G015 + G037 + G038 + G039
12238

VOLTAGE

CURRENT

7.5Ω

...RY ($R_s + R_b$)

+ 1.6) = 182V

= 10

LOAD FOR SVC

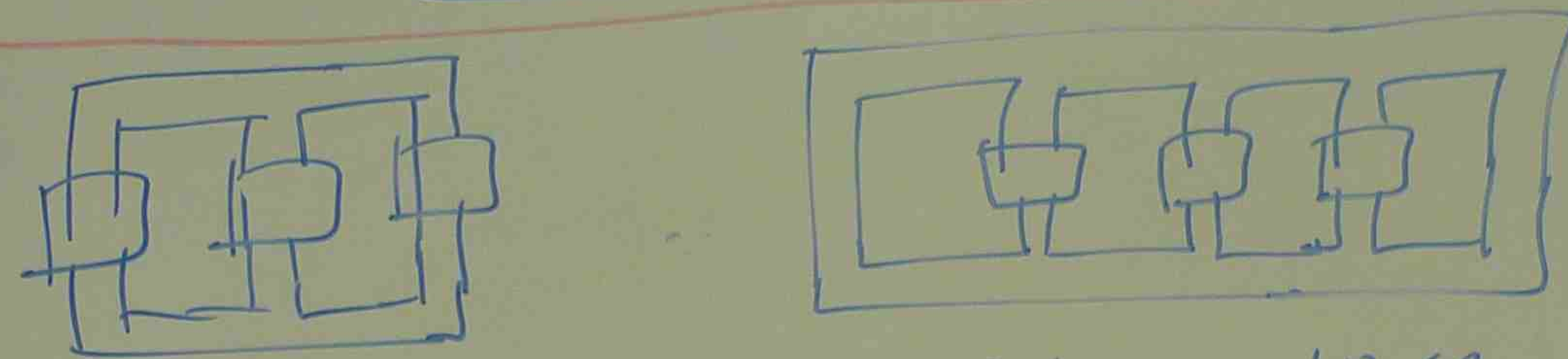
G039

HARMONIC → HIGHER FREQUENCY → REDUCE DIELECTRIC STRENGTH OF INSULATION

→ HARMONIC VOLTAGE

OVER VOLTAGE

I



3 LIMBS → HIGHER HARMONIC

5 LIMBS → LOWER HARMONIC

II INCREASE NEUTRAL CONDUCTOR SIZE.

$$E_t = \sqrt{E_f^2 + E_H^2}$$

E_F = FUNDAMENTAL VOLTAGE

E_H = HARMONIC VOLTAGE

E_t = TOTAL VOLTAGE EFFECTED BY HARMONIC.

$$\text{THD (TOTAL HARMONIC DISTORTION)} = \frac{f_H}{f_F}$$

f_H: HARMONIC FREQUENCY (Hz)

f_F = FUNDAMENTAL FREQUENCY

Q2 pb 1

THE CURRENT IN A SYSTEM IS 62.5A IN WHICH 59 Amp IS FUNDAMENTAL. CALCULATE TOTAL HARMONIC DISTORTION.

IF THE HARMONIC IS COMBINATION OF 3^{rd}, 5^{th} AND 7^{th} HARMONIC AND 3^{rd} HARMONIC IS 15.6 A, 5^{th} HARMONIC IS 10.3 A, FIND 7^{th} HARMONIC.

$$E_t = \sqrt{E_f^2 + E_H^2}$$

$$E_t^2 = E_f^2 + E_H^2$$

$$E_H = \sqrt{E_t^2 - E_f^2}$$

$$E_H = \sqrt{62.5^2 - 59^2} = 20.6 \text{ Amp}$$

$$THD = \frac{E_H}{E_f} = \frac{20.6}{59} = 0.349 \rightarrow 34.9\%$$

$$E_H^2 = E_{H(3rd)}^2 + E_{H(5th)}^2 + E_{H(7th)}^2$$

$$E_{H(7th)} = \sqrt{E_H^2 - E_{H(3rd)}^2 - E_{H(5th)}^2}$$

$$= \sqrt{20.6^2 - 15.6^2 - 10.3^2} = 8.66 \text{ Amp.}$$

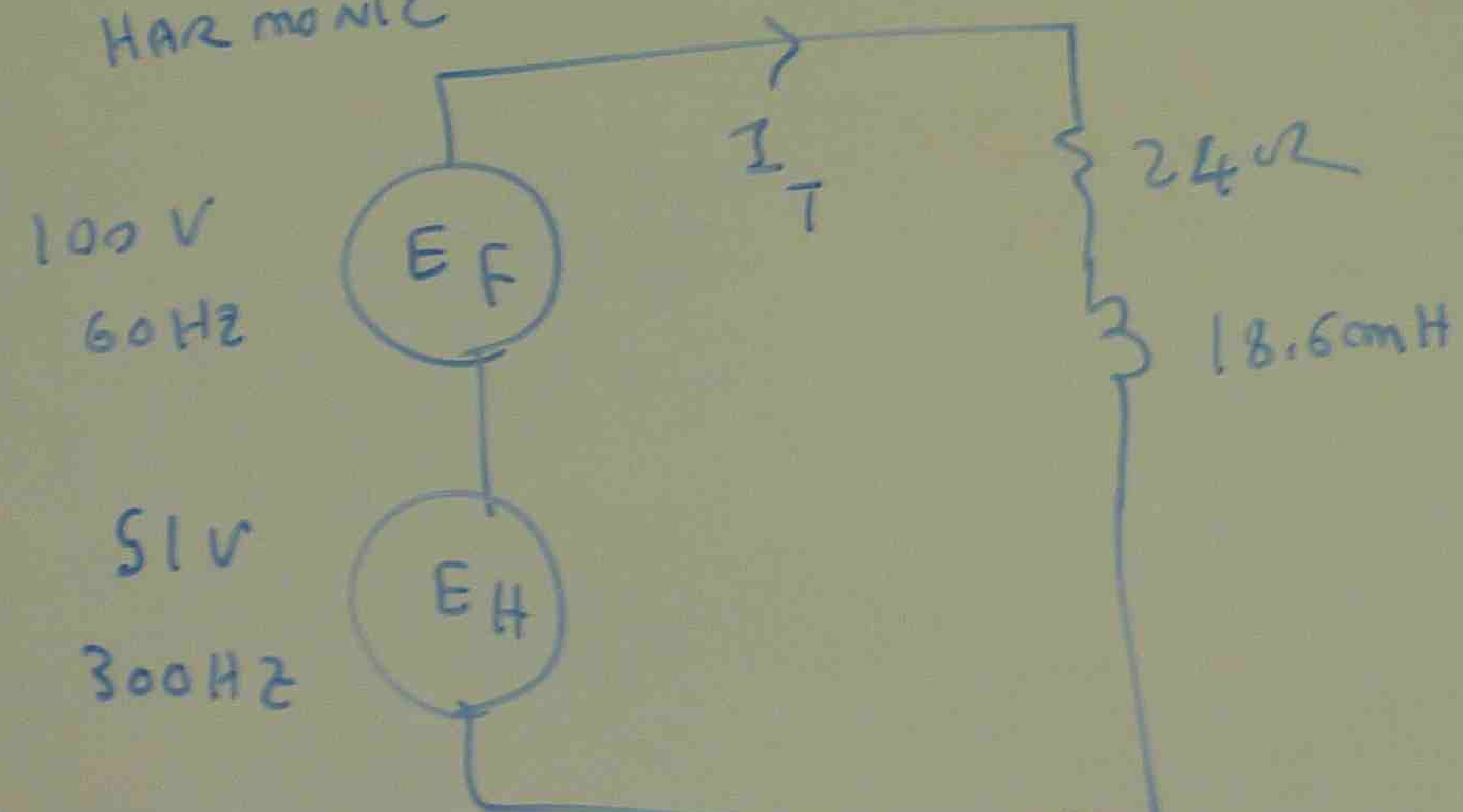
Q1 HOW WILL YOU REDUCE HARMONIC?

Q2 SEE pb 1

Q3

Pb 2

THE GIVEN FIGURE SHOWS A DISTORTED VOLTAGE SOURCE COMPOSED OF A FUNDAMENTAL OF 100V, 60 HZ AND A 5th HARMONIC OF 51V. THE SOURCE IS CONNECTED TO A RESISTOR OF 24 Ω IN SERIES WITH AN INDUCTANCE OF 18.6 mH. CALCULATE (a) TOTAL IMPEDANCE AT FUNDAMENTAL (b) FUNDAMENTAL CURRENT (c) ACTIVE & REACTIVE POWER AT FUNDAMENTAL (d) TOTAL IMPEDANCE AT 5th HARMONIC (e) 5th HARMONIC CURRENT (f) ACTIVE & REACTIVE POWER AT 5th HARMONIC



$X = 2\pi f L$

(a) $X_f = 2 \times 3.1416 \times 60 \times 18.6 \times 10^{-3}$

$= 7\Omega$

$Z_f = \sqrt{R^2 + X_f^2} = \sqrt{24^2 + 7^2} = 25\Omega$

(b) $I_f = \dfrac{E_f}{Z_f} = \dfrac{100}{25} = 4A$

(c) $P_f = I_f^2 \times R = 4^2 \times 24 = 384W$

$Q_f = I_f^2 X = 4^2 \times 7 = 112VAR$

$S_f = \sqrt{384^2 + 112^2}$

$= 400VA$

4.9%

.66 Amp

(d)

Z

(e)

P_s

Q

(f)

GE SOURCE ...
ARMONIC OF 51V.
24 Ω IN SERIES
(a) TOTAL IMPEDANCE
(c) ACTIVE & REACTIVE
CE AT 5^{th} HARMONIC
ACTIVE POWER AT 5^{th}

$2\pi f L$

$= 2 \times 3.1416 \times 60 \times 18.6 \times 10^{-3}$

$= 7\Omega$

$+ X_f^2 = \sqrt{24^2 + 7^2} = 25\Omega$

$S_F = \sqrt{384^2 + 112^2}$

$= 400\,VA$

(d) $X_{5H} = 2\pi f_{5H} L$

$= 2 \times 3.1416 \times 300 \times 18.6 \times 10^{-3} = 35\Omega$

$Z_{5H} = \sqrt{R^2 + X_{5H}^2} = \sqrt{24^2 + 35^2} = 42.4\Omega$

(e) $I_{5H} = \dfrac{E_{5H}}{Z_{5H}} = \dfrac{51}{42.4} = 1.2A$

$P_{5H} = I_{5H}^2 R = 1.2^2 \times 24 = 34.6W$

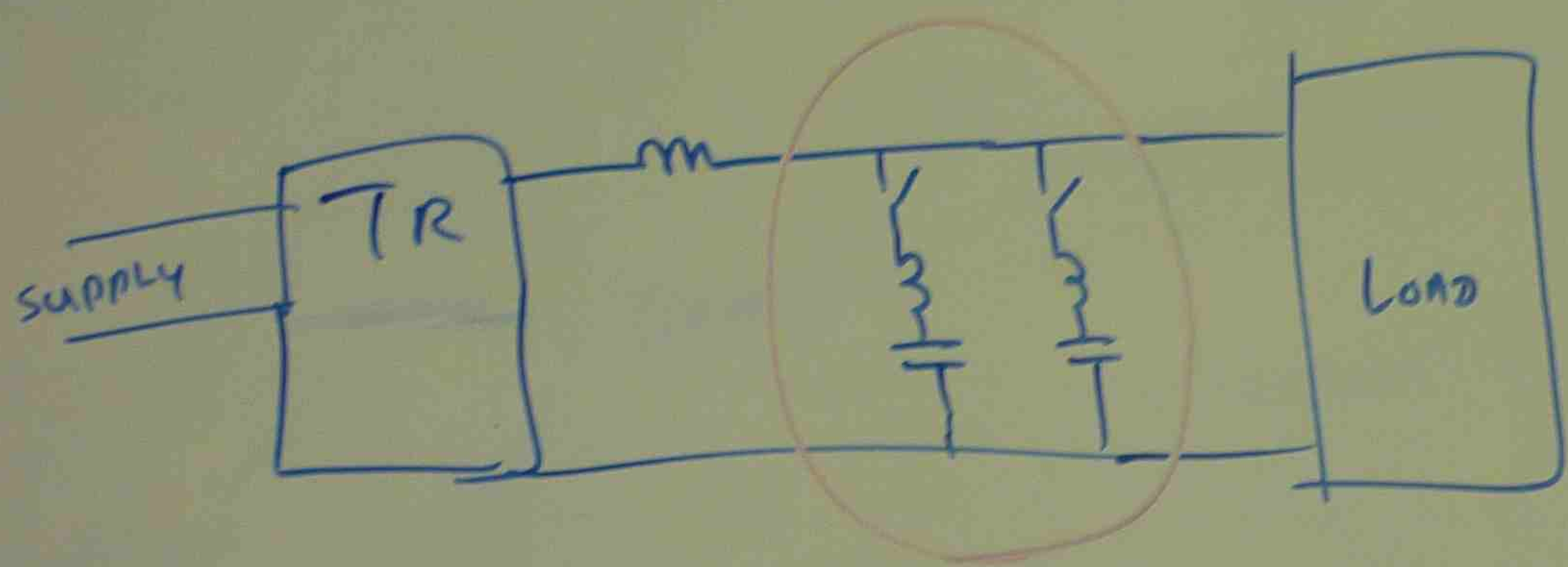
$Q_{5H} = I_{5H}^2 X_{5H} = 1.2^2 \times 35 = 50.4\,VAR$

