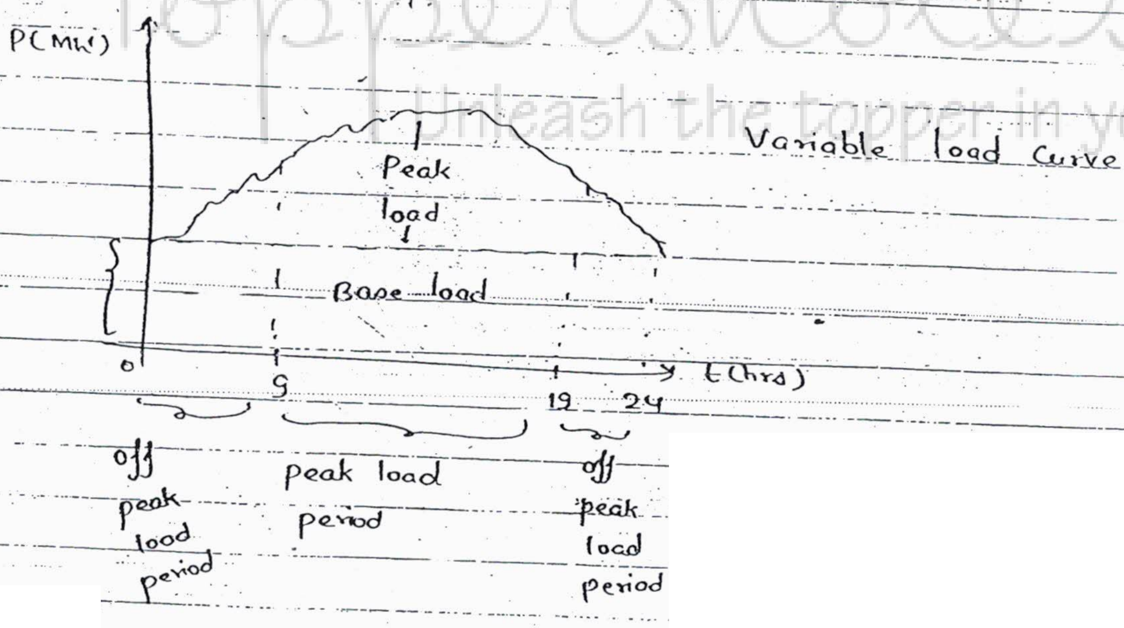

NOIDA
220kV/132kV
11kV/400V
5MVA
MADE EASY
33kV/11kV
10MVA
132kV/11kV
20MVA
30MVA
132kV Bus
AIIMS
220/132 kV
50MVA
220kV Bus
15kV/220kV
R
Y
B
G1
G2
760 MW
100 MVA

Bus bar is a common potential point

Objectives of Power System →

- The cost of electrical energy per kWhr (1 unit) must be minimum.
- Economic factors
- Economic load dispatch
- Power generation method





Base load Generating stations →
1) Thermal
2) Nuclear
3) Hydro
4) Run of river
5) Solar
6) Wind

Peak load Generating stations →
1) Pumped storage plant
2) Hydro
3) Gas
4) Diesel

Advantages of peak load generating station →
Operating time from no load to peak load is very less. (5 - 10 minutes)

