GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

Course Title: POWER SYSTEMS-III

Following documents are available in Course File.

S.No.	Points	Yes	No
1	Institute and Department Vision and Mission Statements	Y	
2	PEO & PO Mapping	Y	
3	Academic Calendar	Y	
4	Subject Allocation Sheet	Y	
5	Class Time Table, Individual Timetable (Single Sheet)	Y	
6	Syllabus Copy	Y	
7	Course Handout	Y	
8	CO-PO Mapping	Y	
9	CO-Cognitive Level Mapping	Y	
10	Lecture Notes	Y	
11	Tutorial Sheets With Solution	Y	
12	Soft Copy of Notes/Ppt/Slides	Y	
13	Sessional Question Papers and Scheme of Evaluation	Y	
14	Best, Average and Weak Answer Scripts for Each Sessional Exam. (Photocopies)		No
15	Assignment Questions and Solutions	Y	
16	Previous Question Papers	Y	
17	Result Analysis	Y	
18	Feedback From Students	Y	
19	CO Attainment for All Mids.	Y	
20	Remedial Action.		No

P. PRASANTH KUMAR

Course Instructor **Course Coordinator**

Vision of the Institute

To be among the best of the institutions for engineers and technologists with attitudes, skills and knowledge and to become an epicentre of creative solutions.

Mission of the Institute

To achieve and impart quality education with an emphasis on practical skills and social relevance.

Vision of the Department

To impart technical knowledge and skills required to succeed in life, career and to help society to achieve self-sufficiency.

Mission of the Department

- To become an internationally leading department for higher learning.
- To build upon the culture and values of universal science and contemporary education.
- To be a center of research and education generating knowledge and technologies which lay groundwork in shaping the future in the fields of electrical and electronics engineering.
- To develop partnership with industrial, R&D and government agencies and actively participate in conferences, technical and community activities.

Programme Educational Objectives (PEOs)

PEO-1: Graduates will have a successful technical or professional careers, including supportive and leadership roles on multidisciplinary teams.

PEO-2: Graduates will be able to acquire, use and develop skills as required for effective professional practices.

PEO-3: Graduates will be able to attain holistic education that is an essential prerequisite for being a responsible member of society.

PEO-4: Graduates will be engaged in life-long learning, to remain abreast in their profession and be leaders in our technologically vibrant society.

Programme Outcomes (POs)

PO-a: Ability to apply knowledge of mathematics, science, and engineering.

PO-b: Ability to identify, formulate, analyze engineering problems using engineering sciences.

PO-c: Ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety..

PO-d: Ability to design and conduct experiments, as well as to analyze and interpret data with valid conclusions.

PO-e: Ability to utilize experimental, statistical and computational methods and tools necessary for modelling engineering activities.

PO-f: Ability to apply reasoning informed by the relative knowledge to evaluate societal, health, safety, legal and cultural issues and tasks applicable to the professional engineering practice.

PO-g: Ability to adapt broad education necessary to understand the impact of engineering solutions and obtain sustainability in a global, economic, environmental, and societal context.

PO-h: Ability to discover ethical principles and bind to professional and ethical responsibility.

PO-i: Ability to function as an individual and in multi-disciplinary teams.

PO-j: Ability to communicate effectively on complex activities in engineering community and society.

PO-k: Ability to develop Project management principles and apply in various disciplinary environments.

PO-l: Recognition of the need for, and an ability to engage in life-long learning

Program Specific Outcomes (PSOs)

PSO-1: Graduates will interpret data and able to analyze digital and analog systems related to electrical and programming them.

PSO-2: Graduates will able to demonstrate, design and model electrical, electronic circuits, power electronics, power systems and electrical machines.

Gokaraju Rangaraju Institute of Engineering and Technology
(Autonomous)
Bachupally, Kukatpally, Hyderabad – 500 090, India

GRIET/DAA/1H/G/22-23 19 July 2022

Revised Academic Calendar
Academic Year 2022-23

IV B.Tech – First Semester

S. No.	EVENT	PERIOD	DURATION
1	Commencement of First Semester class work	04-07-2022	
2	I Spell of Instructions	04-07-2022 to 03-09-2022	9 Weeks
3	I Mid-term Examinations	05-09-2022 to 07-09-2022	3 Days
4	II Spell of Instructions	08-09-2022 to 11-11-2022	9 Weeks
5	II Mid-term Examinations	14-11-2022 to 16-11-2022	3 Days
6	Preparation	17-11-2022 to 23-11-2022	1 Week
7	End Semester Examinations (Theory/ Practical) Regular/ Supplementary	24-11-2022 to 14-12-2022	3 Weeks
8	Commencement of Second Semester, AY 2022-23	16-12-2022	

IV B.Tech – Second Semester

S. No.	EVENT	PERIOD	DURATION
1	Commencement of Second Semester class work	16-12-2022	
2	I Spell of Instructions	16-12-2022 to 13-02-2023	9 Weeks
3	I Mid-term Examinations	14-02-2023 to 16-02-2023	3 Days
4	II Spell of Instructions	17-02-2023 to 26-04-2023	10 Weeks
5	II Mid-term Examinations	27-04-2023 to 29-04-2023	3 Days
6	Preparation & Summer Vacation	01-05-2023 to 13-05-2023	2 Weeks
7	End Semester Examinations (Theory/ Practical) Regular / Supplementary	15-05-2023 to 03-06-2023	3 Weeks

J.Praveen

Dean Academic Affairs

Copy to Principal, All HoDs, CoE

Gokaraju Rangaraju Institute of Engineering and Technology

Department of Electrical and Electronics Engineering

2022 -23 I sem Subject allocation sheet

II YEAR(GR20)	Section-A	
Electrical Circuit Analysis	G Sandhya Rani	
Principles of Analog Electronics	P Ravikanth	
DC Machines and Transformers	Dr Phaneedra Babu B	
Electromagnetic Fields	Dr T Suresh Kumar	
Power Generation and Transmission	V Vijaya Rama Raju	
Java Programming for Engine	CSE Dept. Staff	
Constitution of India	D Karuna Kumar	
Value Ethics and Gender Culture	M Prashanth	
Principles of Analog Electronics Lab	U Vijaya Lakshmi/ M Prashanth	
DC Machines and Transformers Lab	V Vijaya Rama Raju / M Rekha	
III YEAR (GR20)	Section-A	
Power System Analysis	Dr J Sridevi	
Power Electronics	Dr Pakkiraiah B	
Microproces sors and Microcontrol lers	Dr D Raveedhra	
Electrical and Hybrid Vehicles (PE-1)	Dr D G Padhan	
Cloud Computing (NPTEL)	P Ravikanth	
Power Systems Lab	Dr J Sridevi / V Usha Rani/ U Vijaya Lakshmi	
Power Electronics Lab	Dr Pakkiraiah B/ G Sandhya Rani	
Microproces sors and Microcontrol lers Lab	Dr P Srividya Devi/ M N Sandhya Rani	
IV YEAR(GR18)	Section-A	Section-B
Power Systems – III	Dr P Srividya Devi	P Prashanth Kumar
Electronics Design	Dr D S N M Rao	Dr D S N M Rao
Electrical and Hybrid Vehicles (PE-III)	D Srinivasa Rao	D Srinivasa Rao
High Voltage Engineering (PE-IV)	A Vinay Kumar	A Vinay Kumar
Robotics	Anitha (Mech)	
Database Management Systems	D Swathi (CSE)	
Electronics Design Lab	P Ravikanth /Dr DSNM Rao	D Karuna Kumar/ V Usha Rani
Project work - (PhaseI)	A Vinay Kumar/ D Srinivasa Rao	M N Sandhya Rani / G Sandhya Rani
I/I BEE(GR20)	Theory	LAB
EEE (1) BEE	R Anil Kumar/ P Praveen Kumar / P Prashanth Kumar/ K Sudha	
ECE (3) BEE		
IT (3) BEE		
CSBS (1) PEE		
Design Thinking	Dr D G Padhan	
Mech II/I (GR20)	A	
BEEE	M N Sandhya Rani	

Dr Phaneendra Babu B

HOD,EEE

Gokaraju Rangaraju Institute of Engineering and Technology

Department of Electrical and Electronics Engineering

GRIET/PRIN/06/G/01/22-23 — **Wef : 13th June 2022**

BTech - EEE - A — **IV Year - I Semester**

DAY/ HOUR	10:20-11:15	11:15-12:10	12:10-01:05	01:05-01:40	01:40-02:30	02:30-03:20	03:20-04:10
MONDAY	HVE		ED	BREAK	PS-III		RB/DBMS
TUESDAY	PS-III		RB/DBMS		ED Lab/PW-I		
WEDNESDAY	PS-III	EHV			HVE		-
THURSDAY	ED		RB/DBMS		PW-I/ED Lab		
FRIDAY	RB/DBMS		Mentoring		EHV		HVE
SATURDAY	EHV	ED			PW-I		

ROOM NO	
Theory/Tutorial	4404
Lab	MP Phase I - 4404 ED Lab - 4407
Class Incharge:	M. N. Sandhya Rani

Course Code	Course Name	Faculty Code	Faculty Name (Emp ID)
GR18A4012	Power Systems-III (PS-III)	Dr PSVD	Dr. P. Srividya Devi (931)
GR18A4013	Electronics Design (ED)	Dr DSNM	Dr. D. S. Naga Malleswara Rao (1598)
GR18A4014	Electrical and Hybrid Vehicles (EHV)	DSR	D. Srinivasa Rao (1540)
GR18A4021	High Voltage Engineeering (HVE)	AVK	A Vinay Kumar (881)
GR18A4022	Electronics Design Lab (ED Lab)	VUR/ DKK	V. Usharani/ D. Karuna Kumar (1045/760)
GR18A4061	Project Work Phase - I (PW-I)	AVK/DSR	A. Vinay Kumar/D Srinivasa Rao (881/1540)
GR18A4079/ GR18A2068	Robotics (RB)/ Data Base Management System (DBMS)	Dr. AAL/DS	Dr. A. Anitha Lakshmi (AAL) (944)/ D. Swathi (1681)

Almanac	
1st Spell of Instructions	13-06-2022 to 06-08-2022
1st Mid-term Examinations	08-08-2022 to 11-08-2022
2nd Spell of Instructions	12-08-2022 to 06-10-2022
2nd Mid-term Examinations	07-10-2022 to 11-10-2022
Preparation	12-10-2022 to 18-10-2022
End Semester Examinations (Theory/ Practicals) Regular / Supplementary	19-10-2022 to 08-11-2022

Time Table Coordinator — **HOD** — **DAA**

Gokaraju Rangaraju Institute of Engineering and Technology

Department of Electrical and Electronics Engineering

GRIET/PRIN/06/G/01/22-23 | **Wef : 13th June 2022**

BTech - EEE - B | **IV Year - I Semester**

DAY/ HOUR	10:20-11:15	11:15-12:10	12:10-01:05	01:05-01:40	01:40-02:30	02:30-03:20	03:20-04:10
MONDAY	PS-III	EHV		BREAK	ED		RB/DBMS
TUESDAY	HVE		RB/DBMS		EHV		-
WEDNESDAY	PS-III		HVE		PW-I/ED Lab		
THURSDAY	PS-III	EHV	RB/DBMS		Mentoring	ED	
FRIDAY	RB/DBMS		ED		ED Lab/PW-I		
SATURDAY	HVE		PS-III		PW-I		

ROOM NO	
Theory/Tutorial	4412
Lab	MP Phase I - 4412 ED Lab - 4407
Class Incharge:	M. N. Sandhya Rani

Course Code	Course Name	Faculty Code	Faculty Name (Emp ID)
GR18A4012	Power Systems-III (PS-III)	PK	P. Prasanth Kumar (1055)
GR18A4013	Electronics Design (ED)	Dr DSNM	Dr. D. S. Naga Malleswara Rao (1598)
GR18A4014	Electrical and Hybrid Vehicles (EHV)	DSR	D. Srinivasa Rao (1540)
GR18A4021	High Voltage Engineeering (HVE)	AVK	A Vinay Kumar (881)
GR18A4022	Electronics Design Lab (ED Lab)	PRK/Dr. DSNMR	P. Ravi Kanth/ Dr. D. S. Naga Malleswara Rao (1178/1598)
GR18A4061	Project Work Phase - I (PW-I)	GSR/MNSR	G. Sandhya Rani/M. N. Sandhya Rani(888/882)
GR18A4079/ GR18A2068	Robotics (RB)/ Data Base Management System (DBMS)	Dr. AAL/DS	Dr. A. Anitha Lakshmi (AAL) (944)/ D. Swathi (1681)

Almanac	
1st Spell of Instructions	13-06-2022 to 06-08-2022
1st Mid-term Examinations	08-08-2022 to 11-08-2022
2nd Spell of Instructions	12-08-2022 to 06-10-2022
2nd Mid-term Examinations	07-10-2022 to 11-10-2022
Preparation	12-10-2022 to 18-10-2022
End Semester Examinations (Theory/ Practicals) Regular / Supplementary	19-10-2022 to 08-11-2022

Time Table Coordinator | **HOD** | **DAA**

GOKARAJURANGARAJU INSTITUTE OF ENGINEERING AND TECHNOLOGY
(Autonomous)
Department of Electrical and Electronics Engineering

POWER SYSTEMS-III

Course Code: GR18A4012 **L:3 P:0 T:0 C:3**
IV year I semester

Course Objectives: -
The objective of this course is to provide the student:

1 Explain about the operation and control the voltage, frequency
2 Illustrate different methods of Reactive Power compensation
3 Monitoring and control of a power system.
4 Basics of power system economics
5. Basics of Demand Side-management

Course Outcomes:
At the end of this course, students will demonstrate the ability to

1.List methods to control the voltage, frequency and power flow.
2. Summaries about Reactive Power compensation
3.Compose monitoring and control of a power system.
4 Recall the basics of power system economics.
5.Write about Demand Side-management

Unit -1: Control of Frequency and Voltage:
Turbines and Speed-Governors, Frequency dependence of loads, Droop Control and Power Sharing. Automatic Generation Control. Excitation System Control in synchronous generators, Automatic Voltage Regulators(AVR).

Unit 2 Reactive Power Compensation:
Generation and absorption of reactive power byvarious components of a Power System. Shunt Compensators, Static VAR compensatorsand STATCOMs. Tap Changing Transformers. Power flow control using embedded dc links, phase shifters

Unit 3: Monitoring and Control:
Overview of Energy Control Centre Functions: SCADA systems. Phasor Measurement Units and Wide-Area Measurement Systems. State-estimation. System Security Assessment. Normal, Alert, Emergency, Extremis states of a Power System. Contingency Analysis. Preventive Control and Emergency Control.

Unit 4: **Power System Economics:**
Basic Pricing Principles: Generator Cost Curves, Utility Functions, Power Exchanges, Spot Pricing. Electricity Market Models (Vertically Integrated, Purchasing Agency, Whole-sale

competition, Retail Competition),

Unit 5:Power Management:
Demand Side-management, Transmission andDistributions charges, Ancillary Services. Regulatory framework.

Text Books:

1. J. Grainger and W. D. Stevenson, “Power System Analysis”, McGraw Hill Education, 1994.
2. P.Kundur, “Power System Stability and Control” McGraw Hill Education, 1994
3. O. I. Elgerd, “Electric Energy Systems Theory”, McGraw Hill Education, 1995.
4. A. R. Bergen and V. Vittal, “Power System Analysis”, Pearson Education Inc., 1999.
5. D. P. Kothari and I. J. Nagrath, “Modern Power System Analysis”, McGraw Hill Education,2003.

References:

1. B. M. Weedy, B. J. Cory, N. Jenkins, J. Ekanayake and G. Strbac, “Electric Power Systems”,Wiley, 2012.

Gokaraju Rangaraju Institute of Engineering and Technology (Autonomous)Bachupally, Kukatpally, Hyderabad – 500 090, A.P., India. (040) 6686 4440

SCHEDULE OF INSTRUCTIONS
COURSE PLAN

Academic **Y**ear	: **2022 - 2023**		
Semester	: **I**		
Name of the Program	: **B.Tech**	Year: **IV**	Section: **B**
Course/Subject	: **POWER SYSTEMS-III**		
Course Code	: **GR18A4012**		
Name of the Faculty	: **P Prasanth Kumar**		Dept.: **EEE**
Designation	: **ASSISTANT PROFESSOR**		

Lesson No	Date	Unit	Periods	Topics	Objectives & Outcomes Nos.
1	04-07-2022	I	1	Turbines and speed governors	OBJ-1, OUTC-1
2	06-07-2022	I	2	Turbines and speed governors	OBJ-1, OUTC-1
3	07-07-2022	I	1	Frequency dependence of loads	OBJ-1, OUTC-1
4	09-07-2022	I	1	Frequency dependence of loads	OBJ-1, OUTC-1
5	11-07-2022	I	1	Droop control	OBJ-1, OUTC-1
6	13-07-2022	I	2	Droop control	OBJ-1, OUTC-1
7	14-07-2022	I	1	Concept of Power sharing	OBJ-1, OUTC-1
8	16-07-2022	I	1	Concept of Power sharing	OBJ-1, OUTC-1
9	18-07-2022	I	1	Automatic generation control	OBJ-1, OUTC-1
10	20-07-2022	I	2	Automatic generation control	OBJ-1, OUTC-1
11	21-07-2022	I	1	Excitation control in synchronous generators	OBJ-1, OUTC-1
12	23-07-2022	I	1	Excitation control in synchronous generators	OBJ-1, OUTC-1
13	25-07-2022	I	1	Automatic voltage regulators	OBJ-1, OUTC-1
14	27-07-2022	I	2	Automatic voltage regulators	OBJ-1, OUTC-1
15	28-07-2022	II	1	Generation and absorption of reactive power by various components	OBJ-2, OUTC-2
16	30-07-2022	II	1	Generation and absorption of reactive power by various components	OBJ-2, OUTC-2
17	01-08-2022	II	1	Shunt compensators	OBJ-2, OUTC-2

18	03-08-2022	II	2	Shunt compensators	OBJ-2, OUTC-2
19	04-08-2022	II	1	Static VAR compensators	OBJ-2, OUTC-2
20	06-08-2022	II	1	Static VAR compensators	OBJ-2, OUTC-2
21	08-08-2022	II	1	STATCOMs	OBJ-2, OUTC-2
22	10-08-2022	II	2	STATCOMs	OBJ-2, OUTC-2
23	11-08-2022	II	1	Tape changing transformers	OBJ-2, OUTC-2
24	13-08-2022	II	1	Tape changing transformers	OBJ-2, OUTC-2
25	17-08-2022	II	2	Power flow control using embeded DC links and phase shifters	OBJ-2, OUTC-2
26	20-08-2022	II	1	Power flow control using embeded DC links and phase shifters	OBJ-2, OUTC-2
27	22-08-2022	III	1	Overview of energy control centre functions	OBJ-3, OUTC-3
28	24-08-2022	III	1	Overview of energy control centre functions	OBJ-3, OUTC-3
29	25-08-2022	III	1	SCADA systems	OBJ-3, OUTC-3
30	27-08-2022	III	2	SCADA systems	OBJ-3, OUTC-3
31	29-08-2022	III	1	Phasor measurement units	OBJ-3, OUTC-3
32	01-09-2022	III	1	Phasor measurement units	OBJ-3, OUTC-3
33	05-09-2022	III	1	Wide-area measurement systems	OBJ-3, OUTC-3
34	07-09-2022	III	1	Wide-area measurement systems	OBJ-3, OUTC-3
35	08-09-2022	III	1	Static estimation	OBJ-3, OUTC-3
36	10-09-2022	III	2	Static estimation	OBJ-3, OUTC-3
37	12-09-2022		1	MID-I Exam	
38	14-09-2022		2	MID-I Exam	
39	15-09-2022	III	1	System security assessment	OBJ-3, OUTC-3
40	17-09-2022	III	1	System security assessment	OBJ-3, OUTC-3
41	19-09-2022	III	1	Normal, Alert states of power system	OBJ-3, OUTC-3
42	21-09-2022	III	2	Normal, Alert states of power system	OBJ-3, OUTC-3
43	22-09-2022	III	1	Emergency and extremis states of power system	OBJ-3, OUTC-3
44	24-09-2022	III	1	Emergency and extremis states of power system	OBJ-4, OUTC-4
45	26-09-2022	III	1	Contingency analysis	OBJ-4, OUTC-4
46	28-09-2022	III	2	Contingency analysis	OBJ-4, OUTC-4
47	29-09-2022	III	1	Preventive control	OBJ-4, OUTC-4

48	01-10-2022	III	1	Preventive control	OBJ-4, OUTC-4
49	03-10-2022	III	1	Emergency control	OBJ-4, OUTC-4
50	05-10-2022	III	2	Emergency control	OBJ-4, OUTC-4
51	06-10-2022	IV	1	Basic pricing principles	OBJ-4, OUTC-4
52	08-10-2022	IV	1	Basic pricing principles	OBJ-4, OUTC-4
53	10-10-2022	IV	1	Generator cost curves	OBJ-4, OUTC-4
54	12-10-2022	IV	2	Generator cost curves	OBJ-4, OUTC-4
55	13-10-2022	IV	1	Utility functions	OBJ-4, OUTC-4
56	15-10-2022	IV	1	Power exchanges	OBJ-4, OUTC-4
57	17-10-2022	IV	1	Spot pricing	OBJ-4, OUTC-4
58	19-10-2022	IV	2	Electricity market models	OBJ-4, OUTC-4
59	20-10-2022	IV	1	Vertically Integrated	OBJ-4, OUTC-4
60	22-10-2022	IV	1	Purchasing Agency	OBJ-4, OUTC-4
61	26-10-2022	IV	1	Whole-sale competition	OBJ-4, OUTC-4
62	27-10-2022	V	2	Demand side-management	OBJ-5, OUTC-5
63	29-10-2022	V	1	Demand side-management	OBJ-5, OUTC-5
64	31-10-2022	V	1	Transmission and distribution charges	OBJ-5, OUTC-5
65	02-11-2022	V	2	Transmission and distribution charges	OBJ-5, OUTC-5
66	03-11-2022	V	1	Ancillary services	OBJ-5, OUTC-5
67	05-11-2022	V	1	Ancillary services	OBJ-5, OUTC-5
68	07-11-2022	V	1	Regulatory framework	OBJ-5, OUTC-5
69	09-11-2022	V	2	Regulatory framework	OBJ-5, OUTC-5
70	10-11-2022	V	1	Revision	OBJ-5, OUTC-5

Signature of Faculty   Date:

Gokaraju Rangaraju Institute of Engineering and Technology (Autonomous)

Bachupally, Kukatpally, Hyderabad – 500 090, A.P., India. (040) 6686 4440

SCHEDULE OF INSTRUCTIONS
UNIT PLAN-1

Academic Year : **2022 - 2023**

Semester : **I**

Name of the Program : **B.Tech** Year: **IV** Section: **B**

Course/Subject : **POWER SYSTEMS-III**

Course Code : **GR18A4012**

Name of the Faculty : **P Prasanth Kumar** Dept.: **EEE**

Designation : **ASSISTANT PROFESSOR**

Lesson No	Date	Unit	Periods	Topics	Objectives & Outcomes Nos.
1	04-07-2022	I	1	Turbines and speed governors	OBJ-1, OUTC-1
2	06-07-2022	I	2	Turbines and speed governors	OBJ-1, OUTC-1
3	07-07-2022	I	1	Frequency dependence of loads	OBJ-1, OUTC-1
4	09-07-2022	I	1	Frequency dependence of loads	OBJ-1, OUTC-1
5	11-07-2022	I	1	Droop control	OBJ-1, OUTC-1
6	13-07-2022	I	2	Droop control	OBJ-1, OUTC-1
7	14-07-2022	I	1	Concept of Power sharing	OBJ-1, OUTC-1
8	16-07-2022	I	1	Concept of Power sharing	OBJ-1, OUTC-1
9	18-07-2022	I	1	Automatic generation control	OBJ-1, OUTC-1
10	20-07-2022	I	2	Automatic generation control	OBJ-1, OUTC-1
11	21-07-2022	I	1	Excitation control in synchronous generators	OBJ-1, OUTC-1
12	23-07-2022	I	1	Excitation control in synchronous generators	OBJ-1, OUTC-1
13	25-07-2022	I	1	Automatic voltage regulators	OBJ-1, OUTC-1
14	27-07-2022	I	2	Automatic voltage regulators	OBJ-1, OUTC-1

Signature of HOD

Date:

Signature of faculty

Date:

Gokaraju Rangaraju Institute of Engineering and Technology (Autonomous)

Bachupally, Kukatpally, Hyderabad – 500 090, A.P., India. (040) 6686 4440

SCHEDULE OF INSTRUCTIONS
UNIT PLAN-2

Academic Year	: **2022 - 2023**		
Semester	: **I**		
Name of the Program	: **B. Tech**	Year: **IV**	Section: **B**
Course/Subject	: **POWER SYSTEMS-III**		
Course Code	: **GR18A4012**		
Name of the Faculty	: **P Prasanth Kumar**		Dept.: **EEE**
Designation	: **ASSISTANT PROFESSOR**		

Lesson No	Date	Unit	Periods	Topics	Objectives & Outcomes Nos.
1	28-07-2022	II	1	Generation and absorption of reactive power by various components	OBJ-2, OUTC-2
2	30-07-2022	II	1	Generation and absorption of reactive power by various components	OBJ-2, OUTC-2
3	01-08-2022	II	1	Shunt compensators	OBJ-2, OUTC-2
4	03-08-2022	II	2	Shunt compensators	OBJ-2, OUTC-2
5	04-08-2022	II	1	Static VAR compensators	OBJ-2, OUTC-2
6	06-08-2022	II	1	Static VAR compensators	OBJ-2, OUTC-2
7	08-08-2022	II	1	STATCOMs	OBJ-2, OUTC-2
8	10-08-2022	II	2	STATCOMs	OBJ-2, OUTC-2
9	11-08-2022	II	1	Tape changing transformers	OBJ-2, OUTC-2
10	13-08-2022	II	1	Tape changing transformers	OBJ-2, OUTC-2
11	17-08-2022	II	2	Power flow control using embedded DC links and phase shifters	OBJ-2, OUTC-2
12	20-08-2022	II	1	Power flow control using embedded DC links and phase shifters	OBJ-2, OUTC-2

Signature of HOD

Date:

Signature of faculty

Date:

Gokaraju Rangaraju Institute of Engineering and Technology
(Autonomous)

Bachupally, Kukatpally, Hyderabad – 500 090, India. (040) 6686 4440

SCHEDULE OF INSTRUCTIONS
UNIT PLAN-3

Academic Year	: **2022 - 2023**
Semester	: **I**
Name of the Program	: **B. Tech** Year: **IV** Section: **B**
Course/Subject	: **POWER SYSTEMS-III**
Course Code	: **GR18A4012**
Name of the Faculty	: **P Prasanth Kumar** Dept.: **EEE**
Designation	: **ASSISTANT PROFESSOR**

Lesson No	Date	Unit	Periods	Topics	Objectives & Outcomes Nos.
1	22-08-2022	III	1	Overview of energy control centre functions	OBJ-3, OUTC-3
2	24-08-2022	III	1	Overview of energy control centre functions	OBJ-3, OUTC-3
3	25-08-2022	III	1	SCADA systems	OBJ-3, OUTC-3
4	27-08-2022	III	2	SCADA systems	OBJ-3, OUTC-3
5	29-08-2022	III	1	Phasor measurement units	OBJ-3, OUTC-3
6	01-09-2022	III	1	Phasor measurement units	OBJ-3, OUTC-3
7	05-09-2022	III	1	Wide-area measurement systems	OBJ-3, OUTC-3
8	07-09-2022	III	1	Wide-area measurement systems	OBJ-3, OUTC-3
9	08-09-2022	III	1	Static estimation	OBJ-3, OUTC-3
10	10-09-2022	III	2	Static estimation	OBJ-3, OUTC-3
11	12-09-2022		1	MID-I Exam	OBJ-3, OUTC-3
12	14-09-2022		2	MID-I Exam	OBJ-3, OUTC-3
13	15-09-2022	III	1	System security assessment	OBJ-3, OUTC-3
14	17-09-2022	III	1	System security assessment	OBJ-3, OUTC-3
15	19-09-2022	III	1	Normal, Alert states of power system	OBJ-3, OUTC-3
16	21-09-2022	III	2	Normal, Alert states of power system	OBJ-3, OUTC-3
17	22-09-2022	III	1	Emergency states of power system	OBJ-3, OUTC-3
18	24-09-2022	III	1	Extremis states of power system	OBJ-3, OUTC-3
19	26-09-2022	III	1	Contingency analysis	OBJ-3, OUTC-3
20	28-09-2022	III	2	Contingency analysis	OBJ-3, OUTC-3
21	29-09-2022	III	1	Preventive control	OBJ-3, OUTC-3
22	01-10-2022	III	1	Preventive control	OBJ-3, OUTC-3
23	03-10-2022	III	1	Emergency control	OBJ-3, OUTC-3
24	05-10-2022	III	2	Emergency control	OBJ-3, OUTC-3

Signature of HOD   Signature of faculty

Date: Date:

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SCHEDULE OF INSTRUCTIONS
UNIT PLAN-4

Academic Year : **2022 - 2023**

Semester : **I**

Name of the Program : **B.Tech** Year: **IV** Section: **B**

Course/Subject : **POWER SYSTEMS-III**

Course Code : **GR18A4012**

Name of the Faculty : **P Prasanth Kumar** Dept.: **EEE**

Designation : **ASSISTANT PROFESSOR**

Lesson No	Date	Unit	Periods	Topics	Objectives & Outcomes Nos.
1	06-10-2022	IV	1	Basic pricing principles	OBJ-4, OUTC-4
2	08-10-2022	IV	1	Basic pricing principles	OBJ-4, OUTC-4
3	10-10-2022	IV	1	Generator cost curves	OBJ-4, OUTC-4
4	12-10-2022	IV	2	Generator cost curves	OBJ-4, OUTC-4
5	13-10-2022	IV	1	Utility functions	OBJ-4, OUTC-4
6	15-10-2022	IV	1	Power exchanges	OBJ-4, OUTC-4
7	17-10-2022	IV	1	Spot pricing	OBJ-4, OUTC-4
8	19-10-2022	IV	2	Electricity market models	OBJ-4, OUTC-4
9	20-10-2022	IV	1	Vertically Integrated	OBJ-4, OUTC-4
10	22-10-2022	IV	1	Purchasing Agency	OBJ-4, OUTC-4
11	26-10-2022	IV	1	Whole-sale competition	OBJ-4, OUTC-4

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Date: Date:

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SCHEDULE OF INSTRUCTIONS
UNIT PLAN-5

Academic Year : **2022 - 2023**

Semester : **I**

Name of the Program : **B.Tech** Year: **I V** Section: **B**

Course/Subject : **POWER SYSTEMS-III**

Course Code : **GR18A4012**

Name of the Faculty : **P Prasanth Kumar** Dept.: **EEE**

Designation : **ASSISTANT PROFESSOR**

Lesson No	Date	Unit	Periods	Topics	Objectives & Outcomes Nos.
1	27-10-2022	V	2	Demand side-management	OBJ-5, OUTC-5
2	29-10-2022	V	1	Demand side-management	OBJ-5, OUTC-5
3	31-10-2022	V	1	Transmission and distribution charges	OBJ-5, OUTC-5
4	02-11-2022	V	2	Transmission and distribution charges	OBJ-5, OUTC-5
5	03-11-2022	V	1	Ancillary services	OBJ-5, OUTC-5
6	05-11-2022	V	1	Ancillary services	OBJ-5, OUTC-5
7	07-11-2022	V	1	Regulatory framework	OBJ-5, OUTC-5
8	09-11-2022	V	2	Regulatory framework	OBJ-5, OUTC-5
9	10-11-2022	V	1	Revision	OBJ-5, OUTC-5

Signature of HOD Signature of faculty

Date: Date:

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COURSE SCHEDULE

Academic **Y**ear	: **2022 - 2023**
Semester	: **I**
Name of the Program	: **B.Tech**
Year	: **IV**
Section	: **B**
Course/Subject	: **POWER SYSTEMS-III**
Course Code	: **GR18A4012**
Name of the Faculty	: **P Prasanth Kumar** Dept.: **EEE**
Designation	: **ASSISTANT PROFESSOR**

The Schedule for the whole Course / Subject is:

S. No.	Description	Duration (Date)		Total No. Of Periods
		From	To	
1.	**Unit-1**	04-07-2022	27-07-2022	18
2.	**Unit-II**	28-07-2022	20-08-2022	15
3.	**Unit-III**	22-08-2022	05-10-2022	30
4.	**Unit-IV**	06-10-2022	26-10-2022	13
5.	**Unit-V**	27-10-2022	10-11-2022	12

Total No. of Instructional periods available for the course: **88** Hours / Periods

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ASSESSMENT METHODS

Academic Year	: **2022 - 2023**		
Semester	: **I**		
Name of the Program	: **B.Tech**	Year: **IV**	Section: **B**
Course/Subject	: **POWER SYSTEMS-III**		
Course Code	: **GR18A4012**		
Name of the Faculty	: **P Prasanth Kumar**		Dept.: **EEE**
Designation	: **ASSISTANT PROFESSOR**		

Evaluation scheme based on OBE system ---- **30M**

1. Tutorial sheets & assignment ---- **10M**
2. Seminars allotted to students ---- **5M**
   i) Gathering of information (1M)
   ii) Presentation (2M)
   iii) Interaction (2M)
3. Attitude & Classroom assessment ---- **5M**
   i) Punctuality
   ii) Interaction and participation
   iii) Maintaining notes
   iv) Proper dress code
   v) Decent behavior in classroom
4. Rubrics based on each unit ---- **5M**
5. Attendance ---- **5M**

Signature of HOD

Date:

Course Outcome	a	b	c	d	e	f	g	h	i	j	k	l	PSO1	PSO2
List methods to control the voltage, frequency and power flow.	H	H	H	H	H			H	M	H	H	H	M	H
Summaries about Reactive Power compensation	H	H	H		H			M		M	H	H	M	H
Compose monitoring and control of a power system.	H	H	H	M	M	H		H	H	M	H	H	M	H
Recall the basics of power system economics.	H			M	H		M	H	M		H	H	M	H
Write about Demand Side-management	H		H	M	H	M	M		H	M	H	H	M	H

GOKARAJU RANGARAJU
Institute of Engineering and Technology
(Autonomous)

Department of Electrical and Electronics Engineering

POWER SYSTEMS-III

CO – Cognitive Level Mapping

C	1	2	3	4	5	6
CO-1	X	X				
CO-2	X	X				
CO-3		X	X			
CO-4			X	X		
CO-5		X		X		

1-REMEMBER

2-UNDERSTAND

3-APPLY

4-ANALYSE

5-EVALUATE

6-CREATE

CO-1: List methods to control the voltage, frequency, and power flow.

CO-2: Summaries about Reactive Power compensation

CO-3: Compose monitoring and control of a power system.

CO-4: Recall the basics of power system economics.

CO-5: Write about Demand Side-management.

INTRODUCTION

Introduction :

* Power system operation considered so far under conditions of steady load.
* However, both active and reactive power demands are never steady and they continually change with the rising or falling trend.
* Steam input to turbo generators must therefore be continuously regulated to match the active power demand, failing which the machine speed will vary with consequent change in frequency which may be undesirable.
* Also the excitation of generators must be continuously regulated to match the reactive power demand with reactive generation, otherwise the voltages at various system buses may go beyond the prescribed limits.
* The frequency of a power system is dependent entirely upon the speed at which the generators are rotated by their primemovers.
* Therefore, frequency control is basically a matter of speed control of the machines in the generating stations.
* For example, a load is suddenly applied to the system, the individual generators will meet this demand by the action of primemover governors.

* The immediate effect of a sudden load demand is a reduction in speed of synchronous generators.
* However the kinetic energy is normally sufficient to maintain the energy balance until the reduction in speed is detected by the drooping characteristic of the governor, which operates the gate or control valve opening to restore the output and input balance by increasing the prime mover torque.
* Thus the function of load frequency control on a power system becomes one of changing the control valve or gate openings of the generator prime mover as a function of load variations in order to hold system frequency constant.
* Power system operation at a lower frequency than that specified maximum permissible change in frequency is ($\pm 0.5 Hz$) affects the quality of power supply and is not allowed because of the following:
   * When operating at frequencies below 49.5 Hz, some types of steam turbines undergo excessive vibration in certain turbine rotor status resultant metal fatigue and blade failures.
   * When the frequency falls below 49 Hz, the turbine regulating devices fully open and the generating units become completely loaded.

A further decrease in frequency reduces the efficiency of auxillary mechanisms at thermal power stations, especially feed pumps. The result of prolonged operation at a lowered frequency is a drop in the generated output and further loss of power.

* As the frequency decreases, the generator exciters lose their speed and the generator emf falls, the voltage in the power system unit drop. This brings the danger of a 'Voltage Avalanche' and disconnection of Consumers

* Load frequency Control represents the first realization of higher level Control in power systems.

* It has made the operation of interconnected systems possible and to-day it is still the basis of any advanced Concept for the guidance of large systems.

Nature of Control problems:

* A Control problem is recognized as a problem of determining inputs to a given system to achieve desirable responses, in the presence of constraints.

* The system to be controlled is defined as the plant. The plant is characterised by a set of inputs, a set of state variables and a set of outputs.

* These variables are related by differential or difference equations characterising the plant.

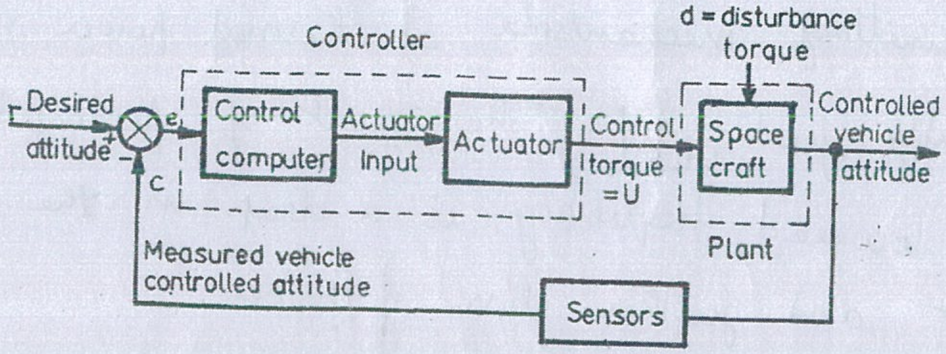


Fig. 15.1. (a) Block diagram for a space craft attitude control system.