(f) $S_{5H} = \sqrt{P_{5H}^2 + Q_{5H}^2} = \sqrt{34.6^2 + 50.4^2}$

$= 61.13\,VAR$

Q4 EXPLAIN THE GENERATION OF HARMONIC IN POWER SYSTEM AND EFFECTS OF HARMONIC

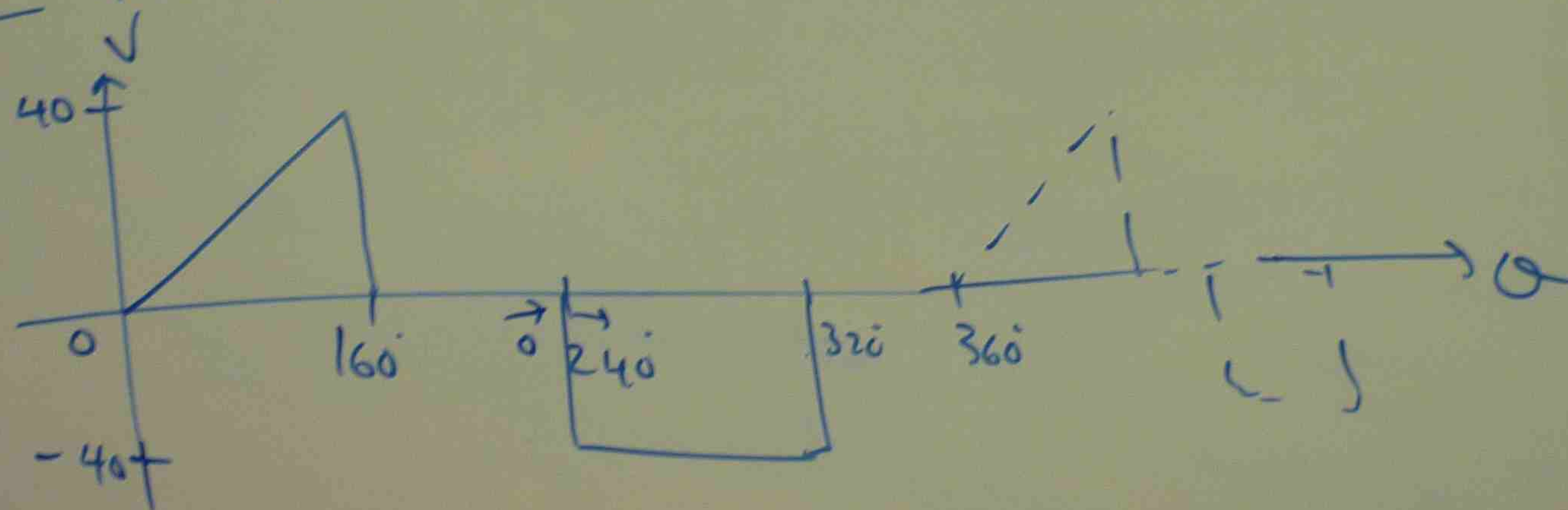
Q5 SKETCH THE DIAGRAM OF HARMONIC FILTER



HARMONIC FILTER.

HARMONIC ANALYSIS

Q6 ANALYZE THE FOLLOWING HARMONIC WAVE



$$X = \frac{S_1 D}{180}$$

$$Y = \frac{S_2 D}{180}$$

$S_1 = \sum$ COSINE COMPONENTS

$S_2 = \sum$ SINE COMPONENTS

D = DEGREE GRADIENT

$$A_H = \sqrt{X^2 + Y^2}$$

LET

H

LOAD

IC

AGE

OPERLY

CAN CAUSE

O BE

Let $D = 30$

θ	A	Cosine component $A\cos\theta$	Sine component $A\,\text{sim}\,\theta$
0	0	$0\cos 0 = 0$	$0\,\text{sim}\,0 = 0$
30	$40\times\frac{30}{160} = 7.5$	$7.5\cos 30 = 6.5$	$7.5\,\text{sim}\,30 = 3.75$
60	$40\times\frac{60}{160} = 15$	$15\cos 60 = 7.5$	$15\,\text{sim}\,60 = 11$
90	$40\times\frac{90}{160} = 22.5$	$22.5\cos 90 = 0$	$22.5\,\text{sim}\,90 = 22.5$
120	$40\times\frac{120}{160} = 30$	$30\cos 120 = -15$	$30\,\text{sim}\,120 = 26$
150	$40\times\frac{150}{160} = 37.5$	$37.5\cos 150 = -32.5$	$37.5\,\text{sim}\,150 = 18.75$
180	0	0	$0\,\text{sim}\,180 = 0$
210	0	0	$0\,\text{sim}\,210 = 0$
240	$\frac{-40+0}{2} = -20$	$-20\cos 240 = 10$	$-20\,\text{sim}\,240 = 17.3$
270	-40	$-40\cos 270 = 0$	$-40\,\text{sim}\,270 = 40$
300	-40	$-40\cos 300 = -20$	$-40\,\text{sim}\,300 = 34.6$
330	0	$0\cos 330 = 0$	$0\,\text{sim}\,330 = 0$
360	0	$0\cos 360 = 0$	$0\,\text{sim}\,360 = 0$
		$S_1 = \Sigma = -47.5$	$S_2 = \Sigma = 175.9$

$$X = \frac{S_1 D}{180} = \frac{-47.5\times 30}{180} = -7.9$$

$$Y = \frac{S_2 D}{180} = \frac{175.9\times 30}{180} = 29.3$$

$$AH = \sqrt{x^2+y^2} = \sqrt{(-7.9)^2+(29.3)^2} = 30.36\ V$$

$\frac{-47.5 \times 30}{180}$

$= -7.9$

$\frac{175.9 \times 30}{180}$

29.3

2

$)^2 + (29.3)^2$

$6\ V$

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SYNCHRONOUS GENERATOR LOADING EFFECT

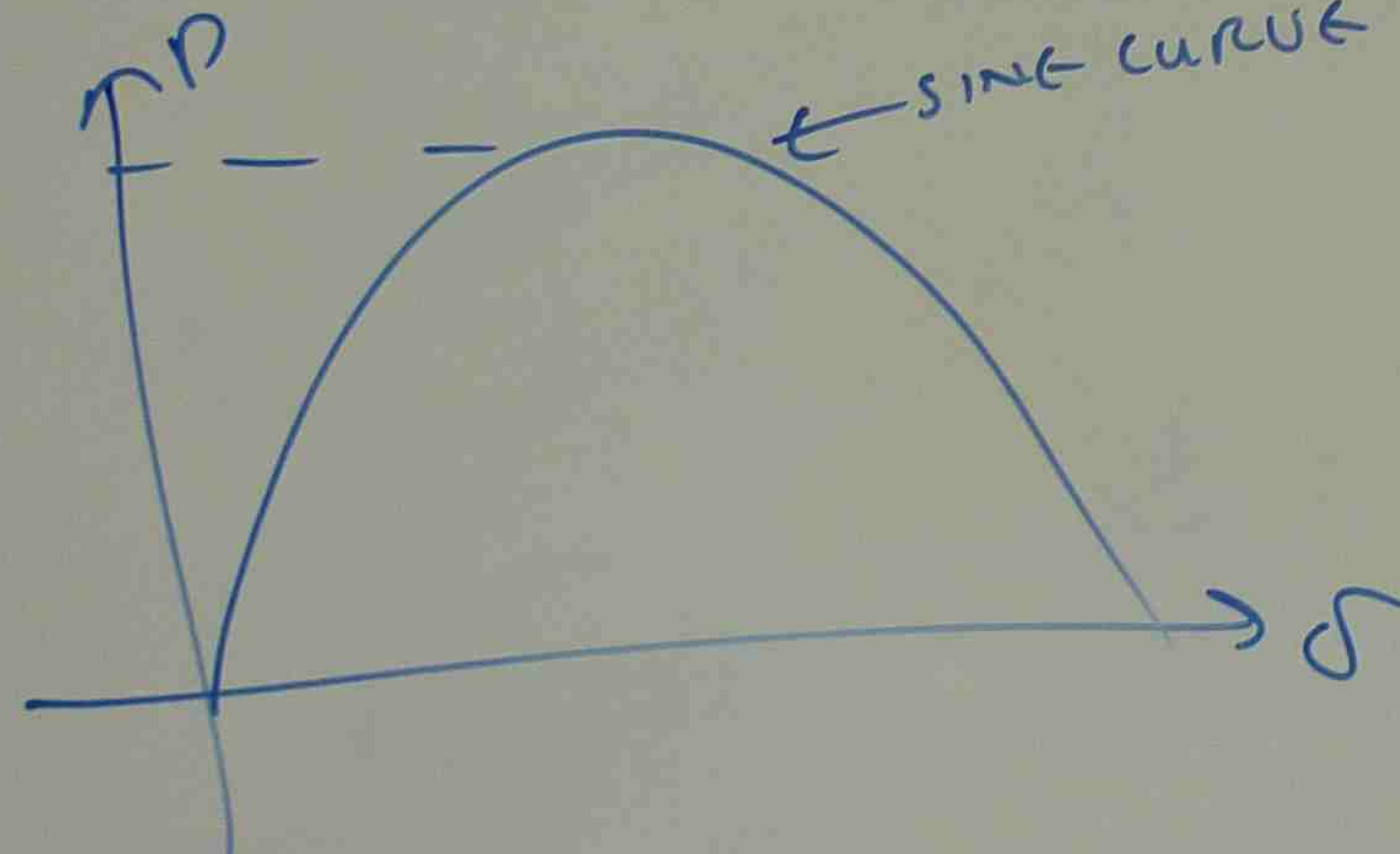
Q9 $$P = \frac{E_F\ E_t}{X_S} \sin\delta$$