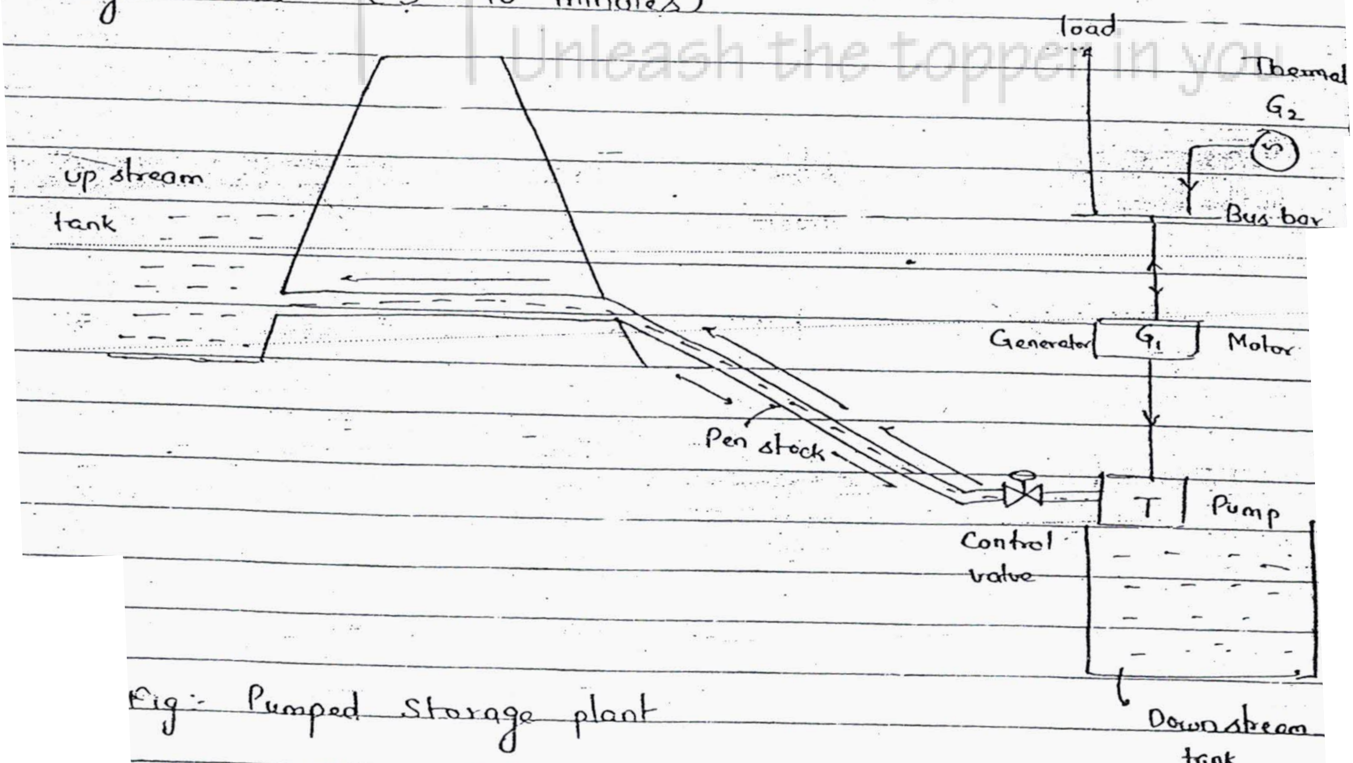
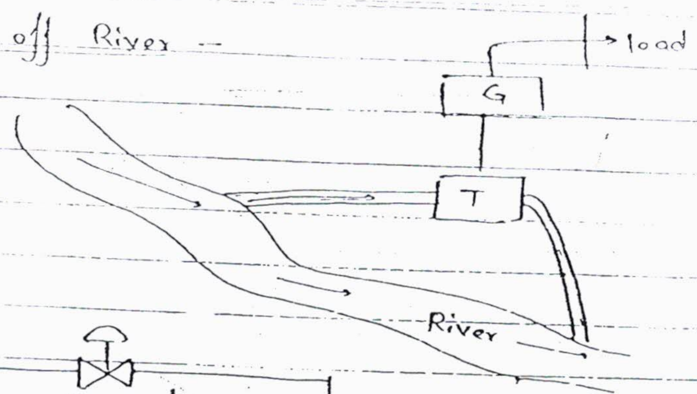
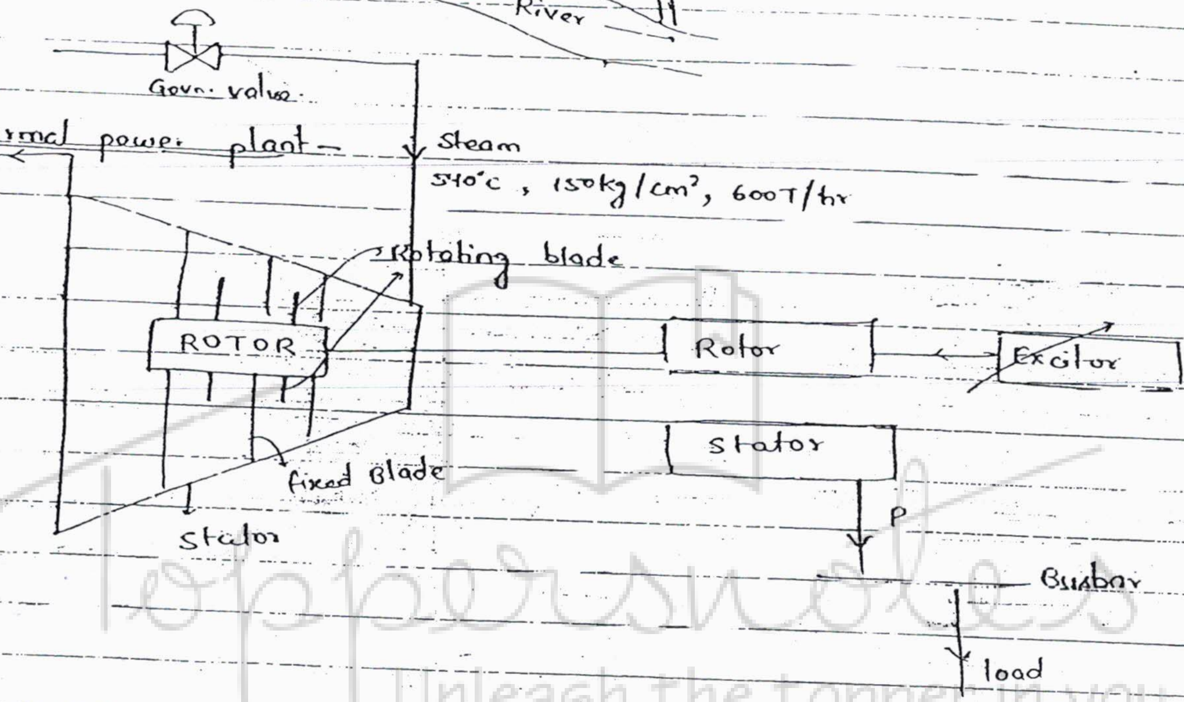