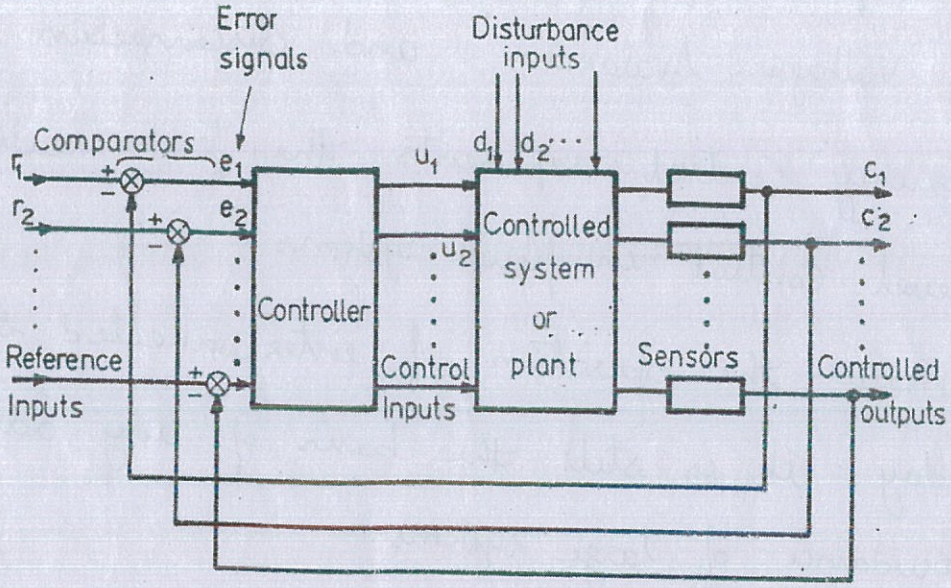


Fig. 15.1. (b) Multiple-input multiple-output control system.

* Fig ⓐ shows a block diagram for a space craft attitude control system where space craft is the plant.

* The control torque is an example of plant control input or simply control input.

* The disturbance input such as disturbance torque from solar radiation is not available for manipulation.

* The Control input on the other hand can be manipulated by the system designer as an output of a sub system called the Controller.

* In our attitude control system example, the control torque is generated by an actuator whose input comes from a Control Computer.

* The input to the Control computer is the error signal which comes from the Comparator.

* The measured vehicle orientation is the set of outputs from sensors such as gyroscopes.

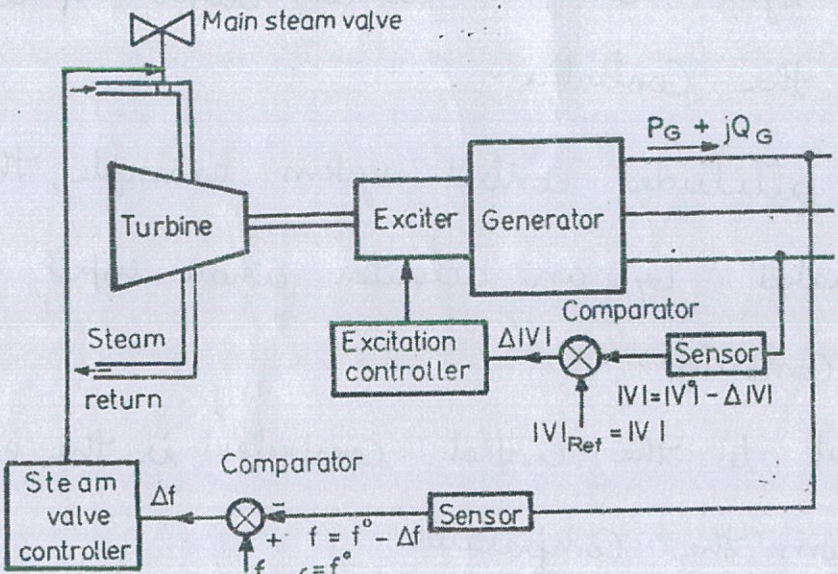
* The desired attitude is an example of an external input and the measured vehicle orientation is an example of feedback signals from the plant.

* Sometimes the sensors or transducers constitute part of the Controller and we refer to the sensors inputs from the plant as feedback signals to the Controller.

* The Composite system consisting of plant, comparators, sensors and the controller is called a Control system.

* A general configuration is shown in fig b.

Automatic Voltage and Frequency Control:



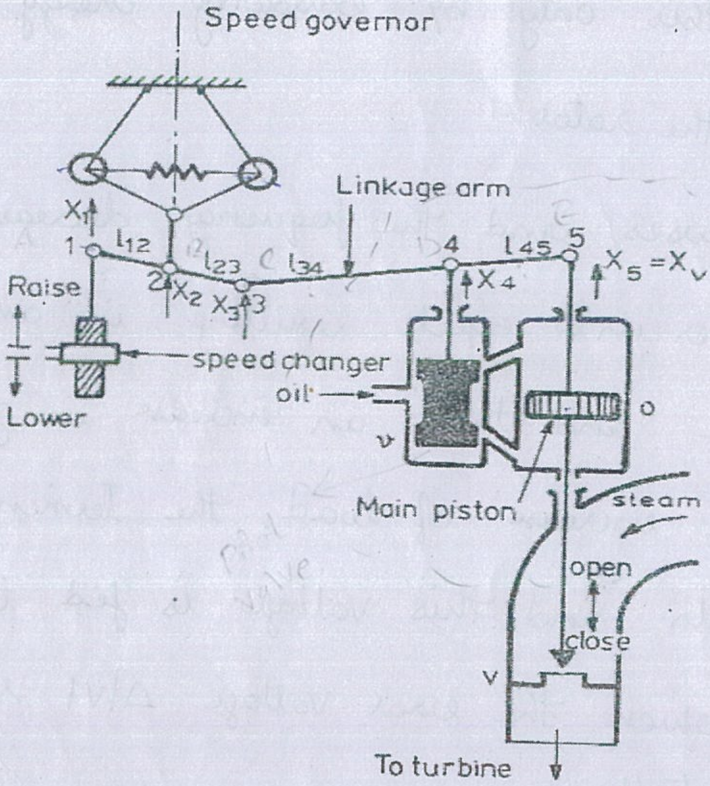
* In modern power systems it is not possible to hold voltage and frequency constant by manual control and therefore automatic control equipments or devices are used in the generation plants.
* In Fig, the system is initially in a constant steady state, characterised by a constant nominal frequency f^0 and constant terminal voltage $|V^0|$ and a constant generator power output $S_G^0 = P_G^0 + jQ_G^0$.
* Suppose there is sudden increase of active load on the generator.
* Upon the onset of the load increase the generator finds itself momentarily in a power-deficiency situation.

delivering more power than it receives.

* It can do this only by borrowing energy from the kinetic energy of the rotor.
* As time passes and the frequency decreases, the steam valve controller goes in to effect resulting in an opening of the steam valve and thus an increase in generation.
* Due to the increase of load, the terminal voltage of the generator falls and this voltage is fed to the comparator and from which the error voltage $\Delta|V|$ signal goes to the excitation controller.
* The excitation controller goes in to action and increase the excitation current of the field rotor and thus increasing the terminal voltage with the exact amount to offset the original voltage decrease.

Basic Concepts of Governor mechanisms and their performance in the steady state:

* The speed governor is the main primary tool for the load frequency control, whether the machine is used alone to feed a smaller system or whether it is a part of the most elaborate arrangement.
* A schematic arrangement of the main features of a speed governing system used in steam turbines ~~are~~ is shown in fig.



(i) Centrifugal Governor:

* This is almost without exception, is purely mechanical speed sensitive device coupled directly to and built directly on the prime movers to adjust the control valve opening via the linkage system.
* For example with the increased speed the flyballs move outwards and the point 2 moves upward and the reverse happens with the decreased speed.

(ii) Hydraulic Amplifier:

* It consists of pilot valve V and oil servomotor, O.
* With this arrangement hydraulic amplification is achieved ie a low power pilot valve movement is converted into high power level movement of oil servomotor piston.

Hydraulic amplification is necessary, so that the steam valve could be operated against high pressure steam.

(iii) Speed Changer:

* It makes it possible to restore the frequency to the initial value after operation of the speed governors having a steady state characteristics.
* Further it provides a steady state power output setting for the turbine.

(iv) Linkage Mechanisms:

* 123 is a rigid link pivoted at point 2 and 345 is another rigid link pivoted at point 4.
* The function of this link mechanism is to control the steam valve V.
* Only one valve V, is shown in fig, but actually steam turbines have a number of them which are opened in succession with as small an overlap as possible in order to maintain high efficiency.
* Further via link 45 we get a feedback form the movement of steam valve.

Speed-Governing System Model:

* Let us suppose that the steam is operating under steady state and is delivering power P_G° from the generator at nominal speed or frequency f°.
* Under this condition the prime mover valve has a constant setting x_5°; pivot value is closed and the

the linkage mechanism stationary.

* With the help of the speed changer, we command a power increase ΔP_c.

* Due to this command, let the linkage point 1 moves upward a small distance Δx_1, which causes the turbine o/p power to change and we may write

$$\Delta x_1 = k \Delta P_c .$$

* With the movement of Δx_1, the link point 3 moves downwards by an amount $\Delta x_3'$ and so does the link point 4 by an amount $\Delta x_4'$ downwards.

* Due to the movement of link point 4 ~~by an amount Δx_4~~ the high pressure oil flows in the bottom of the main piston of the servomotor O and thus causes the motion of the piston upward by an amount Δx_5.

* Due to the opening of steam valve there is increased flow of steam resulting in increased torque and consequently, a power increase ΔP_a.

* The increased power output causes accelerating power in the system and there is slight increase in frequency say by Δf if the system is connected to a finite size

* However if the system is very large, the increase power will not noticeably affect the frequency.

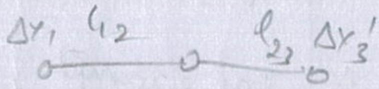
* Now with increased speed the flyballs of the governor move outwards, thus causing the link point 2 to move slightly upwards a small distance Δx_2 proportional to Δf.

* Due to the upward movement of link point 2, the link point 3 also moves upwards by an amount $\Delta x_3''$ which is also proportional to Δf.

* The net movement of link point 3 is

$$\Delta x_3 = \Delta x_3' + \Delta x_3'' \quad \text{.... (2)}$$

where $\quad -\Delta x_3'(l_{12}) = \Delta x_1(l_{23})$



(or) $$\Delta x_3' = -\left(\frac{l_{23}}{l_{12}}\right)\Delta x_1$$

$$= -k_1 \Delta P_c \quad \text{— (3)}$$

and $$\Delta x_3'' = k_2 \Delta f \quad \text{— (4)}$$

* Thus $$\Delta x_3 = -k_1 \Delta P_c + k_2 \Delta f \quad \text{— (5)}$$

* The movement of link point 4, is contributed by the movement Δx_3 and Δx_5.

* Thus the net movement of link point 4 as

$$\Delta x_4 = \Delta x_4' + \Delta x_4'' \quad \text{— (6)}$$

where $$\Delta x_4'(l_{34} + l_{45}) = \Delta x_3(l_{45}) \quad \text{— (7)}$$

and $$\Delta x_4''(l_{34} + l_{45}) = \Delta x_5(l_{34}) \quad \text{— (8)}$$

* Therefore we may express as

$$\Delta x_4 = k_3 \Delta x_3 + k_4 \Delta x_5 \quad \text{— (9)}$$

* If assumption is that the flow of oil in to the servomotor is proportional to position Δx_4 of the pilot valve V, then the movement of Δx_5 of the piston can be expressed as (The volume of oil admitted is proportional to time integral of Δx_4)

$$\Delta x_5 = \Delta x_v = k_5 \int_0^t (-\Delta x_4)\, dt \quad \text{—(10)}$$

The move of Δx_5 is obtained by dividing oil volume by area of crossection of Piston.

* The negative sign has been taken because the movements of link points 4 and 5 are in opposite direction.

* For example, the small movement of Δx_4 in the negative direction (ie downwards) causes the movement Δx_5 in the positive direction (ie upwards)

* Taking the laplace transform, we get.

$$\Delta x_3(s) = -k_1 \Delta P_c(s) + k_2 \Delta F(s) \quad \text{—(11)}$$

$$\Delta x_4(s) = k_3 \Delta x_3(s) + k_4 \Delta x_5(s) \quad \text{—(12)}$$

$$\therefore \Delta x_5(s) = -k_5 \frac{1}{s} \Delta x_4(s) \quad \text{—(13)}$$

Eliminating $\Delta x_3(s)$ and $\Delta x_4(s)$, we obtain the following equations:

$$\Delta x_5(s) = \frac{k_1 k_3 \Delta P_c(s) - k_2 k_3 \Delta F(s)}{\left(k_4 + \frac{s}{k_5}\right)} \quad \text{—(14)}$$

The above equation may be expressed as:

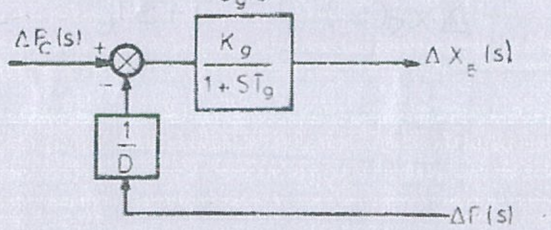
$$\Delta x_5(s) = \left[\Delta P_c(s) - \frac{1}{R}\Delta F(s)\right] \times \frac{k_g}{1+sT_g} \quad \text{—(15)}$$

* where $D \triangleq \frac{k_1}{k_2}$ = speed regulation of the governor

$$k_g \triangleq \frac{k_1 k_3}{k_4} = \text{Gain of speed governor}$$

$$T_g \triangleq \frac{1}{k_4 k_5} = \text{Time constant of speed governor.}$$

$$T_g < 100\,ms.$$



Turbine Model:

* In the above analysis, we found the expression for the change in steam value position.

* Now, we are interested in the increased power generation ΔP_G due to the increased steam valve opening.

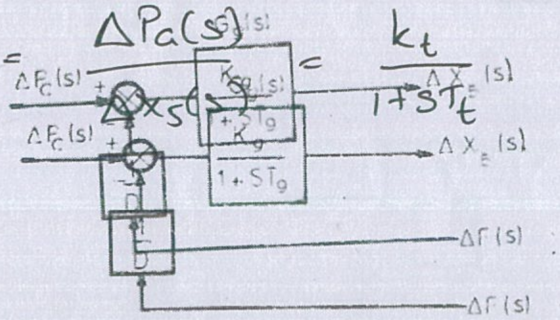
* There is an incremental increase in turbine power, ΔP_T due to the change in value position, ΔX_E, which will result in an increased generator power ΔP_G.

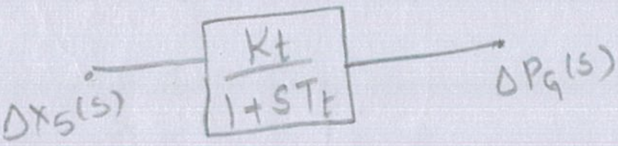
* If the generator incremental loss is neglected then
$\Delta P_T = \Delta P_G$.

* A nonreheat steam turbine is characterized by a single gain factor k_t and a single time constant T_t. ~~to~~

We thus write as

$$G_t(s) = \frac{\Delta P_G(s)}{\Delta X_S(s)} = \frac{k_t}{1+sT_t} \quad -(16)$$





$$G_t(s) = \frac{\Delta P_G(s)}{\Delta X_S(s)}$$

Generator Load Model:

* To develop the mathematical model of an isolated generator, which is only supplying local load and is not supplying power to another area via a tie line.
* Suppose there is a real load change of ΔP_D.
* Due to the action of turbine controllers, the generator increases its output by the amount ΔP_G.
* The net surplus power $\Delta P_G - \Delta P_D$ will be absorbed by the system in two ways:
    * By increasing the kinetic energy W_{kin} in the rotor generator at the rate $(d/dt)\, W_{kin}$.

* By an increased load consumption. All typical loads experience an increase

$$B = \frac{\partial P_D}{\partial f} \ \text{MW/Hz}$$

with frequency. B is called damping coefficient.

* In general, motor loads are more predominant and for them B is positive and found out emphirically.

* Mathematically,

$$\Delta P_G - \Delta P_D = \frac{d}{dt} W_{kin} + B\Delta f \quad \text{MW} \qquad -(17)$$

* First derive an expression for the first term on RHS of eq (17)

* At nominal frequency f°, the kinetic energy of the generator rotor is expressed as

$$W^\circ_{kin} = H \times S_{3\phi} \quad \text{MW-S (or) MJ} \qquad -(18)$$

where $S_{3\phi}$ is MW rating of turbogenerator

H is inertia constant of the generator

* Since kinetic energy is proportional to the square of speed therefore, the kinetic energy at a frequency

$$\frac{W_{kin}}{W^\circ_{kin}} = \left(\frac{f^\circ + \Delta f}{f^\circ}\right)^2$$

$$f = (f^\circ + \Delta f)$$

is given by

$$W_{kin} = W^\circ_{kin}\left[\frac{f^\circ + \Delta f}{f^\circ}\right]^2 = \left(1 + \frac{\Delta f}{f^\circ}\right)^2$$

$$\left(1 + 2\frac{\Delta f}{f^\circ}\right) + \left(\frac{\Delta f}{f^\circ}\right)^2 \qquad (1+x)^n \qquad 1+nx$$

$$= W^\circ_{kin}\left[1 + 2\frac{\Delta f}{f^\circ}\right] \qquad -(19)$$

(or)

$$W_{kin} = HS_{3\phi}\left(1 + 2\frac{\Delta f}{f^\circ}\right] \qquad -(20)$$

* Therefore, rate of change of kinetic energy is

$$\frac{d}{dt}(W_{kin}) = \frac{2HS_{3\phi}}{f^0}\frac{d}{dt}\Delta f \qquad -(21)$$

* Substituting Eq (21) in Eq (17), we get

$$\Delta P_G - \Delta P_D = \frac{2HS_{3\phi}}{f^0}\frac{d}{dt}\Delta f + B\Delta f \ \ MW \qquad -(22)$$

* If we divide all terms by $S_{3\phi}$ the total megawatt rating of the generator, we can write the above equation as

$$\Delta P_G - \Delta P_D = \frac{2H}{f^0}\frac{d}{dt}\Delta f + B\Delta f \ \ pu\ MW \qquad -(23)$$

where the variables ΔP and B now measured in P.u of $S_{3\phi}$

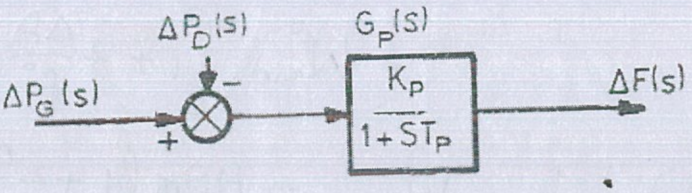
* Taking laplace transform of Eq (23) we get

$$\Delta F(s) = \frac{\Delta P_G(s) - \Delta P_D(s)}{B + \frac{2H}{f^0}s} \qquad -(24)$$

$$\therefore \Delta F(s) = \left[\Delta P_G(s) - \Delta P_D(s)\right] \times \frac{k_P}{1+sT_P} \qquad -(25)$$

where $T_P = \frac{2H}{Bf^0}$ = Power system time constant, in sec

$k_P = \frac{1}{B}$ = reciprocal of load damping parameter, in Hz/pu MW.

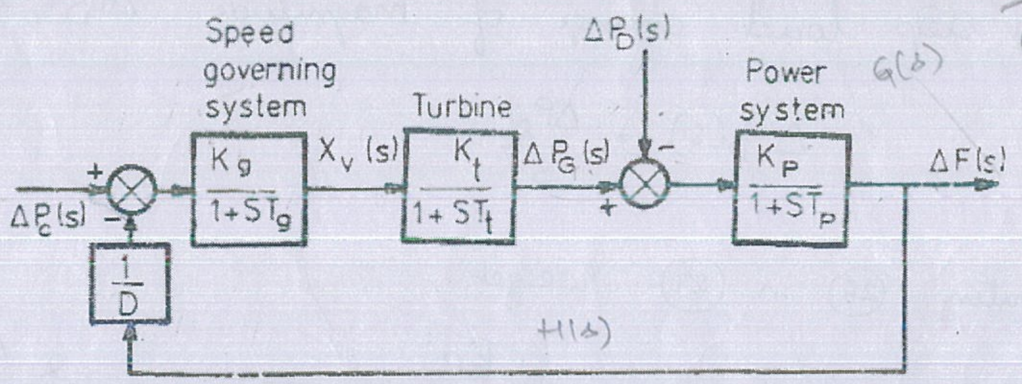


Analysis of Load Frequency Control of an Isolated Power System:

* Consider the case of a single generator supplying power to a local load only.
* Note that the generator is not connected to a network of very large size. (ie infinite bus)
* In order to analyze the load frequency control of an isolated system, we need to build its mathematical model.
* The Complete block diagram of an isolated system is shown in fig.

$-\frac{K_P}{1+ST_P}$

$$\frac{\Delta F(s)}{\Delta P_D(s)} = \frac{G(s)}{1-G(s)H(s)}$$



* There are two incremental inputs:

$\Delta u = \Delta P_C$ (Incremental Control input)

$\Delta d = \Delta P_D$ (Incremental disturbance input)

The incremental control input is due to the change in the speed changer setting while the incremental disturbance input is due to the change in load demand.

Steady State Response:

* First consider the uncontrolled case, ie speed changer has a fixed setting.
* under this condition, we have $\Delta P_c = 0$.
* For the step load change, from the block diagram, we obtain for $\Delta P_c = 0$.

$$\Delta F(s) = \frac{-k_P}{(1+sT_P) + \frac{k_g k_t k_P / D}{(1+sT_g)(1+sT_t)}} \Delta P_D(s) \quad -(26)$$

* For the step load change of magnitude ΔP_D, we have

$$\Delta P_D(s) = \frac{\Delta P_D}{s} \quad -(27)$$

* Substituting (26) in (27) we get.

$$\Delta F(s) = -\frac{k_P}{(1+sT_P) + \frac{k_g k_t k_P / D}{(1+sT_g)(1+sT_t)}} \times \frac{\Delta P_D}{s} \quad -(28)$$

* Using final value theorem, the static frequency drop

$$\Delta f_{stat} = \underset{s \to 0}{Lt} \left[s \Delta F(s) \right]$$

$$= - \frac{k_p}{1 + \frac{k_g k_t k_p}{D}} \times \Delta P_D \qquad -(29)$$

* Practically the product of k_g and k_t can be arranged to unity.
* This is achieved by adjusting k_g. which can be achieved by changing lengths of various links.
* However, the turbine gain k_t remains fixed and is not in our control to change it.
* Thus with $k_g k_t = 1$ Eq (29) is reduced to

$$\Delta f_{stat} = - \frac{k_p}{1 + k_p/D} \Delta P_D \qquad -(30)$$

Since $k_p = \frac{1}{B}$

* Therefore Eq (30) as

$$\Delta f_{stat} = - \frac{1}{B + 1/D} \Delta P_D = \frac{-\Delta P_D}{\beta} \qquad -(31)$$

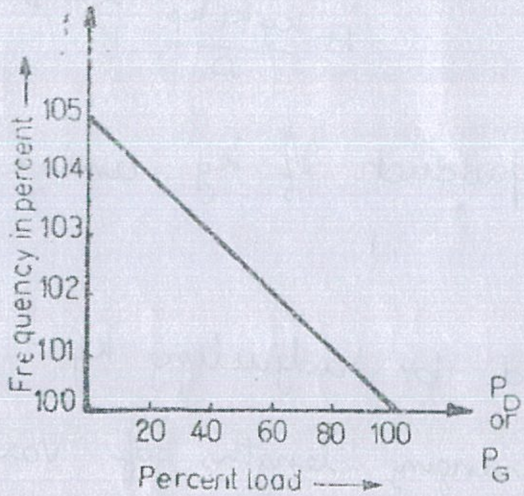
where $\beta = B + \frac{1}{D}$

* In practice $B << \frac{1}{D}$
* Hence neglecting B, we reduce as

$$\Delta f_{stat} = -D (\Delta P_D) \text{ Hz} \qquad -(32)$$

$$\text{(or)} \quad \frac{\Delta f_{stat}}{\Delta P_D} = -D \text{ Hz/MW} \qquad -(33)$$

* The relation gives steady state changes in frequency caused by changes in load which the load frequency characteristics of speed governor system.



* The droop or the slope of this characteristic is $-D$ as given by Eq (33)

* An important feature of the governor system is the mechanism by which the governor sleeve and hence main steam-valve position can be changed and adjusted quite apart from when actuated by speed changes.

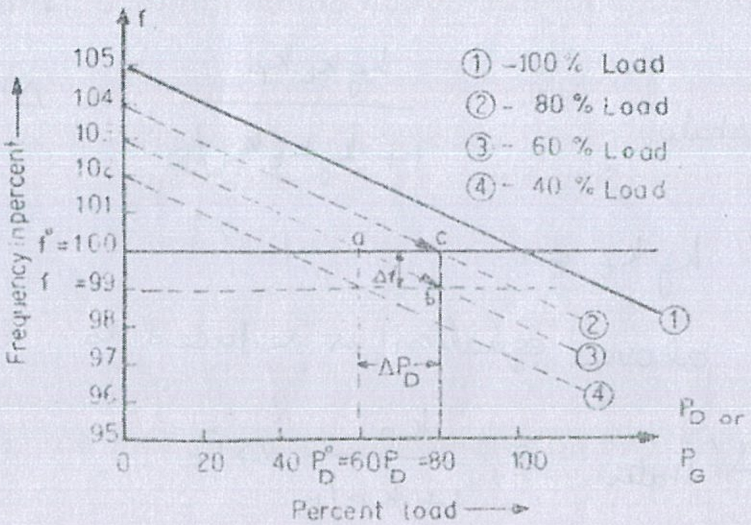
* This is accomplished by speed changer.

* With the help of speed changer, we can restore the frequency to the initial value at various loads.

* To understand this point let us consider that at 60% of the rated output of the generator (or 60% load), the system is running at nominal frequency $f^0 = 50Hz$ (100% frequency $= 50Hz$) as depicted by the operating point a on the characteristic (3).

* With an incremental load ΔP_D, the turbine speed (or frequency) drops and the new operating point is b and system frequency is 99% (49.5Hz).

* Now a Controlling force $\Delta U = \Delta P_C$ is applied to the speed changer and the characteristic -(3) is shifted upwards as shown by new position of characteristic (2).



* Thus the point b is shifted to point c and the system is again operating at rated.

* It means both the controlling forces and disturbance forces are acting simultaneously.

* Let us now consider the controlled case, that is there is step change ΔP_c force for speed changer setting and the load demand remains fixed ie $\Delta P_D = 0$.

* For the step change ΔP_C, from the block diagram, we obtain for $\Delta P_D = 0$

$$\Delta F(s) = \frac{k_g k_t k_p}{(1+sT_g)(1+sT_t)(1+sT_p) + k_g k_t k_p / D} \times \Delta P_C(s) \quad - (34)$$

* For the step change ΔP_c magnitude, we have,

$$\Delta P_C(s) = \frac{\Delta P_c}{s} \quad - (35)$$

* Substituting Eq (35) in Eq (34), we get

$$\Delta F(s) = \frac{k_g k_t k_p}{(1+sT_g)(1+sT_t)(1+sT_p) + k_g k_t k_p / D} \times \frac{\Delta P_c}{s} \quad - (36)$$

* Using the final Value theorem, the static frequency rise

$$\Delta f_{static} = \frac{k_g k_t k_p}{1 + k_g k_t k_p / D} \times \Delta P_C \quad -(37)$$

Since $k_g k_t \approx 1$

* Therefore, the above equation is reduced to

$$\Delta f_{static} = \frac{k_p}{1 + k_p / D} \Delta P_C \quad -(38)$$

* If the Controlling force ΔP_C is applied to speed Changer and as well as the load demand changes by ΔP_D, the static frequency change is obtained by superposition.

* Thus Eq (30) & Eq (38) we get
(add)

$$\Delta f_{static} = \frac{k_p}{1 + k_p / D} (\Delta P_C - \Delta P_D) \quad -(39)$$

* From above equation, for $\Delta f_{static} = 0$, we get

$$\Delta P_C = \Delta P_D.$$

* Therefore, we Conclude that by applying ΔP_C to the speed changer the frequency of the system can be adjusted.

Dynamic Response :

* The dynamic response representing the change in frequency as function of time for the uncontrolled case, when there is a step change in load is obtained by taking the inverse Laplace transform of Eq (28).

* In Eq 28 three time constants are involved, which will have the result that the characteristic equation will be of third order.

* Set $T_g = T_t = 0$ ie we assume that the action of speed governor and turbine is instantaneous.

* In actual practice $T_g < T_t < T_p$.

$$\therefore \Delta F(s) = \frac{-k_p}{1 + sT_p + k_p/D} \times \frac{\Delta P_D}{s}$$

$$= -\Delta P_D \frac{k_p}{T_p} \times \frac{1}{\left[s + \frac{k_p + D}{DT_p}\right]} \quad - 40$$

* Taking inverse laplace transform,

$$\Delta f(t) = -\Delta P_D \frac{D k_p}{D + k_p} \left[1 - e^{-t\left(\frac{k_p + D}{DT_p}\right)}\right] \quad - 41$$

Problem : A 100 MVA synchronous generator operates initially at no load at 3000 rpm, 50 Hz. A 25 MW load is suddenly applied to the machine. Due to the time lag in governor system, the steam values of the turbine commence to open after 0.6 second. Determine the frequency of the system before the steam flow commences to increase to ~~new~~ meet new load. Given $H = 5$ MW-sec/MVA of generator capacity.

Sol: Given $H = 5$

$S_{3\phi} = 100\ MVA$

$f^0 = 50\ Hz$

$$H = \frac{W^0_{kin}}{S_{3\phi}}$$

Therefore, kinetic energy of the rotating parts of generator and turbine is

$$W^0_{kin} = H \times S_{3\phi} = 5 \times 100$$
$$= 500\ MW \cdot sec$$

Before the steam valves start to open the machine loses $25 \times 0.6 = 15\ MW\text{-}sec$ of the stored energy in order to supply the load.

Thus the stored energy after 0.6 sec is

$$W_{kin} = W^0_{kin} - 15\ MW$$
$$= 500 - 15 = 485\ MW \cdot sec.$$

$$\frac{W_{kin}}{W^0_{kin}} = \left(\frac{f}{f^0}\right)^2$$

$$f = f^0 \sqrt{\frac{W_{kin}}{W^0_{kin}}} = 50 \sqrt{\frac{485}{500}} = \underline{49.24\ Hz}.$$

Problem : Two synchronous generators operate in parallel and supply a total load of 400MW. The capacities of the machines are 200 MW and 500MW and both have generator droop characteristics of 4% from no load to full load. Calculate the load taken by each machine, assuming free governor action. Also find the system frequency at this load.

Sol : Since the generators are operating in parallel, they will operate at the same frequency at steady load.

Let x MW be the power supplied from the 200 MW generator.

$$\frac{\Delta f}{x} = \frac{4}{200} \quad \text{and} \quad \frac{\Delta f}{400-x} = \frac{4}{500}$$

From Eqs. we find

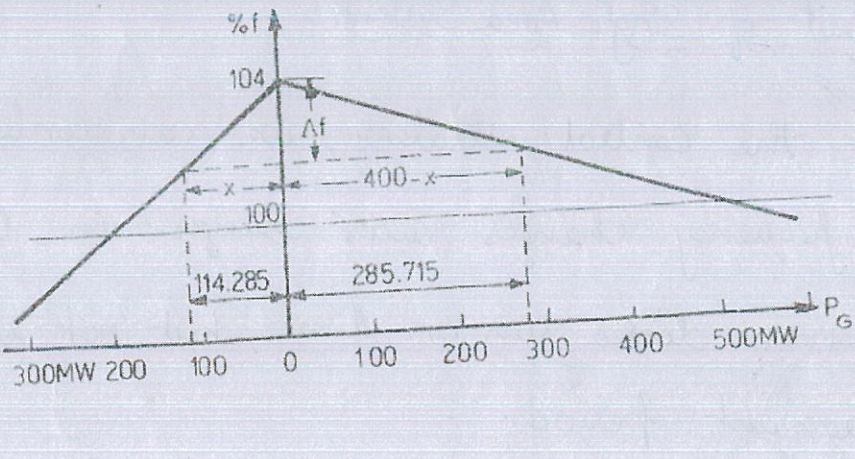
$x = 114.285$ MW (load on 200 MW generator)

$400 - x = 285.715$ MW (load on 500 MW generator)

$\Delta f = 2.2857\%$

Therefore system frequency at 400 MW load is

$$= \frac{1}{100}(104 - 2.2855) \times 50 = 50.857 \text{ Hz}.$$



Basic Concept of Control Area :

* Electric power systems are usually operated as individual units because they started as isolated systems.
* Interconnection is advantageous economically because fewer machines are required as a reserve for operation at peak loads and fewer machines running without load are required to take care of sudden, unexpected jumps in load.
* Therefore, all generating plants are interconnected to form state grid, regional grid and the national grid.
* Load dispatch centres are required for the control of power flow in these grids.
* It is feasible to divide a very large power system, say a national grid into sub areas in which all the generators are assumed to be tightly coupled, ie they swing in unison with change in load or due to speed changer settings.
* Such a area, where all the generators are running coherently is termed as a control area.
* All machines in a area exporting power can be reduced to an equivalent generator.

Integral Control of Single Area System :

* By using the control strategy, we can control the intolerable dynamic frequency changes with changes in load and also the synchronous clocks run on time, but not without error during transient period.

Typical Excitation Control Scheme:

* The excitation system comprises of an exciter and automatic voltage regulator.
* The duty of an exciter is to provide the necessary field current to the rotor winding of the alternator.

  Fundamentally simplest excitation system consists of an exciter only.
* When the excitation system has also the task of maintaining the terminal voltage of the alternator constant under varying load conditions, it incorporates voltage regulator.
* Voltage regulator sensing the requirement from the terminal voltage of the alternator actuates the exciter for the necessary increasing or decreasing the voltage across the alternator field.

A typical Excitation Control Scheme:

* The voltage regulator measures the terminal voltage, compares it with a reference voltage and utilizes the error signal to be amplified.
* The output of the amplifier is fed to the exciter field winding.

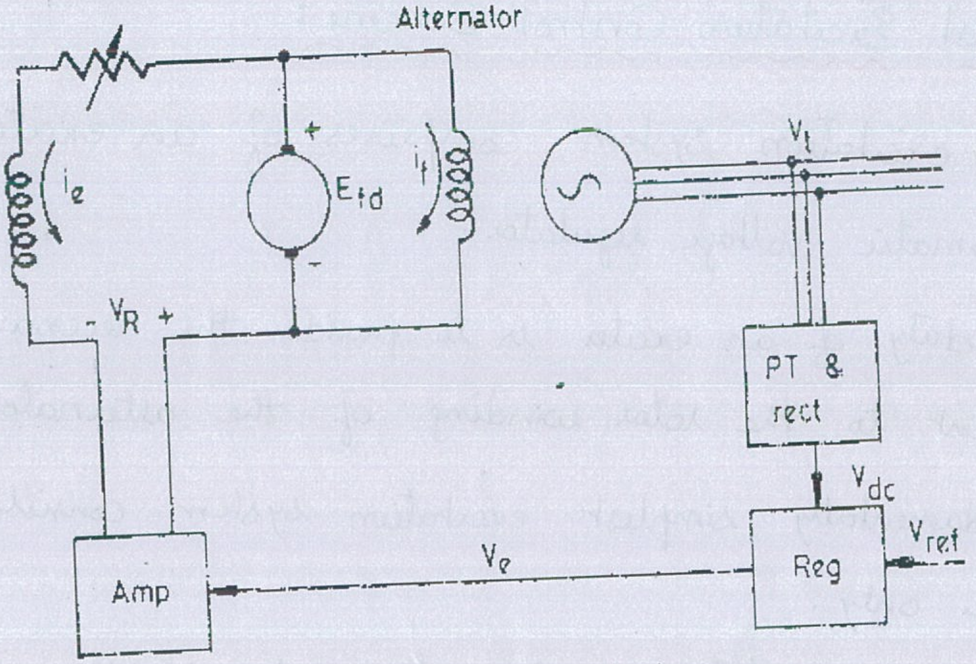


Fig. 20.7. Excitation control scheme.

* When the terminal voltage is nominal, then there is no error signal and the field current in the field winding of the exciter is constant.
* Suppose with increase of load on the generator, the terminal voltage decreases.
* Due to the decrease of terminal voltage there will be a positive error signal, which when amplified will increase the field current of the exciter field and consequently the terminal voltage of the generator will increase to the nominal value.
* The above operation will be reversed when there is

increase of terminal voltage with decrease of load on the generator.

Excitation Systems:

* The excitation systems can be broadly classified in to following:
    * D.C Excitation System
    * A.C. Excitation System
    * Static excitation System
* In d.c. excitation system, there are various configurations of rotating exciters.
    * Self excited exciter with direct acting rheostatic type voltage regulator.
    * Main and pilot exciters with indirect-acting rheostatic type voltage regulator.
    * Main exciter, amplidyne and static voltage regulator.
    * Main exciter, magnetic amplifier and static voltage regulator.
* The main drawbacks of d.c. excitation systems are: large time constants and commutation difficulties.
* In view of this d.c. excitation systems have been superseded by a.c excitation and static systems.

* An a.c. excitation system consists of an a.c generator and thyristor rectifier bridge directly connected to the alternator shaft.

* The advantage of this method of excitation is that the moving contacts such as slip rings and brushes are completely eliminated thus offering smooth and maintainance free operation.

* Such a system is called brushless excitation system.

* A static excitation system draws the excitation power from the alternator terminals through step down transformer and a rectifier system using mercury arc rectifiers of silicon controlled rectifiers.

Block diagram of excitation systems:

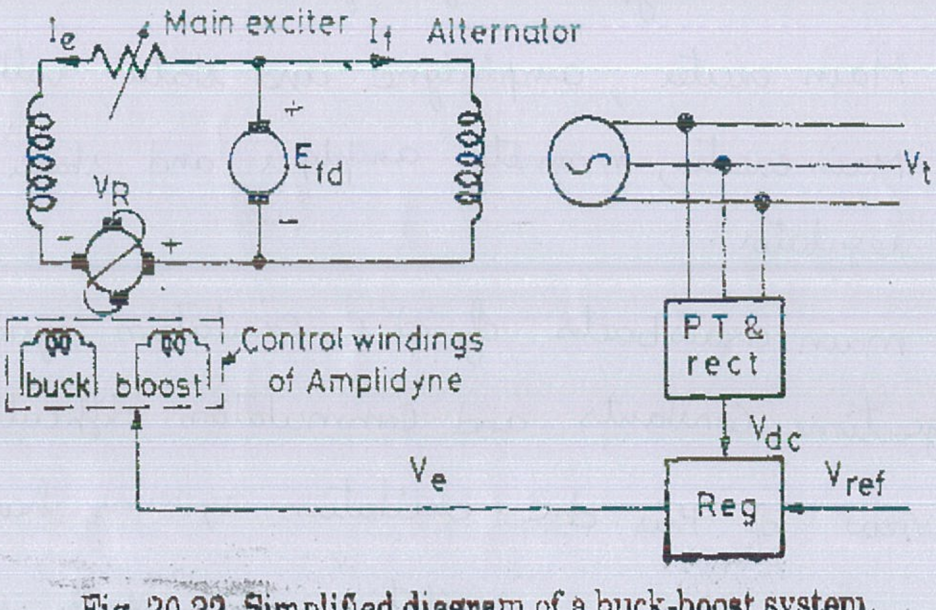


Fig. 20.22. Simplified diagram of a buck-boost system.