P = POWER, E_F = NO LOAD VOLTAGE GENERATED VOLTAGE

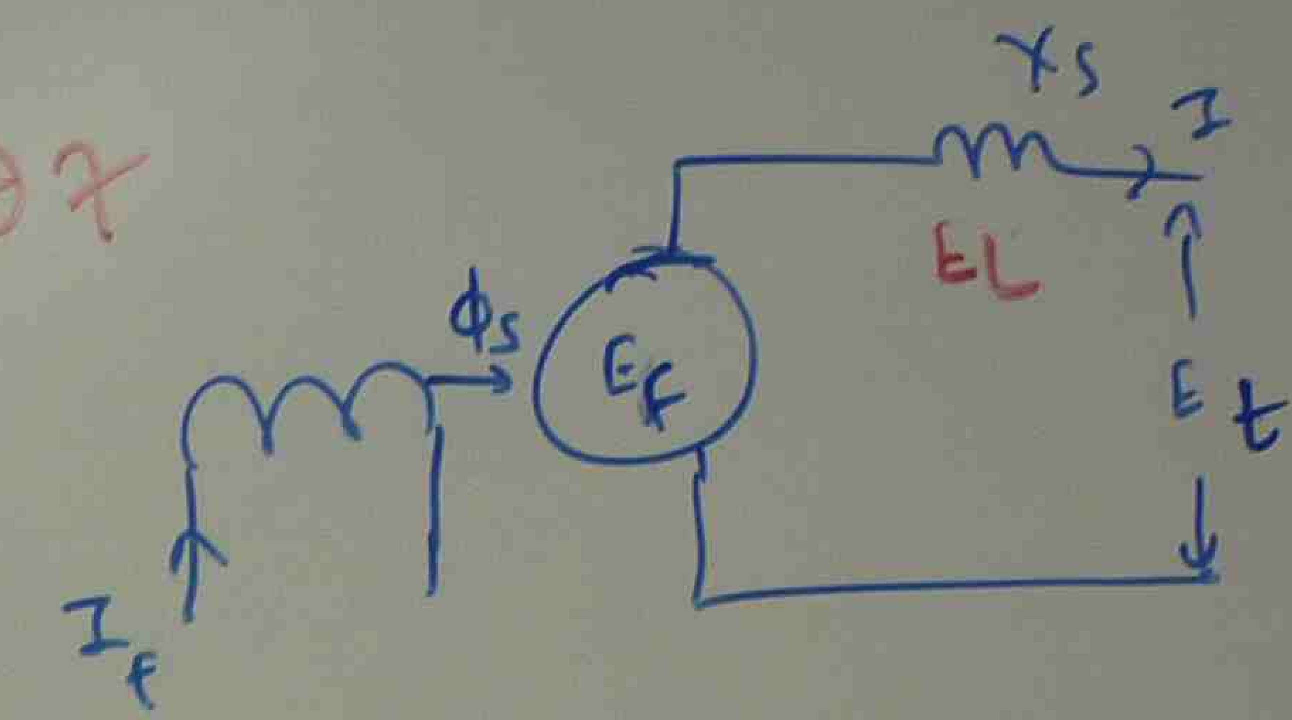
E_t = LOAD TERMINAL VOLTAGE

δ = COUPLING ANGLE

X_S = SYNCHRONOUS REACTANCE

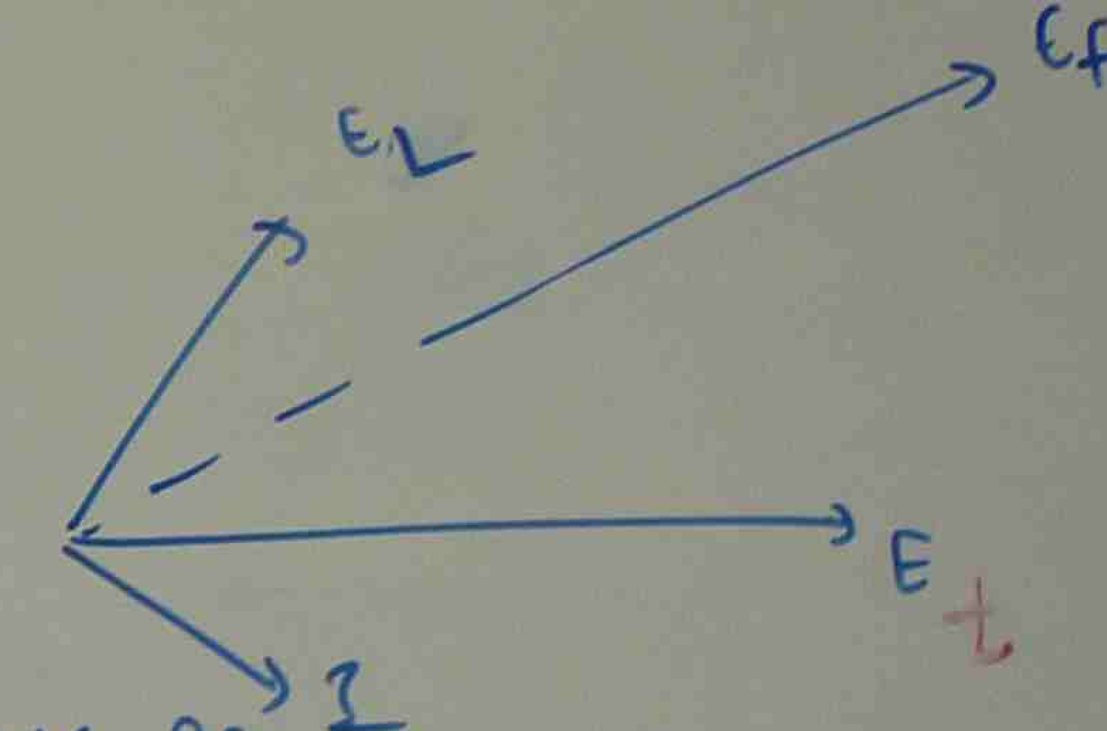


Q7

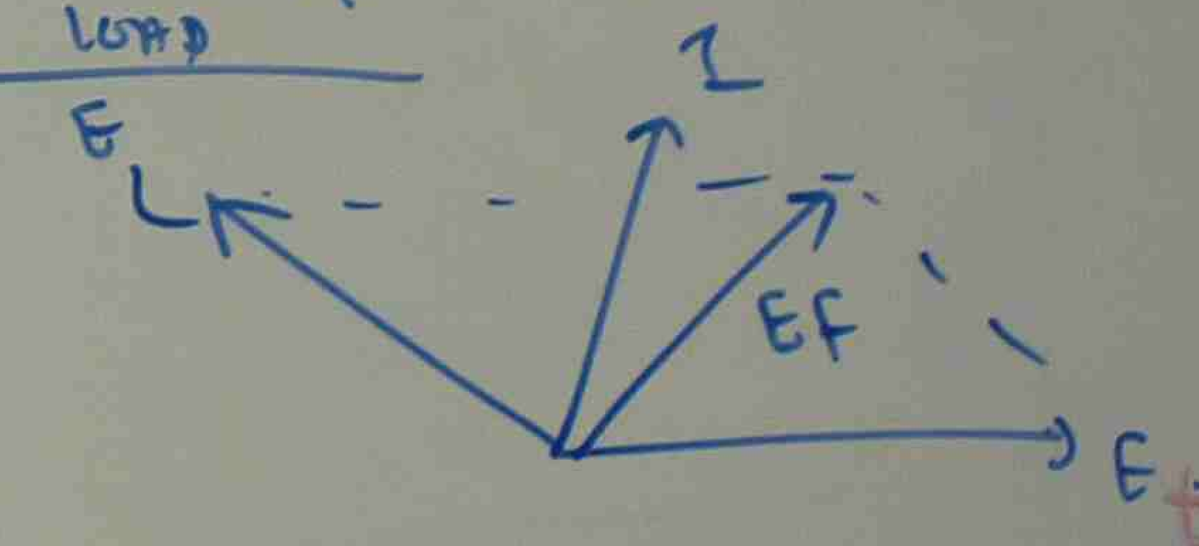


Q8

LAGGING P.F LOAD



LEADING PF LOAD



Q7

Q8

Q9

SYNCHRONOUS GENERATOR LOADING EFFECT

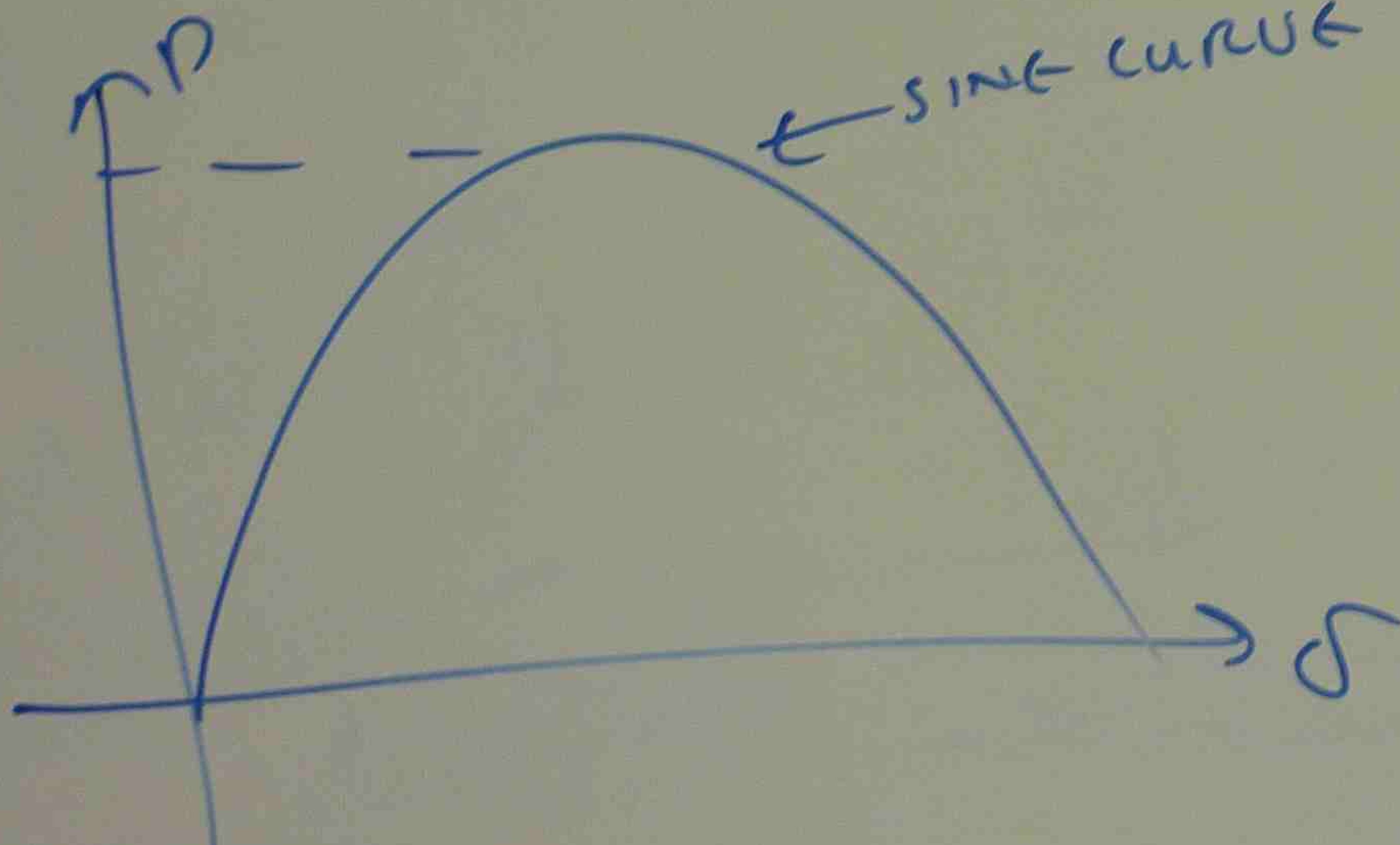
Q9 $$P = \frac{E_F \; E_t}{X_S} \sin \delta$$

