IES/GATE

Electrical Engineering

VOLUME-VII

Power System-I

Contents

POWER SYSTEM

i) Transmission
- Basics
- voltage / Reactive power control
- TL parameters
- TL performance
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- Corona
- Cables
- Insulators
- Distribution

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

III) Fault analysis

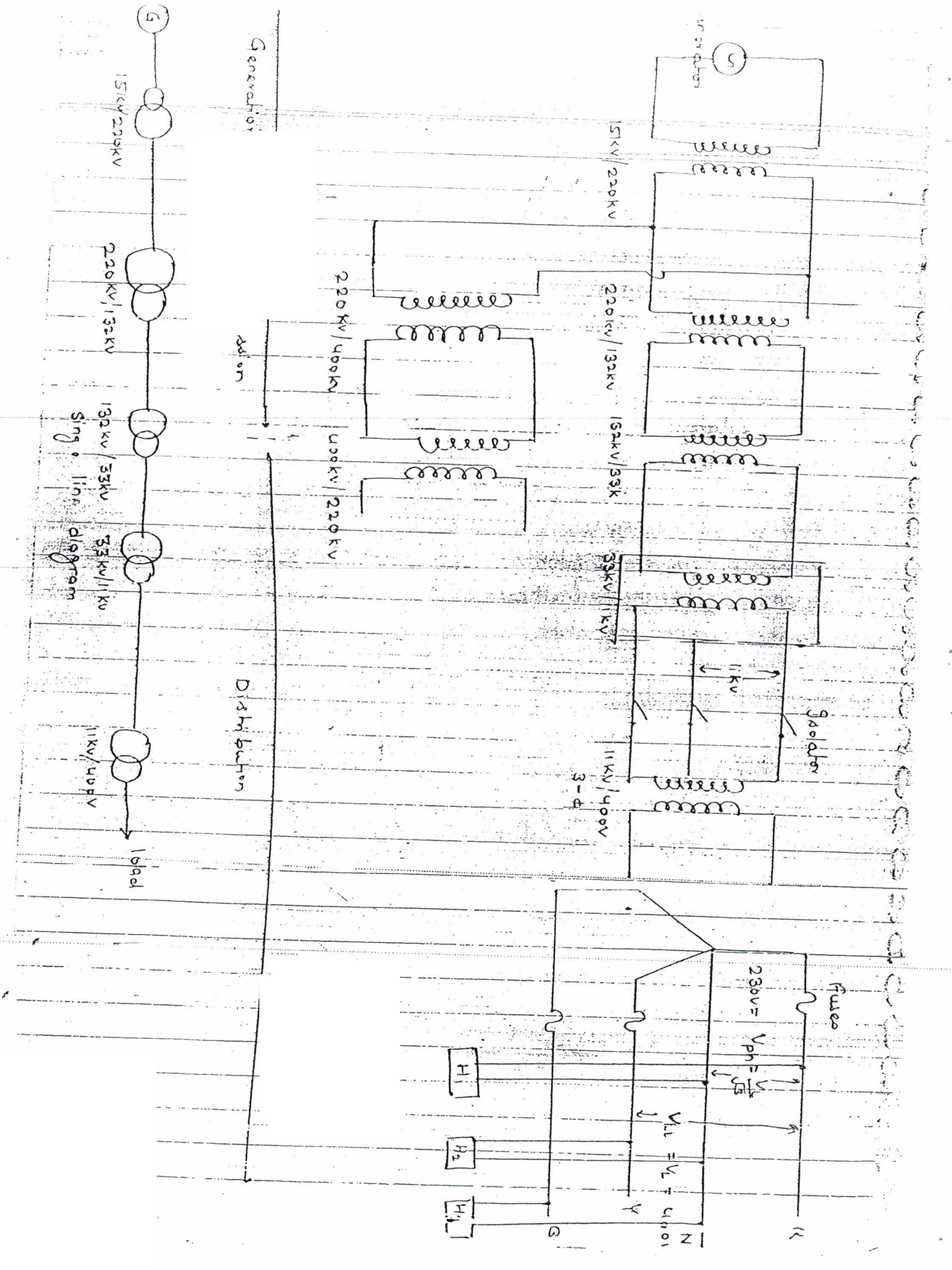
IV) Stability

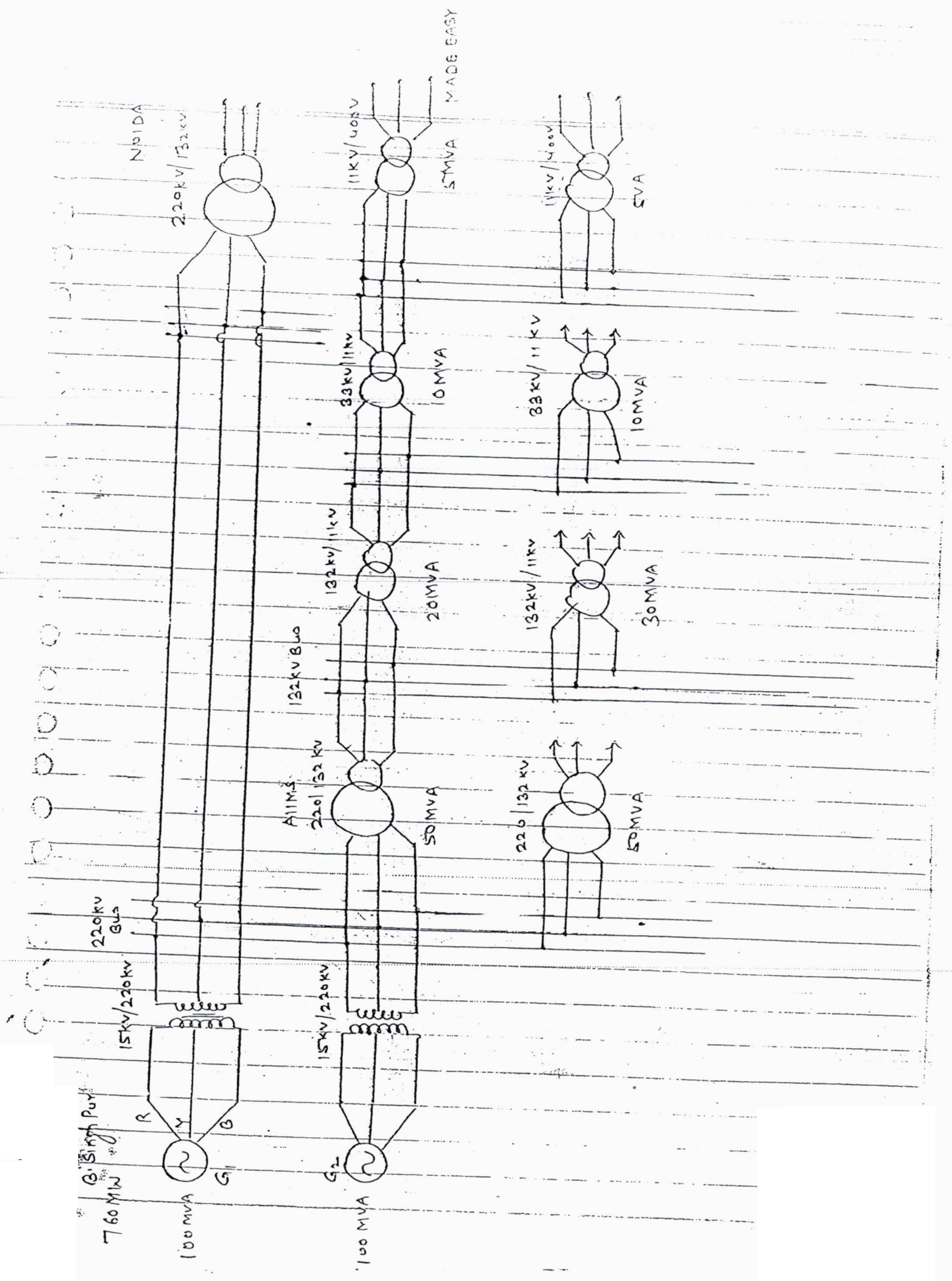
V) Switch Gear and protection

VI) HVDC

Text books

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

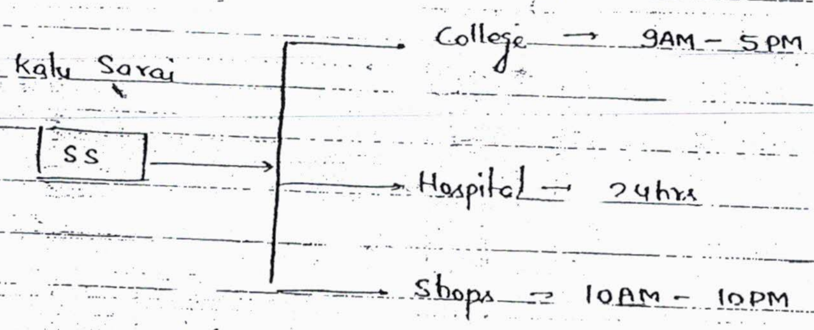

Generation
Distribution
15kV/220kV
220kV/132kV
132kV/33kV
33kV/11kV
11kV/400V
load
Single line diagram
Generator
220kV/400kV