For analyzing any excitation system, it is very essential to compute its transfer function.

Therefore the building of block diagram for finding the transfer function is very important.

For the complete analysis of the excitation system it is necessary to develop the transfer function of each component and hence of the over all excitation system.

Transfer function of potential transformer and rectifier

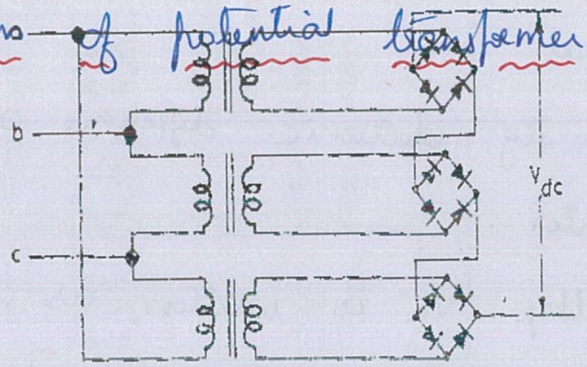


Fig. 20.14. Connections of potential transformer and rectifier.

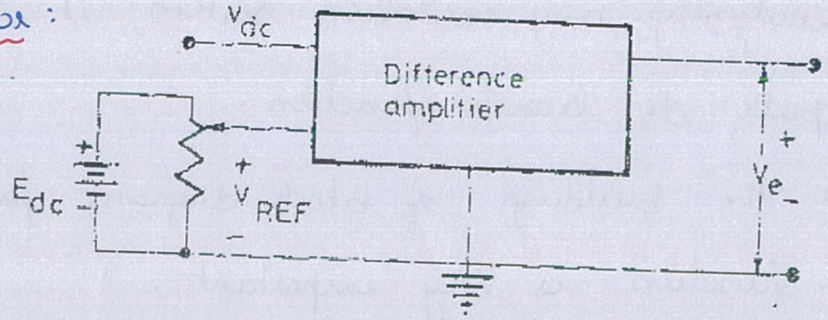
With the help of this unit the terminal voltage of the generator is stepped down and rectified to get d.c voltage V_{dc} proportional to average r.m.s. voltage of the terminal voltage V_t.

Its transfer function is given by

$$\frac{V_{dc}(s)}{V_t(s)} = \frac{k_R}{1 + sT_R}$$

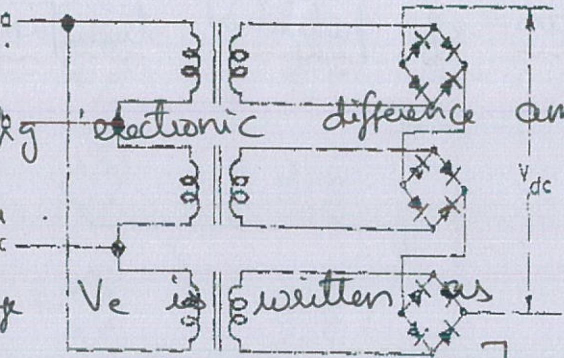
k_R = Proportionality Constant ; T_R = Time Constant due to filtering in transformer – rectifier assembly.

Comparator :



The Comparator Compares the d.c Voltage V_{dc} against a preselected V_{ref} and supplies an output voltage V_e called the error signal.

As shown in fig electronic difference amplifier is depicted as a comparator.



The error voltage V_e is written as

$$V_e(s) = K\left[V_{ref}(s) - V_{dc}(s)\right]$$

Fig. 30.14. Connections of potential transformer and rectifier.

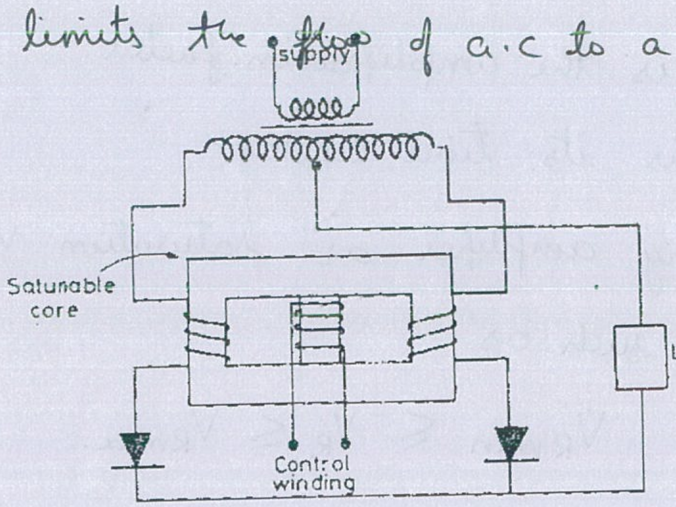
Magnetic Amplifier :

If the B-H curve of magnetic material is plotted and the permeability H curve is also plotted.

It is seen that the permeability is low for small and very large values of H and assumes good level for moderate values of H.

With increase in values of H, the permeability can be reduced.

The saturable core reactor can be designed so that when no d.c is flowing in the d.c control winding, the inductive reactance of a.c coils is very high and this limits the flow of a.c to a small value.



Basically, with moderately large d.c through the control winding, the core is saturated, the permeability is greatly decreased and the reactance of a.c. coils decreases, so more a.c current flows.

The a.c. current is rectified by means of rectifiers so as to feed the load with d.c output.

Thus controlling a large output current by means of a small control current is the main feature of this amplifier.

If an error signal V_e is applied to the control winding, then its transfer function may be written as

$$\frac{V_R(s)}{V_e(s)} = \frac{k_A}{1+sT_A}$$

where V_R is the output voltage

k_A is the amplification factor

T_A is its time constant

As with any amplifier as saturation value must be specified such as

$$V_{R\,min} \leq V_R \leq V_{R\,max}.$$

Self excited exciter and amplidyne:

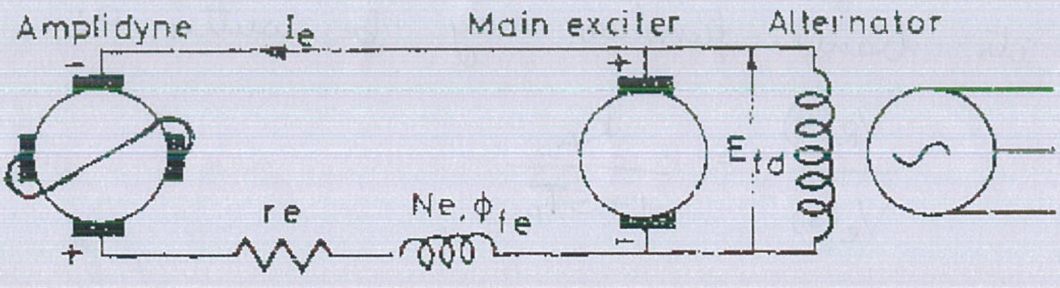
In this type of combination the amplidyne is in series with the shunt field of the main exciter.

In formulating the dynamic equations we have a notational problem.

In exciter variables are essentially d.c but do change under transient conditions

For exciter field circuit,

$$V_R + e_{fd} = i_e r_e + N_e \frac{d\phi_{fe}}{dt}$$



with the armature emf.

* V_R of the amplidyne as positive when boosting E_{fd}, the armature e.m.f of main exciter.

* Here N_e, φ_{fe}, r_e, i_e are no. of field turns, flux in field core, field circuit resistance, field current of the exciter under no load conditions, e_{fd} is related to the effective flux ϕ_e by the relation

$$e_{fd} = k\phi_e.$$

with $k = ZnP/a$ a constant for the armature.

* Difference of φ_{fe} and ϕ_e is on account of leakage flux ϕ_e and we may write

$$\varphi_{fe} = \phi_e + \varphi_l$$

* It may be assumed that this leakage flux is proportional to the field current i_e.

* In the former case, then

$$\varphi_l = C_1 \varphi_e$$

with C_1 as proportionality constant, we get

$$\phi_{fe} = \phi_e + C_1 \phi_e$$

$$= (1 + C_1)\phi_e$$

$$\phi_{fe} = \sigma \phi_e.$$

where σ is known as coefficient of dispersion having value in the range of 1.1 & 1.2.

* Using the above equations, we get

$$V_R + e_{fd} = i_e r_e + \frac{N_e \sigma}{k} \frac{de_{fd}}{dt}$$

$$(or) \quad V_R + e_{fd} = i_c r_e + T_e \frac{de_{fd}}{dt}.$$

where T_E is called time constant of exciter.

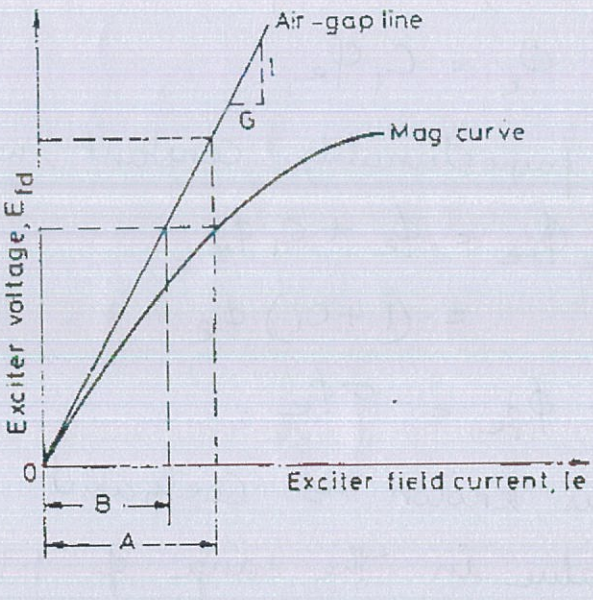
* The effect of saturation of exciter voltage e_{fd} is taken in to account while solving the above equation.

* Referring to fig, the saturation is defined as

$$S_E = \frac{(A-B)}{B}$$

* As evident from the magnetisation curve, we find that S_E is a non linear function of exciter voltage e_{fd}.

$$(or) \quad B = \frac{A}{1+S_E}$$



* If the slope of the air gap line is $\frac{1}{G}$, then using the above equation, we write

$$e_{fd}\, G = \frac{i_e}{1+S_E}$$

(or) $i_e = G(1+S_E)\, e_{fd}$.

* Substituting the above expression of i_e in $V_R + e_{fd} = i_e r_e + T_E \frac{de_{fd}}{dt}$ we get

$$V_R + e_{fd} = r_e G(1+S_E)\, e_{fd} + T_E \frac{de_{fd}}{dt}.$$

* The above equation in Laplace transform is

$$V_R(s) + E_{fd}(s) = r_e G(1+S_E)\, E_{fd}(s) + sT_E\, E_{fd}(s).$$

* The above equation is reduced to

$$E_{fd}(s) = \frac{V_R(s) - S_F\, E_{fd}(s)}{K_E + sT_E}$$

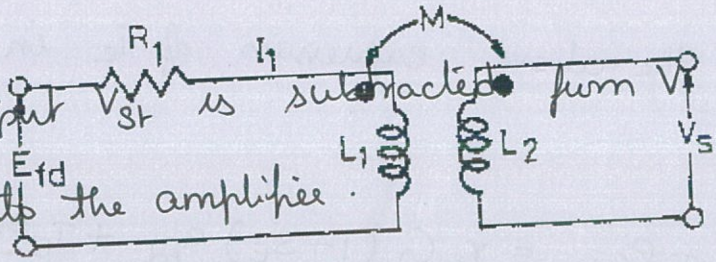
where $K_E = r_e G - 1$

* If saturation is neglected, ie $S_E = 0$, we may write the transfer function of the exciter as

$$\frac{E_{fd}(s)}{V_R(s)} = \frac{1}{K_E + sT_E}$$

Transfer function of the Stabilizing transformer:

* The excessive overshoot and stability problems can be corrected by the addition of a stabilizing transformer whose input is E_{fd} and whose output is V_{st}.



* The output V_{st} is subtracted from V_f to provide the input to the amplifier.

$$E_{fd}(s) = (R_1 + sL_1)\, I_1(s)$$

$$V_{st} = M \frac{di_1}{dt}$$

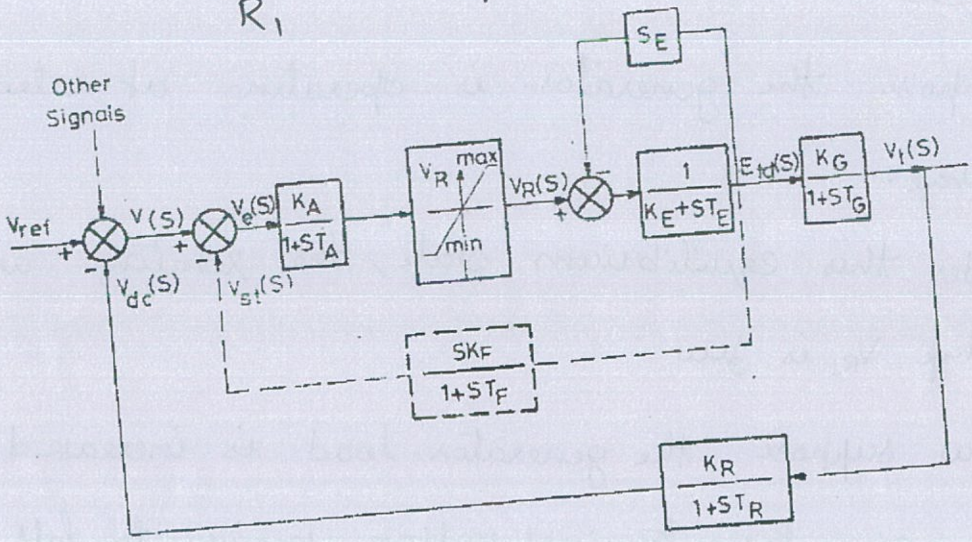
(or) $\quad V_{st}(s) = sMI_1(s)$

From the above equations, we get

$$\frac{V_{st}(s)}{E_{fd}(s)} = \frac{sk_F}{1+sT_F}$$

where $\quad k_F = \dfrac{M}{R_1}$ = Transformer gain

$$T_F = \frac{L_1}{R_1} = \text{Transformer time Constant}$$



Transfer function of Synchronous Generator:

The transfer function of rotating amplifiers, the transfer function of the generator is written as

$$\frac{V_t(s)}{E_{fd}(s)} = \frac{k_G}{1+sT_G}$$

where k_G is gain of the generator

T_G is time Constant of rotor field.

By interconnecting all the components in the forward path and the feedback loop the complete block diagram of the excitation system is shown in fig.

Operation :

* Suppose the generator is operating at rated terminal voltage.
* Under this equilibrium state, the rotating amplifier voltage V_R is zero.
* Now suppose the generator load is increased and the generator terminal voltage begins to fall.
* The voltage sensing circuit detects this fall and causes the rotating amplifier ie amplidyne to increase the field current I_e in the exciter field.
* This increases the exciter voltage, which in turns increases I_f the generator field current that ultimately should rise V_t.
* The effect of change in E_{fd} to the generator terminal voltage.
* The voltage E and E_{fd} are scaled in per unit in such a way that under steady state conditions $E = E_{fd}$
* under transient conditions any mismatch between E & E_{fd} will cause E_q' to change after some delay.

Mathematically,

$$\frac{dE_q'}{dt} = \frac{1}{T_{do}'}(E_{fd} - E)$$

where T_{do}' is open circuit generator direct axis transient time constant.

Transfer function of Excitation System:

* The transfer function of the system as shown in fig.
* For sake of conveience, we neglect the effect of saturation ($S_E = 0$) and also remove the stabilizing transformer from the excitation system.
* The system transfer function is written as

$$\frac{V_t(s)}{V_{ref}(s)} = \frac{G(s)}{1+G(s)H(s)}$$

where $G(s)$ is known as feed-forward transfer function
$H(s)$ is known as feedback transfer function.

* We have

$$G(s) = \frac{k_A k_G}{(1+sT_A)(K_E+sT_E)(1+sT_G)}$$

$$H(s) = \frac{k_R}{1+sT_R}$$

* We get

$$\frac{V_t(s)}{V_{ref}(s)} = \frac{k_A k_G(1+sT_R)}{(1+sT_A)(K_E+sT_E)(1+sT_G)(1+sT_R)+k_A k_G k_R}$$

* knowing the mathematical values of different constants, we can analyse the response of the system.

UNIT-IV

REACTIVE POWER-VOLTAGE CONTROL, MODELLING OF EXCITATION SYSTEMS

Introduction:

* The voltage of the power supply at the customers service entrance must be held substantially constant. Variations in supply voltage are deterimental in various aspects.
* For example, below-normal voltage substantially reduces the light output from incandescent lamps and above normal voltage reduces the life of the lamps.
* Motors operated at below-normal voltage draw abnormally high currents and may over-heat, even when carrying no more than the rated horse power load.
* It is not economically possible to maintain the voltage absolutely constant at every consumer's service terminals.
* Service voltage are usually specified by a nominal value and the voltage then maintained close to this value, deviating less than 5 percent above or below the nominal value.
* Although the absolute magnitude of the voltage is only one aspect of its adequacy.
* The magnitude and speed of its variations are equally important.

* The voltage at a bus can be controlled by the injection of reactive power of the correct sign.
* Other methods for controlling voltage are the use of tap-changing transformers, regulating transformer etc.
* Synchro condensers, static capacitors and shunt reactors are the common sources of reactive power.

Generation and Absorption of Reactive power:

* Power system components which generate reactive power and / or absorb reactive power.

Synchronous Machine:

* An over excited synchronous machine operated either as generator or motor generates KVAR and acts as a shunt capacitor as viewed from the network.
* While the under-excited synchronous machine, absorbs KVAR from the network and acts consequently as a shunt reactor if viewed from the network.
* Synchronous generators provide the cheapest means of reactive power supply or absorption when required to supply active power also.
* The present trend towards large generators in a limited number of stations divided from the distribution system

makes this source of KVAR generation less attractive, since it is generally undesirable to transmit large amounts of KVAR over transmission lines as this produces excessive voltage drop.

* The KVAR required by a Consumer are usually produced locally, therefore either by static capacitors or by synchronous motors running idle and at increased excitation.

Shunt Capacitors :

* Apart from synchronous machines, static shunt capacitors offer the cheapest means of reactive power supply but these are not as flexible as synchronous condenser.

Shunt Reactors :

* The shunt reactors offer the cheapest means of reactive power absorption and these are connected in the transmission line during light load conditions.

Overhead Lines :

* An overexcited synchronous machine generates KVAR, as does a static capacitor.

* In the same way, an underexcited synchronous

machine consumes kVAR as does a static shunt reactor.

* Transmission lines can therefore be considered as generating kVAR in their shunt capacitance and consuming kVAR in their series inductance.

* The inductive kVAR vary with the current which the line carries, where as the capacitive kVAR vary with the system potential.

* For example let the transmission line be loaded such that load current be $|I|$ amperes and load voltage $|V|$ volts.

* If we assume the transmission line to be lossless, the reactive power absorbed by the line will be

$$\Delta Q_L = |I|^2 X_L = |I|^2 \omega L$$

where ω is the supply angular frequency and L the inductance of the line.

* Due to the capacitance of the line, the reactive power generated by the line will be

$$\Delta Q_c = \frac{|V|^2}{X_c} = |V|^2 \omega c$$

where c is the shunt capacitance of the line.

* Suppose the reactive power generated by the line is equal to the reactive power absorbed by the line, then under this condition we get

$$|V|^2 \omega C = |I|^2 \omega L$$

$$\frac{|V|}{|I|} = \sqrt{\frac{L}{C}} = Z_n$$

where Z_n is called the natural impedance of the line

* A line is said to be operating at its surge impedance loading (SIL) when it is terminated by a resistance equal to its natural impedance.
* Under this loading condition the Vars absorbed are equal to the Vars generated by the line.
* The power transmitted under this condition is called natural power and is given by

$$P_N = \frac{|V|^2}{Z_n} \text{ MW}$$

where $|V|$ is the voltage in kV at the receiving end.

* In case $\Delta Q_L > \Delta Q_C$

(or) $|I|^2 \omega L > |V|^2 \omega C$

the variation of voltage along the line will be shown in fig.

* We find that the voltage sags if the voltages at the

if the voltages at the two ends are maintained constant.

* In case $\Delta Q_L < \Delta Q_c$

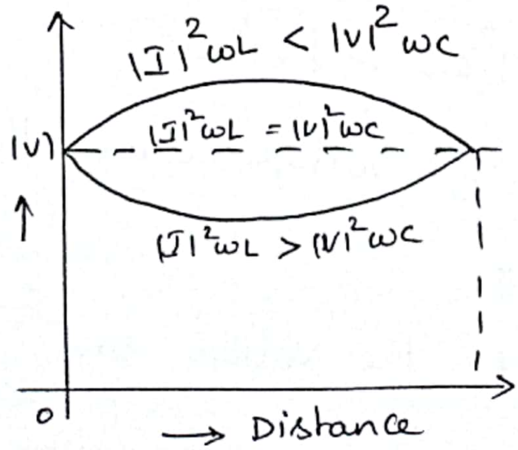
(or) $|I|^2 \omega L < |V|^2 \omega C$

the variation of voltage along the line will be as shown in fig; we find that voltage rises.

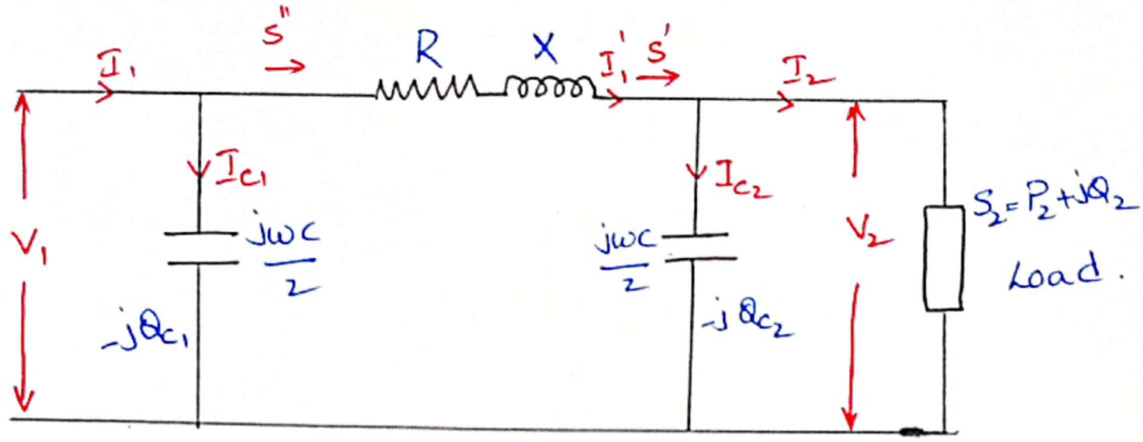
* From the previous equation $|I|^2 \omega L > |V|^2 \omega C$, we find that the line is loaded below its surge impedance loading and this is known as light load conditions.

* In actual practice, the loading is greater than SIL and therefore the condition given by the eq exists, which means that the net effect of the line will be to absorb the reactive power.

* We find that under light load conditions the effect of shunt capacitors is predominating and the line will generate reactive power.



Now we will consider a π model of the transmission line as shown in fig.



* The KVAR generated by the line is

$$Q_C = Q_{C1} + Q_{C2}$$
$$= |V_1|^2 \frac{\omega C}{2} + |V_2|^2 \frac{\omega C}{2} \text{ per phase}$$

* However, the rated voltage is used for finding power generated.

* Thus $Q_{C1} = Q_{C2} = |V_r|^2 \frac{\omega C}{2}$ VAR/phase

where V_r is the phase to neutral rated voltage in volts.

* The reactive power absorbed by the line/Phase is

$$\Delta Q_L = |I'|^2 X \text{ VAR/Phase.}$$

where X is the reactance of the line in ohms and $|I'|$ is the magnitude of current in amperes.

* Thus for the above system if we have inductive load at the receiving end, then the power at the sending end can be calculated as

$$S' = P' + jQ'$$
$$= S_2 - jQ_{C_2}$$
$$= P_2 + jQ_2 - jQ_{C_2}$$
$$S'' = P'' + jQ''$$
$$= S' + \Delta P_L + j\Delta Q_L$$

where $\Delta P_L = |I'|^2 R$
$\Delta Q_L = |I'|^2 X$

* Thus the power at the sending end is

$$S_1 = P_1 + jQ_1$$
$$= S'' - jQ_{C_1}$$

$$\therefore S_1 = P_1 + jQ_1 = P_2 + jQ_2 - j|V_r|^2 \omega C + |I'|^2 R + j|I'|^2 X$$
$$= (P_2 + |I')^2 R) + j(Q_2 + |I'|^2 X - |V_r|^2)\omega C$$

where $$|I'| = \frac{|S'|}{|V_r|} = \frac{\sqrt{P'^2 + Q'^2}}{|V_r|}$$

* It should be noted that on light loads the shunt capacitances of longer lines may become predominant and the lines become VAR generators.

Transformers:

* Transformers always absorb reactive power.
* If X_T is the transformer reactance per phase and $|I|$ is the current flowing through it then the total reactive power absorbed is

$$Q_T = 3\,|I|^2 X_T \text{ VAR}$$

where X_T is in ohms
$|I|$ is in amperes.

Cables:

* Cables generate more reactive power than transmission lines because the cables have high capacitance.
* A 275 kV, 240 MVA cable produces 6 to 7.5 MVAR per kilometre; a 132 kV cable roughly 1.856 MVAR per kilometre and a 33 kV cable, 0.12 MVAR per kilometer.

Loads:

* A load at 0.95 powerfactor implies a reactive power demand of 0.33 kVAR per kW of power, which is more appreciable than the mere quoting of the powerfactor would suggest.
* In planning a network it is desirable to assess the reactive power requirements to ascertain whether the generators are able to operate at the required power

factors for the extremes of load to be expected.

* The variation of the power and the reactive power taken by a load with various voltages is of importance when considering the manner in which such loads are to be represented in load flow and stability studies.

10.7 STATIC VAR COMPENSATOR (SVC)

(UPTU 2009-10)

An SVC is a shunt connected static generator and/or absorber of reactive power in which the output is varied to maintain or control specific parameters of an electrical power system. An SVG (Static Var Generators) is an integral part of an SVC. The SVS is the combination of Static and mechanically switched var compensators (capacitors and/or reactors) in which the outputs are coordinated. A VCS is the var compensating system is a combination of static and rotating var compensators in which the outputs are coordinated.

The general characteristics of SVC are (advantages and disadvantages):

Advantages

- Absence of rotating parts – less maintenance requirements
- Fast control – response time is less
- Feasibility of individual phase control
- Diminished losses
- High reliability.

Disadvantages

- Lack of contribution to system short circuit capacity
- Generation of harmonics by SVCs except thyristor switched capacitors
- Variations of SVC reactive-power generation as the square of terminal voltage when it operates out of linear control range, leading to substantial reduction in reactive-power support at lower voltages.

10.8 THYRISTOR CONTROLLED REACTOR (TCR)

A shunt connected, thyristor controlled inductor whose effective reactance is varied in continuous manner by partial conduction control of the thyristor valve.

A basic single phase TCR comprises an antiparallel connected thyristor valves T_1 and T_2, in series with the linear air core reactor, as illustrated in Fig. 10.1, T_1 conducts for Ist half cycle and T_2 conducts for negative half cycle of supply voltage. The firing angle is measured from zero crossing of the voltage wave form.

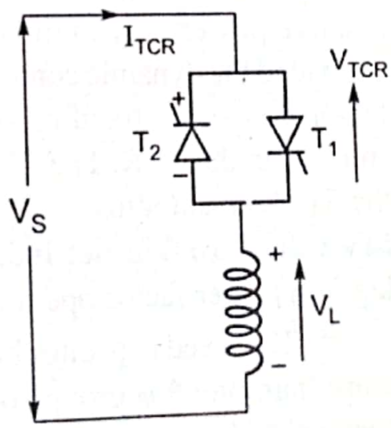


Fig. 10.1

Firing angle of 90° to 180° is used. Below 90° firing angle introduces dc components in the current. At $\alpha = 90°$, there is continuous sinusoidal current flow in TCR. As the firing angle varied from 90° close to 180°, the current flows in the form of discontinuous pulses symmetrically located in positive and negative half cycles.

A three-phase TCR comprises of 3 single-phase TCRs connected in delta. The inductor in each phase is split into two halves, one on each side of the antiparallel thyristor pair, to prevent the fuel AC voltage appearing across the thyristor valves and damaging them if a short circuit fault occurs across the reactor's two end terminals.

The delta connected arrangement does not allow triplen harmonics to percolate into the line as they cancel out in the delta connection.

Operating characteristics of TCR.

- Operating characteristics without voltage control (Ref. to Fig. 10.2 (*a*)).

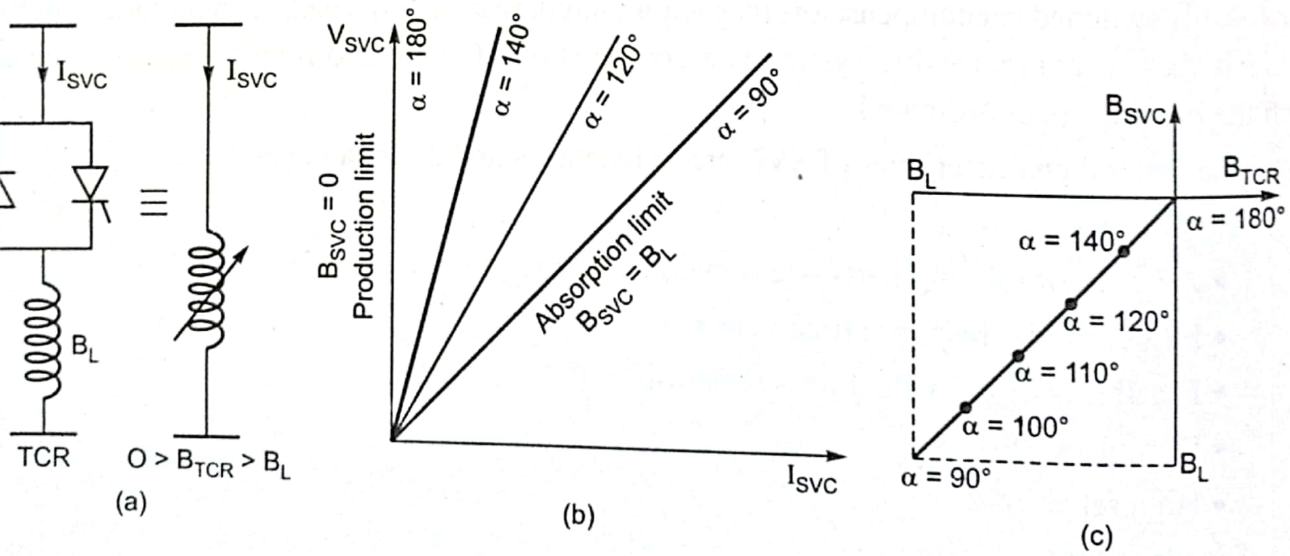


Fig. 10.2

- VI characteristics or operating characteristics is shown in Fig. 10.2 (*b*) and (*c*).

Fig. 10.2 (*c*) shows change in total SVC susceptance when TCR susceptance is varied. In this case only one TCR is considered. Hence, linear characteristics.

10.10 THYRISTOR SWITCHED CAPACITOR (TSC)

A shunt connected, thyristor switched capacitor whose effective reactance is varied in stepwise manner by full or zero conduction operation of thyristor valve.

The basic single phase TSC consists of an antiparallel-connected thyristor valve pair that acts as a bidirectional switch in series with a capacitor and a current limiting small reactor as shown in Fig. 10.5. The thyristor switch allows the conduction for integral number of half cycles. The TSC current is sinusoidal and free from harmonics.

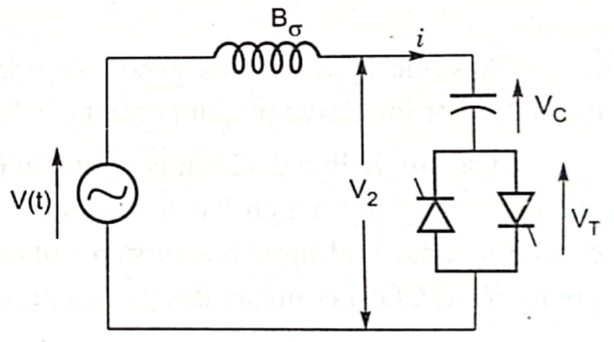
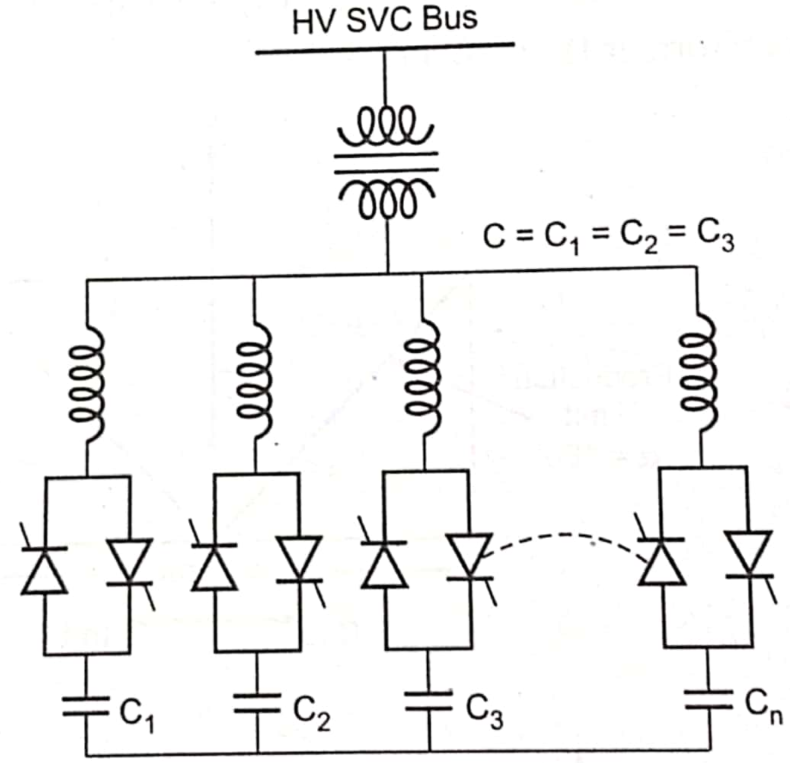


Fig. 10.5

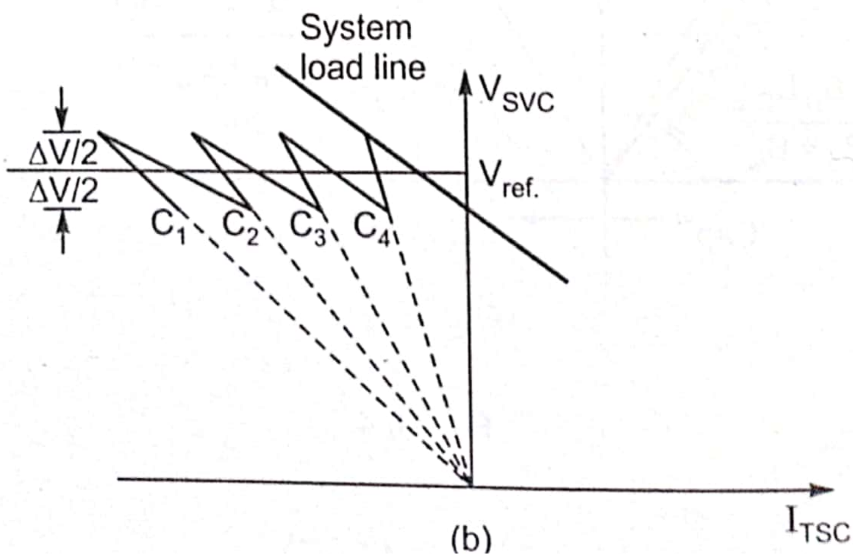
The small-series inductor is installed to limit current transients during over voltage conditions and planned switching operations as well as when switching at incorrect instants or at the inappropriate voltage polarity. Another function of the series inductor is to act in combination with capacitor as a filter for harmonics generated by associated TCR.

A 3 ϕ TSC unit consists of three single-phase TSCs connected in delta.



(a)

10.10.1 Operating Characteristics of TSC



(b)

10.11 STATCOM: STATIC SYNCHRONOUS COMPENSATOR

(UPTU 2006-07; 2007-08; 2008-09; 2011-12)

A static synchronous generator operated as shunt connected static var compensator whose capacitive or inductive output current can be controlled independent of the AC system voltage.

The single line diagram is shown in Fig. 10.7 (*a*). A VSC is connected to the utility bus through magnetic coupling which has a adjustable voltage source behind the reactance. This means that the capacitor banks and shunt reactors are not needed for reactive power generation and absorption thereby giving STATCOM compact design, small foot print, low noise, and low magnetic impact.

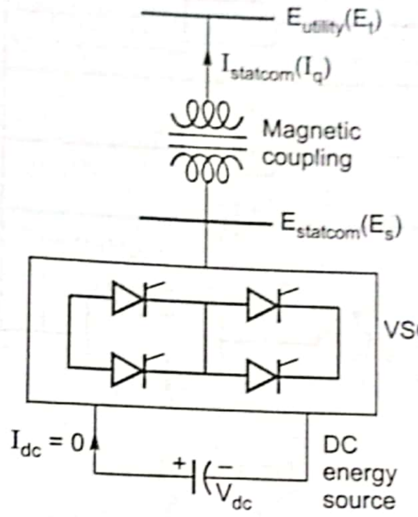


Fig. 10.7 (a)

The exchange of reactive power between the converter and AC system can be controlled by varying the amplitude of 3 ϕ output voltage, E_S. If $E_s > E_t$ supplies Q and $E_s > E_t$ absorbs Q if $E_s = E_t$ (AC system voltage) the statcom is in floating state.

Adjusting phase shift between the converter output voltage and AC system voltage can control real power exchange between the converter and ac system. Supplies AC power if leading and absorb real power if lagging.

The reactive power is generated internally by the action of converter switches. The DC capacitor is connected across the input terminals of the converter to provide circulating path as well as voltage storage.