P = POWER , E_F = NO LOAD VOLTAGE
GENERATED VOLTAGE

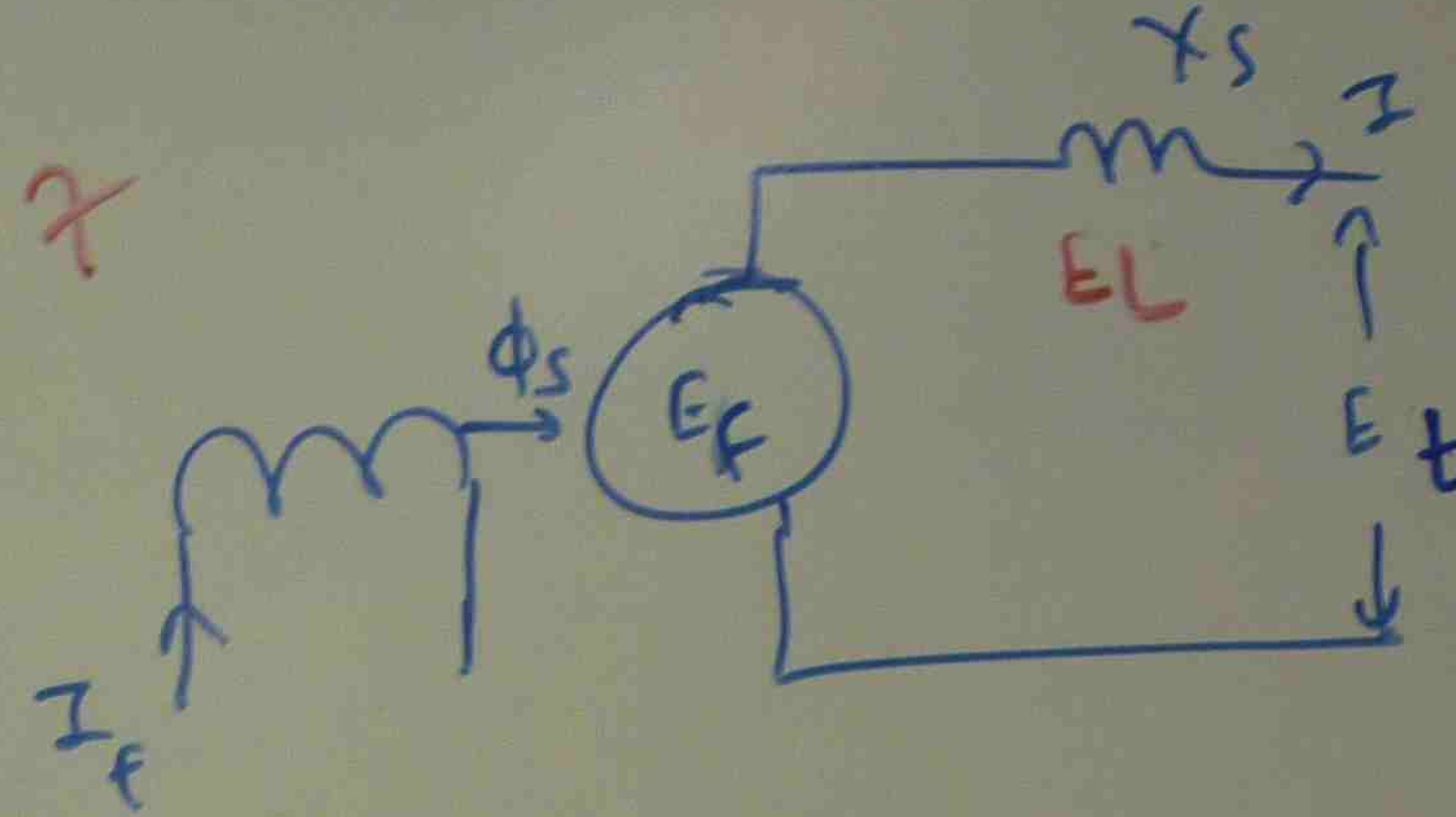
E_t = LOAD TERMINAL VOLTAGE

δ = COUPLING ANGLE

X_S = SYNCHRONOUS REACTANCE

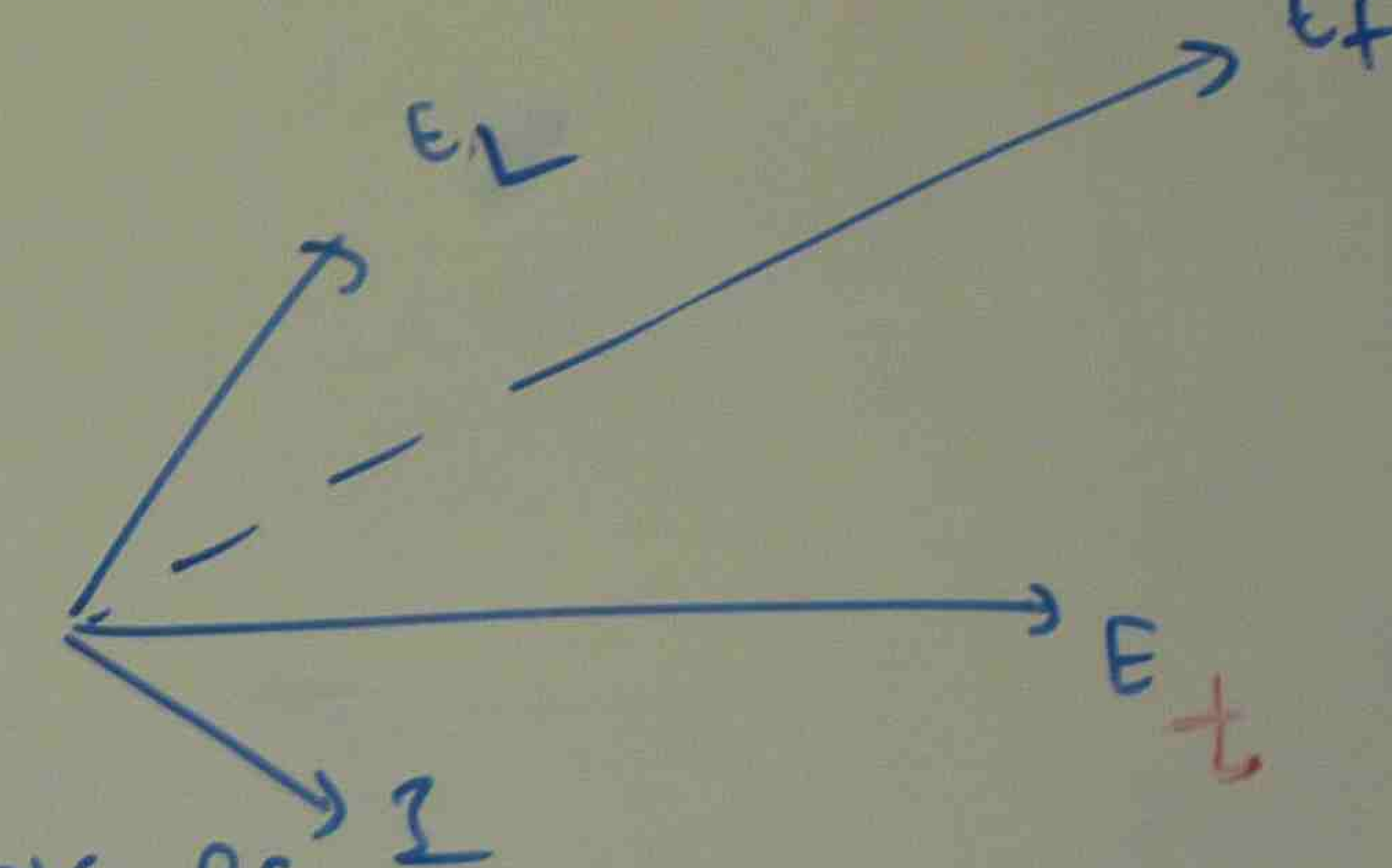


Q7

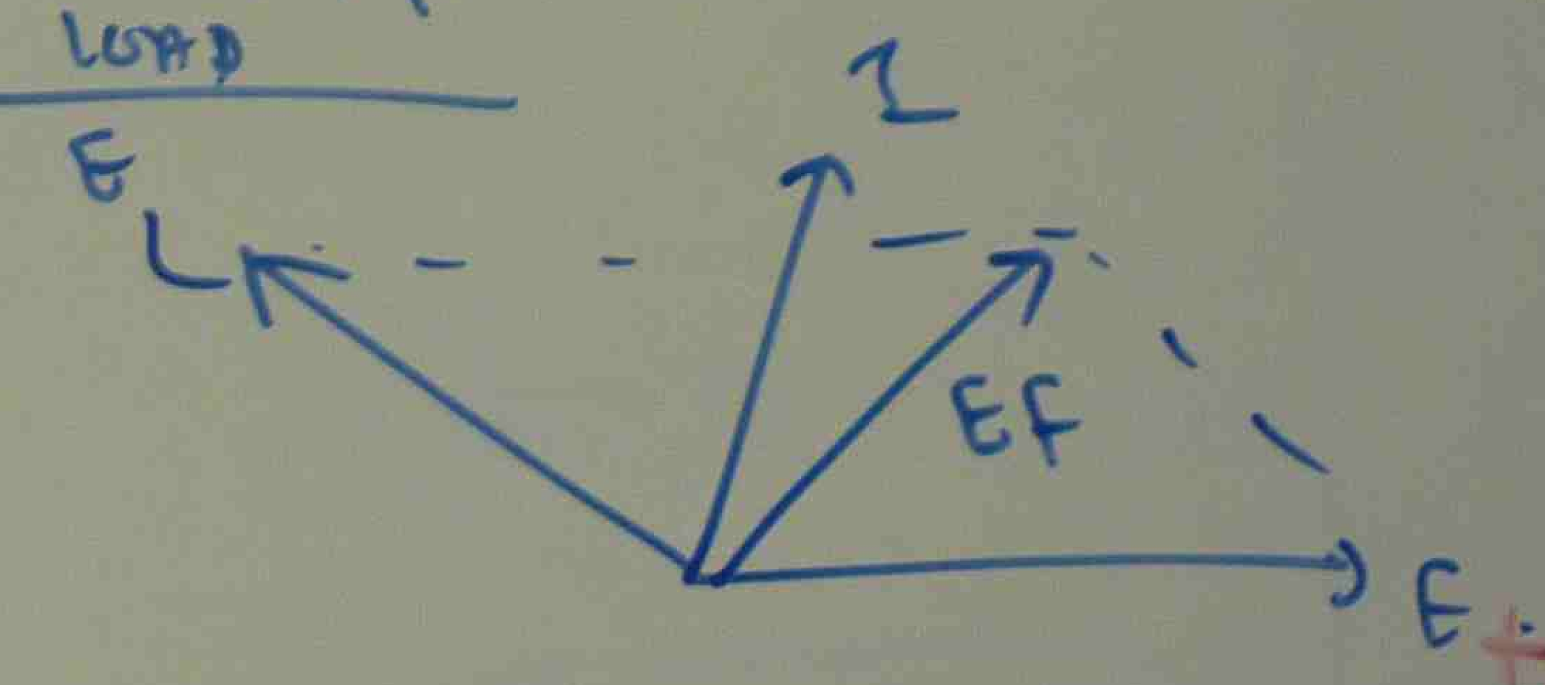


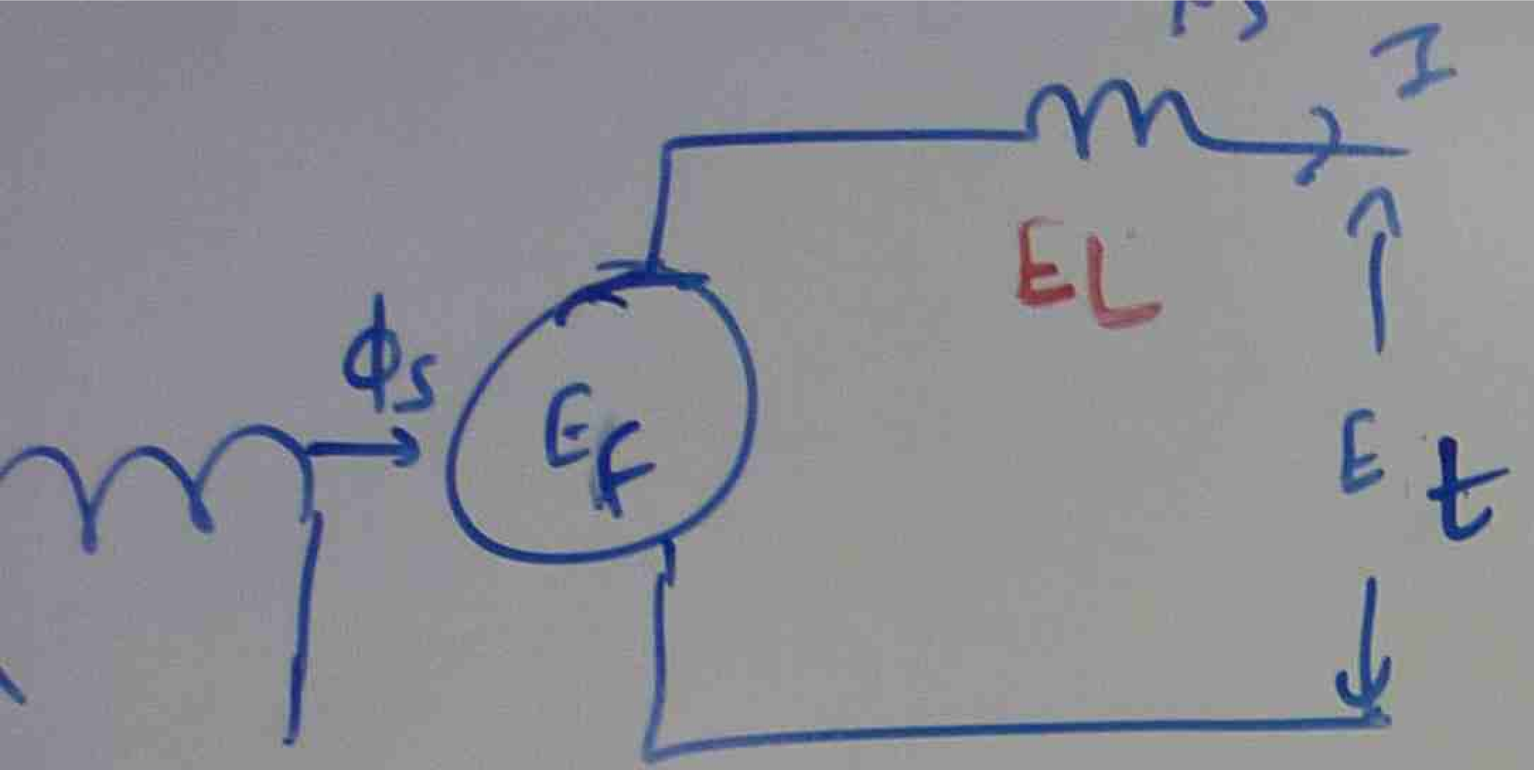
Q8

LAGGING P.F LOAD

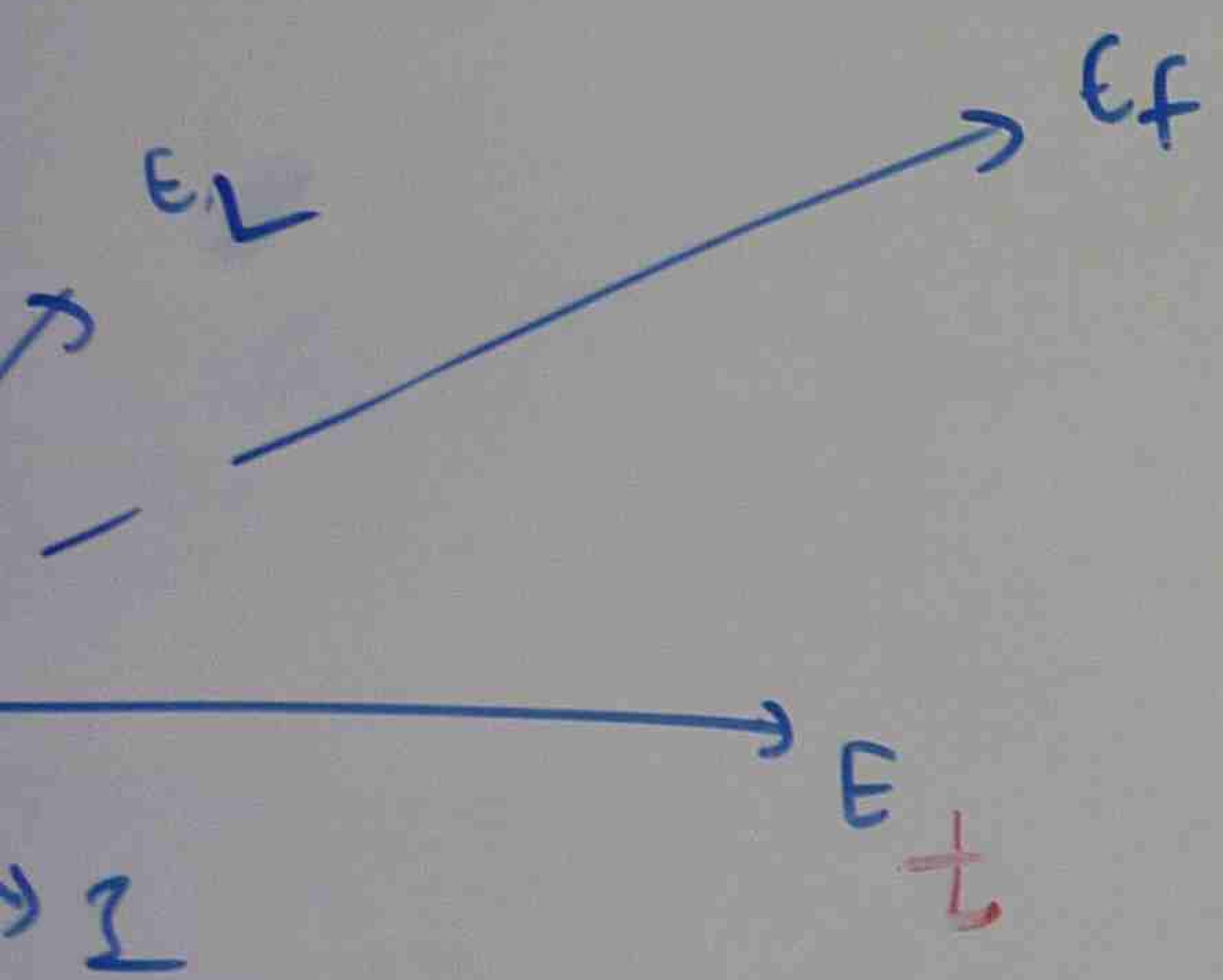


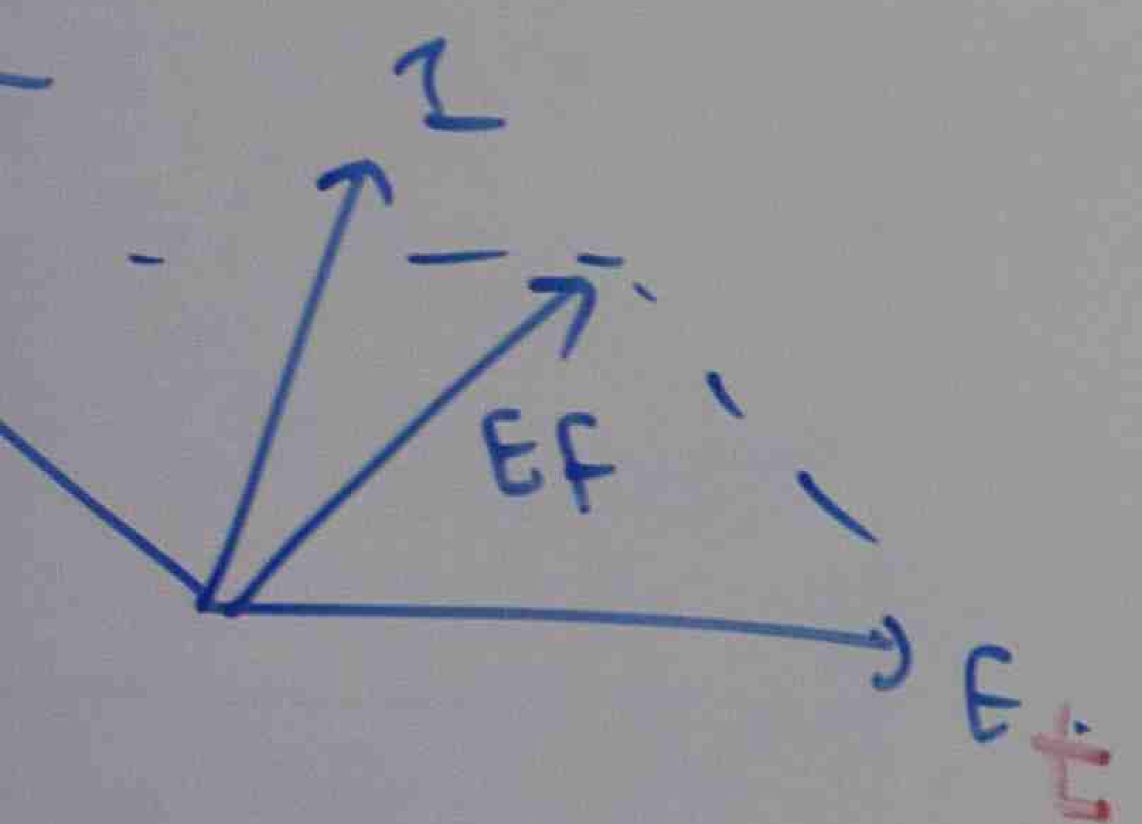
LEADING PF LOAD