400kV/220kV
132kV/33kV
11kV
Isolator
11kV/400V
3-Φ
Fuses
230V = Vph = VL/√3
VL = VL = 400V
R
Y
B
N
H1
H2
H3

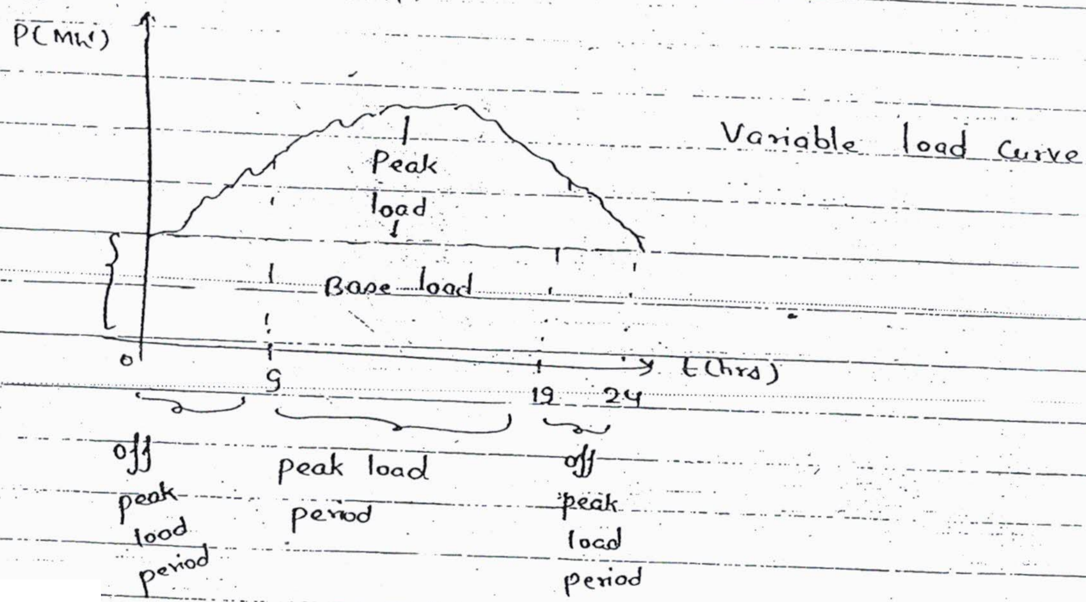

NOIDA
220KV/132KV
11KV/400V
5MVA
MADE EASY
33KV/11KV
10MVA
132KV/11KV
20MVA
30MVA
132KV Bus
AIIMS
220/132 KV
50MVA
220KV Bus
15KV/220KV
R
Y
B
G1
G2
100 MVA
760MW

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)