10.11.1 VI Characteristics

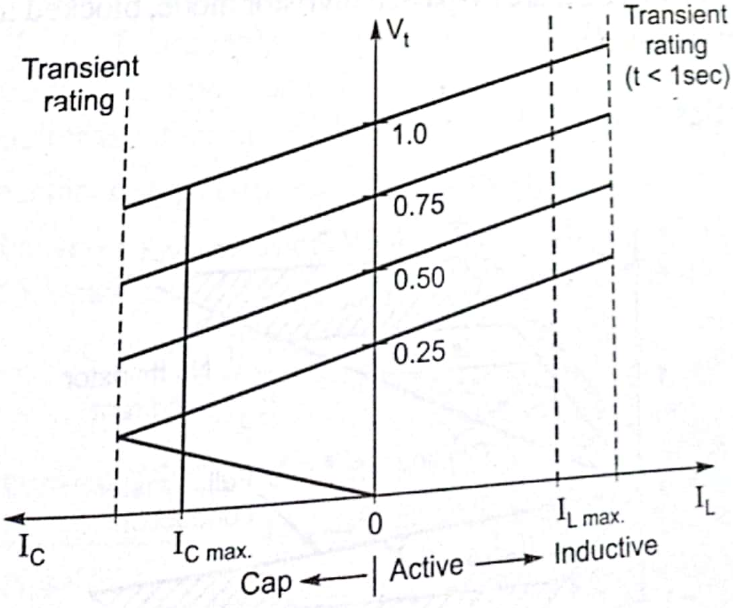


Fig. 10.7 (b)

Tap Changing Transformers

In transmission and distribution systems there can be voltage fluctuations (i.e., increase or decrease in voltage levels) when the load on the system varies. These fluctuations can also be caused due to a voltage drop in the distribution system. Sometimes these variations in voltage levels can result in quite unsatisfactory performance.

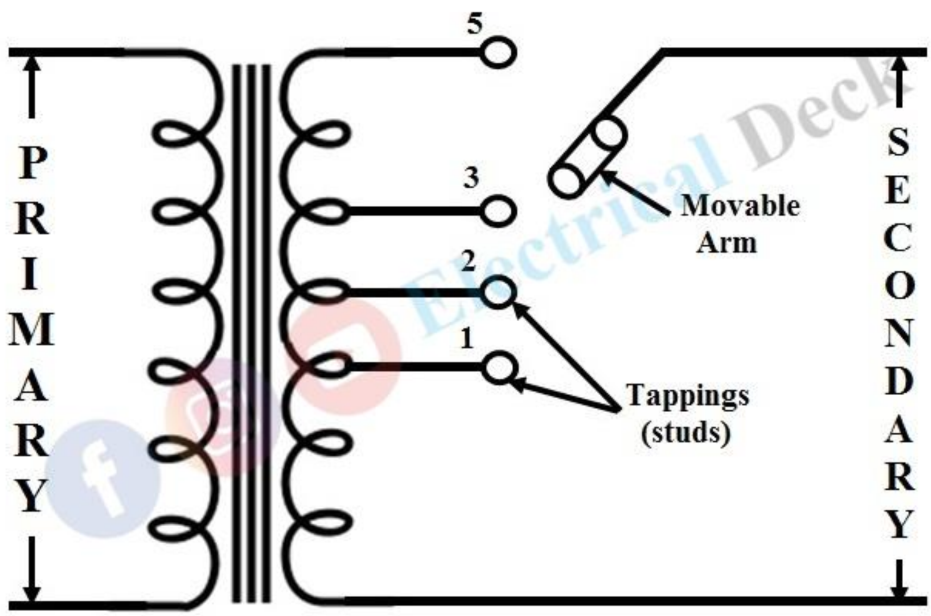
In order to maintain a constant voltage or to maintain within the prescribed limits transformer tap-changing is used. In tap-changing, the tappings on the coils of the transformer are placed so that by varying the turn-ratio voltage induced can be varied.

This arrangement is done externally to the transformer by taking coil terminals out of the transformer tank. Usually, the maximum allowable variation of the turn-ratio can be up to ±2% to 5%. There are two types of tap-changing transformers,

- Off-Load Tap-Changing Transformer.
- On-Load Tap-Changing Transformer.

Off-Load Tap-Changing Transformer :

The below figure shows the off-load tap-changing transformer provided with tappings (1 to 5) on the secondary winding. The position of the movable arm on the first stud will give minimum secondary voltage and on the fifth stud will give maximum voltage across secondary.

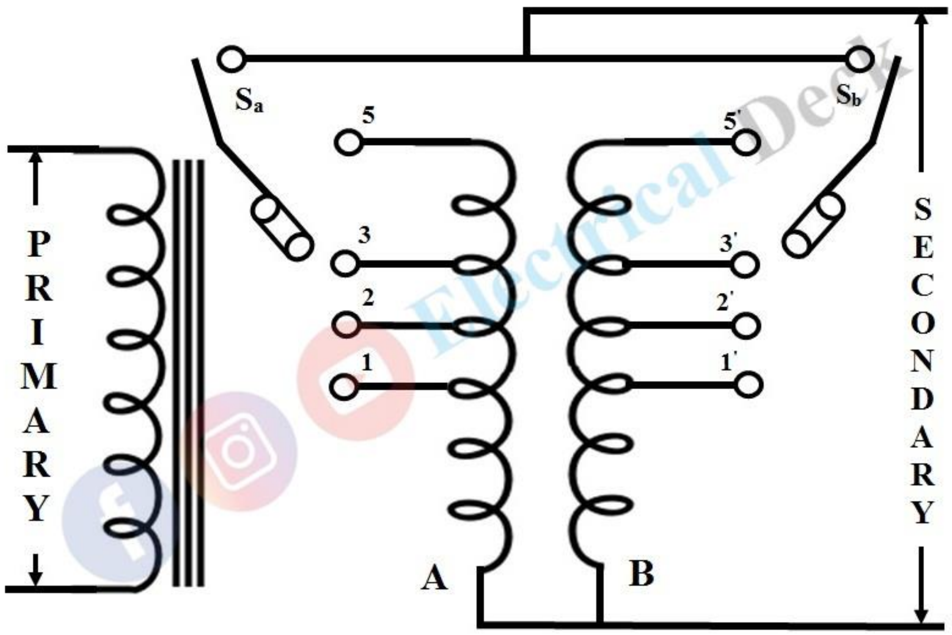


During the light load period, the movable arm is placed on the first stud and with an increase in load, the movable arm is taken to a stud (2, 3, 4, or 5) giving higher turns-ratio so that voltage drop in the line is compensated and the output secondary voltage is maintained.

The disadvantage of this scheme is whenever the tapping is to change load must be disconnected first from the transformer thus it is referred to as off-load tap-changing. This type of tap-changing cannot be used where continuity of the supply to the load is the main priority and it is limited where there will be a need for only slight changing in the turn-ratio.

On-Load Tap-Changing Transformer :

The drawback of off-load tap-changing can be overcome by using a special arrangement of coil connections to the transformer known as on-load tap-changing of the transformer. The transformer connection for on-load tap-changing is shown below.



Here, the coils of the winding in which tappings are to be done are divided into two parallel sections with equal tapping on both sections of the coil. This forms the two winding A & B as shown above. Under normal operating conditions both the switches (S_a & S_b) are in the closed (short-circuit) condition with identical tappings (i.e., 1 & 1'). As the winding is divided into parallel sections the total current will be the sum of the currents in winding A and B.

When the tappings are to be changed, to maintain the continuity of the supply the tap-changing process is made in such a way that,

- At first, any one of the winding (either A or B) from the parallel section is to be disconnected by open the respective switch.
- Now, the tap-changing is to be done to the disconnected winding.
- At this instant, the full-load current will pass through the connected winding (i.e., double of its rated current).
- After changing the tapping to the disconnected winding is reconnected by closing the switch.

- At this moment there will be an unequal share of the load on both windings due to their different turn ratios.
- Now the other winding is disconnected and tapping is to be changed (which is equal to the tapping of previously disconnected winding).
- So that there will be an equal amount of load share on both the windings (A & B).

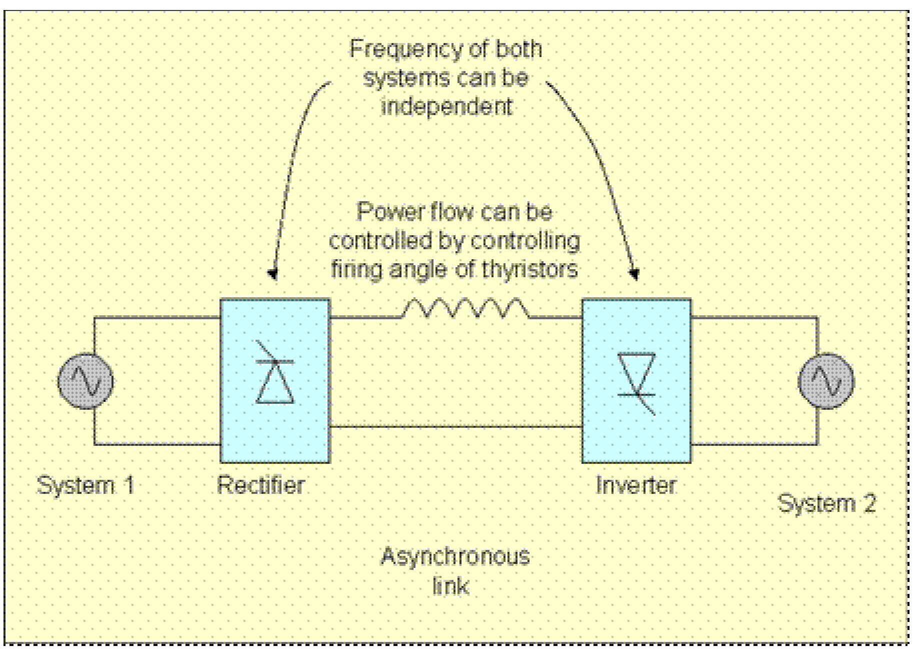
In this way, the continuity of the supply is maintained and more turn-ratio of tap-changing can possibly compare to off-load tap-changing of the transformer. Care must be taken to prevent the short-circuit with the windings while the tap-changing process.

Power flow control using embedded dc links

Power Flow can also be controlled by converting AC to DC by thyristor bridges or Voltage Source Converters and reconverting the DC to AC (at another bus) again by the same means. The converters are connected in shunt with the AC transmission system at 2 buses. If a substantial distance between the 2 buses is involved, then high voltage DC transmission is done. The power flow is a function of the converter firing angles and is practically independent of the voltage phase angle and frequency at either end.

Normally, DC links embedded in an AC system are mainly used to transfer power over long distances which is difficult with AC lines (see problems with long distance AC transmission in module 2).

DC links are also used to allow for controlled power inter-changes between two systems which are not synchronously connected is shown in the figure on the right.

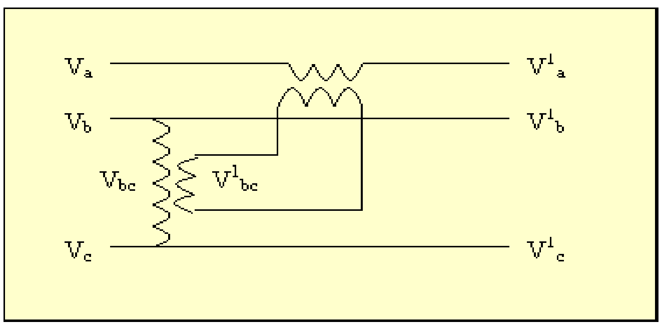


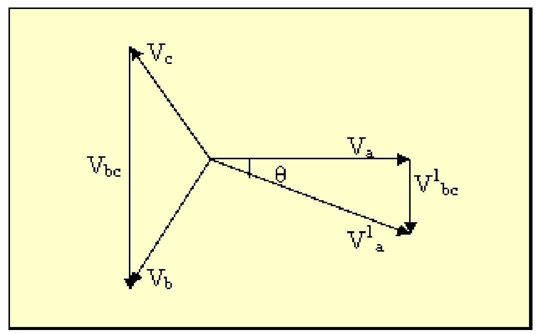
If the two systems in the figure above were to be connected using AC line(s), then the frequencies of both systems would have to be the same and the total power transfer from one system to another cannot be controlled even if variable reactance type devices like TCSC are connected. At best, such devices can control the sharing of power flow between parallel AC paths. The only way to control the total power flow in AC tie-lines is by controlling the generation/load in the two systems using AGC,

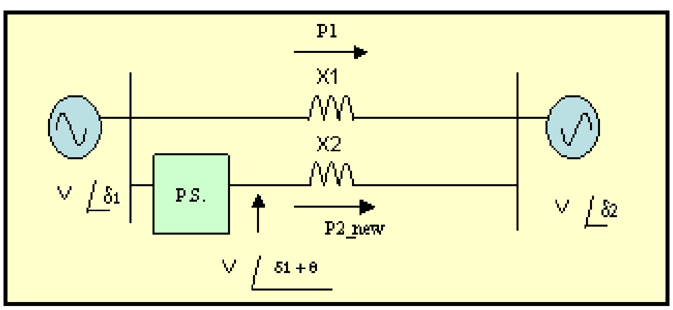
All the options for power flow control involve substantial cost, but can allow for better utilization of network by not only allowing desired power flow through various paths but enhancing overall power transfer levels.

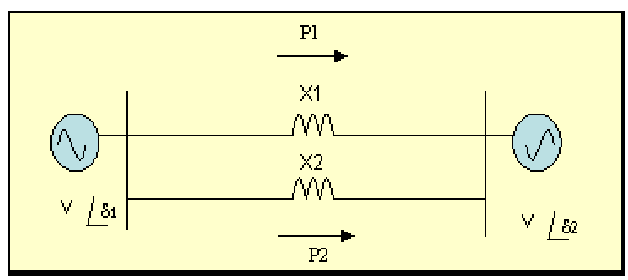
Phase shifters

Another method of changing power flow through a transmission line is by use of a phase shifter. A phase shifter introduces a small phase shift in the voltage at its two terminals by injection of a series voltage. The series injected voltage of one phase is in phase with the line voltage across the other 2 phases. This implies that the voltage injected in one phase is in quadrature to the bus voltage at one terminal of that phase. This small quadrature voltage injection mainly affects the bus voltage angle at the other terminal (which has superscript 1). The magnitude is not affected much if the series injected voltage is small. This is illustrated in the figures below. In the phasor diagram, the mechanism of obtaining a phase shift of q is shown. Similarly, a phase shift of -q can be obtained by reversing the injected voltage.









A phase shifter can alter the power flows in a transmission system. In the figures shown ,for the given phasor angles at both ends, the power flow in line 2 can be altered. Thus the *sharing* of the total power flow

$$\frac{P2_{new}}{P2_{new} + P1}$$

The expression for power flow in line 2 is given by,

$$P2_{new} = \frac{V^2 \sin(\delta_1 + \theta - \delta_2)}{x2}$$

SCADA

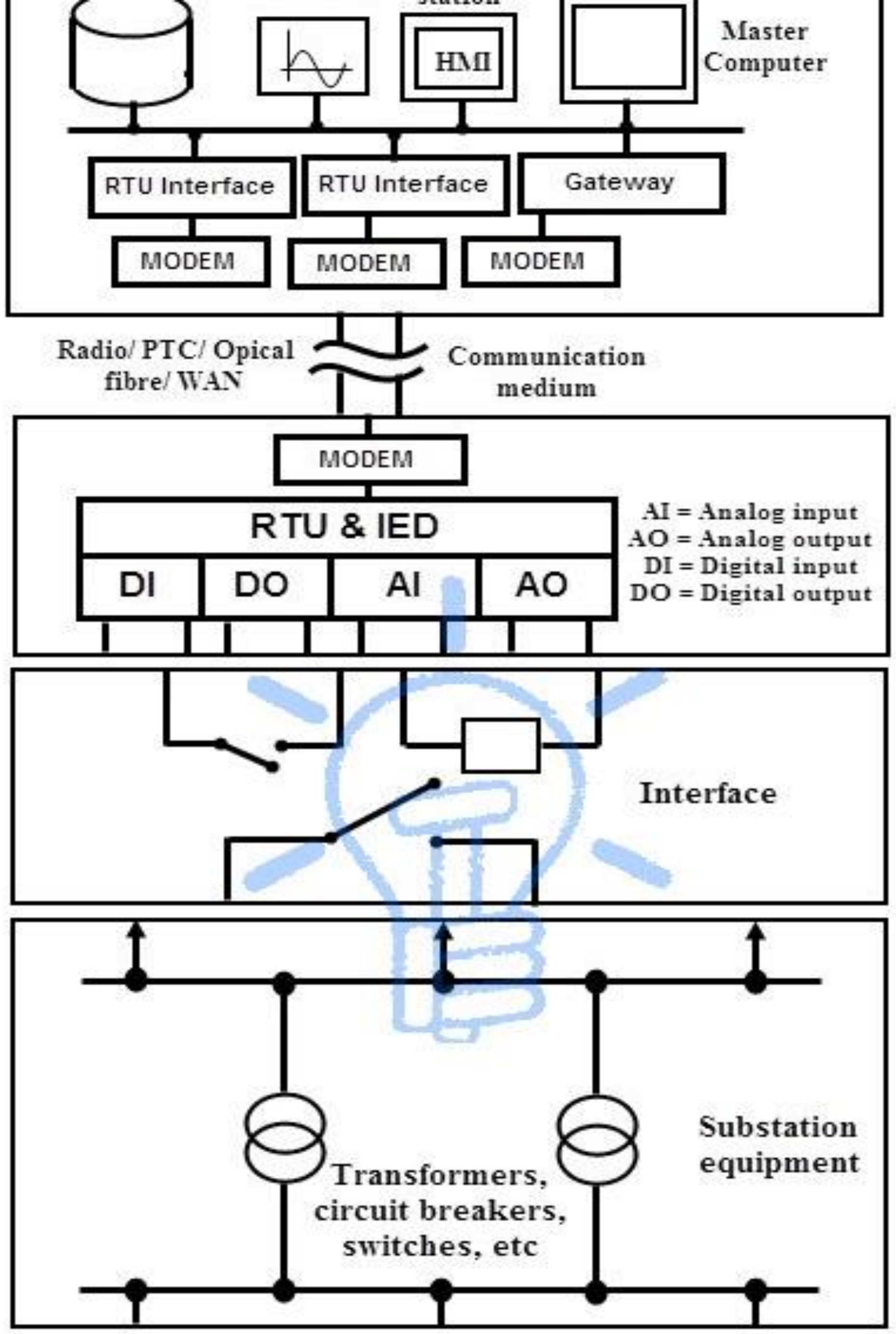
- SCADA performs *automatic monitoring, protecting and controlling of various equipments in power systems with the use of Intelligent Electronic Devices (or RTUs).* It restores the power service during fault condition and also maintains the desired operating conditions.
- SCADA improves the reliability of supply by reducing duration of outages and also gives the cost-effective operation of power system

Typical functions of SCADA

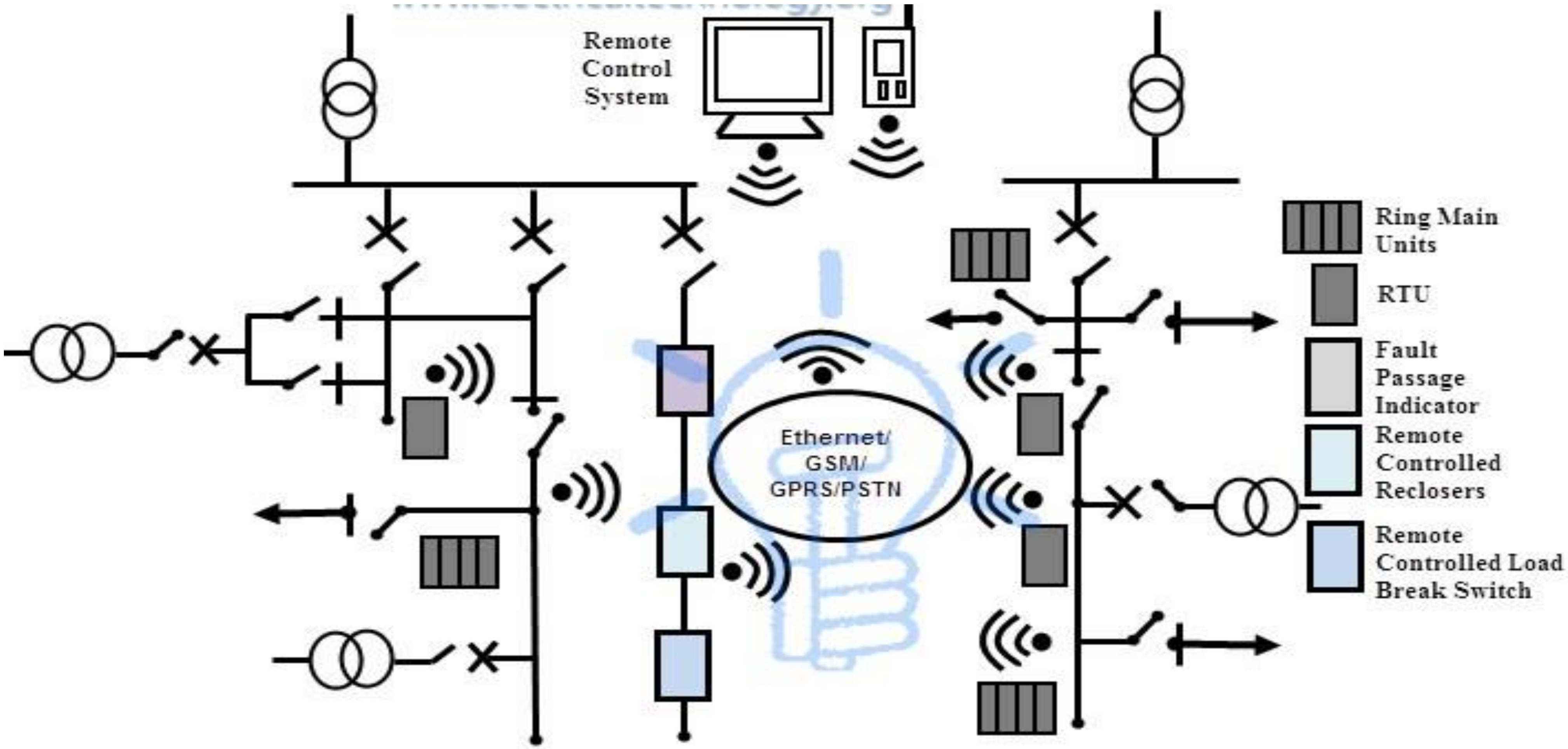
1. Control and indication of the position of a two- or three-position device, for example, a motor-driven switch or a circuit breaker.
2. State indication without control, for example, transformer fans on or off.
3. Control without indication, for example, capacitors switched in or out.
4. Set point control of remote control station, for example, nominal voltage for an automatic tap changer.
5. Alarm sensing, for example, fire or the performance of a noncommanded function.
6. Permit operators to initiate operations at remote stations from a central control station.
7. Initiation and recognition of sequences of events, for example, routing power around a bad transformer by opening and closing circuit breakers, or sectionalizing a bus with a fault on it.
8. Data acquisition from metering equipment, usually via analog/digital converter and digital communication link.

Substation Control using SCADA

- In substation automation system, SCADA *performs the operations like bus voltage control, bus load balancing, circulating current control, overload control, transformer fault protection, bus fault protection*, etc.
- SCADA system continuously monitors the status of various equipments in substation and accordingly sends control signals to the remote control equipments. Also, it collects the historical data of the substation and generates the alarms in the event of electrical accidents or faults.



Feeder Control using SCADA



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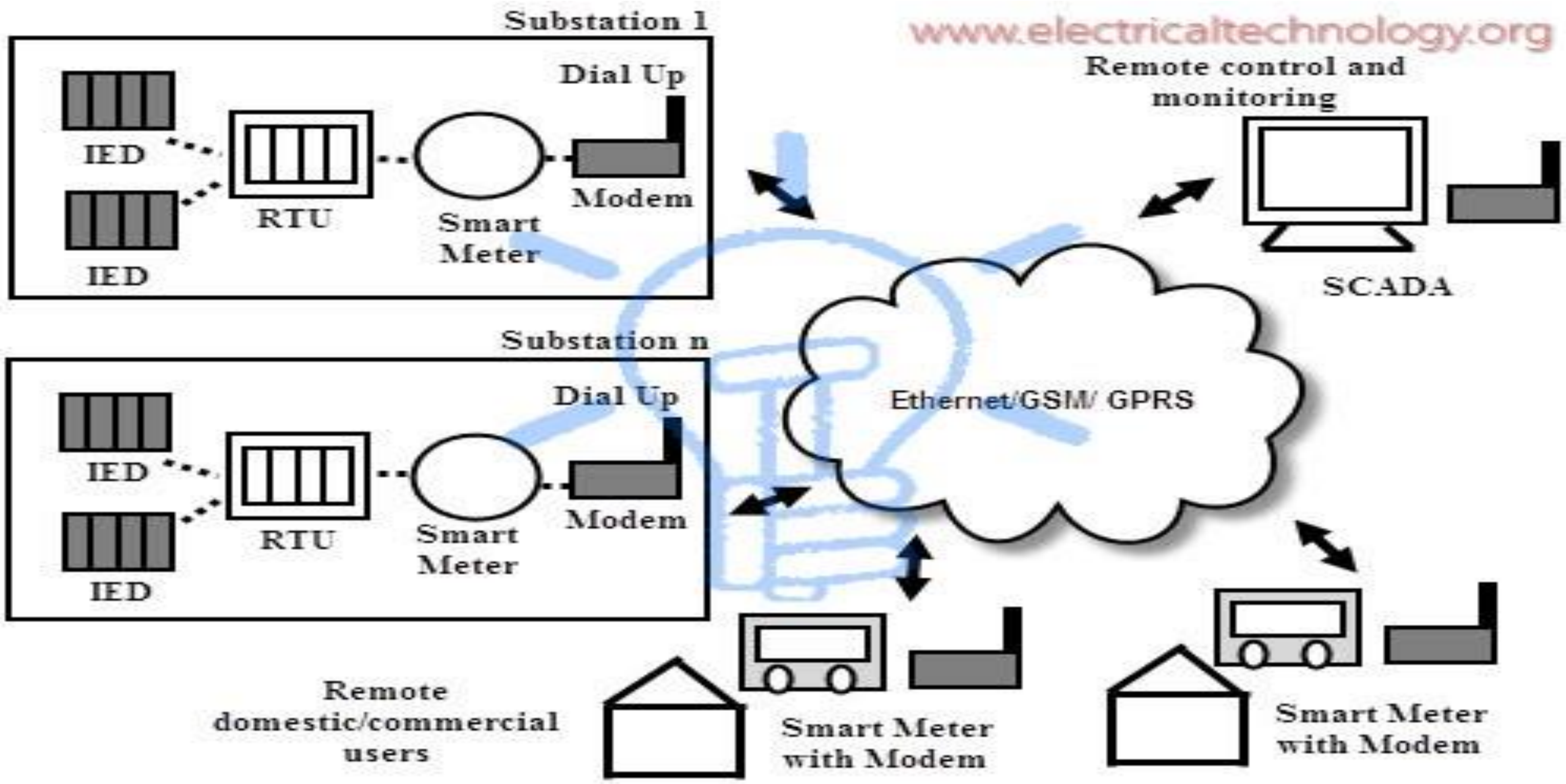
- This automation includes feeder voltage or VAR control and feeder automatic switching. Feeder voltage control performs voltage regulation and capacitor placement operations while feeder switching deals with remote switching of various feeders, detection of faults, identifying fault location, isolating operation and restoration of service.
- In this system, SCADA architecture continuously checks the faults and their location by using wireless fault detector units deployed at various feeding stations. In addition, it facilitates the remote circuit switching and historical data collection of feeder parameters and their status. The figure below illustrates feeder automation using SCADA.

End User Load Control Automation by SCADA



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- This type of automation at user end side implements functions like remote load control, automatic meter reading and billing generation, etc. *It provides the energy consumption by the large consumers and appropriate pricing on demand or time slots wise. Also detects energy meter tampering and theft and accordingly disconnects the remote service.* Once the problem is resolved, it reconnects the service.
- In this, smart meters with a communication unit extract the energy consumption information and made it available to a central control room as well as local data storage unit. At the central control room, AMR control unit automatically retrieves, stores and converts all meter data.
- Modems or communication devices at each meter provide secure two-way communication between central control and monitoring room and remote sites.

Synchro-phasors

- Synchro-phasors are time-synchronized numbers that represent both *magnitude and phase angle* of the sine waves found in Electricity or any power system network,
- They are measured by high-speed monitors called

  "Phasor Measurement Units (PMUs)"
- synchro phasors provide a real-time measurement of electrical quantities across the power system.

Applications of synchro phasors

- Wide-area control
- System model validation
- Determining stability margins
- Maximizing stable system loading
- System-wide disturbance recording,
- Visualization of dynamic system response

Phasor Measurement Unit (PMU)

- A **phasor measurement unit** (PMU) is a device used to *estimate the magnitude and phase angle of an electrical quantity (such as voltage or current) in the Electric grid or power system* using a common time source for synchronization.
- The resultant magnitude + phase angle = synchro phasor
- PMUs provide up to *60 measurements per second,* which is much more than the typical *one measurement every 2 to 4 seconds* provided by conventional SCADA systems.
- PMUs have a big advantage over traditional means of collecting data because all PMU data is time-stamped using Global Positioning System (GPS) data. This means that data collected across a grid is well synchronized by using the same exact method of associating time with data.

Advantages of PMUs

Phasor Measurement Units (PMUs) have the potential to play an essential role in power system monitoring, protection and control

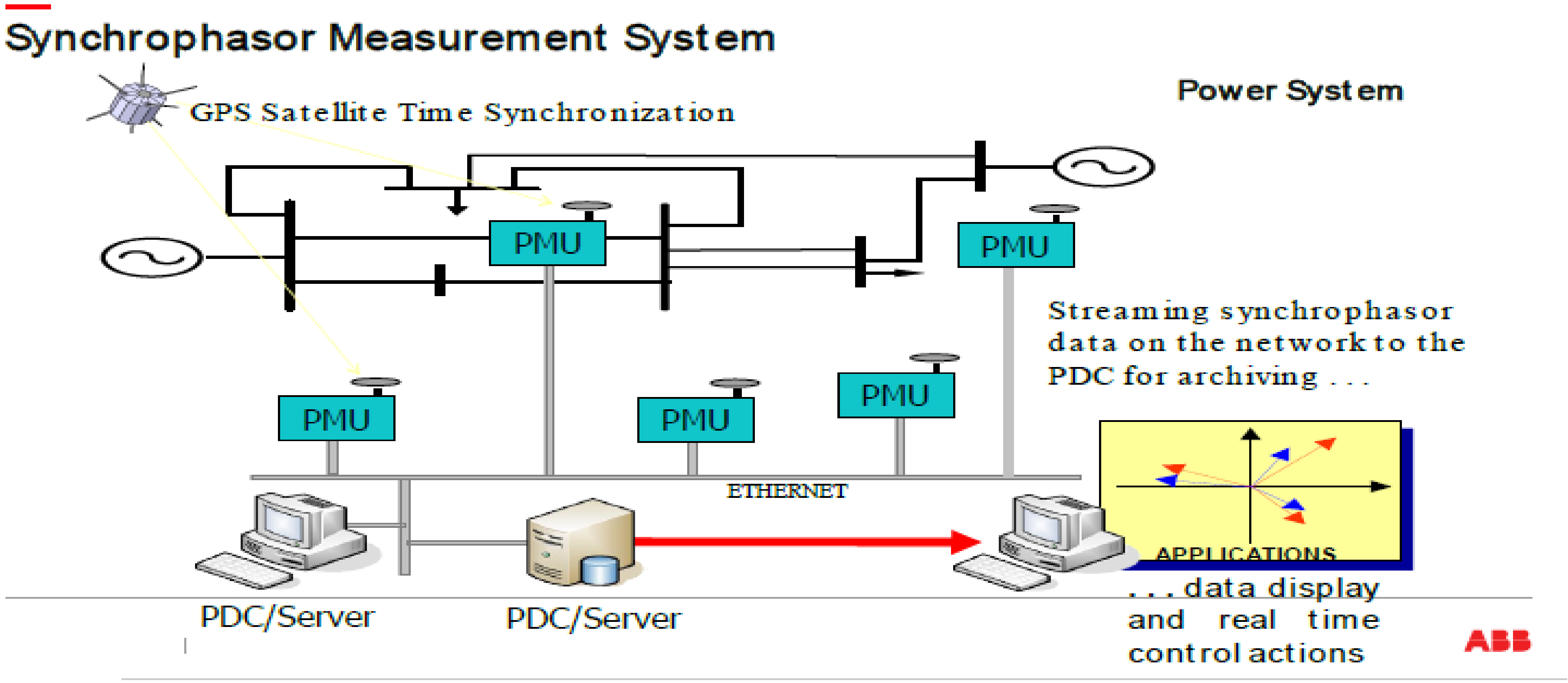
PMUs can also be used to measure the frequency in the power grid.

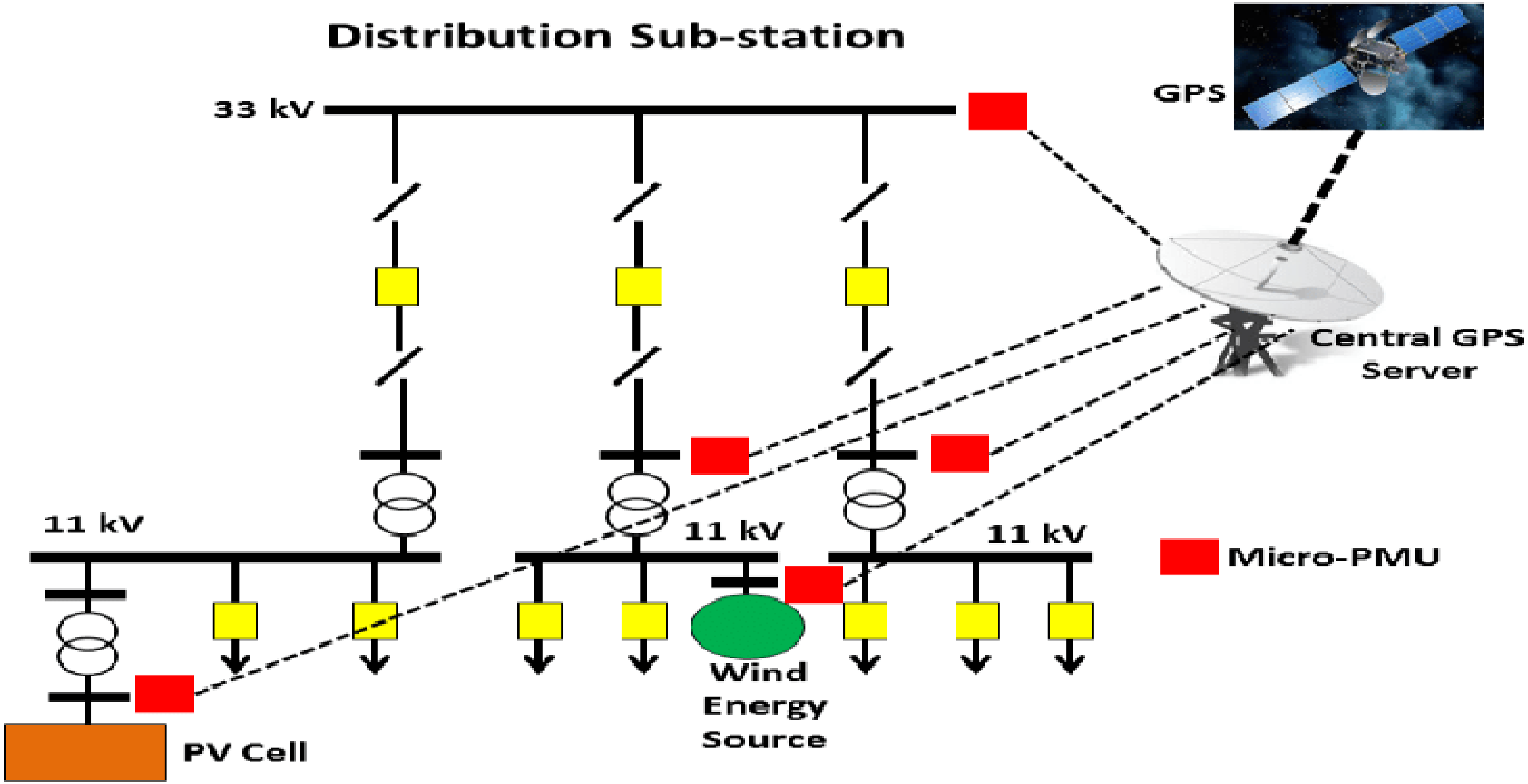
The status of faults and Nature of power system can be easily accessed and analyzed with the information provided by PMU.