Fig:- Pumped Storage plant

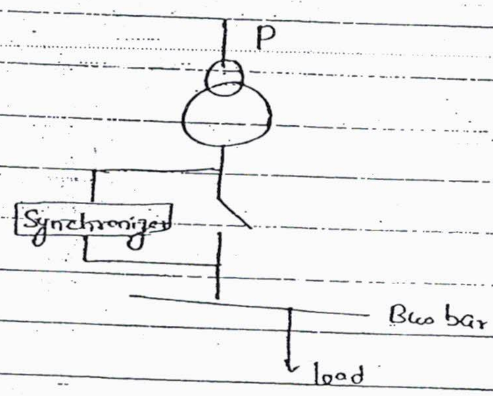
Run off River -





Thermal power plant -

Turbine metal temperature is the main problem in the thermal and nuclear power plant and it must increase slowly for the safe operation of the turbine.



Toppersnotes
Unleash the topper in you

Cold Start up → T → turbine metal temperatu

* T < 100°C ⇒ 8 to 10 hrs

Warm Start up →

* 100°C < T < 300°C ⇒ 4 to 6hrs

Hot start up →

* T > 300°C ⇒ 2 to 3hrs. *

At the generating transformer we must check the following parameters

1) voltage level → the voltage must be equal to the rated voltage if their is any mismatch then we correct it by the help of excitor.

2) Frequency → The frequency mismatch is there then we increase the steam so the speed of turbine will ↑ ⇒ frequency will ↑.

3) Phase sequence.

Due to turbine metal temperature constraint thermal and nuclear plants are used as a base load plants.