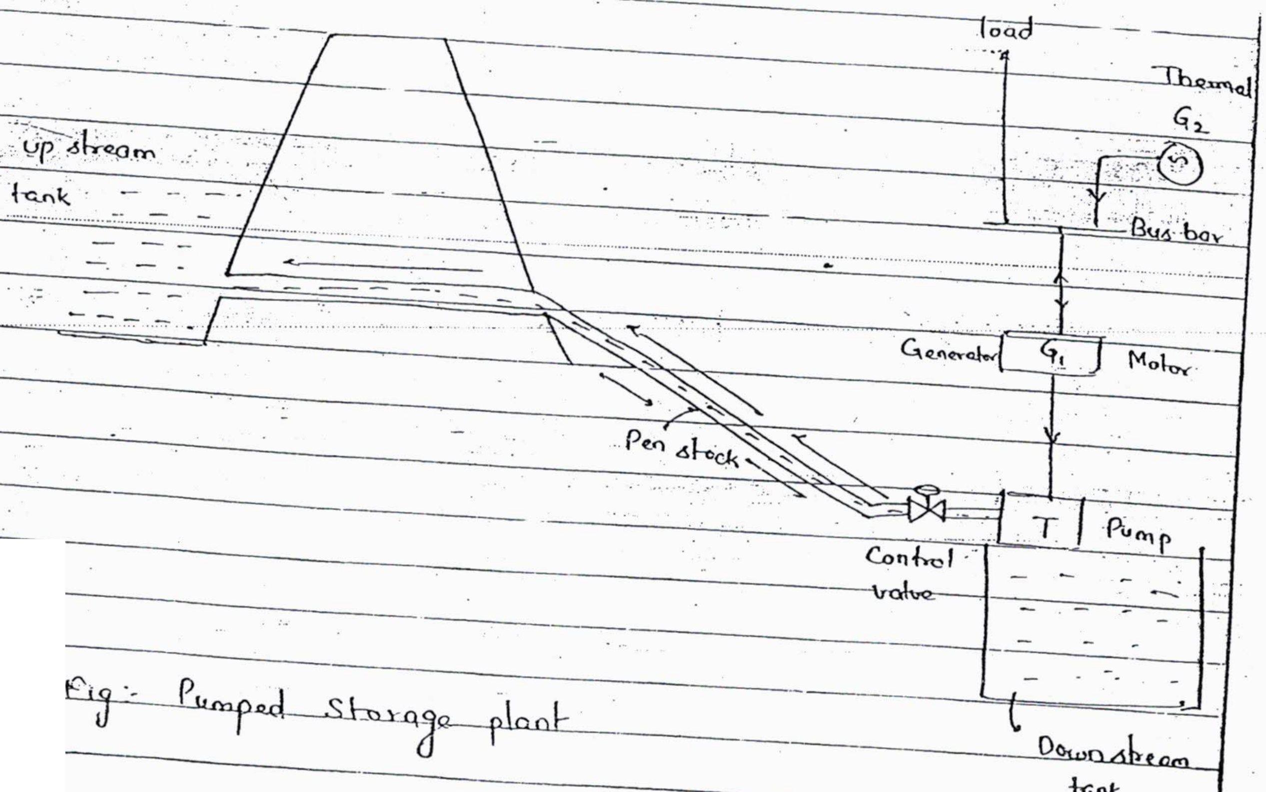
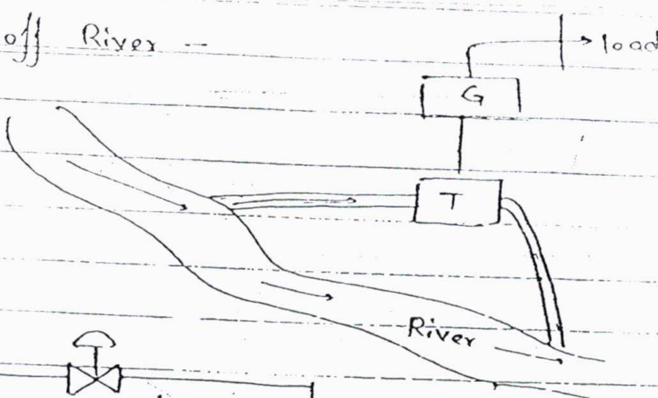