Typical applications of PMUs

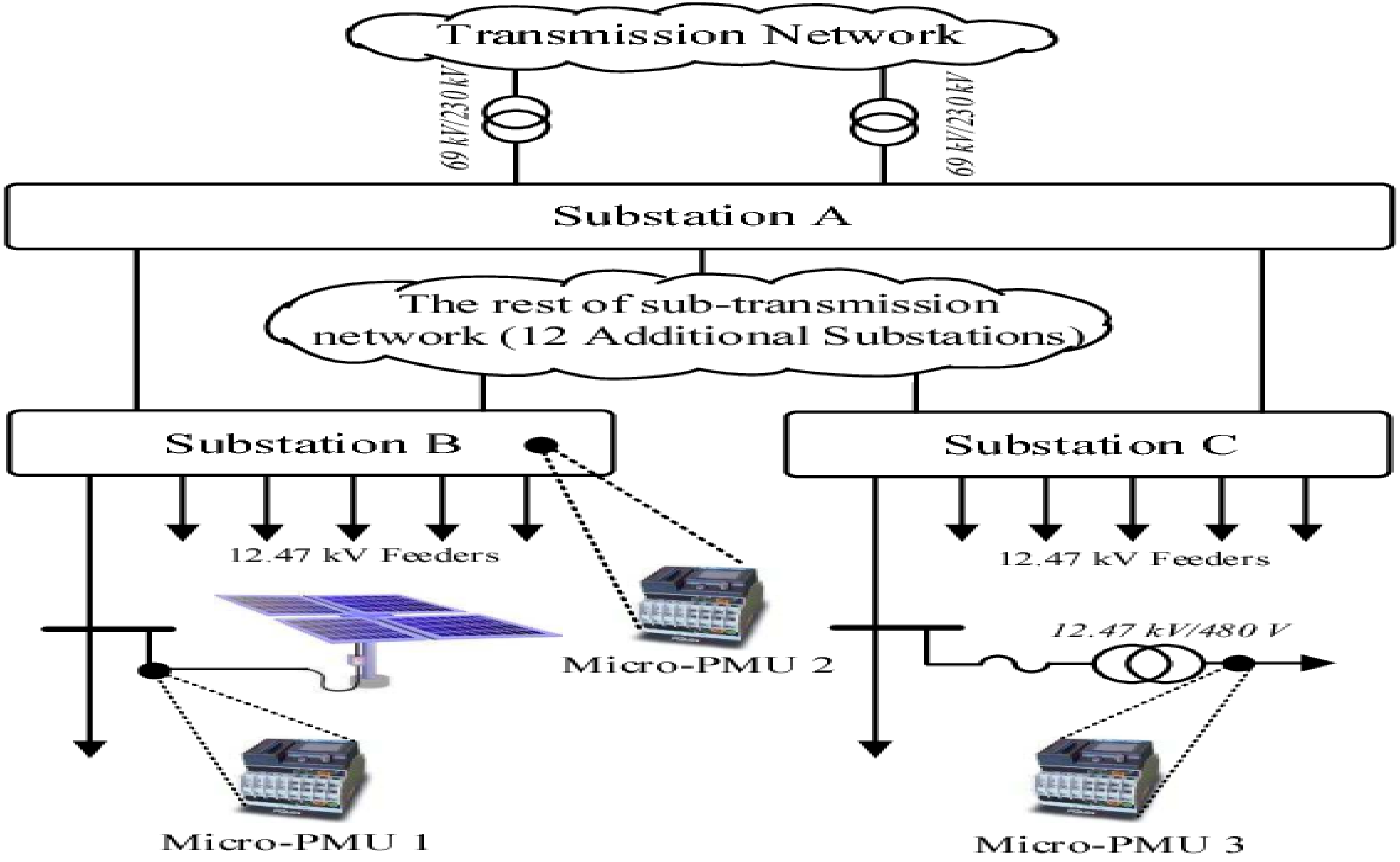
- Network state estimation
- Dynamic supervision
- Instability prediction and control
- Protection
- Finding fault location
- Power Quality monitoring

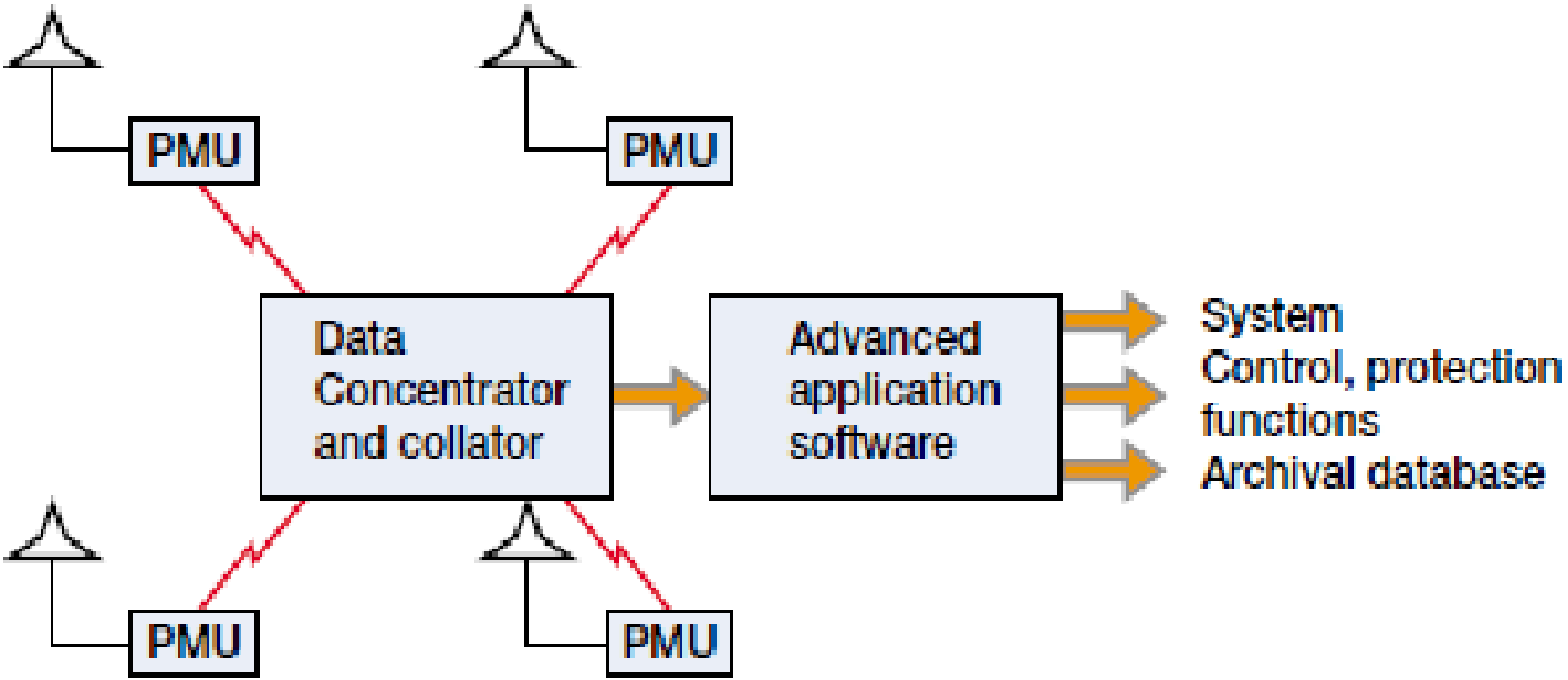
Various Power system networks with PMUs





Distribution Sub-station
33 kV
GPS
Central GPS Server
11 kV
11 kV
11 kV
Micro-PMU
Wind Energy Source
PV Cell


Transmission Network
69 kV/230 kV
69 kV/230 kV
Substation A
The rest of sub-transmission network (12 Additional Substations)
Substation B
Substation C
12.47 kV Feeders
12.47 kV Feeders
12.47 kV/480 V
Micro-PMU 1
Micro-PMU 2
Micro-PMU 3


PMU
PMU
Data Concentrator and collator
Advanced application software
System
Control, protection functions
Archival database
PMU
PMU

Wide area monitoring system(WAMS)

- Wide area monitoring system (WAMS) is a advanced new data acquisition technology of phasor measurement and allow *monitoring various conditions of power system over large areas in view of detecting faults* and further counteracting grid instabilities.
- The Wide Area Monitoring Systems (**WAMS**) gives control of transmission and distribution networks,
- Used for *network stability, ampacity* of lines and detection of critical network conditions.

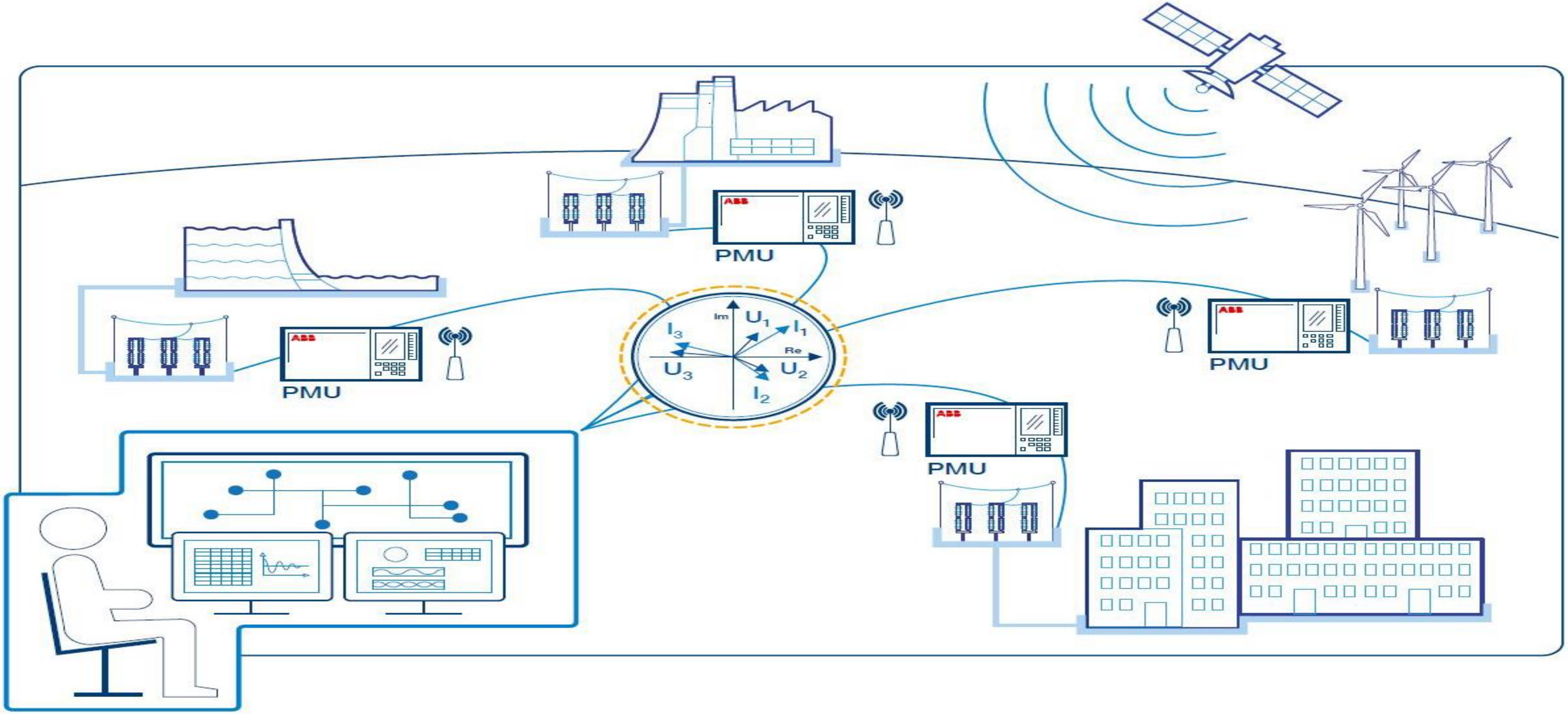
Components of WAMS

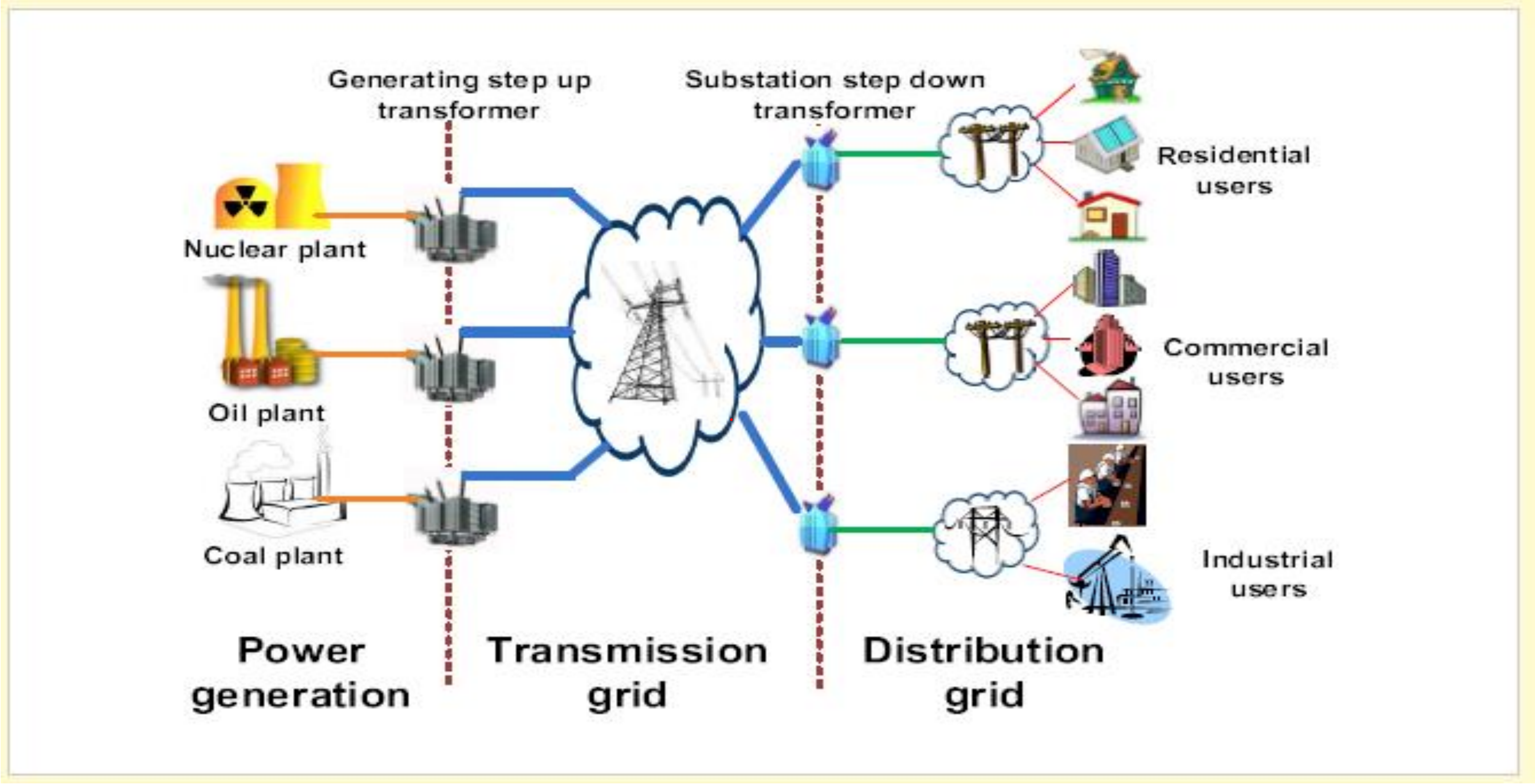
- Phasor Measurement Unit(PMU)
  - They are devices which use synchronization signal from the global positioning system(GPS) satellite and provide the phasor voltage and currents measured at a given substation.
  - A phasor is a complex number that represents both magnitude and phase angle of the sine waves found in electricity.
  - PMU can different Date Rate i.e. 60,30,10 frame per second.
- Phasor Data Concentrator(PDC)
  - It is node in a system where phasor data from a number of PMUs or PDCs is correlated and fed out as a single stream to other applications.
  - PDC would performs the Real time monitoring, alarming, event triggering.
  - It perform loacal archiving.
  - It perform various quality checks on the phasor data.

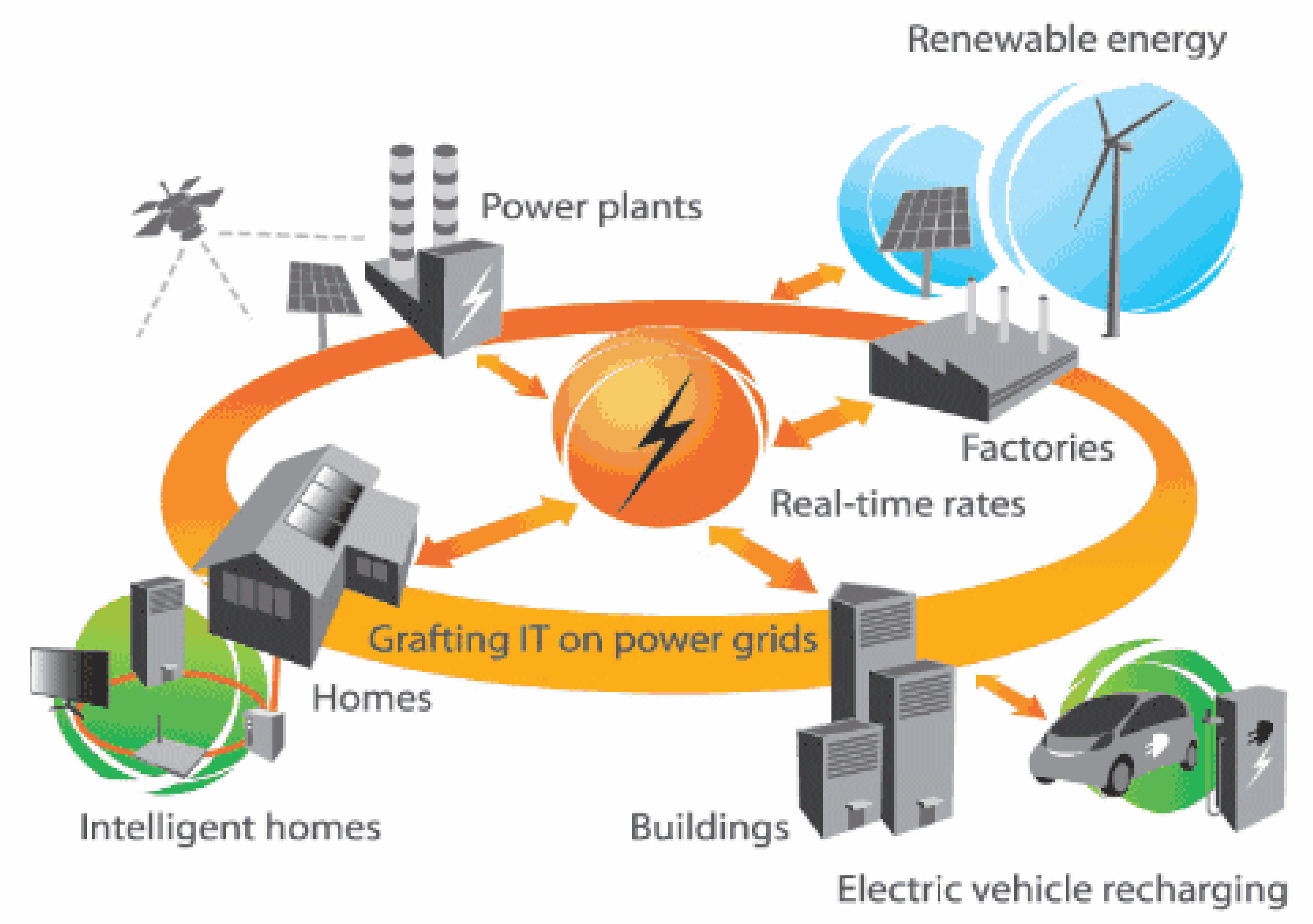
Major Applications of WAMS

- Measurement of symmetrical components(+ve, -ve, Zero sequence)
- Active & Reactive Power Monitoring
- Frequency & Rate of Change of Frequency Monitoring
- Voltage Magnitude & Angle Difference Monitoring
- System Condition Monitoring
- Prediction of fault locations and detection of critical network conditions.
- Network Stability Monitoring
- Estimating Short Circuit Capacity
- Line Parameter Estimation
- Controlling the network

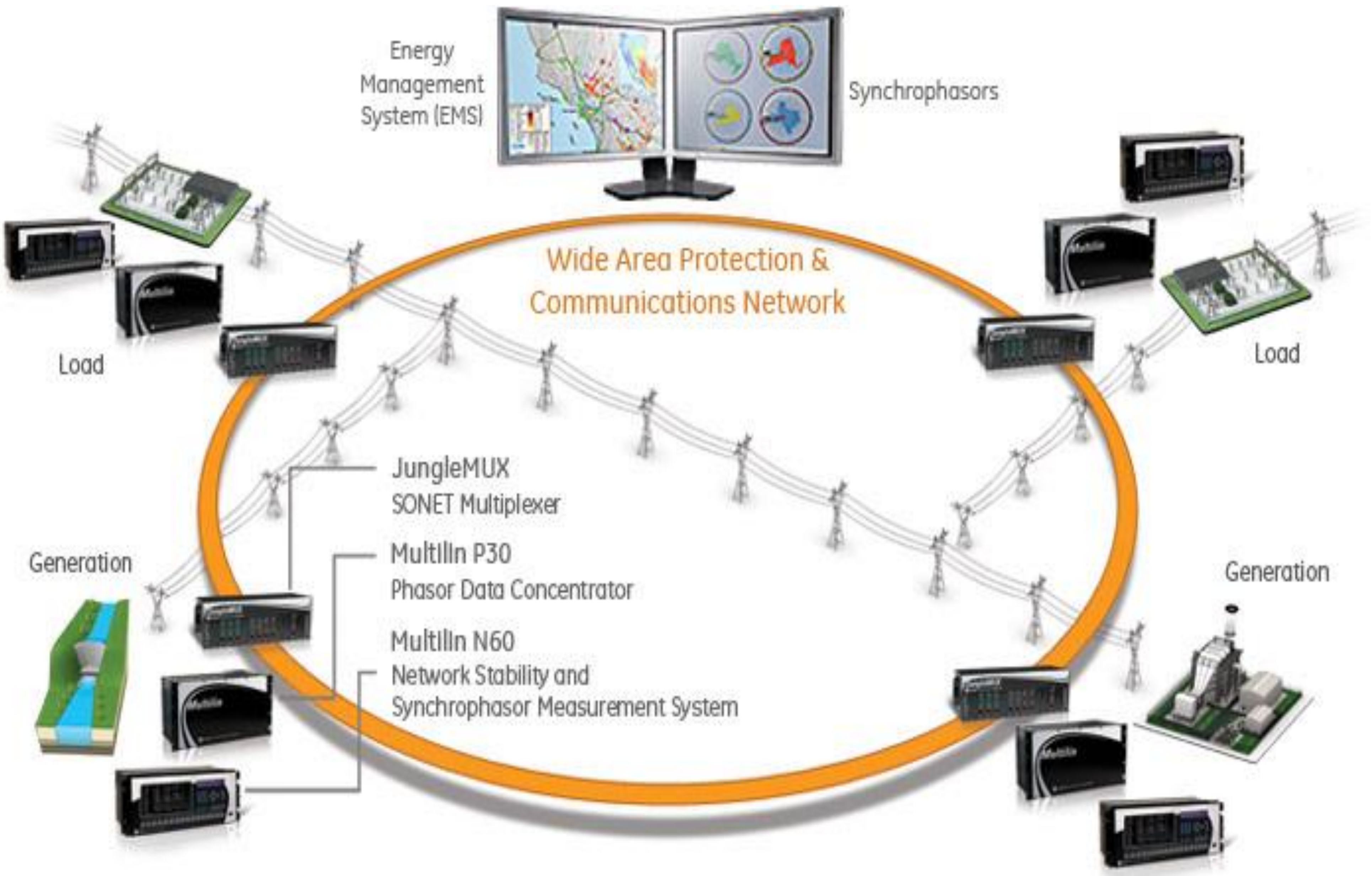
Wide area monitoring system with PMUs




Generating step up transformer
Substation step down transformer
Nuclear plant
Oil plant
Coal plant
Residential users
Commercial users
Industrial users
Power generation
Transmission grid
Distribution grid

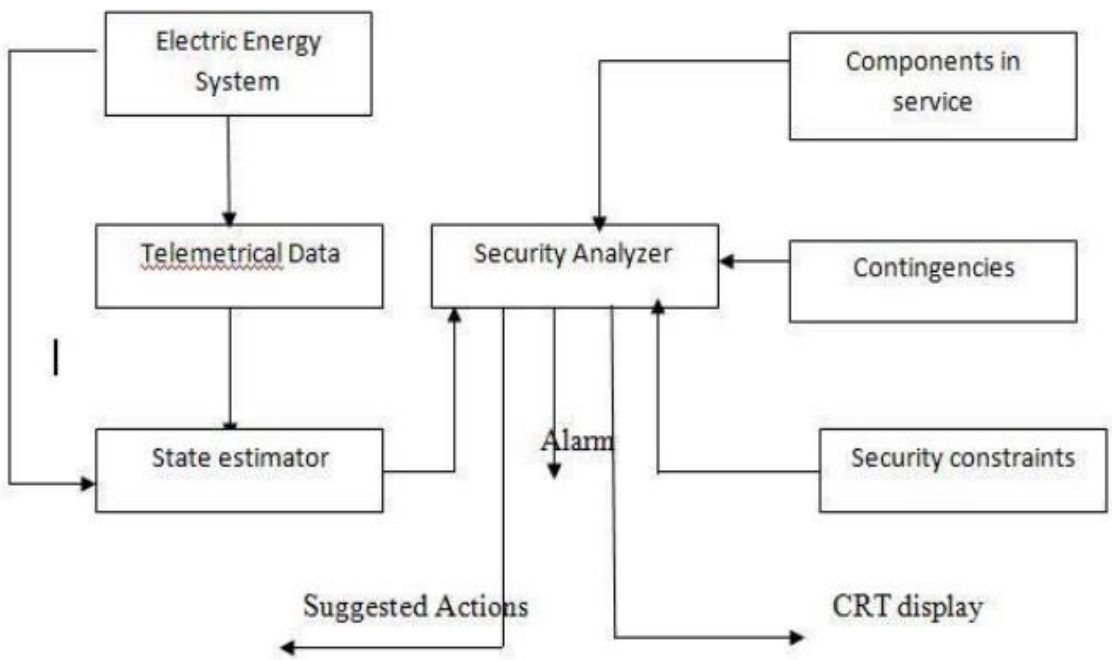


Renewable energy
Power plants
Factories
Real-time rates
Grafting IT on power grids
Homes
Intelligent homes
Buildings
Electric vehicle recharging


Energy Management System (EMS)
Synchrophasors
Wide Area Protection & Communications Network
Load
Load
JungleMUX
SONET Multiplexer
Multilin P30
Phasor Data Concentrator
Multilin N60
Network Stability and Synchrophasor Measurement System
Generation
Generation

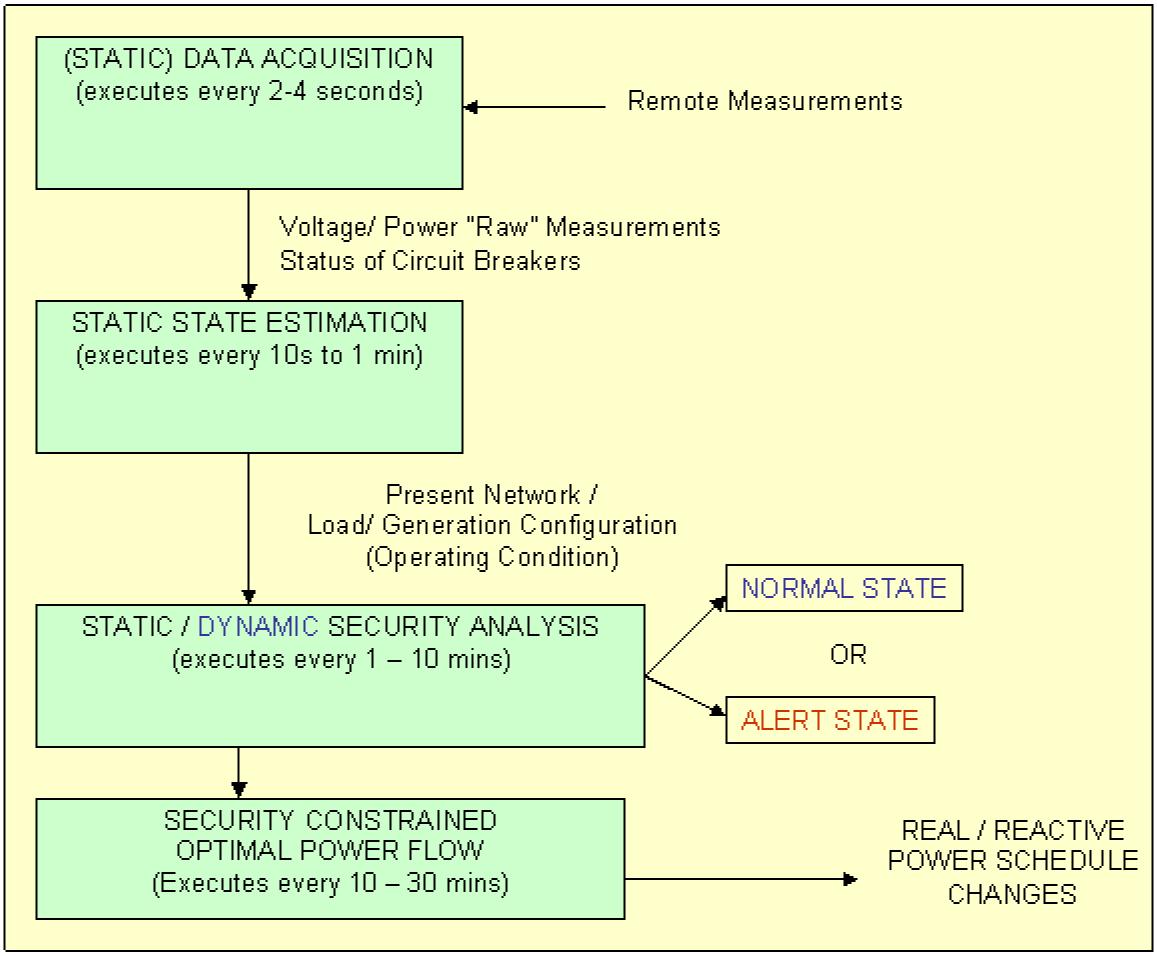
System Security Assessment / Security Analysis & Control:

Security monitoring is the on line identification of the actual operating conditions of a power system. It requires system wide instrumentation to gather the system data as well as a means for the on line determination of network topology involving an open or closed position of circuit breakers. A state estimation has been developed to get the best estimate of the status .the state estimation provides the database for security analysis shown in fig.



Practical Security Monitoring System

Schematic of Security Assessment Procedure



- **Data acquisition**:

    1. To process from RTU
    2. To check status values against normal value
    3. To send alarm conditions to alarm processor
    4. To check analog measurements against limits.

- **Alarm processor:**
  1. To send alarm messages
  2. To transmit messages according to priority

- **Status processor:**
  1. To determine status of each substation for proper connection.
- **Reserve monitor:**
  1. To check generator MW output on all units against unit limits
- **State estimator:**
  1. To determine system state variables
  2. To detect the presence of proxy/ garbage measurement values.
  3. To identify the location of proxy measurements
  4. To initialize the network model for other programs

Security Control Function:

- Network Topology processor-mode of the N/W
- State estimator.
- Power flow- V, δ, P, Q.
- Optimal power flow.
- Contingency analysis.

Security enhancement-existing overload using corrective control action.

System Security

1. System monitoring
2. Contingency analysis.
3. Security constrained optimal power flow

Security Assessment

- Security assessment determines first, *whether the system is currently residing in an acceptable state* and

second, *whether the system would respond in an acceptable manner and reach an acceptable state* following any one of a pre-defined contingency set.

- ***A contingency is the unexpected failure of a transmission line, transformer, or generator***.
- Usually, contingencies result from occurrence of a *fault*, or short-circuit, to one of these components.
- When such a fault occurs, the protection systems sense the fault and remove the component, and therefore also the fault, from the system.
- Of course, with one less component, the overall system is weaker, and undesirable effects may occur.
- For example, some circuit may overload, or some bus may experience an undervoltage condition. These are called *static* security problems.
- *Dynamic* security problems may also occur, including uncontrollable voltage decline, generator overspeed (loss of synchronism), or undamped oscillatory behavior

Security Control

- Power systems are designed to survive all probable contingencies.
- A contingency is defined as an event that causes one or more important components such as transmission lines, generators, and transformers to be unexpectedly removed from service.
- Survival means the system stabilizes and continues to operate at acceptable voltage and frequency levels without loss of load.
- Operations must deal with a vast number of possible conditions experienced by the system, many of which are not anticipated in planning.
- Instead of dealing with the impossible task of analyzing all possible system states, security control starts with a specific state: the current state if executing the real-time network sequence; a postulated state if executing a study sequence.
- Sequence means sequential execution of programs that perform the following steps:

1. Determine the state of the system based on either current or postulated conditions.

2. Process a list of contingencies to determine the consequences of each contingency on the system in its specified state.

3. Determine preventive or corrective action for those contingencies which represent unacceptable risk.

- Security control requires topological processing to build network models and uses large-scale AC network analysis to determine system conditions.
- The required applications are grouped as a network subsystem that typically includes the following functions:

Topology processor:

Processes real-time status measurements to determine an electrical connectivity (bus) model of the power system network.

• State estimator:

Uses real-time status and analog measurements to determine the best estimate of the state of the power system. It uses a redundant set of measurements; calculates voltages, phase angles, and power flows for all components in the system; and reports overload conditions.

• Power flow:

Determines the steady-state conditions of the power system network for a specified generation and load pattern. Calculates voltages, phase angles, and flows across the entire system.

Contingency analysis:

Assesses the impact of a set of contingencies on the state of the power system and identifies potentially harmful contingencies that cause operating limit violations.

Optimal power flow: Recommends controller actions to optimize a specified objective function (such as system operating cost or losses) subject to a set of power system operating constraints.

• Security enhancement:

Recommends corrective control actions to be taken to alleviate an existing or potential overload in the system while ensuring minimal operational cost.

• **Preventive action**:

Recommends control actions to be taken in a “preventive” mode before a

contingency occurs to preclude an overload situation if the contingency were to occur.

• Bus load forecasting:

Uses real-time measurements to adaptively forecast loads for the electrical connectivity (bus) model of the power system network

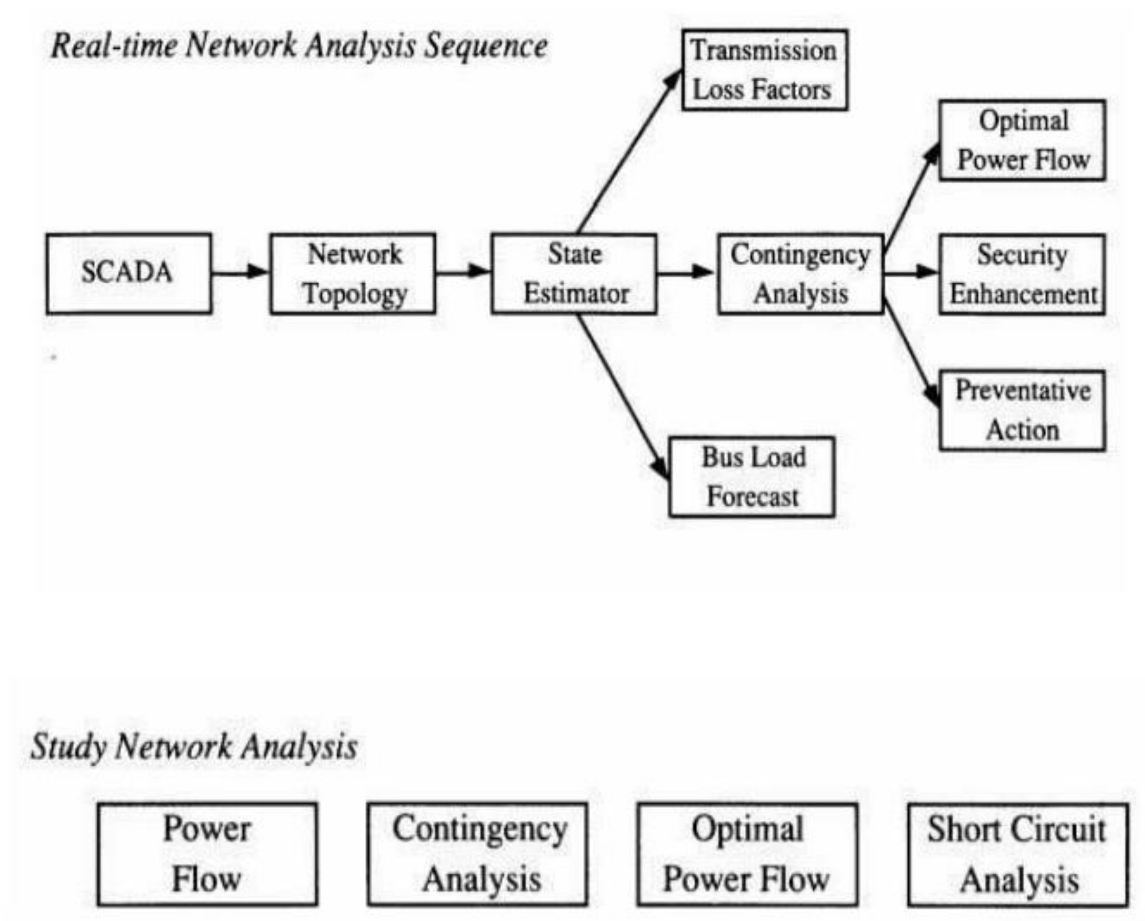
• Transmission loss factors:

Determines incremental loss sensitivities for generating units;

calculates the impact on losses if the output of a unit were to be increased by 1 MW.

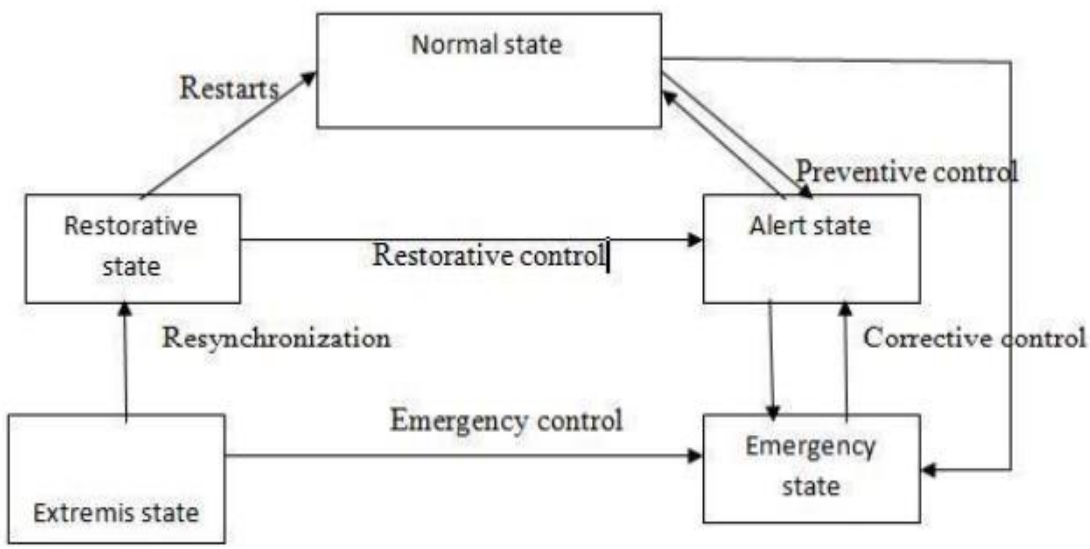
• Short-circuit analysis:

Determines fault currents for single-phase and three-phase faults for fault locations across the entire power system network.



Real-time and study network analysis sequences.

VARIOUS OPERATING STATES OF POWER SYSTEMS:



Operating states

1. Normal state

2. Alert state

3. Emergency state

4. Extremis state

5. Restorative state

Normal state (secure state):

A system is said to be in normal if both load and operating constraints are satisfied.

It is one in which the total demand on the system is met by satisfying all the operating constraints.

Alert state (insecure state):

- A normal state of the system said to be in alert state if one or more of the contingency states, consists of the constraint limits violated.

- *When the system security level falls below a certain level or the probability of disturbance increases, the system is said to be in alert state* .

- All equalities and inequalities are satisfied, but on the event of a disturbance, the system may not have all the inequality constraints satisfied.

Emergency state:

***If severe disturbance occurs, the system will push into emergency state*.**

To bring back the system to secure state, preventive control action is carried out.

- The system will return to the normal or alert state by means of corrective actions, disconnection of faulted section or load sharing.

Extremis state:

- When the system is in emergency, if no proper corrective action is taken in time, then it goes to extremis state.
- In this regard neither the load or nor the operating constraint is satisfied, this result is islanding.
- Also the generating units are strained beyond their capacity .
- So emergency control action is done to bring back the system state either to the emergency state or normal state.