Plant load Factor →

$$P_{LF} = \frac{P_{av.}}{P_{max.}}$$

$$= \frac{P_{avg.} \times t}{P_{max} \times t}$$

$$= \frac{\text{Area under load Curve}}{\text{(Rectangular Area corresponding to } P_{max})}$$

Practically $P_{LF} < 1$
Ideally $P_{LF} = 1$

Plant Capacity Factor (P_{CF})

$$P_{CF} = \frac{P_{avg}}{P_c}$$

$P_c \rightarrow$ Plant capacity

$$P_{CF} = \frac{\text{Avg. Energy in Total hours}}{\text{Energy able to produce in total hrs as per } P_c}$$

$\boxed{P_{CF} < 1}$

Plant Usage factor → (P_{UF})

$$P_{UF} = \frac{\text{Avg. Energy in used hours}}{\text{(Energy able to produce in used hours as per } P_c)}$$

$\boxed{P_{UF} < 1}$

Utilization Factor (U_f) →

$$U_f = \frac{P_{max}}{P_c} \qquad \boxed{U_f \le 1}$$

Reverse capacity factor → (R_c)

$$R_c = P_c - P_{max}$$

$$= P_{max}\left[\frac{P_c}{P_{max}} - 1\right]$$

$$= P_{max}\left[\frac{P_{avg}}{P_{max} \cdot P_{cf}} - 1\right]$$

$$\boxed{R_c = P_{max}\left(\frac{P_{lf}}{P_{cf}} - 1\right)}$$

Demand Factor → (D_f)

$$D_f = \left(\frac{\text{Sum of Connected load}}{P_{max}}\right)^{-1} = \frac{P_{max}}{\text{Sum of Connected load}}$$

$$\boxed{D_f < 1}$$

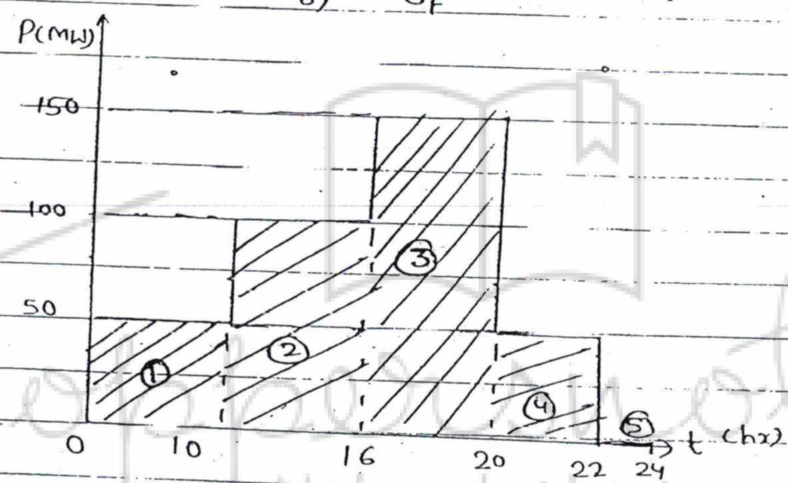
Diversity Factor → (Div_f)

$$(Div)_f = \frac{\text{Sum of Individual max demand}}{P_{max}}$$

$$\boxed{Div_f > 1}$$

Q. A power generating station has a plant capacity of 200 MW. The power delivered by the station to the consumer is given by the load curve. Calculate

1) P_{max}
2) P_c
3) P_{avg}.
4) P_{Lf}
5) P_{cf}
6) P_{uf}
7) Reserve capacity.
8) U_f



Sol^n ① $P_{max} = 150 \text{ MW}$

② $P_c = 200 \text{ MW}$

③ $P_{avg} = \dfrac{50 \times 10 + 100 \times 6 + 150 \times 4 + 50 \times 2 + 0 \times 2}{24}$

$= 75 \text{ MW}$

④ $P_{Lf} = \dfrac{P_{avg}}{P_{max}} = \dfrac{75}{150} = 0.5 < 1$

or $P_{Lf} = \dfrac{P_{avg} \times 24}{P_{max} \times 24} = \dfrac{1800}{150 \times 24} = 0.5$