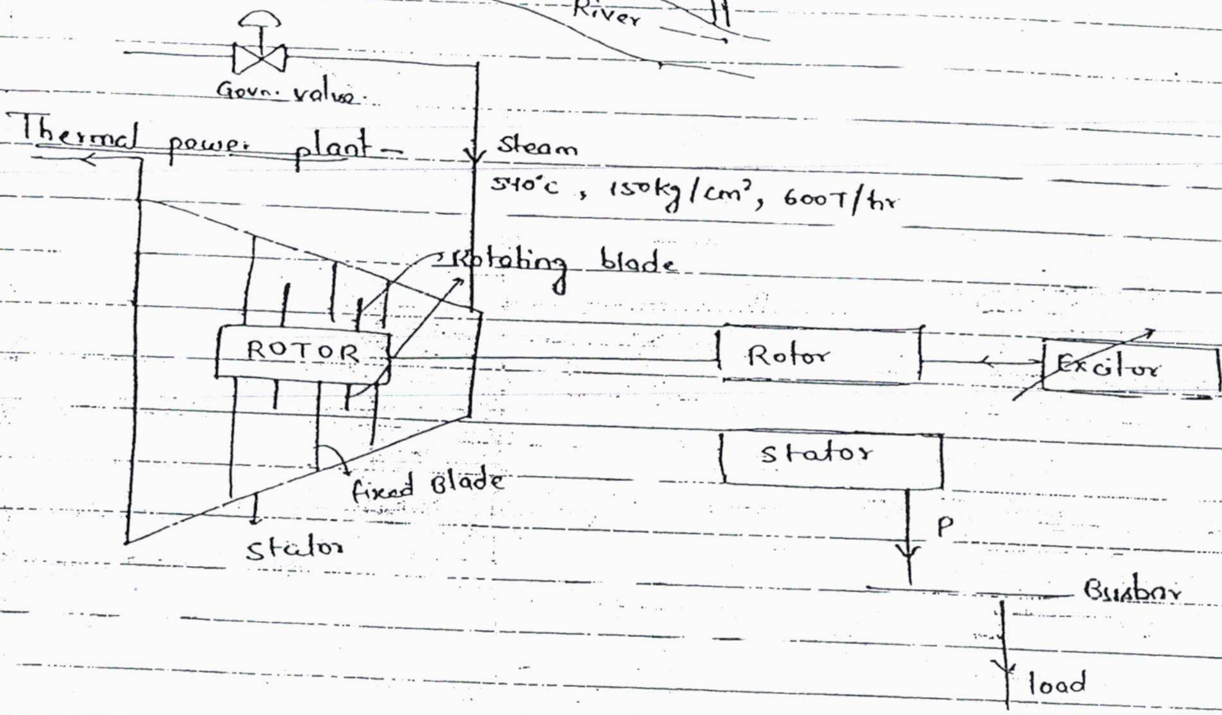