Restorative state:

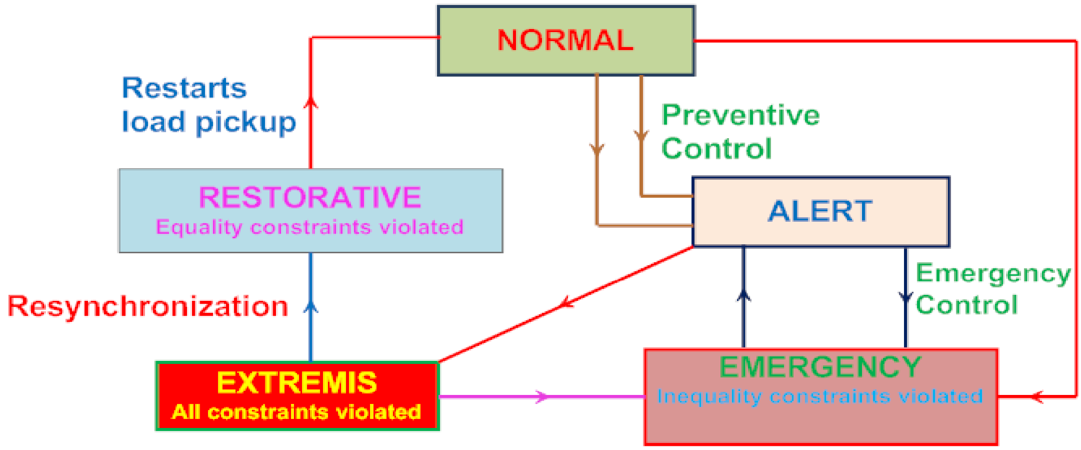
- From this state, the system may be brought back either to alert state or secure state .
- In certain cases, first the system is brought back to alert state and then to the secure s.
- This is done using restorative control action.

Preventive Control and Emergency Control:

- The preventive state is actually the normal state. The term 'preventive' was used to stress the 'Security' aspect of the normal operation. I Normal operating condition usually means that all the apparatus are running within their prescribed limits, and all the system variables are within acceptable ranges. I The system should also continue to operate 'normally' even in the case of credible contingencies. The operator should 'foresee' such contingencies (disturbances) and take preventive control actions (as economically as possible) such that the system integrity and quality of power supply is maintained
- The power system enters an emergency state when some of the components operating limits are violated; some of the states wander outside the acceptable ranges, or when the system frequency starts to decrease. I The control objective in the emergency state is to relieve system stress by appropriate actions. I Economic considerations become secondary at this stage
- The preventive control aims **at changing the operating condition of the system once it is found to be transiently insecure for a particular disturbance for given operating conditions when the system is still** in secure state. Preventative actions, such as generation shifting and increase of reactive power reserves, can be taken to restore the system to the normal state
- Emergency control measures are proposed for improving the stability of power systems. Majority of these measures includes **load shedding and generation shedding**. ... For emergency operating state, two emergency control methods, namely generator shedding and load shedding are proposed.

How is preventive control different from emergency control

- Uncertainty: in preventive control, the state of the system is well known but **disturbances are uncertain**;
- in emergency control, the disturbance is certain, but the state of the system is often only partially known; in both cases, dynamic behavior is uncertain
- There are several forms of emergency controls in use: load shedding, generator tripping, steam turbine fast-valving, generation ramping, dynamic braking, controlled system separation, rapid power control of HYDC links, transient excitation boosting of generators, capacitor/reactor switching, and transformer tap-changer blocking. In many situations, anyone method of control may not be adequate; the best approach is likely to be a combination of several controls judiciously chosen so as to most effectively assist in coping with different contingencies and system conditions. In applying these methods, it is particularly important to keep in mind the overall power system performance, possible side effects, and cost.



NORMAL
Restarts
load pickup
Preventive
Control
RESTORATIVE
Equality constraints violated
ALERT
Emergency
Control
Resynchronization
EXTREMIS
All constraints violated
EMERGENCY
Inequality constraints violated

Contingency Analysis:

Contingency analysis The contingency analysis basically involves the simulation of ever contingency of the power system. But this analysis involves three major difficulties 1. *Difficulty to develop the appropriate power system model. 2. Confusion to choose contingency case. 3. Difficulty in computing the power flow and the bus voltages which leaves to high time consumption.* The contingency analysis is divided into three different stages 1**.** **Contingency definition** – It comprise of set of contingency that occur in the power system. 2. **Selection** – It is the process of selecting the most severe contingencies from the contingency list. Thus this process removes the unimportant contingencies and hence the contingency list is shortened. 3**. Evaluation** – In this process it involves the necessary security action or control to function in order to remove the affect of contingency. **contingency analysis using sensitivity factor** It is one of the easiest calculation way to provide quick calculation of the possible overloads. These factors show the changes in generation on the network configuration and are derived from dc load flow. The system security assessment is carried out by calculating system operating limits in the **pre contingency and post contingency** operating states**. Pre contingency** – It is the state of the power system before the contingency has occurred. **Post contingency**– It is the state of the power system after the contingency has occurred.It is assumed that this type of the contingency has the security violations such as the line or transformer are beyond its flow limit or the bus voltage is within its limit.

METHODS OF CONTINGENCY ANALYSIS The different methods used for analyzing the contingencies are based on full AC load flow analysis or reduced load flow or sensitivity factors. But these methods need large computational time and are not suitable for on line applications in large power systems. It is difficult to implement on line contingency analysis using conventional methods because of the conflict between the faster solution and the accuracy of the solution. Some important methods are

1. AC load flow methods
2. DC load flow method.
3. Z-bus contingency analysis.
4. Performance Index method.

LOAD FLOW METHODS The objective of power flow study is to determine the voltage and its angle at each bus, real and reactive power flow in each line and line losses in the power system for specified bus or terminal conditions. Power flow studies are conducted for the purpose of planning (viz. short, medium and long range planning), operation and control. The other purpose of the study is to compute steady state operating point of the power system, that is voltage magnitudes and phase angles at the buses. By knowing these quantities, the other quantities like line flow (MW and MVAr) real and reactive power supplied by the generators and loading of the transformers can also be calculated. The conditions of over loads and under or over voltages existing in the parts of the system can also be detected

For accurate contingency evaluation purpose load flow analysis is an important tool to simulate various equipment outages.

MODELLING CONTINGENCY ANALYSIS Since contingency analysis involves the simulation of each contingency on the base case model of the power system, three major difficulties are involved in this analysis. First is the difficulty to develop the appropriate power system model. Second is the choice of which contingency case to consider and third is the difficulty in computing the power flow and bus voltages which leads to enormous time consumption in the Energy Management System. It is therefore apt to separate the on-line contingency analysis into three different stages namely contingency definition, selection and evaluation. Contingency definition comprises of the set of possible contingencies that might occur in a power system, it involves the process of creating the contingency list. Contingency selection is a process of identifying the most severe contingencies from the contingency list that leads to limit violations in the power flow and bus voltage magnitude, thus this process eliminates the least severe contingencies and shortens the contingency list. It uses some sort of index calculations which indicates the severity of contingencies. On the basis of the results of these index calculations the contingency cases are ranked. Contingency evaluation is then done which involves the necessary security actions or necessary control to function in order to mitigate the effect of contingency.

Contingency Analysis using Sensitivity Factors The problem of studying thousands of possible outages becomes very difficult to solve if it is desired to present the results quickly. One of the easiest ways to provide a quick calculation of possible overloads is to use sensitivity factors. These factors show the approximate change in line flows for changes in generation on the network configuration and are derived from the DC load flow**.** These factors can be derived in a variety of ways and basically come down to two types: The **generation shift factors** are designated a_{li} and have the following definition

$$a_{li} = \frac{\Delta f_l}{\Delta P_i} \qquad (2.1)$$

where

l= line index

i=bus index

Δf_l = change in megawatt power flow on line l when a change in generation ΔP_i occurs at bus i

ΔP_i = change in generation at bus i

It is assumed that the change in generation ΔP_i is exactly compensated by an opposite change in generation at the reference bus, and that all other generators remain fixed. The a_{li} factor then represents the sensitivity of the flow on line *l* due to a change in generation at bus *i*. If the generator was generating P_{io} MW and it was lost, it is represented by ΔP_i, as the new

$$\Delta P_i = - P_i^o \tag{2.2}$$

power flow on each line in the network could be calculated using a pre calculated set of ***"a"*** factors as follows:

$$f_l = f_l^0 + a_{li}\, \Delta P_i \text{ for } l = 1 \ldots L \tag{2.3}$$

where,

f_l = flow on line *l* after the generator on bus *i* fails

f_l^0 = flow before the failure

The outage flow f_l on each line can be compared to its limit and those exceeding their limit are flagged for alarming. This would tell the operations personal that the loss of the generator on bus *i* would result in an overload on line *l*. The generation shift sensitivity factors are linear estimates of the change in flow with a change in power at a bus. Therefore, the effects of simultaneous changes on several generating buses can be calculated using superposition. The **line outage distribution factors** are used in a similar manner, only they apply to the testing for overloads when transmission circuits are lost. By definition, the line outage distribution factor has the following meaning:

$$d_{l,k} = \frac{\Delta f_l}{f_k^0} \tag{2.4}$$

where

$d_{l,k}$ = line outage distribution factor when monitoring line *l* after an outage on line *k*

Δf_l = change in MW flow on line *l*

f_k^0 = original flow on line *k* before it was outaged i.e., opened

If one knows the power on line *l* and line *k*, the flow on line *l* with line *k* out can be determined using ***"d"*** factors.

$$f_l = f_l^0 + d_{l,k} f_k^0 \tag{2.5}$$

where

f_l^0 and f_k^0 = pre outage flows on lines *l* and *k*, respectively

f_l = flow on line *l* with line *k* out

By pre calculating the line outage distribution factors, a very fast procedure can be set up to test all lines in the network for overload for the outage of a particular line. Furthermore, this procedure can be repeated for the outage of each line in turn, with overloads reported to the operations personnel in the form of alarm messages. The generator and line outage procedures can be used to program a digital computer to execute a contingency analysis study of the power system. It is to be noted that a line flow can be positive or negative so that we must check f_l against – *flmax* as well as *flmax*. It is assumed that the generator output for each of the generators in the system is available and that the line flow for each transmission line in the network is also available and the sensitivity factors have been calculated and stored.

Contingency Analysis using AC Power Flow The calculations made with the help of network sensitivity factors for contingency analysis are faster, but there are many power systems where voltage magnitudes are the critical factor in assessing contingencies. The method gives rapid analysis of the MW flows in the system, but cannot give information about MVAR flows and bus voltages. In systems where VAR flows predominate, such as underground cables, an analysis of only the MW flows will not be adequate to indicate overloads. Hence the method of contingency analysis using AC power flow is preferred as it gives the information about MVAR flows and bus voltages in the system. When AC power flow is to be used to study each contingency case, the speed of solution for estimating the MW and MVAR flows for the contingency cases are important, if the solution of post contingency state comes late, the purpose of contingency analysis fails. The method using AC power flow will determine the overloads and voltage limit violations accurately. It does suffer a drawback, that the time such a program takes to execute might be too long. If the list of outages has several thousand entries, then the total time to test for all of the outages can be too long. However, the AC power flow program for contingency analysis by the Fast Decoupled Power Flow (FDLF) provides a fast solution to the contingency analysis since it has the advantage of matrix alteration formula that can be incorporated and can be used to simulate the problem of contingencies involving transmission line outages without re inverting the system Jacobian matrix for all iterations. Hence to model the contingency analysis problem the AC power flow method, using FDLF method has been extensively chosen.

CONTINGENCY SELECTION

Since contingency analysis process involves the prediction of the effect of individual contingency cases, the above process becomes very tedious and time consuming when the power system network is large. In order to alleviate the above problem contingency screening or contingency selection process is used. Practically it is found that all the possible outages does not cause the overloads or under voltage in the other power system equipments. The process of identifying the contingencies that actually leads to the violation of the operational limits is known as contingency selection. The contingencies are selected by calculating a kind of severity indices known as Performance Indices (PI) . These indices are calculated using the conventional power flow algorithms for individual contingencies in an off line mode. Based on the values obtained the contingencies are ranked in a manner where the highest value of PI is ranked first. The analysis is then done starting from the contingency that is ranked one and is continued till no severe contingencies are found. There are two kind of performance index which are of great use, these are **active power performance index (PIP)** and **reactive power performance index (PIV)**. PIP reflects the violation of line active power flow and is given by eq.2.6.

$$PI_P = \sum_{i=1}^{L} \left(\frac{P_i}{P_{imax}}\right)^{2n} \qquad (2.6)$$

where,

P_i = Active Power flow in line i,

P_i^{max} = Maximum active power flow in line i,

n is the specified exponent,

L is the total number of transmission lines in the system.

If n is a large number, the PI will be a small number if all flows are within limit, and it will be large if one or more lines are overloaded. Here the value of n has been kept unity. The value of maximum power flow in each line is calculated using the formula

$$P_i^{max} = \frac{V_i * V_j}{X} \qquad (2.7)$$

where, V_i= Voltage at bus i obtained from FDLF solution

V_j= Voltage at bus j obtained from FDLF solution

X = Reactance of the line connecting bus 'i' and bus 'j'

Another performance index parameter which is used is reactive power performance index corresponding to bus voltage magnitude violations. It mathematically given by eq.2.8

$$PI_V = \sum_{i=1}^{Npq} \left[\frac{2(Vi - Vinom)}{Vimax - Vimin}\right]^2 \qquad (2.8)$$

where, V_i= Voltage of bus i

V_{imax} and V_{imin} are maximum and minimum voltage limits

State Estimation:

State Estimation (SE) is **mainly used to filter redundant data**, to eliminate incorrect measurements and to produce reliable state estimates. It allows the determination of the power flows in parts of the power system which are not directly metered.

State Estimation is the process of assigning a value to an unknown system state variable based on measurements from that system according to some criteria.

1.14 STATE ESTIMATION IN POWER SYSTEM

The main goal of the power systems state estimator is to find a robust estimate for the unknown complex voltage at every bus in the network. Since inexact measurements–such as those from a SCADA system–are used to calculate the complex voltages, the estimate will also be inexact. This introduces the problem of how to devise a "best" estimate for the voltages given the available measurements. Of the many criteria used to develop a robust state estimator, the following three are regarded as the most common:

- **Maximum Likelihood:** Maximizes the probability that the estimated state variable is near the true value.
- **Weighted Least-Squares (WLS):** Minimizes the sum of the squared weighted residuals between the estimated and actual measurements.
- **Minimum Variance:** Minimizes the expected value of the sum of the squared residuals between components of the estimated state variable and the true state variable.

The variables of interest or the state of the system is indicative of the margins of operating limits, health of the equipment and required operator action. The state estimators allow the calculation of these variables of interst with high confidence despite the measurements corrupted by noise and measurements that are missing or grossly inaccurate. The above problems can be mitigated by using state estimator. Figure 1.17 gives the block diagram of a typical state estimator.

The estimate that comes to us from the power system is only using the measurements. Therefore the measurements should be used to estimate the state of the system. The measurements used to calculate the angles at different buses can be used to calculate all the unmeasured power flows, loads and generations. If the measurements of the system are used to estimate the states of the system, then calculations such as the power flows, generations, loads, etc., can be done easily. In case of noisy measurements the best state of the system is guessed using the above mentioned methods. Thus we can formulate the best estimate of the unknown measurements, if there are other measurements available. In general it is necessary to guess the best state of the system due to the noisy measurements which is usually the case.

1.15 STATE ESTIMATION OBJECTIVES

The objectives of the state estimation are:

- To provide a view of real time power system conditions this includes the real time data that comes from the SCADA and state estimation that supplements SCADA data such as filters.
- To provide consistent representation for power system security analysis such as online dispatches power flow, contingency analysis and load frequency control.
- To provide diagnostics for modelling and maintenance.
- To obtain the best estimate of the state of the system based on a set of measurements of the model of the system.

The state estimator uses the following:

- Set of measurements available from PMUs.
- System configurations supplied by the topological processor.
- Network parameters such as line impedances as input.
- Execution parameters such as dynamic weight adjustments.

1.16 STATE ESTIMATION OUTPUT

The state estimator provides the following data:

- Bus voltages, branch flows, etc. (state variables).
- Measurement error processing results.
- Provide an estimate for all metered and unmetered quantities.
- Filter out small errors due to model approximations and measurement inaccuracies.
- Detect and identify discordant measurements, the so-called bad data.

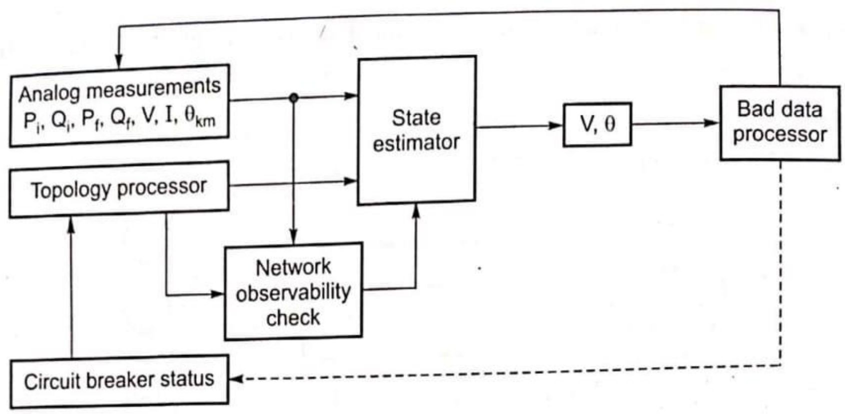


Fig. 1.17 The state estimator.

1.17 WEIGHTED LEAST SQUARE METHOD

One of the most important methods of state estimation is the Weighted Least Square Method (WLS method). This is explained using the following example. In the following article a three bus system is taken and dc load flow is done on that system. This result is provided to evaluate the state of the system. The information available is the meter readings that measure the MW power of the three bus system. The example 1 (Fig. 1.19) shows the three bus system model that has three meters.

1.18 PROBLEM FORMULATION

First, consider the set of inputs, which are measurements taken from the SCADA system, and express them as functions of the exact state of the system, with corresponding measurement error mainly due to voltage and current transformers:

$$Z_{meas} = \begin{bmatrix} Z_1 \\ Z_2 \\ \vdots \\ \vdots \\ Z_m \end{bmatrix} = \begin{bmatrix} f_1(x) \\ f_2(x) \\ \vdots \\ \vdots \\ f_m(x) \end{bmatrix} + \begin{bmatrix} e_1 \\ e_2 \\ \vdots \\ \vdots \\ e_m \end{bmatrix} = f(x) + e \qquad \text{...(1.3)}$$

where f_i = function of the state vector used to calculate the value of the ith measurement.

x = system state vector (unknown).

e_i = the error of the ith measurement.

For simplicity, the error vector e is assumed to be standard Gaussian, with zero mean and independent covariance given in equation 1.4.

$$\sigma^2 = \begin{bmatrix} \sigma_1^2 & & & & \\ & \sigma_2^2 & & & \\ & & \sigma_3^2 & & \\ & & & \ddots & \\ & & & & \sigma_m^2 \end{bmatrix} \qquad \text{...(1.4)}$$

The state (x) is defined as the voltage magnitude and angle at each bus as in equation (1.5)

$$\tilde{V}_i = V_i e^{j\delta_i} \quad X = [V_1, V_2, \ldots\ V_n, \delta_1, \delta_2 \ldots \delta_b] \qquad \ldots(1.5)$$

All variables of interest can be calculated from the state and the measurement mode $z = h(x)$. The arrangement of the measurement model of the state estimation system is shown in Fig. 1.18.

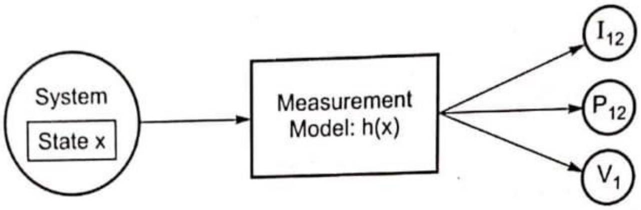


Fig. 1.18 State system for three bus system.

Generally the state of the system cannot be observed. It can be inferred from the measurements and the measurements tends to be noisy. The noise may be gross measurement errors and communication channel outage.

Example 1: For the three bus system shown in Fig. 1.19, find the value of the phase angles according to the flow of power. Generator at bus 1 produces 65 MW and the one at bus 3 produces 35 MW. The transfer of power between the bus 1 and bus 2 is 60 MW, between bus 3 and bus 2 is 40 MW and that between 1 and 3 is 5 MW. These are given in the Fig. 1.19. The reactances on 100 MVA base is $X_{12} = 0.2$, $X_{13} = 0.4$, $X_{32} = 0.25$. Install meters at appropriate places in the lines.

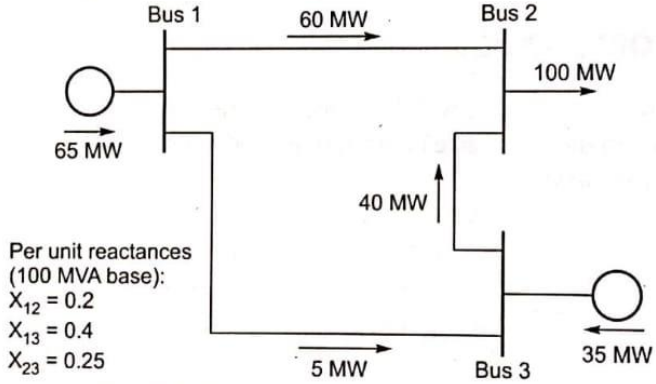


Fig. 1.19 Three bus system for D.C. load flow.

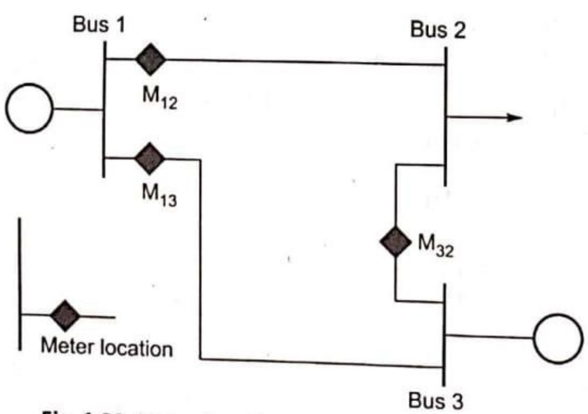


Fig. 1.20 Meter location for the three bus system.

The meter arrangement is shown in Fig. 1.20. It is enough if we had only two meters for this arrangement. These are expected to measure all the phase angles, generations and loads fully. For example, if M_{13} measures 5 MW and M_{32} measures 40 MW then the state estimation is started as follows.

$$M_{13} = 5 \text{ MW} = 0.05 \text{ pu}$$
$$M_{32} = 40 \text{ MW} = 0.40 \text{ pu}$$

$$f_{13} = \frac{1}{x_{13}}(\theta_1 - \theta_3) = M_{13} = 0.05 \text{ pu}$$

$$f_{32} = \frac{1}{x_{23}}(\theta_3 - \theta_2) = M_{32} = 0.40 \text{ pu}$$

By solving the above simultaneous equations the values of θ are as follows:

$$\theta_1 = 0.02 \text{ rad}$$
$$\theta_2 = -0.10 \text{ rad}$$

UNIT-4
POWER SYSTEM ECONOMICS

Basic Pricing Principles:

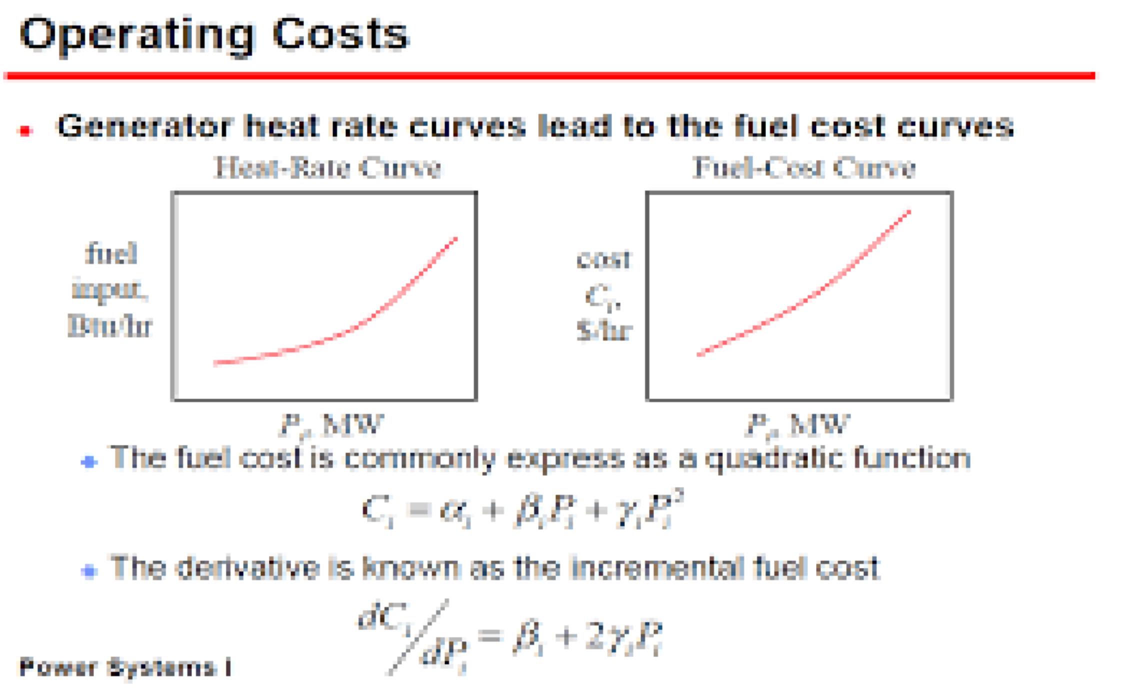
1. Generator cost curves

Generator cost functions in the state-of-the-art are derived based on input–output characteristics, efficiency, and fuel costs of the major energy contributors such as natural gas, coal, nuclear, and hydro/renewable. The input–output characteristic of a thermal generator is the ability to convert thermal energy into electrical energy; these data may be obtained from design parameters of that generator. The cost function for an ith thermal generator can be represented by equation (1), where a_{0i} (\$/h) is its no-load cost to operate, and b_{1i} (MBtu/MWh) and b_{2i} (MBtu/MWh^2) are the quadratic coefficients of the thermal input–output curve of that generator with fuel cost F_i, expressed as \$/MBtu. To obtain the quadratic cost coefficients for a generator, (1) relates to (2), where $F_i b_{2i}$ equals γ_i, $F_i b_{1i}$ equals β_i, and a_{0i} equals α_i.

The function of hydro/renewable generators comprises only no-load cost because they are non-thermal units and do not have fuel costs associated with generating electricity

$$C_i(P_i) = a_{0i} + F_i(b_{1i}P_i + b_{2i}P_i^2) \qquad (1)$$

$$C_i(P_i) = \alpha_i + \beta_i P_i + \gamma_i P_i^2 \qquad (2)$$



Utility functions

An **electric utility** is a company in the electric power industry (often a public utility) that engages in electricity generation and distribution of electricity for sale generally in a regulated market. Power & Utilities includes electricity power generation, transmission and distribution of a public service (Utilities), usually in the form of electricity, water and heating (gas), but depending on the jurisdiction, can include telecommunications and broadband services also. The major goals of an electrical utility can be broadly categorized into three: -

- Control the long-term costs of the electric system: The regulatory framework should promote a broad range of resources to increase the ratio of average to peak electric load, helping to right-size the electric system to customer's needs.
- Give customers more energy choices: The regulatory framework should allow customers to use emerging technologies and commercial arrangements to manage their energy production and use.
- Build a flexible grid to integrate more clean energy generation: The regulatory framework should promote the flexibility needed to allow the electric grid to incorporate an increasing proportion of variable clean energy through use of demand response and energy storage, for example.

Regarding the utility "Data Connectivity, i.e. telecommunications and broadband services" it can be stated that "the electric system of the 21st century will depend on operation of data networks to allow the utility to gain visibility and control of the electric system. Many of the functions associated with operation of a data network are outside the electric utility's traditional area of operations and include strategically important, but not capital intensive, software and service components. Taken together, these considerations may guide the inquiry into what the utility of the 21st century should do, how it should earn revenue, and what kind of metrics should shape its operation.

The potential functions of a twenty-first century electric utility may include:

- Reliability services, such as pole and line maintenance, circuit reconfiguration, supplemental power supply, undergrounding, power factor correction, distribution system engineering and voltage variation optimization.
- Connectivity services including operation of the communications backbone to support distribution line automation and to enable potential advanced metering functionality.

- Network integration services, such as scheduling, multi-directional power flow and management services, storage-based power "loan" services, electric vehicle charging services, and the necessary distribution system planning and data analysis for load, voltage and hosting capacity.
- Transaction management services, such as aggregation, clearing and settlement among parties, integration of distributed energy resources and metering customers.
- Customer engagement services, such as home energy optimization, appliance automation, intelligent load management, backup energy services including energy storage, energy efficiency program delivery, customer support, low-income engagement, and electric vehicle education.

Many of these functions are so connected with one another that they are best undertaken by a single enterprise. However, there may be functions that could be undertaken separately or which the electric utility may not be optimally organized to perform.

Power Exchanges (PX)

A power exchange may refer to the entity that operates an electricity market at which electricity is traded. PX is a trading center where utilities, power marketers, and other electricity suppliers submit price and quantity bids to sell energy or services, and potential customers submit offers to purchase energy or services. Key points of a power exchange include:

• Foster the development of competition: It provides a competitive market place by running an electronic auction where market participants buy and sell electricity and may do business quickly and easily. Through an electronic auction, PX establishes an MCP (marginal cost price) for each hour of the following day for trades between buyers (demands) and sellers(suppliers).

• Transparency: It submits balanced demand and supply schedules for successful bidders to ISO(Independent System Operator) and performs settlement functions with ISO as well as PX participants such as UDCs (Utility Distribution Companies), marketers, aggregators etc · It also submits ancillary service bids to ISO for maintaining system reliability , adjustment bids(may be used to relieve or eliminate congestion on transmission grid) · PX guarantees an equal and non discriminatory access and competitive opportunities to all participants.

• Liquidity: In this market place PX does not deal with small consumers. PX manages settlement and credit arrangements for scheduling and balancing of loads and generation resources.

Spot Pricing

There is a need for fundamental changes in the ways society views electric energy. Electric energy must be treated as a commodity which can be bought, sold, and traded, considering its time-and space-varying values and costs. A framework based on the use of spot prices is used for the establishment of such an energy marketplace. The spot price is the current market price at which an asset is bought or sold for immediate payment and delivery. That is a spot price is the price retailers pay when they buy electricity from the wholesale market. Spot prices change every hour and can vary quite dramatically depending on supply and demand balance.

In general terms: An hourly spot price (in dollars per kilowatt hour) reflects the operating and capital costs of generating, transmitting and distributing electric energy. It varies each hour and from place to place. The spot price based energy marketplace involves a variety of utility-customer transactions (ranging from hourly varying prices to long-term, multiple-year contracts), all of which are based in a consistent manner on hourly spot prices. These transactions may include customers selling to, as well as buying from, the utility. Some advantages of using spot pricing may be as follows:

- Any given level of system capacity will be used more efficiently, because price will reflect the operating cost of the marginal plant or the market-clearing price when demand would otherwise exceed capacity. When demand is slack, customers will benefit from the fall in price and be encouraged to expand consumption;
- when demand is high, price will rise to ration out available capacity. Because price can be used to ration capacity, less reserve capacity needs to be held to meet uncertain demand, so required investment is less and hence average costs and prices are lower.
- Because spot pricing more accurately reflects cost and demand conditions, it can be used as an efficient means of coordination in a decentralized system. Efficient merit order running can be secured without the need for integration of ownership and control.
- Large monopolistic generating companies can be replaced by smaller competitive ones, thereby securing the benefits of competition, notably greater efficiency and lower prices.

- In a less centralized system with spot prices, generating companies will acquire a better understanding of the needs and responsiveness of their customers, which will lead to better forecasting and investment policy.
- By flattening the load curve, spot pricing would facilitate system operations, and thereby reduce operating costs.
- It would provide additional benefits, both to the utility and of a more general kind, via the establishment of a two-way communications network between utility and consumer.

The likely disadvantages of spot pricing have not been so clearly identified but the following may summarize a few:

- There will be the costs of repeatedly calculating and revising the spot price, informing customers, and metering and more finely billing usage.
- Many customers may initially be confused by the proposed approach.

Electricity Market Models

Market participants can avoid congestion charge by forming a pool and entering into financial contracts. A pool model with locational market prices defined for every node is often considered as an ideal market model as the nodal prices perfectly reflect all costs of supplying electricity at given nodes and, manage congestion at the same time.

Two main technical features determine the complexity of such models: the product ‘‘electricity’’ which cannot be stored and its transportation that requires a physical link (transmission lines). Proper market models, in most cases, must deal with imperfectly competitive markets, which are much more complex to represent. Some market models used in the power industry are as follows:

(i)Vertical Market Model

The electric power industry has over the years been dominated by large utilities that had an overall authority over all activities in generation, transmission and distribution of power within its domain of operation. Such utilities have often been referred to as vertically integrated utilities. Such utilities served as the only electricity provider in a region and were obliged to provide electricity to everyone in the region. The typical structure of a vertically integrated electric utility is shown in figure 5.1 below. In the figure, the money flow is unidirectional, i.e. from the consumer to the electric company. Similarly, the information flow exists only between the generators and the transmission systems. In vertically integrated utilities, it was often difficult to segregate the costs involved in generation, transmission or distribution. So, the utilities often charged their customers an average tariff rate depending on their aggregated cost during a period.

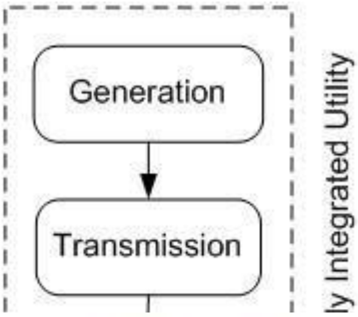


Figure 5.1: Vertically integrated market model

Demerits: -

- Generally one firm, once with a franchise.
- Regulators approve what utilities build. This may or may not be the lowest cost investment, and may or may not be technologically innovative.
- Traditional utility regulation accommodates the use of more debt, but limits innovation.
- Risk and return expectations will be relatively lower. This will affect what types of entities hold ownership stakes.
- Reduced need for marketing and business development. Largely focused on providing onesize-fits-all solutions for customers.

(ii)Wholesale Competition Model

This model is one step closer towards competition. There is an organized market in which the generators can sell their energy at competitive rates. The market may be organized either by a separate entity or may be run by the system operator itself. There is not much choice for the end user. The end user is still affiliated to the Discom (Distribution company) or retailer working in that geographical area of operation. The large customers or the bulk customers, so to say, are privileged to choose their energy provider. However, the definition of bulk customer is a subjective matter and changes from system to system.

This model, as shown in Figure 5.2, provides the choice of supplier to Discoms, along with competition in generation. Implementation of this model requires open access to the transmission network. Also, a wholesale spot market needs to be developed. Discoms can purchase energy for their customers either from a wholesale market or through long term contracts with generators.

The customers within a service area still have no choice of supplier. They will be served by a Discom in their area. With this model, the Discoms are under Universal Service Obligation (USO), as they have monopoly over the customers. They own and operate the distribution wires. The transmission network is owned and maintained either by government and/or private transmission companies. System operators manage the centrally accomplished task of operation and control.

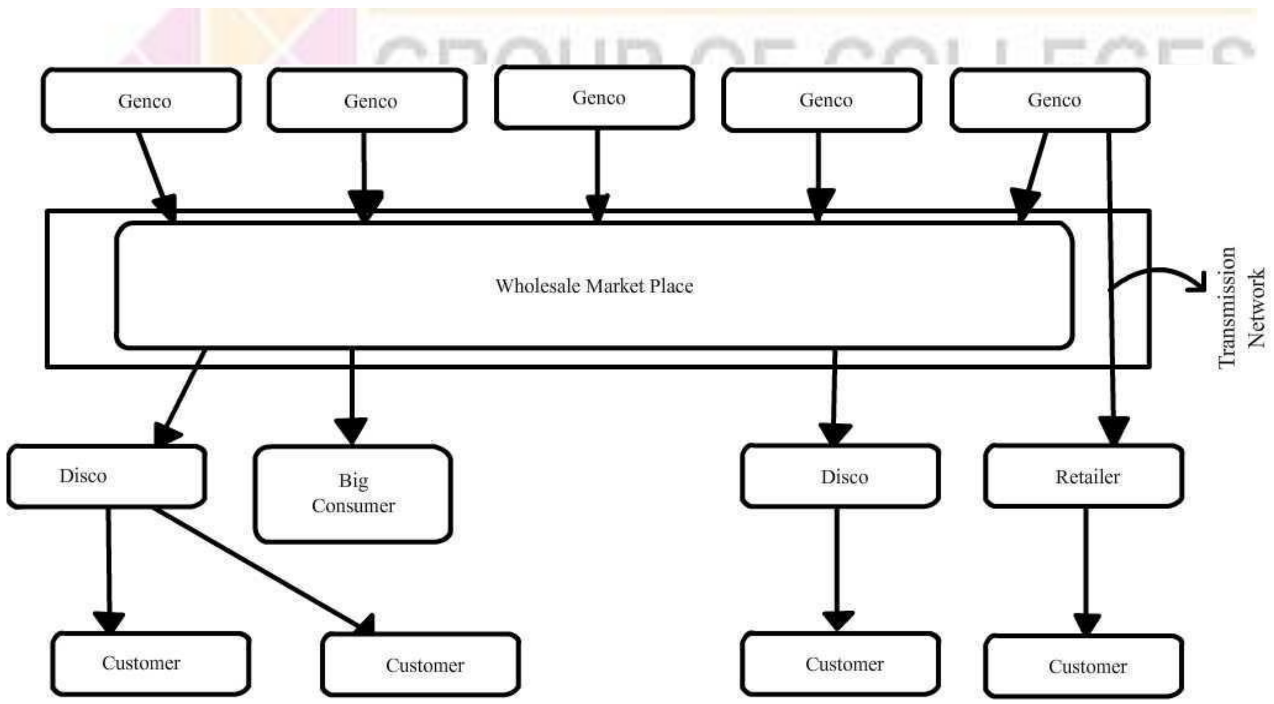


Figure 5 Wholesale Competition Model

The model provides a competitive environment for generators because the wholesale price is determined by the interaction between supply and demand. In contrast, the retail price of electrical energy remains regulated because the small consumers still do not have a choice for their supplier. The distribution companies are then exposed to vagaries of the wholesale price of the commodity. The merits and demerits of this model are as follows:

Merits: -

- Choice of seller provided for Discoms and bulk consumers.
- The buyers and sellers can make forward contracts or buy from a wholesale marketplace.
- The price is decided by interaction between demand and supply. Hence, indicates truly competitive price.

Demerits: -

- The end consumer still doesn't have a choice. It buys power from the affiliated Discom.
- Rates for end consumers are regulated rather than competitive.
- Discoms face competition at wholesale level, while their returns are regulated.
- Structural and institutional changes required at wholesale level.