(5) $P_{cf} = \frac{P_{avg}}{P_c} = \frac{75}{200} = 0.375 < 1$

Or

$P_{cf} = \frac{1800}{200 \times 24} = 0.375$

↳ Total hours

(6) $P_{uf} = \frac{1800}{200 \times 22} = 0.409 < 1$

↳ used hours

(7) $R_c = P_c - P_{max} = 200 - 150 = 50\ MW$

Or

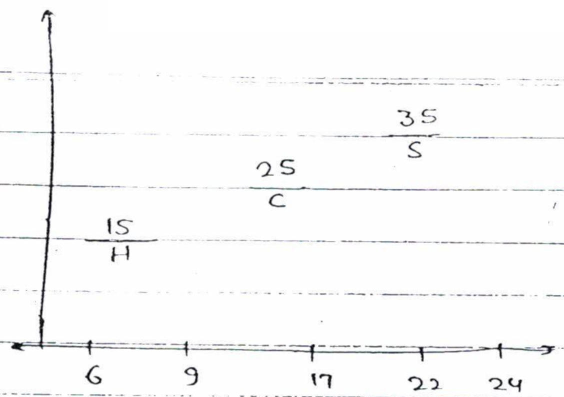
$R_c = P_{max}\left[\frac{P_{LF}}{P_{CF}} - 1\right]$

$= 150\left[\frac{0.5}{0.375} - 1\right] = 50\ MW$

(8) $U_f = \frac{P_{max}}{P_c} = \frac{150}{200} = 0.75 < 1$

SS →

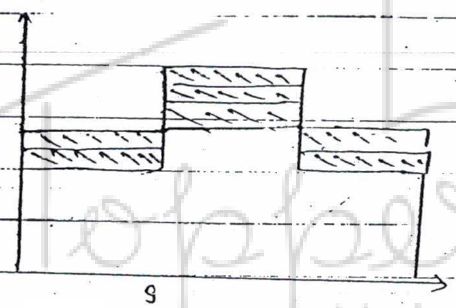
		Connected load	Individual max. demand
Hospitals (H)	→ 24 hrs	20	15
Colleges (C)	→ 9 to 5pm	30	25
Shops (S)	→ 10 to 10pm	40	35
		$\Sigma = 90\ kW$	$\Sigma = 75\ kW$

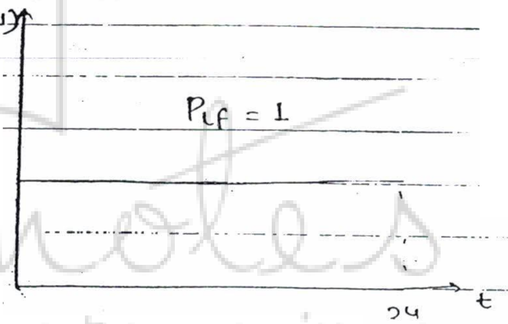


let $P_{max} = 60 kW$

$D_f = \frac{60}{90} < 1$ (Demand factor)

$Div_f = \frac{75}{60} > 1$ (Diversity factor)





$P_{Lf}\uparrow = \frac{P_{avg.}}{P_{max}\downarrow}$ $(Div)_f \uparrow = \frac{\Sigma \text{ Individual max. demand}}{\downarrow P_{max}}$

Methods to improving high P_{Lf} and Diversity factor →

$P_{Lf} \geq 1$ and $(Div)_f > 1$ is always preferred so that the max. demand is reduced and hence the initial investment on equipments like generators, transformers, TL is minimized which reduces the overall cost of electrical energy.

① By providing subsidy to the industries to running their equipments during off peak load period.

$$Q_R = \left|\frac{V_S \cdot V_R}{B}\right| \sin(\beta - \delta) - \left|\frac{A V_R^2}{B}\right| \sin(\beta - \alpha) \quad * \quad — (5)$$