Fig:- Pumped Storage plant

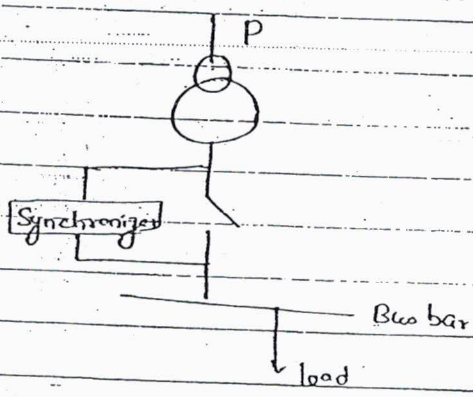
Run off River -



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.



Cold Start up → T → turbine metal temperature
* 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 → 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) →

$$U_f = \frac{P_{max}}{P_c}$$

$U_f \le 1$

Reserve capacity factor → (R_c)

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

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

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

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

Demand Factor → (D_f)

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

$D_f < 1$

Diversity Factor → (Div_f)

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

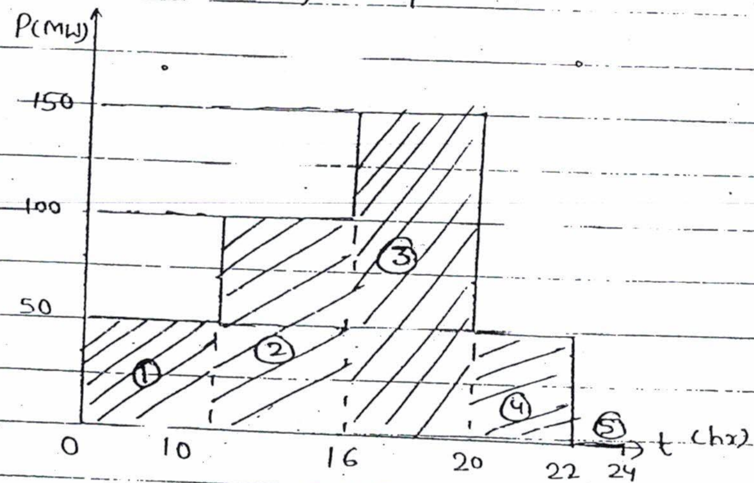
$Div_f > 1$

$P_{avg} \times t$ =

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 $P_{max} = 150\ MW$

② $P_c = 200\ MW$

③ $P_{avg} = \dfrac{50\times10 + 100\times6 + 150\times4 + 50\times2 + 0\times2}{24}$

$= 75\ MW$

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

or $P_{Lf} = \dfrac{P_{avg}\times24}{P_{max}\times24} = \dfrac{1800}{150\times24} = 0.5$

(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

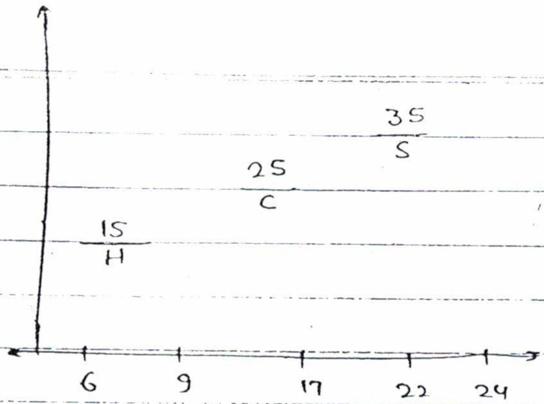
$R_c = P_{max}\left[\frac{P_{Lf}}{P_{cf}} - 1\right]$

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

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

SS →

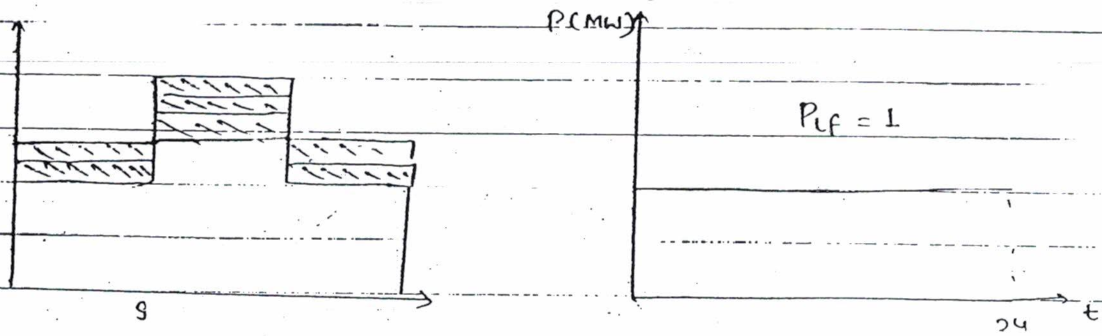
	Connected load	Individual max. demand
Hospitals (H) → 24 hrs	20	15
Colleges (C) → 9 to 5pm	30	25
Shops (S) → 10 to 10pm	40	35
	$\Sigma = 90$ kW	$\Sigma = 75$ kW



let $P_{max} = 60KW$

$D_f = \frac{60}{90} < 1$ (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.

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

Sending end power

$$I_S = CV_R + DI_R$$

substitute (1) in (6)

$$I_S = CV_R + D\left(\frac{V_S}{B} - \frac{AV_R}{B}\right)$$

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

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

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

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

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

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

***

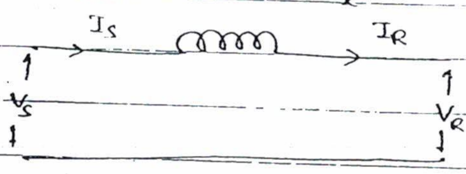
$$\boxed{P_S = \left|\frac{DV_S^2}{B}\right| \cos(\beta - \alpha) - \left|\frac{V_S \cdot V_R}{B}\right| \cos(\beta + \delta)} \quad —— (9)$$