G P.F LOAD





Q7 SKETCH EQUIVALENT CIRCUIT DIAGRAM OF SYNCHRONOUS MACHINE

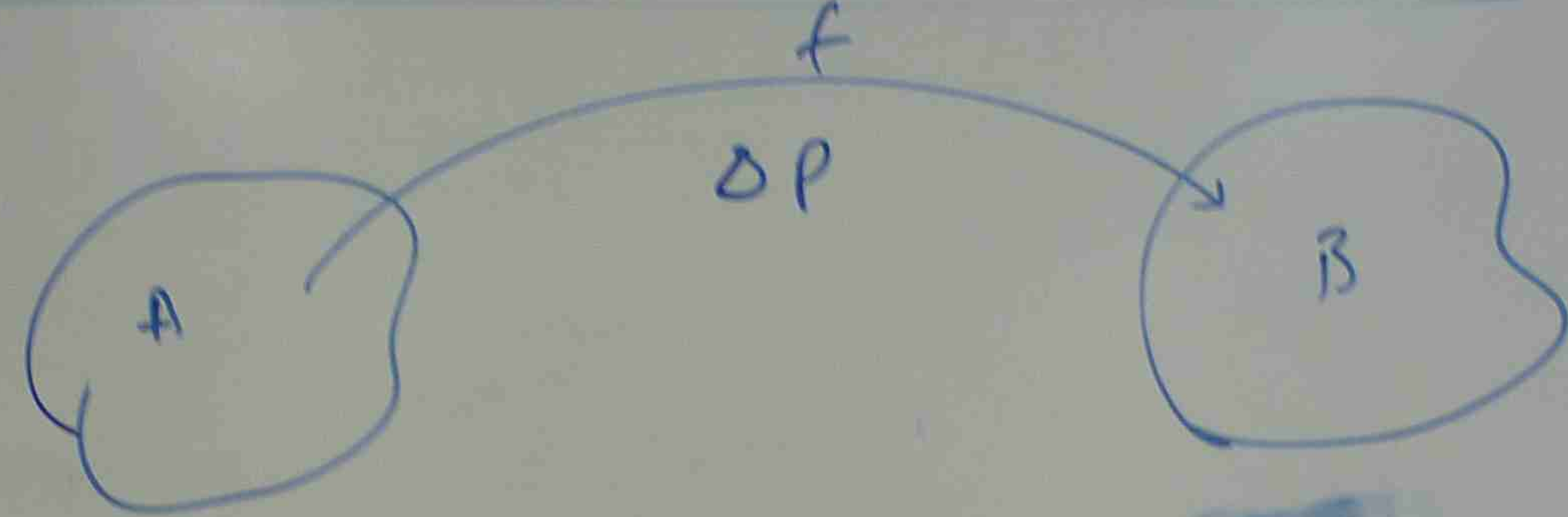
Q8 SKETCH THE VECTOR DIAGRAM OF SYNCHRONOUS MACHINE FOR

(i) P.F LAGGING LOAD

(ii) PF LEADING LOAD

Q9 WRITE THE POWER OUTPUT EQUATION OF SYNCHRONOUS MACHINE AND PLOT POWER-ANGLE CHARACTERISTICS CURVE

EFFECT OF GOVERNOR CHARACTERISTICS & POWER TRANSFER



SOURCE

FREQUENCY f_A

IMPEDANCE/POWER K_A (P.U)