(iii) <u>Retail Competitive market</u>

In this model, as shown in Figure , all customers have access to competing generators either directly or through their choice of retailer. This would have complete separation of both generation and retailing from the transport business at both transmission and distribution levels. Both, transmission and distribution wires provide open access in this model. There would also be free entry for retailers. In this model, retailing is a function that does not require the ownership of distribution wires, although, the owner of distribution wires can also compete as a retailer.

This model is a multi-buyer, multi-seller model and the power pool in this model acts like an auctioneer. It behaves like a single transporter, moving power to facilitate bilateral trading and this is achieved through an integrated network of wires. In this pooling arrangement, there is a provision for bidding into a spot market to facilitate merit order dispatch. The pool matches the supply and demand and determines the spot price for each hour of the day. It collects money from purchasers and distributes it to producers.

The advantage of this model over monopoly utilities is that competition is introduced in both wholesale and retail areas of the system. This model is supposed to be a truly deregulated power market model.

The retail price is no longer regulated because small consumers can change their retailer for better price options. This model is economically efficient as the price is set by interaction of demand and supply. In wholesale competition model, with relatively few customers, all of them regulated Discoms, a spot market can be preferable but not essential.

However, in retail competition model, spot markets become essential, since contractual arrangements between customers and producers are carried out over a network owned by a third party. In retail competition model, metering becomes a major problem. If the number of customers is increasing and metering capability for all the customers is not sufficient, it may create logistical problem and provoke disputes.

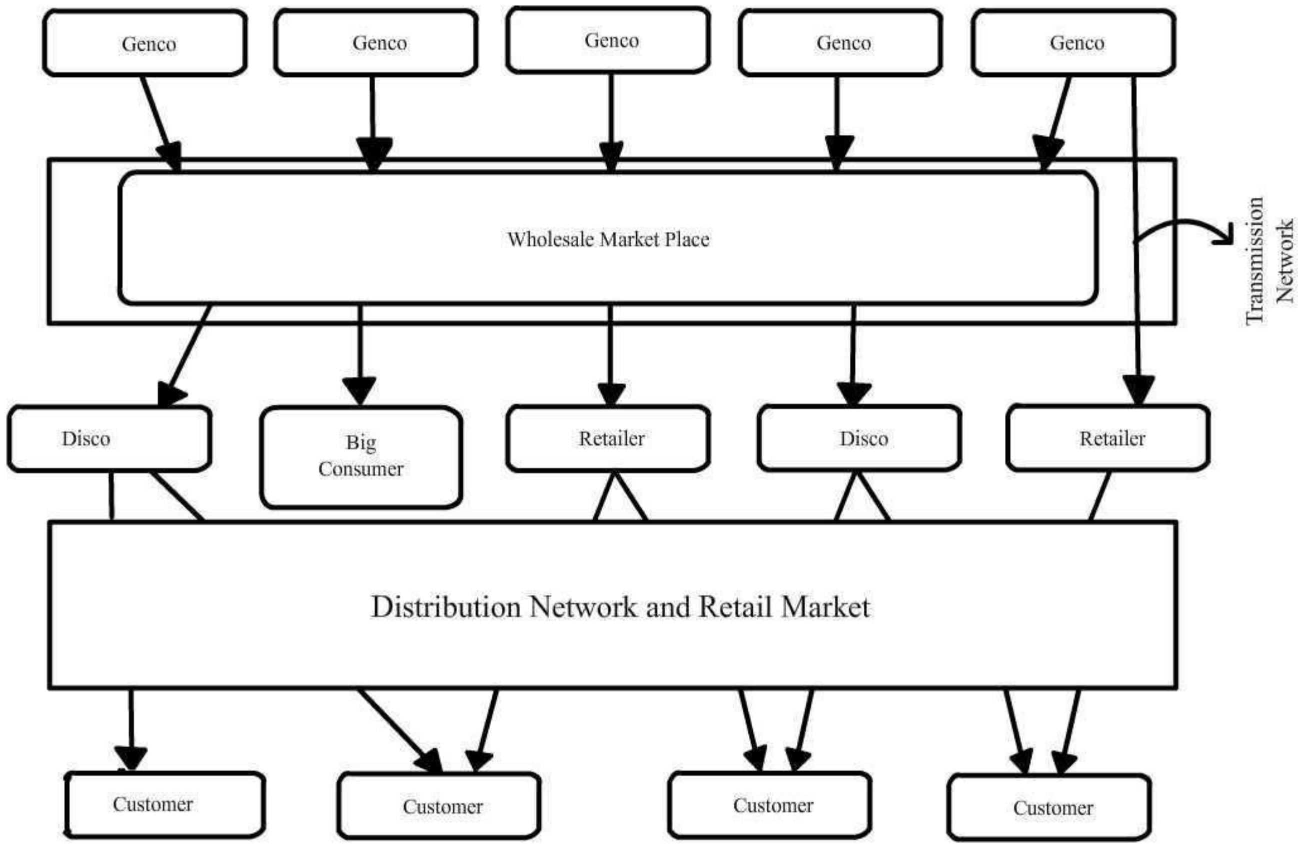


Figure : Retail Competition Model

Merits:

- Supposed to be 100% deregulated model.
- Every consumer has a choice of buying power.
- The price is decided by interaction of demand and supply. Hence, it is truly competitive price.
- There is no regulation in energy pricing.

Demerits:

- Need constitutional and structural changes at both, wholesale and retail level.
- Extremely complex settlement system due to large number of participants.
- Requirement of additional infrastructural support

Unit-5 :POWER MANAGEMENT

Demand side Management

Demand Side Management (DSM) is used to describe the actions of a utility, beyond the customer's meter, with the objective of altering the end-use of electricity - whether it be to increase demand, decrease it, shift it between high and low peak periods, or manage it when there are intermittent load demands - in the overall interests of reducing utility costs. In other words, DSM is the implementation of those measures that help the customers to use electricity more efficiently and in doing so reduce the customers use and the utility costs.

DSM can be achieved through.

- Improving the efficiency of various end-uses through better housekeeping correcting energy leakages, system conversion losses, etc

- Developing and promoting energy efficient technologies, and

- Demand management through adopting soft options like higher prices during peak hours, concessional rates during off-peak hours seasonal tariffs, interruptible tariffs, etc.

DSM, in a wider definition, also includes options such as renewable energy systems, combined heat and power systems, independent power purchase, etc, that utility to meet the customer's demand at the lowest possible cost. Hence DSM can be achieved through energy efficiency by reducing energy consumption on the one hand and on the other hand by managing the load demand itself. The first may be achieved through awareness on use of energy efficient equipment on the part of consumer. Thus, it leads to conservation of energy. However, the latter calls for reduction in power demand or shifting it to off-peak hours. This can be achieved with utility providing incentive like time-of-use tariff giving rebate during off-peak. Of course, utility has a leading role always through its actions that effect quantity or pattern of energy consumption by the consumer through reduction of drawl during peak period. This will in turn help the utility to reduce investment for generation vis-à-vis transmission and distribution, as the case may be.

Transmission pricing (Transmission and Distribution charges)

Federal Energy Regulatory Commission (FERC) recognized that transmission grid is the key issue to competition, and issued guidelines to price the transmission. The guidelines are summarized such that the transmission pricing would:

- Meet traditional revenue requirements of transmission owners
- Reflect comparability: i.e. a transmission owner would charge itself on the same basis that it would charge others for the same service.
- Promote economic efficiency.
- Promote fairness.
- Be practical.
- Even though transmission costs are small as compared to power production expenses and represent a small percent of major investor owned utilities' operating expenses, a transmission system is the most important key to competition because it would provide price signals that can create efficiencies in the power generation market.

Transmission pricing methods:

1. Contract Path Method

2. MW-Mile method

1. Contract Path Method: · It has been used between transacted parties to price transmission where power flows are assumed to flow over a predefined path(s). · Despite its ease, this technique was

claimed be a bad implementation of true transmission pricing as power flows would very seldom correspond to predefined paths. · Physically, electrons could flow in a network over parallel paths owned several utilities that may not be on the contract path. · Parallel path flows refer to the unscheduled transmission flows that occur on adjoining transmission systems when power is transferred in an interconnected electrical system. · As a result, transmission owners may not be compensated for the actual use of their facilities. · Added to parallel flows, the pancaking of transmission rates is another shortcoming of this method. · Pancaking is when contract path crosses a boundary defining transmission ownership, additional transmission charges would be added to a transaction, which in turn might increase the price of the transaction. · In-efficient method

2. MW –Mile method: · Several ISOs are using a MW-Mile approach to price transmission. · The MW-Mile rate is basically based on the distance between transacted parties (from the generating source to the load) and flow in each line resulted from the transaction. · This approach takes into account parallel power flows and eliminates the previous problem that transmission owners were not compensated for using their facilities. · This approach does not give credit for counter-flows on transmission lines. · The method is complicated because every change in transmission lines or transmission equipment requires a recalculation of flows and charges in all lines.

Ancillary Services

Ancillary services are defined as services which are required to support the transmission of capacity and energy from resources to loads while keeping a reliable operation of the transmission system of a transmission provider in accordance with Good utility practice.

Ancillary services are the specialty services and functions provided by the electric grid that facilitate and support the continuous flow of electricity so that supply will continually meet demand. The term ancillary services is used to refer to a variety of operations beyond generation and transmission that are required to maintain grid stability and security. These services generally include, frequency control, spinning reserves and operating reserves. Traditionally ancillary services have been provided by generators, however, the integration of intermittent generation and the development of smart grid technologies have prompted a shift in the equipment that can be used to provide ancillary services.

A large number of activities on the interconnected grid can be termed as ancillary services. However, in order to remove this large discrepancy, the North American Electric Reliability Council (NREC) along with Electric Power Research Institute (EPRI) has identified 12 functions as ancillary services. These are:

1. **Regulation:** The use of generation or load to maintain minute-to-minute generation-load balance within the control area.
2. **Load Following:** This service refers to load-generation balance towards end of a scheduling period.
3. **Energy Imbalance**: The use of generation to meet the hour-to-hour and daily variations in load.
4. **Operating Reserve (Spinning):** The provision of unloaded generating capacity that is synchronized to the grid and can immediately respond to correct for generation-load imbalances, caused by generation and /or transmission outages and that is fully available for several minutes.
5. **Operating Reserve (Supplemental):** The provision of generating capacity and curtailable load to correct for generation-load imbalances, caused by generation and /or transmission outages, and that is fully available for several minutes. However, unlike spinning reserves, supplemental reserve is not required to respond immediately.
6. **Backup Supply:** This service consists of supply guarantee contracted by generators with other generators or with electrical systems, to ensure they are able to supply their consumers in case of scheduled or unscheduled unavailability.
7. **System Control:** This activity can be compared with the functions of the brain in the human body. System control is all about control area operator functions that schedule generation and transactions and control generation in real time to maintain generation load balance.
8. **Dynamic Scheduling:** It includes real-time metering, tele-metering along with computer software and hardware to virtually transfer some or all of generator's output or a customer's load from one control area to another.
9. **Reactive Power and Voltage Control Support:** The injection or absorption of reactive power from generators or capacitors to maintain system voltages within required ranges.
10. **Real Power Transmission Losses:** This service is necessary to compensate for the difference existing between energy supplied to the network by the generator and the energy taken from the network by the consumer.
11. **Network Stability Services from Generation Sources:** Maintenance and use of special equipment (e.g., PSS, dynamic braking resistances) to maintain secure transmission system.

12. **System Black Start Capability:** The ability of generating unit to proceed from a shutdown condition to an operating condition without assistance from the grid and then to energize the grid to help other units start after a blackout occurs.

It should be noted that identification and definition of a particular ancillary service is system dependent. There is no global definition of a particular ancillary service that is applicable in all systems.

Regulatory framework:

Regulatory standards must be met because international and domestic standards are required for the power-management section of the end-item equipment. These standards vary from one country to another, so the power subsystem manufacturer and the end-item system manufacturer must adhere to these standards where the system will be sold. Design engineers must understand these standards even though they may not perform standards certification. Understanding these regulatory standards usually poses problems for power-management subsystem designers.

• Many standards are technically complex, requiring an expert to be able to decipher them.

• Often, standards are written in a form that is difficult for the uninitiated to interpret because there are usually exemptions and exclusions that are not clear.

• Several different agencies may be involved, so some may be specific to one country or group of countries and not others.

• Standard requirements vary and sometimes conflict from one jurisdiction to another.

• Standards are continually evolving, with new ones introduced periodically, so it is difficult to keep pace with them.

What standards agencies are encountered at the product and system level?

ANSI: The American National Standards Institute oversees the creation, promulgation, and use of norms and guidelines that directly impact businesses, including energy distribution.

EC (European Community) Directives: Companies responsible for the product intended for use in the European Community must design and manufacture it in accordance with the requirements in the relevant directives.

EN (European Norm): Standard directives for the European community.

IEC (International Electrotechnical Commission): Generates standards for electrical and electronic systems.

UL (Underwriter's Laboratory): Safety approvals for electrical and electronics products within the United States. A UL approval can also be obtained through the CSA.

CSA (Canadian Standards Association): Safety approval required to use an electrical or electronic product within Canada. A CSA approval can also be obtained through the UL.

Telcordia: Standards for telecom equipment in the United States.

ETSI (European Telecommunications Standards Institute): Standards for telecom equipment.

Required safety standards for power supplies include EN60950 and UL60950 "Safety of Information Technology Equipment" based on IEC60950, containing requirements to prevent injury or damage due to hazards such as: electric shock, energy, fire, mechanical, heat, radiation, and chemicals. As of January 1997, the EC Low Voltage Directive (LVD) 73/23/EEC and the amending directive 93/68/EEC requires the manufacturer to make a declaration of conformity if the product is intended to be sold in the European Community.

Specific standards power-supply acoustics define maximum audible noise levels that may be produced by the product. The main contributor to the acoustic noise is usually the fan in a power supply with an internal fan.

ESD (Electrostatic Discharge) standards include EN61000-4-2 that tests immunity to the effects of high-voltage low-energy discharges, such as the static charge built up on operating personnel.

Power-Line Standards for Power Supplies

EN61000-3: Limits voltage changes the power supply under test can impose on the input power source (flicker test).

EN61000-4: Tests the effects of transients and determines the ability of the power supply to survive without damage or operate through temporary variations in main voltage. These transients can be in either direction (undervoltage or overvoltage).

EN61000-3-2: Limits the harmonic currents that the power supply generates onto the power line. The standard applies to power supplies rated at 75 W with an input line current up to 16A/phase.

EN61000-4-11: Checks the effect of input voltage dips on the ac input power supplies.

EMC Standards for Power Supplies

The most commonly used international standard for emissions is C.I.S.P.R. 22 "Limits and Methods for Measurement of Emissions from ITE." Most of the immunity standards are contained in various sections of EN61000. As of January1996, EC Directive 89/336/ EEC on EMC requires the manufacturer to make a declaration of conformity if the product is sold in the European Community.

Sections of EN61000 for EMC include:

EN61204-3: This covers the EMC requirements for power supplies with a dc output up to 200V at power levels up to 30kW, and operating from ac or dc sources up to 600 V.
EN61000-2-12: Compatibility levels for low-frequency conducted disturbances and signaling in public medium-voltage power supply systems
EN61000-3-12: Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16A and < 75A per phase
EN61000-3-2: Limits harmonic currents injected into the public supply system. It specifies limits of harmonic components of the input current, which may be produced by equipment tested under specified conditions
EN61000-4-1: Test and measurement techniques for electric and electronic equipment (apparatus and systems) in its electromagnetic environment.
EN61000-4-11: Measurement techniques for voltage dips, short interruptions, and voltage variations immunity tests.
EN61000-4-12: Testing for non-repetitive damped oscillatory transients (ring waves) occurring in low-voltage power, control, and signal lines supplied by public and non-public networks.
EN61000-4-3: Testing and measurement techniques for immunity requirements of electrical and electronic equipment to radiated electromagnetic energy. It establishes test levels and the required test procedures.
EN61000-4-4: Testing and measurement techniques for electrical fast transient/burst immunity test.
EN61000-4-5: Recommended test levels for equipment to unidirectional surges caused by overvoltage from switching and lightning transients. Several test levels are defined that relate to different environment and installation conditions.
EN61000-6-1: Electromagnetic compatibility (EMC) immunity for residential, commercial, and light-industrial environments
EN61000-6-2: Generic standards for EMC immunity in industrial environments
EN61000-6-3: Electromagnetic compatibility (EMC) emission requirements for electrical and electronic apparatus intended for use in residential, commercial, and light-industrial environments.
EN61000-6-4: Generic EMC standards for industrial environments intended for use by test laboratories, industrial/medical product designers, system designers, and system installers.

Restriction of Hazardous Substances (RoHS) Affects Power Supplies
RoHS is a directive that restricts use of hazardous substances in electrical and electronic equipment. Designated 2002/95/EC, it is commonly referred to as the Restriction of Hazardous Substances Directive. This RoHS directive took effect in July 2006, and includes power supplies. Often referred to as the lead-free directive, RoHS restricts the use of: lead; mercury; cadmium; hexavalent chromium (Cr6+); polybrominated biphenyls (PBB) (flame retardant); and polybrominated diphenyl ether (PBDE) (flame retardant).

Electronic Waste Directives

RoHS is closely linked to the Waste and Electronic Equipment Directive (WEEE). Designated 2002/96/EC, it makes power-supply manufacturers responsible for the disposal of their waste electrical and electronic equipment. Companies are compelled to use the collected waste in an ecologically friendly manner, either by ecological disposal or by reuse/refurbishment of the collected WEEE.

Directives for Disposal of Batteries

Batteries are not included within the scope of RoHS. However, in Europe, batteries are under the European Commission's 1991 Battery Directive (91/157/EEC), which was recently increased in scope and approved in the form of the new battery directive, version 2003/0282 COD, which will be official when submitted to and published in the EU's Official Journal. This new directive explicitly highlights improving and protecting the environment from the negative effects of the waste contained in batteries.

POWER SYSTEMS-III
LOAD FREQUENCY CONTROL

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INTRODUCTION

- Energy management system
  - Monitoring, coordinating and controlling the generation, transmission and distribution of electrical energy.
  - Generating plants that produce energy fed through transformers to the HV transmission network(grid), interconnecting generating plants, and load centers.
- Since transmission systems provide negligible energy storage, supply and demand must be balanced by either generation or load.
- Production is controlled by turbine governors at generating plants, and automatic generation control is performed by control center computers remote from generating plants.

- Load management, sometimes called demand-side management, extends remote supervision and control to sub transmission and distribution circuits, including control of residential, commercial, and industrial loads.

- Energy management is performed at control center, typically called system control centers, by computer systems called energy management systems /EMS/. Data acquisition and remote control is performed by SCADA.

- AGC consists of two major and several minor functions that operate on –line in real time to adjust the generation against load at minimum cost.
- Major functions
  - load frequency control
  - Economic dispatch
- Minor functions
  - Reserve monitoring, - Assures enough reserve on the system;
  - Interchange scheduling
- Generation control and ED minimize the current cost of energy production and transmission within the range of available controls.

- Energy management is a supervisory layer responsible for economically scheduling production and transmission on a global basis and over time intervals consistent with cost optimization.

LF and QV Control

- Although there are many things to control in power system, majorly we control voltage and frequency by controlling other parameters of the generators, load and other devices in the system.
- For efficient and secured power system- maintain reliability, security, stable, operate in most economical way, better quality (frequency with in the limit (3%), voltage (5% HV, 10% LV)).
- Frequency is global phenomena (same in one node and other), voltage is local phenomena (one point and another point is different). Eg. Change of frequency and voltage affect normal operation of the system.

- Frequency control can be achieved by controlling active power which is possible at generation (injecting power) and load end (consuming power). It is preferred to control the power at generation side and load end control is done during the emergencies.
- Total Generation < demand = frequency fall. -- generation increase, or load decrease/ very expensive b/c it affect power reliability.
- Total Generation > demand = frequency rise. – generation decrease /load increase not at hand/
- Reactive power control is responsible mainly for voltage control which is a local problem.

REASONS FOR THE NEED OF MAINTAINING CONSTANT FREQUENCY:

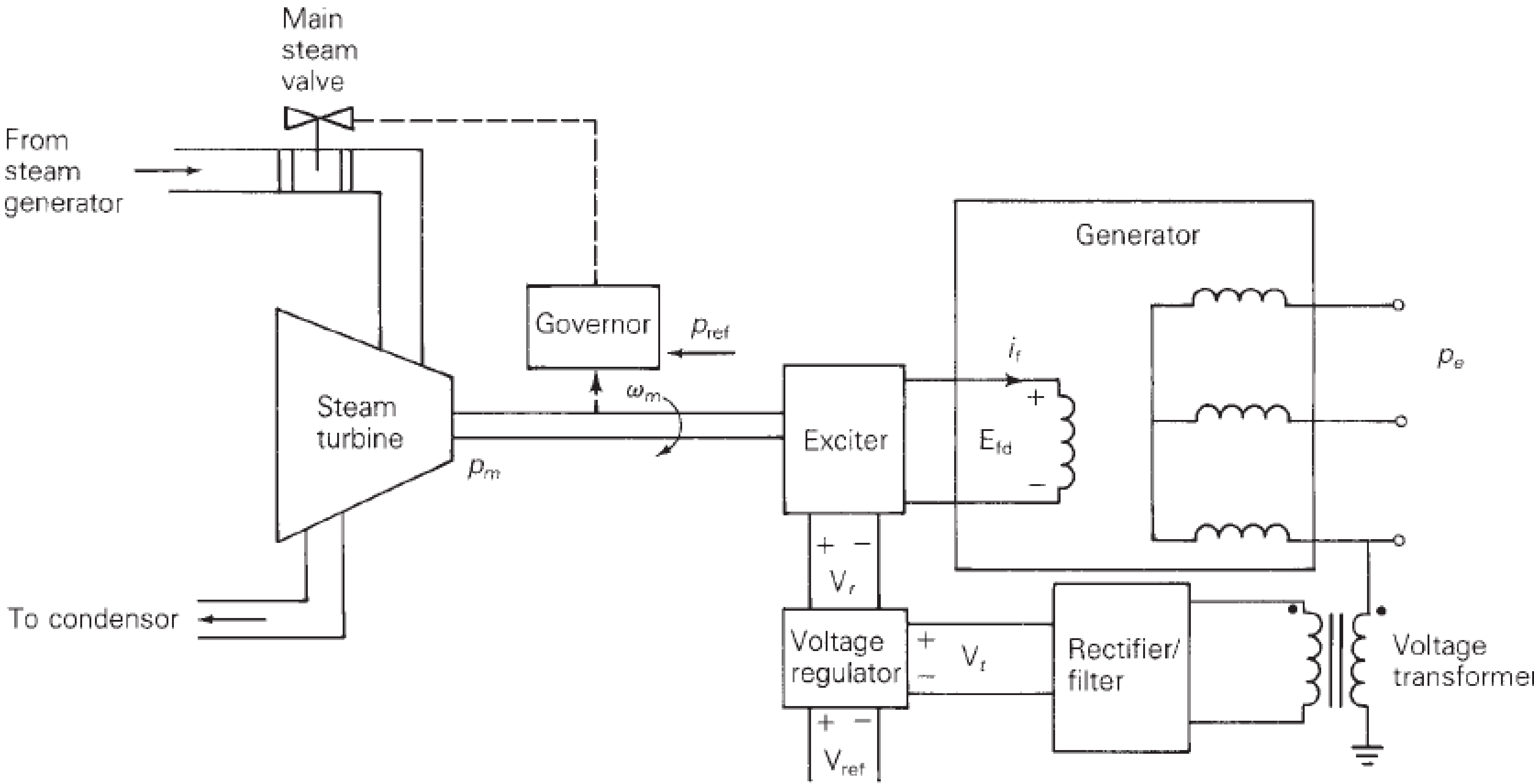
- The speed of a.c. motors are directly related to the frequency.
- If the normal operating frequency is 50 Hz and the turbines run at speeds corresponding to frequencies less than 47.5 Hz or above 52.5 Hz, then the blades of the turbines may get damaged.
- The operation of a transformer below the rated frequency is not desirable. When frequency goes below rated frequency at constant system voltage then the flux in the core increases and then the transformer core goes into the saturation region.
- With reduced frequency the blast by ID fans and FD fans decrease, and so the generation decreases and thus it becomes a multiplying effect and may result in shut down of the plant.

There are two basic generation control loops:

(i) LFC, AGC, MW-f control loop

(ii)MVAR-Voltage, Q-V control loop

- In steady state, they are non-interactive.



Load Frequency Control

- In a power system the load demand is continuously changing. In accordance with it the power input has also to vary. If the input - output balance is not maintained a change in frequency will occur. The control of frequency is achieved primarily through speed governor mechanism aided by supplementary means for precise control.
- LFC consists of three major parts.

(i) Speed governing system

(ii) Rotating components (turbine-generator)

(iii) load and power system.

2.1.1 Speed governing system

- The speed governing mechanism includes

A- Speed Governor

- The essential part are centrifugal flyballs driven directly or through gearing by the turbine shaft. The mechanism provides upward and downward vertical movements proportional to the change in speed.

B- Linkage Mechanism

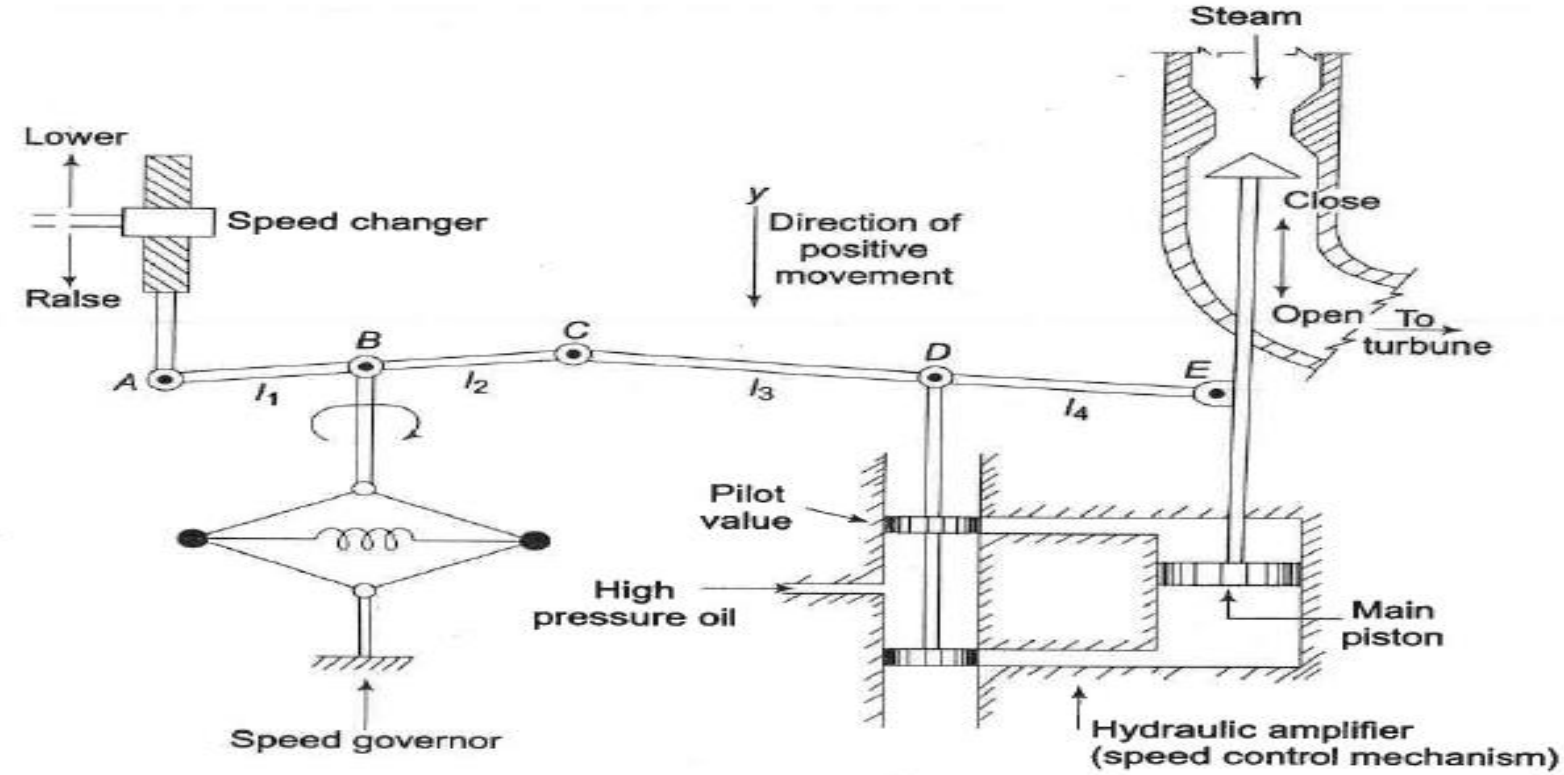
- These are links for transforming the flyballs movement to the turbine valve through a hydraulic amplifier and providing a feedback from the turbine valve movement.

C- Hydraulic Amplifier

- Very large mechanical forces are needed to operate the steam valve. Therefore, the governor movements are transferred into high power forces via several stages of hydraulic amplifiers.

D- Speed Changer

- The speed changer consists of a servomotor which can be operated manually or automatically for scheduling load at nominal frequency. By adjusting this set point, a desired load dispatch can be scheduled at nominal frequency.



- The speed governing system is the primary LFC loop and its simple schematic representation is shown above.
- In order to understand the operation, we should consider two cases, i.e. the first is when speed changer is given Raise or Lower command but speed of the turbine remains constant and second when speed of turbine is changed but command is not given to the speed changer. Under these conditions, the position of the joints will be changed according to the applied phenomena.

Thus the nominal conditions are

Power delivered	=	P_G^0
Turbine Speed	=	ω_0
Nominal Frequency	=	f_0
Prime mover valve position	=	X_E^0

Let us change the speed changer to command a power increase ΔP_C [ΔP_{ref}]. The speed changer movement gives rise to linkage point 'A' moves downwards a small distance ΔX_A.

It can be established

$$\Delta X_A = K \Delta P_C$$

$$\Delta X_C = \Delta X_C' + \Delta X_C''$$

$$- X_C' (l_{AB}) = X_A (l_{BC})$$

$$- \Delta X_C' = \frac{l_{BC}}{l_{AB}} \Delta X_A$$

$$\text{and } X_C'' = K_2 \Delta f$$

Thus the net movement of C is therefore

$$\Delta X_C = - K_1 \Delta P_C + K_2 \Delta f$$

$$\Delta X_D = \Delta X_D' + \Delta X_D''$$

$$\Delta X_D' (l_{CD} + l_{DE}) = \Delta X_C (l_{DE})$$

$$\Delta X_D'' = (l_{CD} + l_{DE}) = \Delta X_E (l_{CD})$$

Thus, it can written as

$$\Delta X_D = K_3 \Delta X_C + K_4 \Delta X_E$$

$$\Delta X_E = \Delta X_V = K_5 \int_0^t (-\Delta X_D)\, dt$$

$$\Delta X_C(s) = - K_1 \Delta P_C (s) + K_2 \Delta f(s)$$

$$\Delta X_D (s) = K_3 \Delta X_C (s) + K_4 \Delta X_E(s)$$

$$\Delta X_E(s) = K_5 \frac{1}{s} \Delta X_D (s)$$

Eliminating $\Delta X_C(s)$ and $\Delta X_D (s)$

$$\Delta X_E(s) = \frac{K_1 K_3 \Delta P_c(s) - K_2 K_3 \Delta f(s)}{K_4 + \dfrac{s}{K_5}}$$

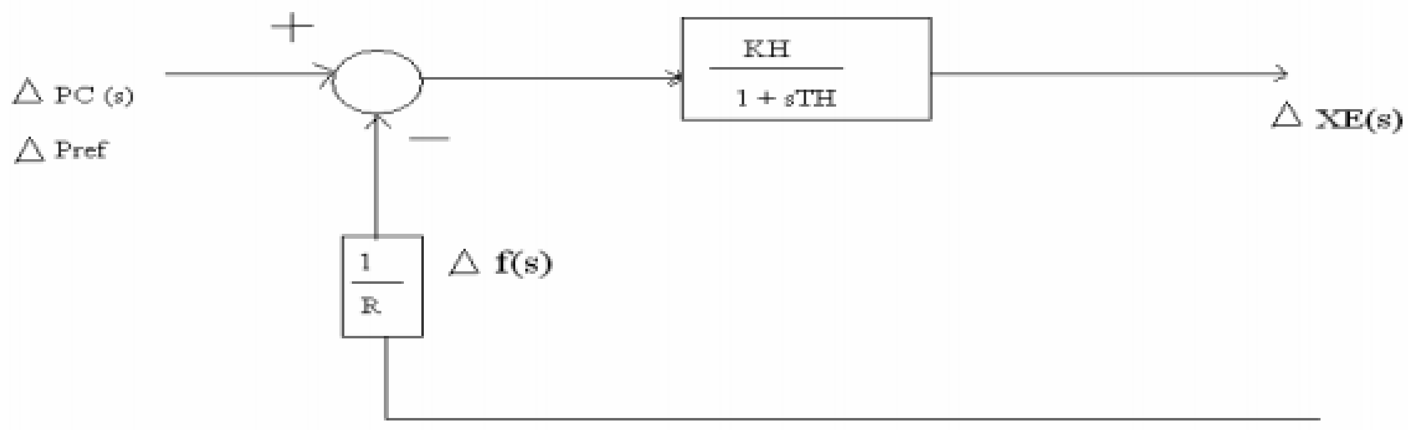
$$\Delta X_E = \left[\Delta P_C(s) - \frac{1}{R}\Delta f(s)\right]\frac{K_H}{1 + sT_H}$$

where

$$R \approx \frac{K_1}{K_2} \text{ = speed regulation of the governor}$$

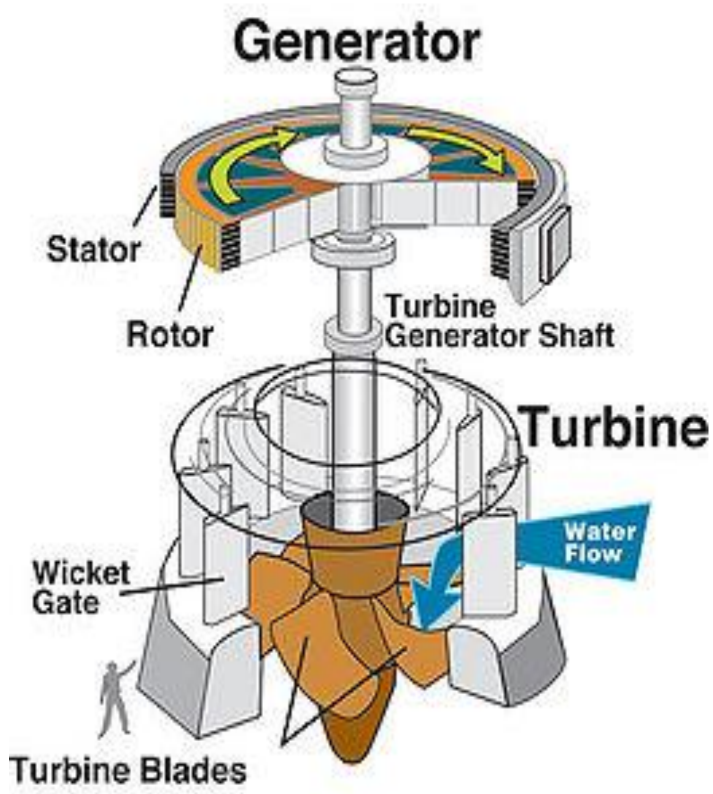
$$K_H \approx \frac{K_1 K_3}{K_4} \text{ = gain of speed governor}$$

$$T_H \approx \frac{1}{K_4 K_5} \text{ = time constant of speed governor}$$



2.1.2 Turbine model

- The figure illustrate the turbine-generator mechanical connection.
- The turbine-generator model depends on whether we have hydro-turbines, or in case of steam turbines we have reheat or non-reheat type of steam turbines.
- For a simple a non-reheat type turbine model is given by a single time constant,



$$G_{TG}(s) = \frac{K_{TG}}{1+sT_{TG}}$$

- Taking input power to the turbine is P_v /power from the valve opening/ and output power is mechanical power P_m, the block diagram becomes

$$\Delta P_V(s) \longrightarrow \boxed{\frac{K_{TG}}{1+sT_{TG}}} \longrightarrow \Delta P_m(s)$$

Model without Reheater

$$\frac{dw}{dt} = Q_{in} - Q_{out}$$

where "w" is the weight of steam in volume d(m^3), t is time in seconds and Q_{in} and Q_{out} are flows assuming the weight flow out of the vessel is proportional to pressure in the vessel.

$$Q_{out} = \frac{P}{P_o} Q_o$$

$$\frac{dQ_{out}}{dt} = \frac{Q_o}{P_o} \frac{dP}{dt}$$

Where,

P = variable vessel pressure

P_o = steady state vessel

Q_o = steady state weight flow out at P_o

Thus

$$\frac{dw}{dt} = \frac{\partial w}{\partial p} \frac{dP}{dt} = \upsilon \frac{\partial}{\partial P}\left(\frac{1}{\upsilon}\right)\frac{dP}{dt}$$

Where, υ is specific volume (m^3/wt) of steam in vessel.

$$Q_{in} - Q_{out} = \frac{P_o}{Q_o}\upsilon\frac{\partial}{\partial P}\left(\frac{1}{\upsilon}\right)\frac{dQ_{out}}{dt}$$

Let

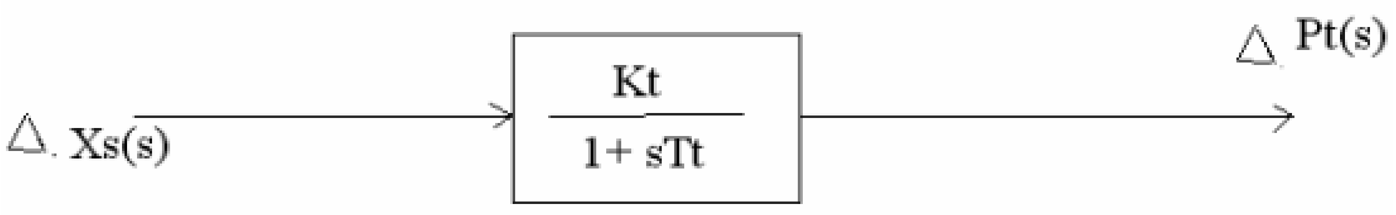
$$T_T = \frac{P_o}{Q_o}\upsilon\frac{\partial}{\partial P}\left(\frac{1}{\upsilon}\right)$$

then

$$Q_{in} - Q_{out} = T_T\frac{dQ_{out}}{dt}$$

or

$$\frac{Q_{out}}{Q_{in}} = \frac{1}{sT_T + 1}$$



The time constant Tt lies in the range 0.2 to 2.5 sec.