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

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

Short transmission line →

Assume $R << X_l$



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

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

substitute ⑪ in ④, ⑤, ⑨ & ⑩

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

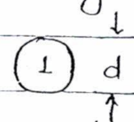
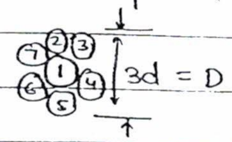
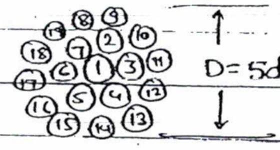
$$= \left|\frac{V_S \cdot V_R}{X_l}\right| \cos(90^\circ-\delta) - \left|\frac{1 \times V_R^2}{X_l}\right| \cos(90^\circ-0^\circ)$$

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

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

valid for short TL having only X_l.

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

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 $80 \le l \le 200\,km$ $4000 \le lf \le 10{,}000$
3) long Transmission line $l > 200\,km$ $lf > 10{,}000$

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

$lf = 80 \times 50 = 4000$

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 ?

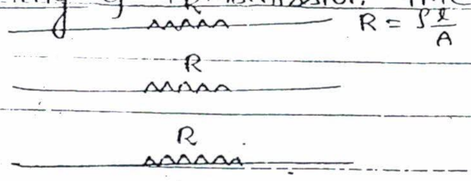
Sol^n a) $Lf = 20 \times 50 = 1000$ (short T.L)

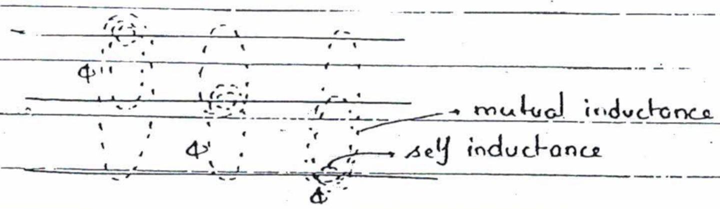
b) $Lf = 5 \times 10^3 \times 20 = 100000$ (long TL)

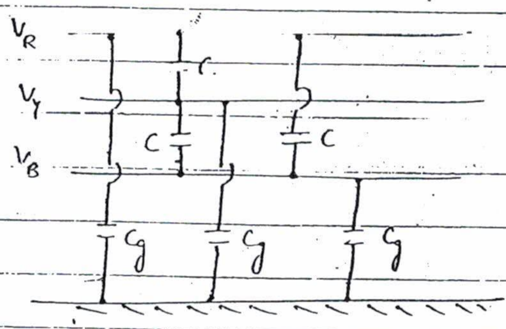
c) $Lf = 20 \times 300 = 6000$ (Medium TL)

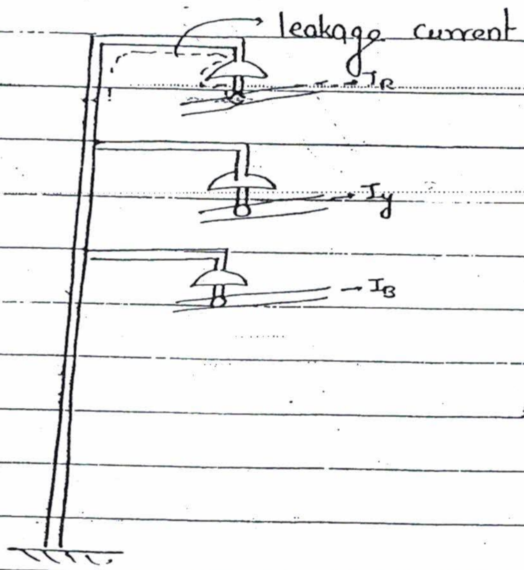
Communication lines are excited with MHz frequency and hence these are considered as a long transmission line always.

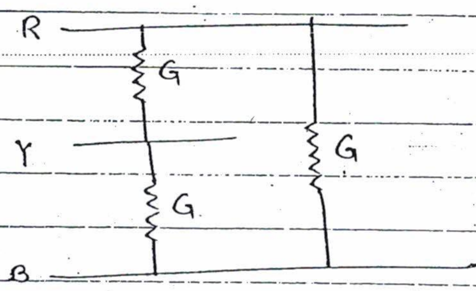
Modelling of Transmission line →











G → Conductance