DESTINATION

f_B

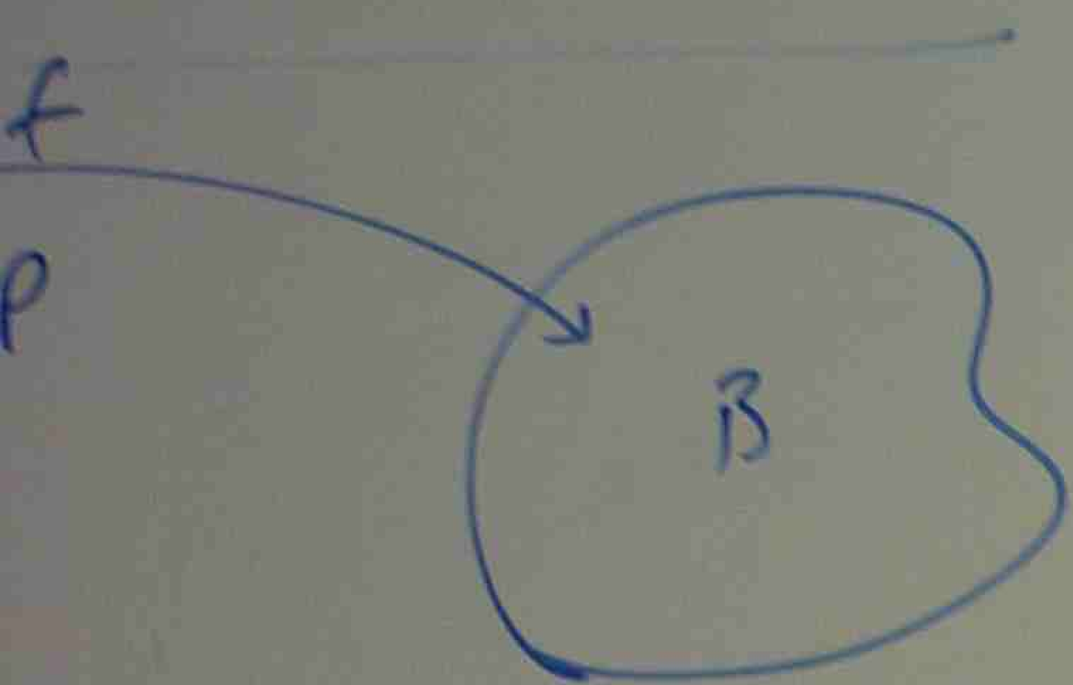
K_B (PU)

$$\frac{\Delta P}{f_A - f_B} = \frac{K_A K_B}{K_A + K_B}$$

PRIME mover

M

...TERISTICS & POWER TRANSFER

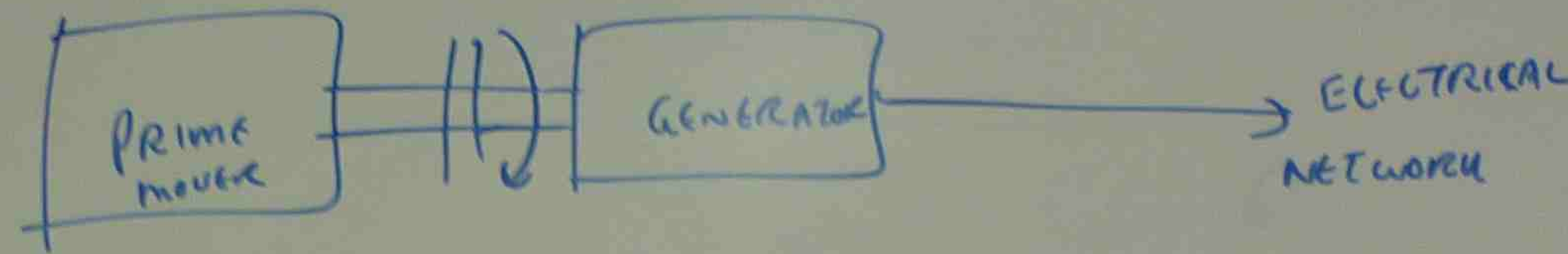


DESTINATION

f_B

K_B (pu)

$$\frac{K_A K_B}{K_A + K_B}$$



M = SHAFT INERTIA

δ = ANGULAR DISPLACEMENT

K = MACHING COEFFICIENT

ΔP = TRANSFER OF POWER

ΔP_L = LOAD POWER CHANGE

$$M \frac{d^2\delta}{dt^2} + K\,\Delta\delta = \Delta P - \Delta P_L$$

BLOCK DIAG...

Q10 SKETCH...

(a) ...

(b) ...

(a)

→ ELECTRICAL NETWORK

BLOCK DIAGRAM OF GOVERNOR CONTROL

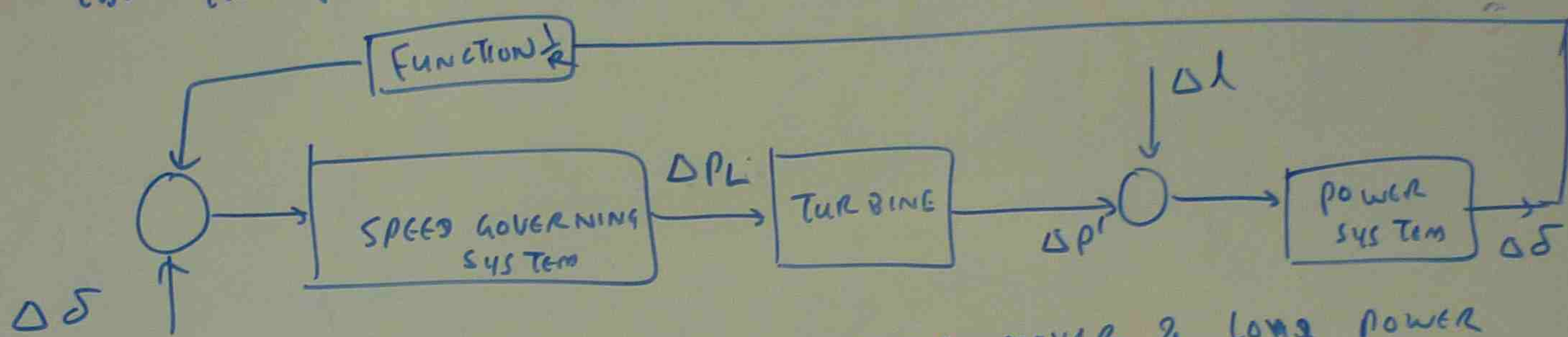
Q 10 SKETCH THE BLOCK DIAGRAMS OF GOVERNOR CONTROL FOR

(a) TURBINE GENERATOR CONNECTED TO A POWER SYSTEM

(b) TWO POWER SYSTEMS CONNECTED BY A TIE LINE

(b)

(a)



ΔP_L

ΔP_L = CHANGE IN PRIME MOVER & LOAD POWER

$\Delta P'$ = CHANGE IN SPEED CHANGER SETTING

$\Delta \delta$ = CHANGE IN ANGULAR POSITION

R = SPEED REGULATION

→ ELECTRICAL NETWORK

BLOCK DIAGRAM OF GOVERNOR CONTROL

Q 10 SKETCH THE BLOCK DIAGRAMS OF GOVERNOR CONTROL FOR

(a) TURBINE GENERATOR CONNECTED TO A POWER SYSTEM

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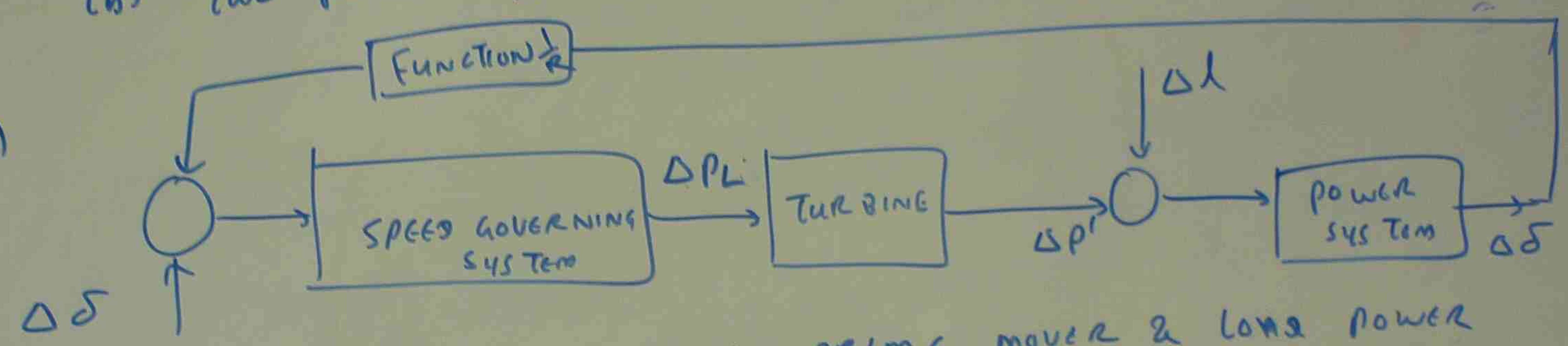
(b)

(a)



E

— ΔPL

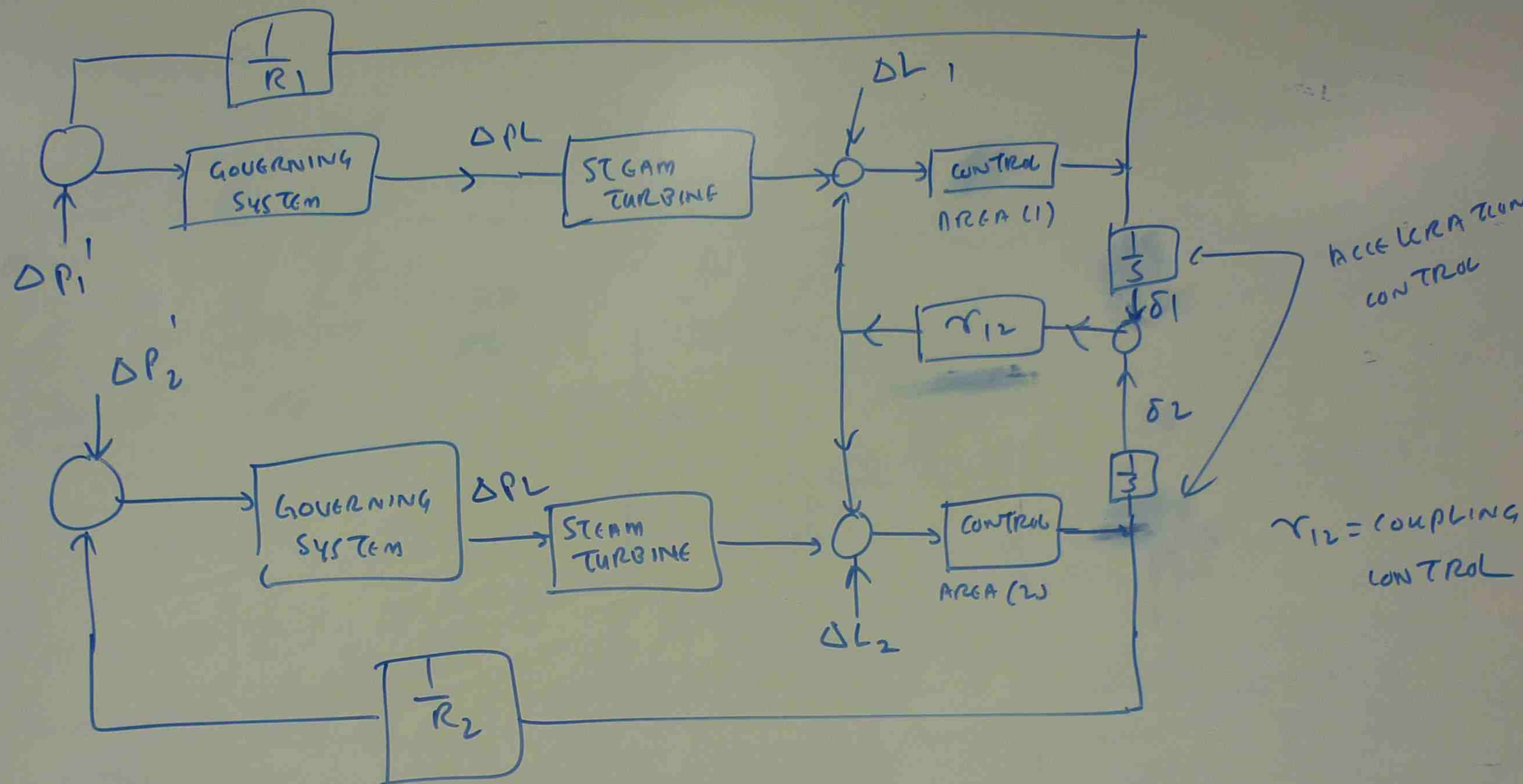
ΔP_L = CHANGE IN PRIME MOVER & LOAD POWER