Sending end power

$$I_S = C V_R + D I_R$$

substitute (1) in (6)

$$I_S = C V_R + D\left(\frac{V_S}{B} - \frac{A V_R}{B}\right)$$

$$= \frac{D V_S}{B} + \left(\frac{BC - AD}{B}\right) V_R$$

$$I_S = \frac{|D|\angle\alpha \; |V_S|\angle\delta}{|B|\angle\beta} - \frac{|V_R|\angle 0}{|B|\angle\beta}$$

$$I_S = \left|\frac{D V_S}{B}\right| \angle\alpha + \delta - \beta - \left|\frac{V_R}{B}\right| \angle -\beta$$

$$I_S^* = \left|\frac{D V_S}{B}\right| \angle\beta - \alpha - \delta - \left|\frac{V_R}{B}\right| \angle\beta \quad — (7)$$

$$S_S = P_S + j Q_S = V_S I_S^* = |V_S| \angle\delta \; I_S^* \quad — (8)$$

Substitute (7) in (8) and seperate real and Img terms

***

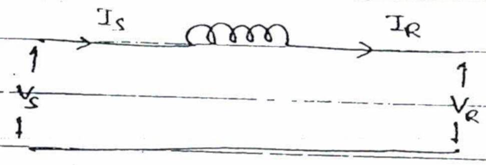
$$P_S = \left|\frac{D V_S^2}{B}\right| \cos(\beta - \alpha) - \left|\frac{V_S \cdot V_R}{B}\right| \cos(\beta + \delta) \quad — (9)$$

$$Q_S = \left|\frac{D V_S^2}{B}\right| \sin(\beta - \alpha) - \left|\frac{V_S \cdot V_R}{B}\right| \sin(\beta + \delta) \quad — (10)$$

* Equations (4), (5), (9) & (10) are applicable to short, medium and long transmission lines.

Short transmission line –

Assume $R << X_l$



$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} 1 & jX_L \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

$$\left.\begin{aligned} |A|\angle\alpha &= |D|\angle\alpha = 1\angle 0^\circ \\ |B|\angle\beta &= X_l \angle 90^\circ \\ C &= 0 \end{aligned}\right\} \text{—— (11)}$$

substitute (11) in (4), (5), (9) & (10)

$$P_R = \left|\frac{V_S \cdot V_R}{B}\right| \cos(\beta-\delta) - \left|\frac{AV_R^2}{B}\right| \cos(\beta-\alpha)$$

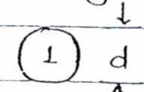
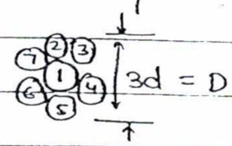
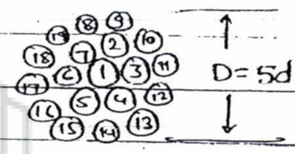
$$= \left|\frac{V_S \cdot V_R}{X_l}\right| \cos(90^\circ-\delta) \quad \left|\frac{1 \times V_R^2}{X_l}\right| \cos(90^\circ-0^\circ)$$

$$\boxed{P_R = \left|\frac{V_S \cdot V_R}{X_l}\right| \sin\delta - P_S}$$

$$\boxed{Q_R = \left|\frac{V_S \cdot V_R}{X_l}\right| \cos\delta - \left|\frac{V_R^2}{X_l}\right|}$$

valid for short TL having only X_l.

$$\boxed{Q_S = \left|\frac{V_S^2}{X_l}\right| \quad \left|\frac{V_S \cdot V_R}{X_l}\right| \cos\delta}$$

x	N	D	Arrangement
1	1	d	
2	7	3d	
3	19	5d	

Classification of Transmission lines –

1) Short Transmission line $l < 80\,km$ $lf = 4000$
2) Medium Transmission line $80 \le l \le 200km$ $4000 \le lf \le 10{,}000$
3) long Transmission line $l > 200km$ $lf > 10{,}000$

e.g; $l = 80km$, $f = 50\,Hz$

$lf = 80 \times 50 = 4000$

Q. A 20 km transmission line is excited by the following frequency

a) 50 Hz

b) 5 KHz

c) 300 KHz

Find the type of line ?

Sol^n a) $Lf = 20 \times 50 = 1000$ (short T.L)

b) $Lf = 5 \times 10^3 \times 20 = 100000$ (long TL)

c) $Lf = 20 \times 300 = 6000$ (Medium TL)