$\Delta P'$ = CHANGE IN SPEED CHANGER SETTING

$\Delta \delta$ = CHANGE IN ANGULAR POSITION

R = SPEED REGULATION

(b)



1/R1
ΔL 1
ΔPL
GOVERNING SYSTEM
STEAM TURBINE
CONTROL AREA (1)
ΔP1'
1/S
δ1
r12
ACCELERATION CONTROL
ΔP2'
δ2
1/S
ΔPL
GOVERNING SYSTEM
STEAM TURBINE
CONTROL AREA (2)
ΔL2
r12 = COUPLING CONTROL
1/R2

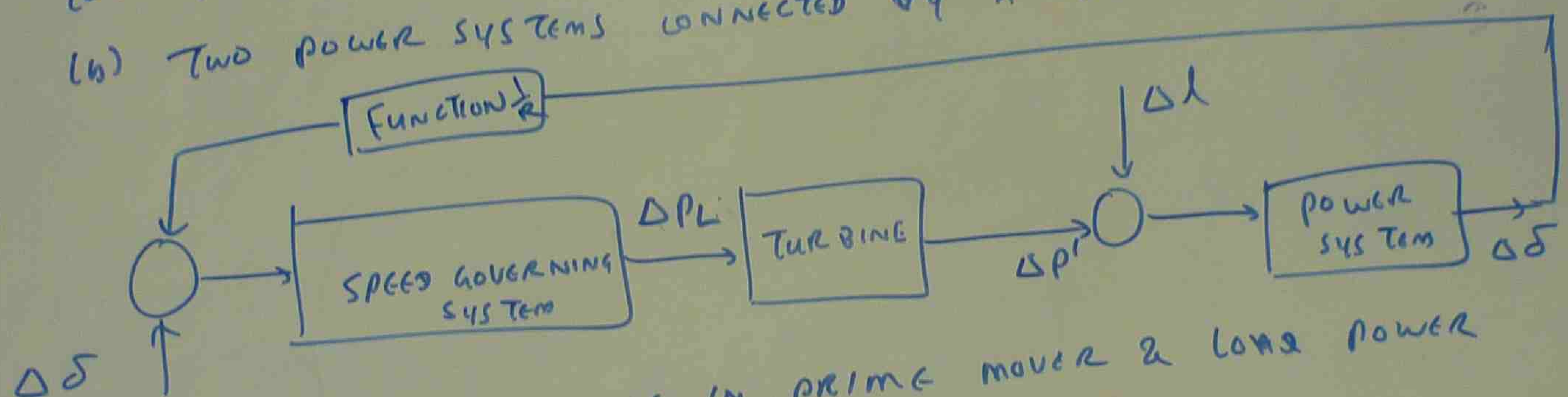
ELECTRICAL
ETWORK

ΔPL

BLOCK DIAGRAM OF GOVERNOR CONTROL

Q10 SKETCH THE BLOCK DIAGRAMS OF GOVERNOR CONTROL FOR
(a) TURBINE GENERATOR CONNECTED TO A POWER SYSTEM
(b) TWO POWER SYSTEMS CONNECTED BY A TIE LINE

(a)



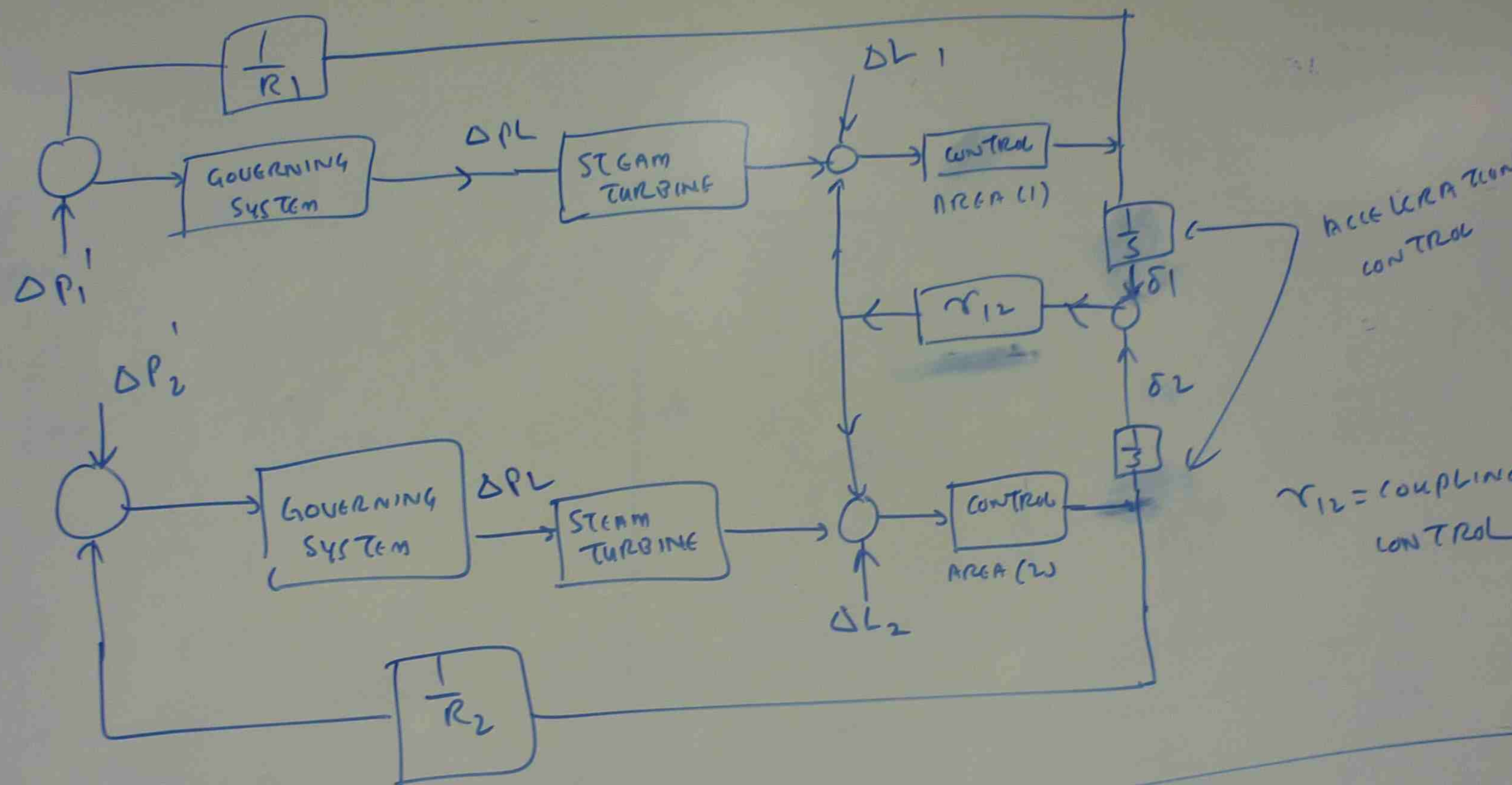
ΔP_L = CHANGE IN PRIME MOVER & LOAD POWER
$\Delta P'$ = CHANGE IN SPEED CHANGER SETTING
$\Delta \delta$ = CHANGE IN ANGULAR POSITION

R = SPEED REGULATION

(b)

ΔP

(b)



Q11

CA

THE

GO

CH

$$P_{12} = \text{POWER TRANSFER} = T_{12}(\delta_1 - \delta_2) = \frac{-\Delta P(K_2+1)/R_B}{\left(K_A + \frac{1}{R_A}\right) + \left(K_B + \frac{1}{R}\right.}$$

$$= \frac{-100(1000+1) \times \frac{6}{1000}}{\left(1500 + \frac{6}{1500}\right) + \left(1000 + \right.}$$

$$= -6\ \text{MW}$$

Q11 TWO POWER SYSTEMS A & B, EACH HAS A REGULATION R_1 OF 0.1 pu (ON RESPECTIVE CAPACITY BASE) AND A STIFFNESS K OF 1 pu.

THE CAPACITY OF SYSTEM (A) IS 1500 MW & B 1000 MW.

THE TWO SYSTEMS ARE INTERCONNECTED THROUGH A TIE LINE AND ARE INITIALLY AT 60 HZ. IF THERE IS A 100 MW LOAD CHANGE IN SYSTEM (A), CALCULATE THE CHANGE IN THE STEADY STATE VALUE OF FREQUENCY AND POWER TRANSFER.

$K_A = \text{STIFFNESS}(K) \times P_A = 1 \times 1500 = 1500$

$K_B = \text{STIFFNESS}(K) \times P_B = 1 \times 1000 = 1000$

$$R_A = \frac{\Delta f}{\text{FULL LOAD CAPACITY}} = \frac{R \times f}{\text{FULL LOAD CAPACITY OF (A)}} = \frac{0.1 \times 60}{1500} = \frac{6}{1500} \text{ Hz/MW}$$

$$R_B = \frac{\Delta f}{\text{FULL LOAD CAPACITY}} = \frac{R \times f}{\text{FULL LOAD CAPACITY OF (B)}} = \frac{0.1 \times 60}{1000} = \frac{6}{1000} \text{ Hz/MW}$$

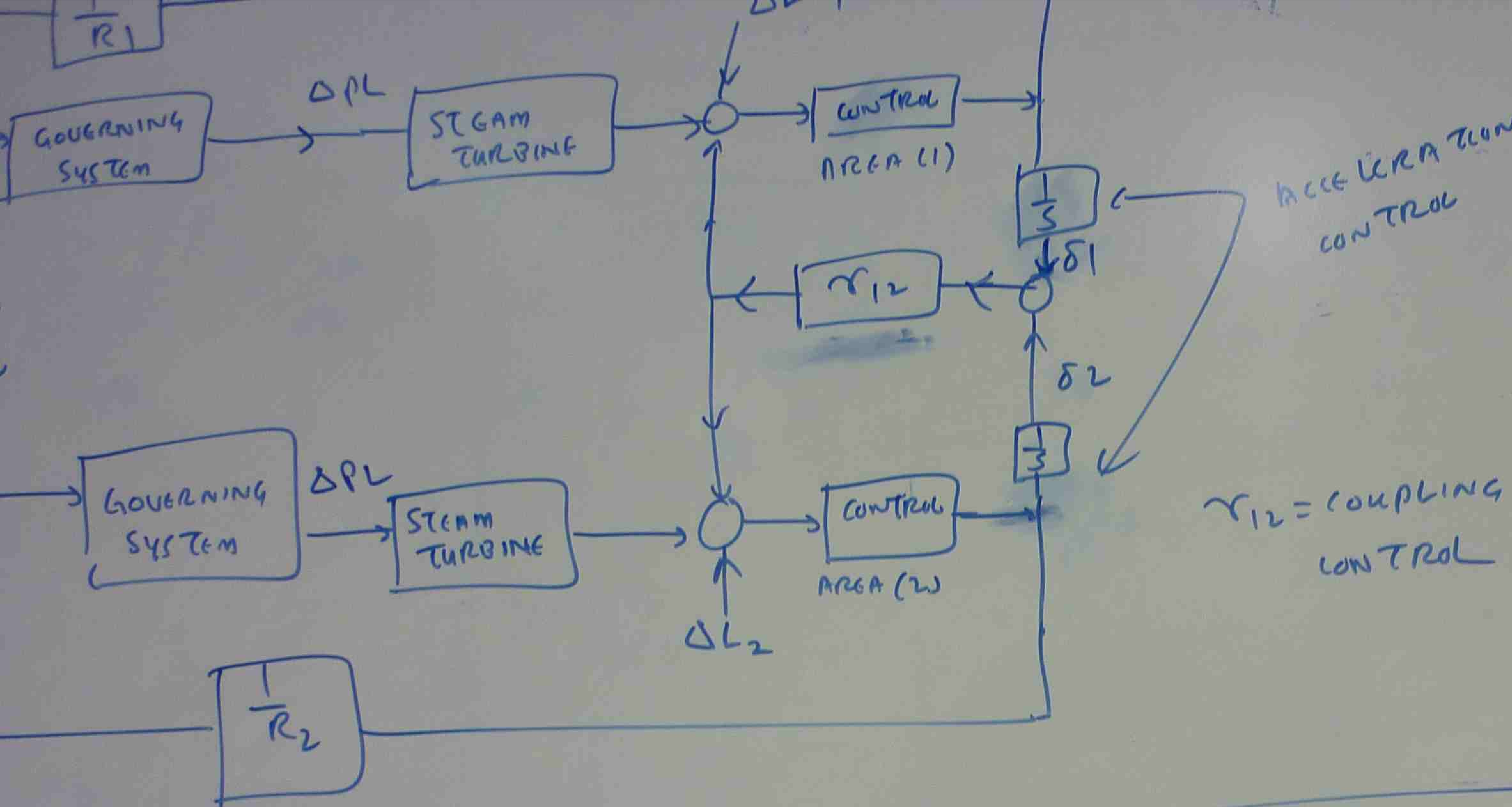
$$\Delta f = \frac{-\Delta P_L}{(P_A + R_A) + (P_B + R_B)} = \frac{-100}{\left(1500 + \frac{6}{1500}\right) + \left(1000 + \frac{6}{1000}\right)} = -0.034 \text{ Hz}$$

$+1)/R_B$

$) + \left(K_B + \frac{1}{R_B}\right)$

$+1) \times \frac{6}{1000})$

$+\left(1000 + \frac{6}{1000}\right)$



$$P_{12} = \text{power transfer} = T_{12}(\delta_1 - \delta_2) = \frac{-\Delta P(K_2+1)/R_B}{(K_A + \frac{1}{R_A}) + (K_B + \frac{1}{R_B})}$$

$$= \frac{-100(1000+1) \times \frac{6}{1000})}{(1500 + \frac{6}{1500}) + (1000 + \frac{6}{1000})}$$

$$= -6 \text{ MW}$$

Q11 Two power systems

capacity base) and

the capacity of sys

The two systems are

60 Hz. If there is

change in the stead

K_A = stiffness (

K_B = stiffness (

$R_A = \frac{\Delta f}{\text{full lo}}$

$R_B = \frac{\Delta f}{\text{full l}}$

Δf

11

TWO POWER SYSTEMS A & B, EACH HAS A REGULATION R_1 OF 0.1 pu (ON RESPECTIVE CAPACITY BASE) AND A STIFFNESS K OF 1 pu.
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$$R_B = \frac{\Delta f}{\text{FULL LOAD CAPACITY}} = \frac{R \times f}{\text{FULL LOAD CAPACITY OF (B)}} = \frac{0.1 \times 60}{1000} = \frac{6}{1000}\ \text{Hz/MW}$$

$$\Delta f = \frac{-\Delta P_L}{(P_A + R_A) + (P_B + R_B)} = \frac{-100}{\left(1500 + \frac{6}{1500}\right) + \left(1000 + \frac{6}{1000}\right)} = -0.034\ \text{Hz}$$

R_B

$\ldots + R_B)$

$\frac{6}{1000}$

$\ldots \text{of}\ \frac{6}{1000})$

Q11 Two power systems A & B, each has a regulation R_1 of 0.1 pu (on respective capacity base) and a stiffness K of 1 pu.

The capacity of system (A) is 1500 MW & B 1000 MW.

The two systems are interconnected through a tie line and are initially at 60 Hz. If there is a 100 MW load change in system (A), calculate the change in the steady state value of frequency and power transfer.

$$K_A = \text{STIFFNESS}(K) \times P_A = 1 \times 1500 = 1500$$

$$K_B = \text{STIFFNESS}(K) \times P_B = 1 \times 1000 = 1000$$

$$R_A = \frac{\Delta f}{\text{FULL LOAD CAPACITY}} = \frac{R \times f}{\text{FULL LOAD CAPACITY OF (A)}} = \frac{0.1 \times 60}{1500} = \frac{6}{1500} \text{ Hz/MW}$$

$$R_B = \frac{\Delta f}{\text{FULL LOAD CAPACITY}} = \frac{R \times f}{\text{FULL LOAD CAPACITY OF (B)}} = \frac{0.1 \times 60}{1000} = \frac{6}{1000} \text{ Hz/MW}$$

$$\Delta f = \frac{-\Delta P_L}{(P_A + R_A) + (P_B + R_B)} = \frac{-100}{\left(1500 + \frac{6}{1500}\right) + \left(1000 + \frac{6}{1000}\right)} = -0.034 \text{ Hz}$$

$$)\times R_B$$

$$(K_B + R_B)$$

$$) \times \frac{6}{1000}$$

$$1000 + \frac{6}{1000})$$

Q11 Two power systems A & B, each has a regulation R_1 of 0.1 pu (on respective capacity base) and a stiffness K of 1 pu.
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$$R_A = \frac{\Delta f}{\text{full load capacity}} = \frac{R \times f}{\text{full load capacity of (A)}} = \frac{0.1 \times 60}{1500} = \frac{6}{1500} \text{ Hz/MW}$$

$$R_B = \frac{\Delta f}{\text{full load capacity}} = \frac{R \times f}{\text{full load capacity of (B)}} = \frac{0.1 \times 60}{1000} = \frac{6}{1000} \text{ Hz/MW}$$

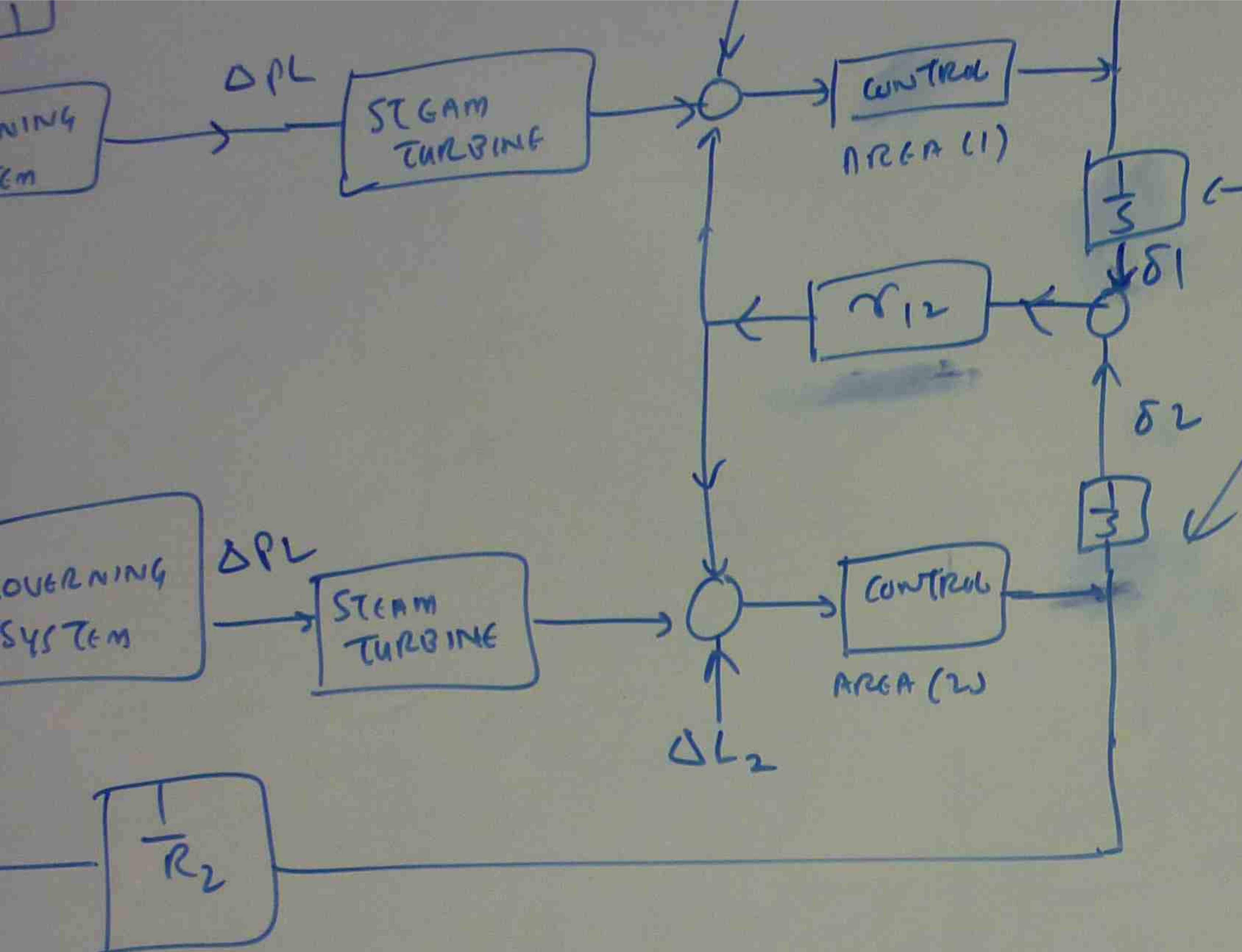
$$\Delta f = \frac{-\Delta P_L}{(P_A + R_A) + (P_B + R_B)} = \frac{-100}{\left(1500 + \frac{6}{1500}\right) + \left(1000 + \frac{6}{1000}\right)} = -0.034 \text{ Hz}$$

$)\times R_B$

$K_B + R_B)$

$\times \frac{6}{1000}$

$000 + \frac{6}{1000})$



ACCELERATION CONTROL

r_{12} = COUPLING CONTROL

$$P_{12} = \text{POWER TRANSFER} = T_{12}(\delta_1 - \delta_2) = \frac{-\Delta P (K_2 + 1) \times R_B}{(K_A + R_A) + (K_B + R_B)}$$

$$= \frac{-100(1000+1) \times \frac{6}{1000}}{\left(1500 + \frac{6}{1500}\right) + \left(1000 + \frac{6}{1000}\right)}$$

$$= -6\,MW$$

TWO POW...

CAPACITY BASE)

THE CAPACITY OF

THE TWO SYSTEMS AR...

60 HZ. IF THER...

CHANGE IN THE ST...

K_A = STIFFN...

K_B = STIFFN...

$R_A = \frac{\Delta}{fu...}$

$R_B = \frac{...}{f...}$

Δ