2.1.3 Generator Model

Suppose there is real load change of ΔP_E. Due to the action of turbine controllers, the generator increases its output by the amount ΔP_T. The net surplus power $\Delta P_T - \Delta P_E$ will be absorbed by the system in two ways.

1. By increasing the kinetic energy W_{kin} in the rotor generator at the rate $\frac{d(W_{kin})}{dt}$.
2. By an increased load consumption. All typical loads experiences on increase

$$B = \frac{\partial P_E}{\partial d}$$

B is called damping coefficient

Thus this surplus power can be expressed as

$$\Delta P_T - \Delta P_E = \frac{dW_{kin}}{dt} + B\Delta f$$

As the kinetic energy is proportional to the square of the speed,

$$W_{kin} = W_{kin}^{o}\left(\frac{f}{f_o}\right)^{2\ 2}$$

where $f = f_o + \Delta f$ where f_o nominal frequency and f is new frequency after disturbances.

$$W_{kin} = W_{kin}{}^o\left(\frac{f_o + \Delta f}{f_o}\right) = W_{kin}{}^o\left[1 + 2\frac{\Delta f}{f_o} + \left(\frac{\Delta f}{f_o}\right)^2\right]$$

$$\cong W_{kin}{}^o\left[1 + 2\frac{\Delta f}{f_o}\right]$$

$\frac{\Delta f}{f_o}$ refers to per unit frequency.

$$\frac{d\left(W_{kin}\right)}{dt} = \frac{2W_{kin}{}^o}{f_o}\frac{d(\Delta f)}{dt}$$

Substituting equation (3.34) in equation (3.31)

$$\Delta P_T - \Delta P_E = \frac{2W_{kin}}{f_o}\frac{d(\Delta f)}{dt} + B\Delta f$$

$$H = \frac{W_{kin}}{P_r}$$

(H=Inertia constant of Generator)

$$\Delta P_T - \Delta P_E = \frac{2H}{f_o}\frac{d(\Delta f)}{dt} + B\Delta f$$

Taking the Laplace transform,

$$\Delta P_T(s) - \Delta P_E(s) = \frac{2H}{f_o} s\Delta f(s) + B\Delta f(s)$$

or it can be written as

$$\Delta f(s) = G_P(s)\left[\Delta P_T(s) - \Delta P_E(s)\right]$$

$$Gp = \frac{\mathrm{Kp}}{1 + \mathrm{Tp\,S}}$$

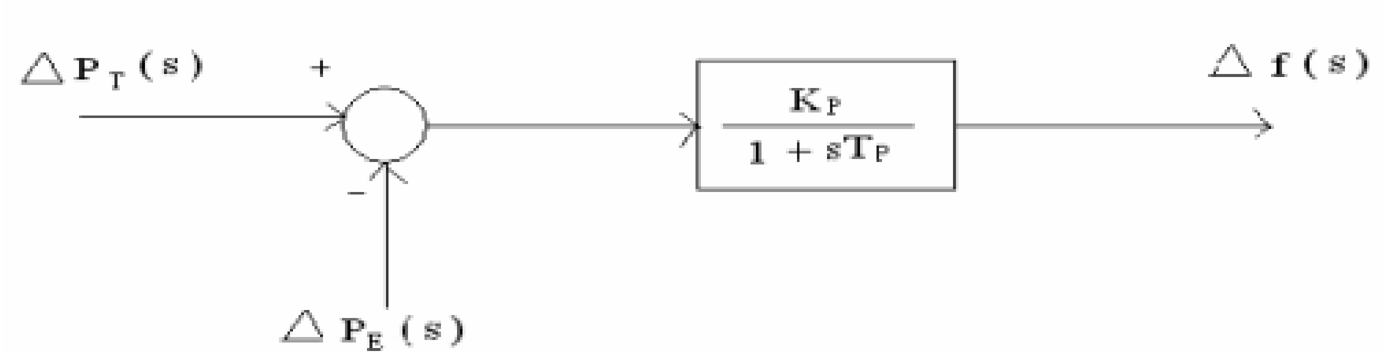
where, $K_p = \dfrac{1}{B}$ = Power system gain

K_p =1/0.0083= 120

B is damping coefficient, value shown in table 3.1

$$Tp = \frac{2\mathrm{H}}{\mathrm{Bf_o}}$$ = Power system time constant

= (2x5)/ (0.0083x60)= 20 sec.



$\Delta P_T(s)$
+
−
$\frac{K_P}{1+sT_P}$
$\Delta f(s)$
$\Delta P_E(s)$

Single control area

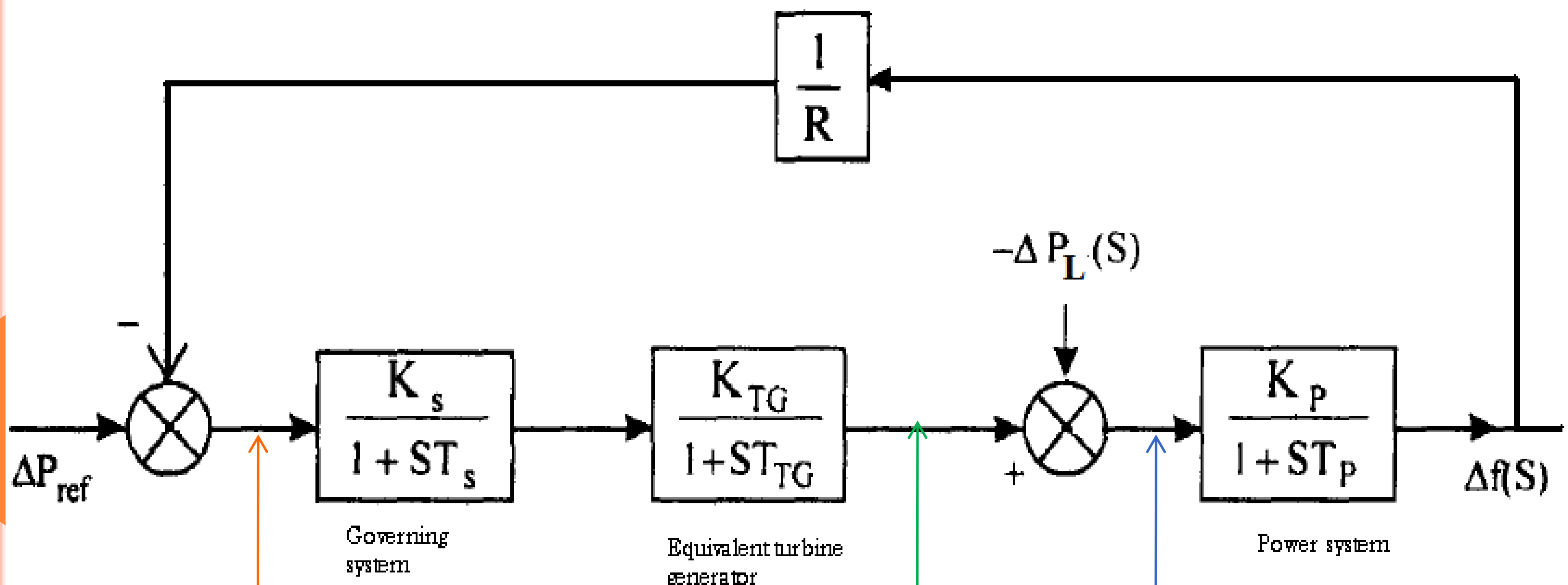
- In the previous sections models for turbine-generator, power system and speed governing systems are obtained.
- In practice, rarely a single generator feeds a large area. Several generators connected in parallel, located also, at different places will supply the power needs of a geographical area.
- Quite normally, all these generators have the same response characteristics in load demand. Such a coherent area is called a control area in which the frequency is assumed to be the same throughout in static as well as dynamic conditions.

- In such a case, it is possible to define a control area, grouping all the generators in the area together and treating them as a single equivalent generator, i.e for purpose of developing a suitable control strategy, a control area can be reduced to a single speed governor, turbo-generator and load system.

- Putting together, the various models derived so far a single control area can be conceived as shown below.

- The basic requirements to be fulfilled for successful operation of the system are
  - (i) The generation must be adequate to meet all the load demand.
  - (ii) The system frequency must be maintained with narrow and rigid limits.
  - (iii) The system voltage profile must be maintained within reasonable limits
  - (iv) In case of interconnected operation, the tie line power flows must be maintained at the specified values.
- Should the generation be not adequate to balance the load demand, it is imperative that on e of the following alternatives be considered for keeping the system in operating condition:
  1. Starting fast peaking units
  2. Load shedding for unimportant loads, and
  3. Generation rescheduling

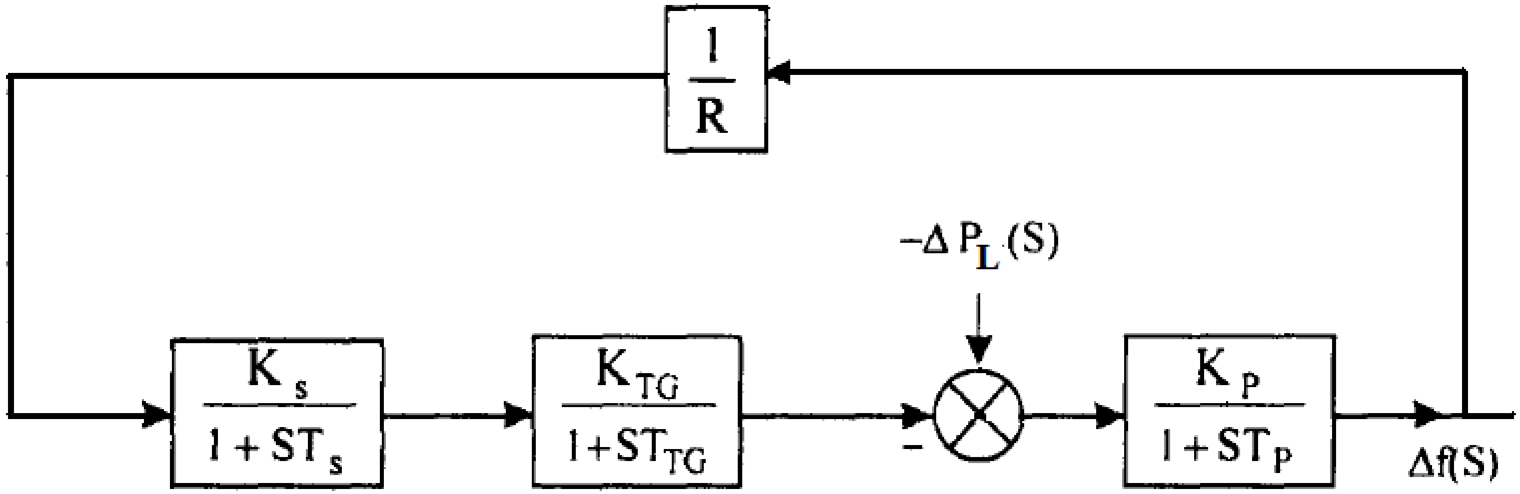
- The block diagram of single area system, where the gain and time constant in each block are as described in the individual section before, is as shown below.



$$\Delta F(s)=\left[\left[\Delta P_{ref}-\frac{\Delta F(s)}{R}\right]\left(\frac{K_s}{1+sT_s}\right)\left(\frac{K_{TG}}{1+sT_{TG}}\right)-\Delta P_L\right]\frac{K_p}{1+sT_p}$$

ANALYSIS OF SINGLE AREA SYSTEM

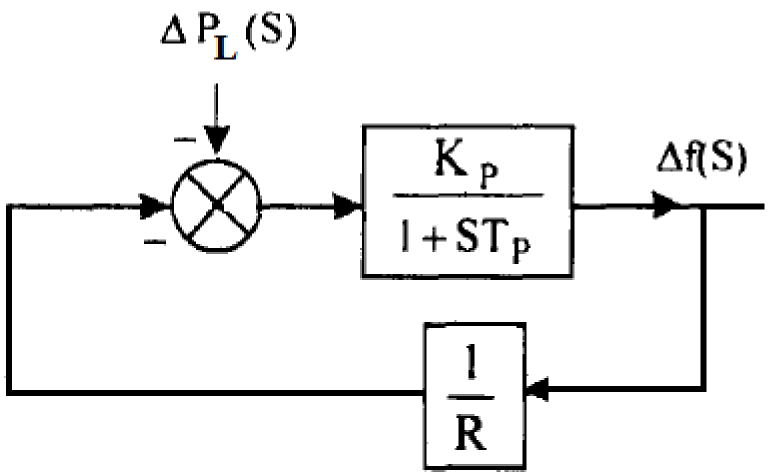
- The above model shows that there are two important incremental inputs to the load frequency control system - ΔP_{ref}, the change in speed changer setting, and ΔP_L, the change in load demand. Let us consider a simple situation in which the speed changer has a fixed setting ($\Delta P_{ref} = 0$.) and the load demand changes. This is known as free governor operation.
- In the given condition, the block diagram will be simplified as



A. LOAD CHANGE ONLY Considering $T_S < T_{TG} << T_P$ and $K_S K_{TG} \cong 1$, the dynamic response which is giving the change in frequency as a function of the time for a step change in load can be obtained as follows:

$$\Delta F(s) = T(s)\Delta P_L$$

$$T(s) = \frac{G(s)}{1+G(s)H(s)}$$



where $G(s) = K_P/(1+sT_P)$ and $H(s) = 1/R$.

- Hence,

$$\underbrace{\Delta F(s)}_{\text{Output}} = -\left[\frac{\dfrac{K_p}{1+sT_p}}{1+\left(\dfrac{K_p}{1+sT_p}\right)\left(\dfrac{1}{R}\right)}\right]\underbrace{\frac{\Delta P_L}{s}}_{\text{Step input}} \Rightarrow \Delta F(s) = -\left[\frac{K_p}{\left(1+\dfrac{K_p}{R}\right)+sT_p}\right]\frac{\Delta P_L}{s}$$

- Partial fractions for the expression can be simplified as follows:

$$\frac{1}{s}\frac{1}{A+Bs}=\frac{C}{s}+\frac{D}{A+BS} \Rightarrow L^{-1}=\left[\frac{C}{s}+\frac{(D/A)}{1+(B/A)s}\right]^{-1} \Rightarrow C+(D/A)\exp(-B/A)t$$

- Based on this, the above expression can be simplified

$$\Delta F(s)=-\Delta P_L\frac{K_p}{T_p}\left[\frac{1}{s+\left(\frac{R+K_p}{RT_p}\right)}\right]\frac{1}{s}$$

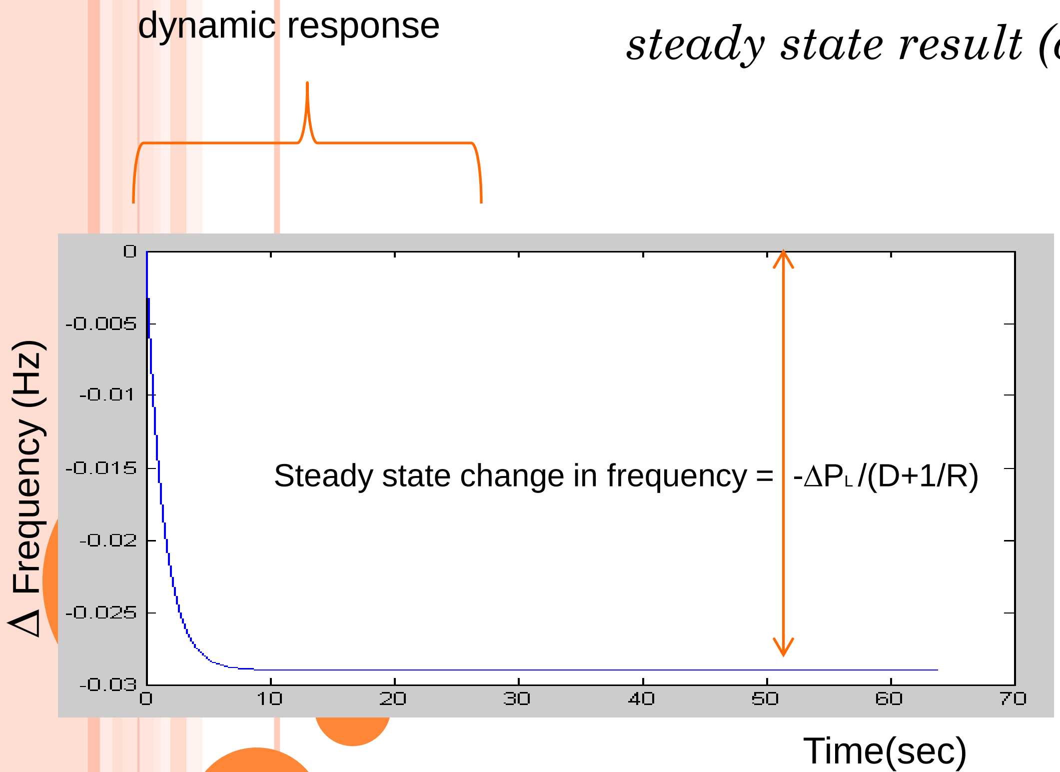
- The laplace transform of the above equation is as follow

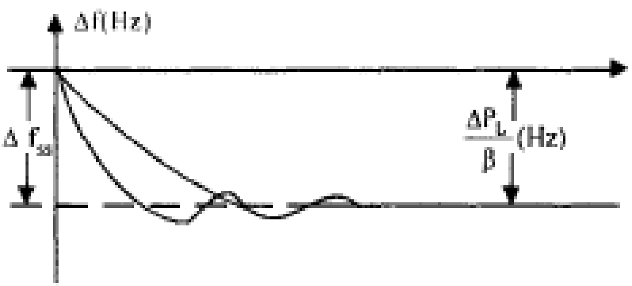
$$\Delta f(t)=-\frac{RK_p}{R+K_p}\left\{1-\exp\left[-\frac{t}{T_p}\left(\frac{R}{R+K_p}\right)\right]\right\}\Delta P_L \Rightarrow \Delta f(t)=-\beta\Delta P_L\left\{1-\exp\left[-\frac{t}{T_p}\kappa\right]\right\}$$

Where $\beta = \frac{1}{(D+1/R)}$ and $k = \frac{1}{(1+1/RD)} = \beta D$

The plot of change in frequency versus time for first order approximation given above is as shown below.

steady state result (at $t = \infty$) $\Rightarrow$ $\Delta f(t) = -\beta \Delta P_L$



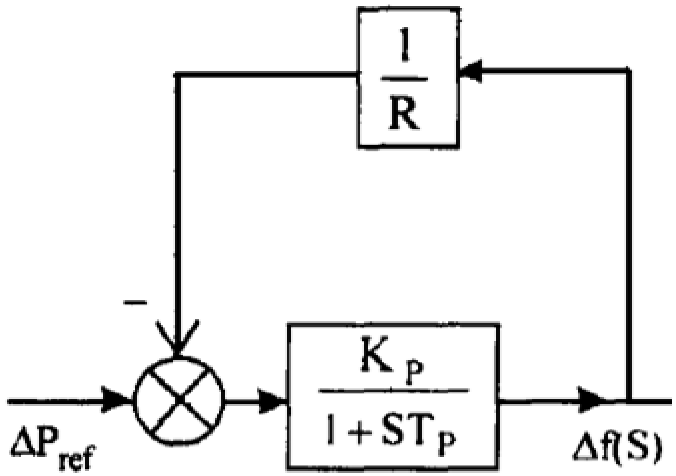


- Therefore, we can say that the LFC system posses inherently steady state error for a step input of load change provided that the reference setting remains unchanged.

- **B. REFERENCE SETTING CHANGE ONLY:** Consider now the steady effect of changing speed changer setting with load demand remaining fixed. Similar to the previous condition, letting $T_S < T_{TG} << T_P$ and $K_S K_{TG} \cong 1$, the simplified block diagram and transfer function becomes

$$\Delta F(s) = T(s)\Delta P_L$$

$$T(s) = \frac{G(s)}{1+G(s)H(s)}$$



Where $G(s) = K_P/(1+sT_P)$ and $H(s) = 1/R$

$$\Delta F(s) = \left[\frac{\dfrac{K_p}{1+sT_p}}{1+\left(\dfrac{K_p}{1+sT_p}\right)\left(\dfrac{1}{R}\right)}\right]\frac{\Delta P_L}{s} \Rightarrow \Delta F(s) = -\left[\frac{K_p}{\left(1+\dfrac{K_p}{R}\right)+sT_p}\right]\frac{\Delta P_L}{s}$$

Output

Step input

- Following the same procedure as case A, the steady state change in frequency due to change in reference setting will have similar expression:

$$\Delta f(t) = \beta \Delta P_{ref}$$

- If the speed change setting is changed by ΔP_{ref} while the load demand changes by ΔP_L, the steady state frequency change is obtained by superposition, i.e.

$$\Delta f = \beta\left(\Delta P_{ref} - \Delta P_L\right)$$

- According to the above equation, the frequency change caused by load demand can be compensated by changing the setting of the speed changer, i.e.

$$\Delta P_{ref} = \Delta P_L \qquad \text{, for } \Delta f = 0.$$

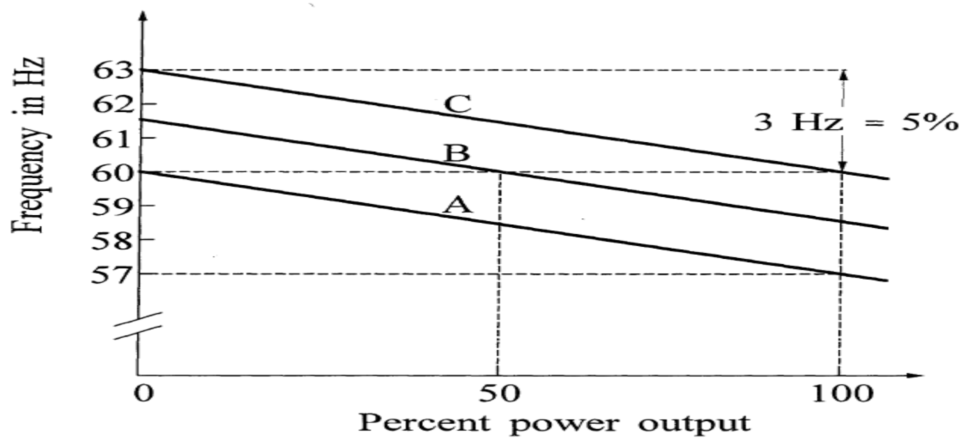
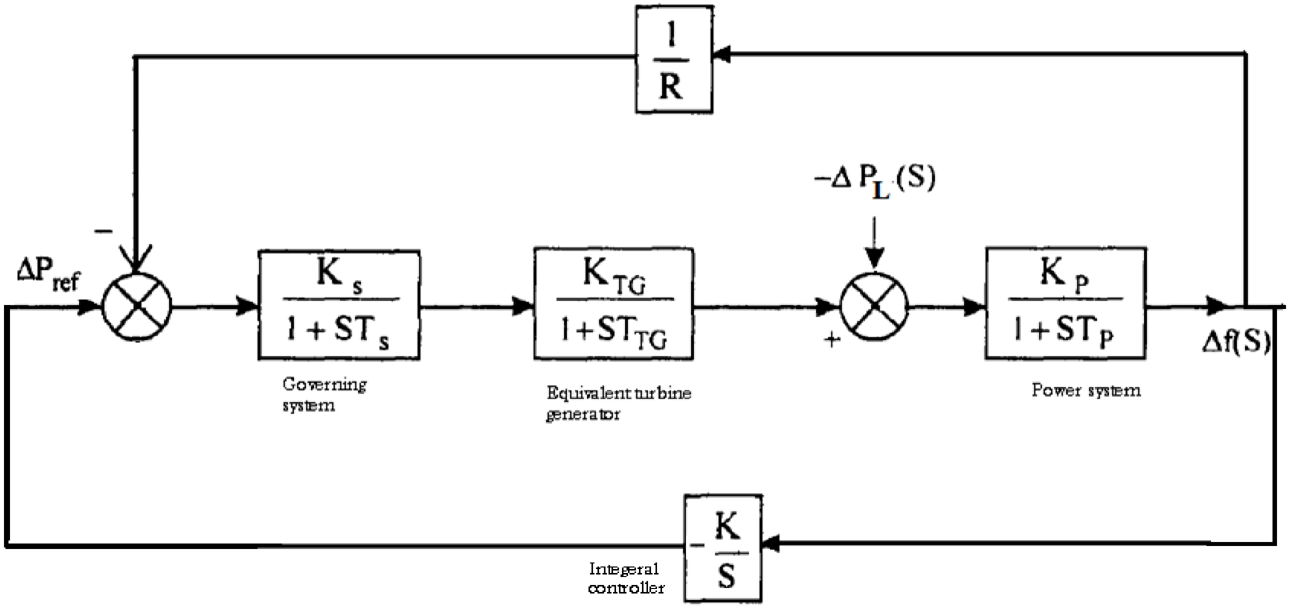


Figure: *Effect of speed changer setting on the frequency stability of the system*

- Therefore, for this purpose, a signal from Δf is fed through an integrator to the speed changer resulting in the block diagram configuration shown below.



- Now, the analysis on input-output relation results

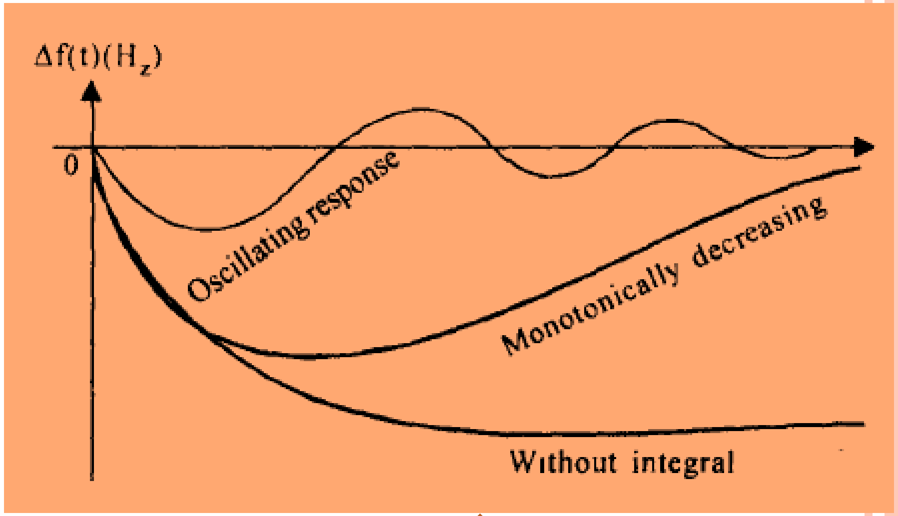
$$\Delta F(s)=\left[\left[-\frac{\Delta F(s)K}{s}-\frac{\Delta F(s)}{R}\right]\left(\frac{K_s}{1+sT_s}\right)\left(\frac{K_{TG}}{1+sT_{TG}}\right)-\Delta P_L\right]\frac{K_p}{1+sT_p}$$

- Neglecting Ts and TTG /both have << Tp/ and KsKTG ≅ 1, the above equation becomes,

$$\Delta F(s)=\left[\left[-\frac{\Delta F(s)K}{s}-\frac{\Delta F(s)}{R}\right]-\Delta P_L\right]\frac{K_p}{1+sT_p}$$

- Rearranging,

$$\Delta F(s)=-\frac{K_p}{\left((1+T_p s)+\left(\frac{K}{s}+\frac{1}{R}\right)K_p\right)}\times\frac{\Delta P_L}{s}$$



- Then, the change in steady state frequency is

$$\Delta f_{steadystate}=\lim_{s\to 0} s\Delta F(s)=\lim_{s\to 0} s\times\left(-\frac{sRK_p}{\left(sR(1+T_p s)+(KR+s)K_p\right)}\times\frac{\Delta P_L}{s}\right)=0$$

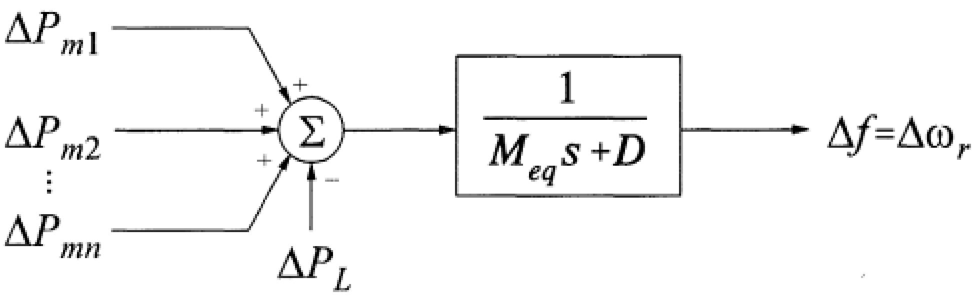
- Here we find that the steady state change in frequency has been reduced to zero by the addition of the integral controller. In central load frequency control of a given control area, the change (error) in frequency is known as Area Control Error (ACE). The additional signal fed back in the modified control scheme presented above is the integral of ACE.

- From the above analysis, it is clear that proportional integral and derivative control strategy can be applied for load frequency control.

- While proportional control is inherent in the feedback through the governor mechanism itself, derivative control when introduced improves transient performance and ensures better margin of stability for the system.

- The selection of the gain controller /in the secondary LFC/ should be such that
  - Control loop must be stable,
  - Frequency error should return to zero

COMPOSITE SYSTEM IN A SINGLE CONTROL AREA: The composite power/frequency characteristics of a power system thus depends on the combined effect of the droops of all generator speed governors. It also depends on the frequency characteristics of all the loads in the system.



where M_{eq} /equivalent generator/ $= \Sigma M$

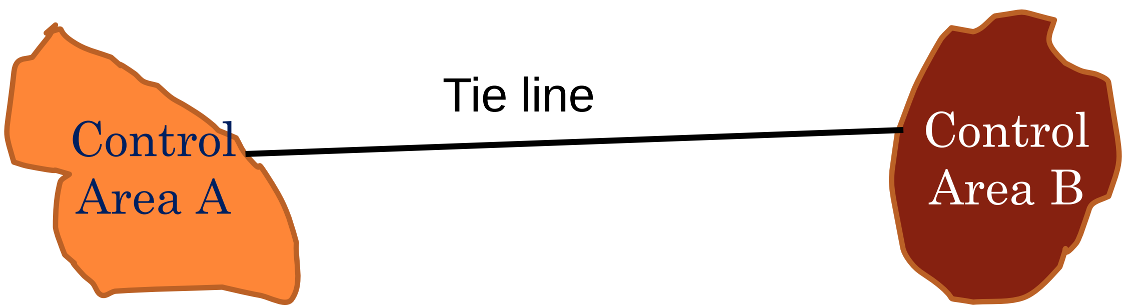
System equivalent for LFC analysis

- For a system with n generators and a composite load-damping constant of D, the steady-state frequency deviation following a load change ΔP_L is given by

$$\Delta f_{ss} = \frac{-\Delta P_L}{(1/R_1 + 1/R_2 + 1/R_3 \ldots 1/R_n) + D}$$

TIE-LINE CONTROL

- An extended power system can be divided into a number of load frequency control areas interconnected by means of tie lines in order ***i.*** *to get commercial benefit from neighboring systems* ***ii.*** *to meet sudden requirement of electric power and improve reliability* ***iv****. Reduce in installed capacity. The major disadvantages are control system becomes complex and any disturbance in one system is reflected in the other area .*



- The control objective now is to regulate the frequency of each area and to simultaneously regulate the tie line power as per inter-area power contracts. As in the case of frequency, PI controller will be installed so as to give zero steady state error in tie line power flow as compared to the contracted power.

- Power transported out of area A is given by

$$P_{tie,1} = \frac{|V_1||V_2|}{X_{12}} \sin(\delta_1^{\,o} - \delta_2^{\,o})$$

where $\delta_1^{\,o}$, $\delta_2^{\,o}$ are power angles of equivalent machines of the two areas.

- For incremental changes in δ_1 and δ_2 , the incremental tie line power can be expressed as

$$\Delta P_{tie,1} = \left[\frac{|V_1||V_2|}{X_{12}} \cos\left(\delta_1^{\,o} - \delta_2^{\,o}\right)\right](\Delta\delta_1 - \Delta\delta_2) \Longrightarrow \Delta P_{tie,1} = T_{12}(\Delta\delta_1 - \Delta\delta_2)$$

Where T_{12} is synchronizing coefficient.

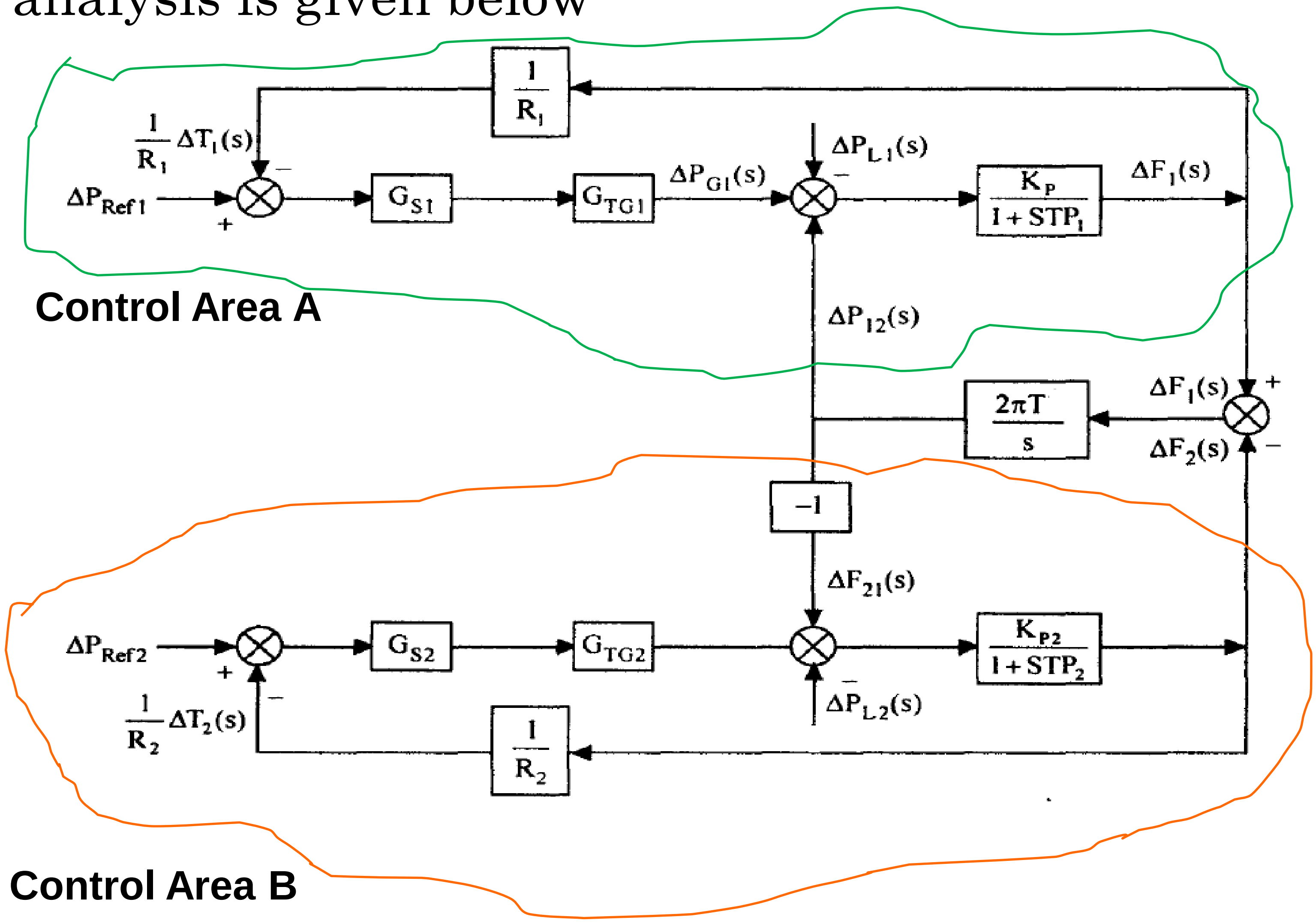
- Since incremental power angles are integrals of incremental frequencies (Δf_1 and Δf_2), the above equation can be written as

$$\Delta P_{tie,1} = 2\pi T_{12}\left(\int \Delta f_1 dt - \int \Delta f_2 dt\right) \Longrightarrow \Delta P_{tie,1} = \frac{2\pi T_{12}}{s}(\Delta F_1 - \Delta F_2) = \Delta P_{12}$$

- Similarly the incremental tie line power out of area B is given by

$$\Delta P_{tie,2} = 2\pi T_{21}\left(\int \Delta f_2 dt - \int \Delta f_1 dt\right) \Longrightarrow \Delta P_{tie,2} = \frac{2\pi T_{21}}{s}(\Delta F_2 - \Delta F_1) = -\Delta P_{12}$$

- The block diagram of the system based on the above analysis is given below



- The steady state response of this two area system can be determined as follows.
  - Consider the speed changer position is fixed (ΔP_{ref1} and ΔP_{ref2}) and there are step load changes in both areas (ΔP_{L1} and ΔP_{L2}).
  - The turbine input change ($\Delta P_{m1\ ss}$ & $\Delta P_{m2\ ss}$) due to the valve opening by the regulation characteristics in the two areas in steady state condition becomes ,

$$\Delta P_{m1\ ss} = -(1/R_1)\,\Delta F_{ss}\ ;\ \ \Delta P_{m2\ ss} = -(1/R_2)\,\Delta F_{ss}$$

  - Under this condition,

$$\left[-\left(\frac{1}{R_1}\right)\Delta F_{ss} - \Delta P_{12} - \Delta P_{L1}\right]D_1 = \Delta F_{ss} \quad \& \quad \left[-\left(\frac{1}{R_2}\right)\Delta F_{ss} + \Delta P_{12} - \Delta P_{L2}\right]D_2 = \Delta F_{ss}$$

  - Solving for steady state frequency and tie line power, we get

$$\Delta F_{ss} = -\frac{[\Delta P_{L1} + \Delta P_{L2}]}{[\beta_1 + \beta_2]} \qquad \& \qquad \Delta P_{12} = \frac{[\beta_1 \Delta P_{L2} - \beta_2 \Delta P_{L1}]}{[\beta_1 + \beta_2]}$$

Where $\beta_1 = D_1 + 1/R_1$ and $\beta_2 = D_2 + 1/R_2$

- We thus conclude from the preceding analysis that the two area system, just as in the case of a single area system in the uncontrolled mode, has a steady state error but to a lesser extent and the tie line power deviation and frequency deviation exhibit oscillations that are damped out latter.
- Hence, in interconnected operation to avoid these deviations and also to enable each area control the changes in such a fashion that it absorbs its own load change in steady state, area control error signals should be sent to reference (speed changer) in the two areas respectively as follows

$$ACE_1 = \Delta P_{12} + \beta_1 \Delta f_1$$
$$ACE_2 = \Delta P_{21} + \beta_2 \Delta f_2$$

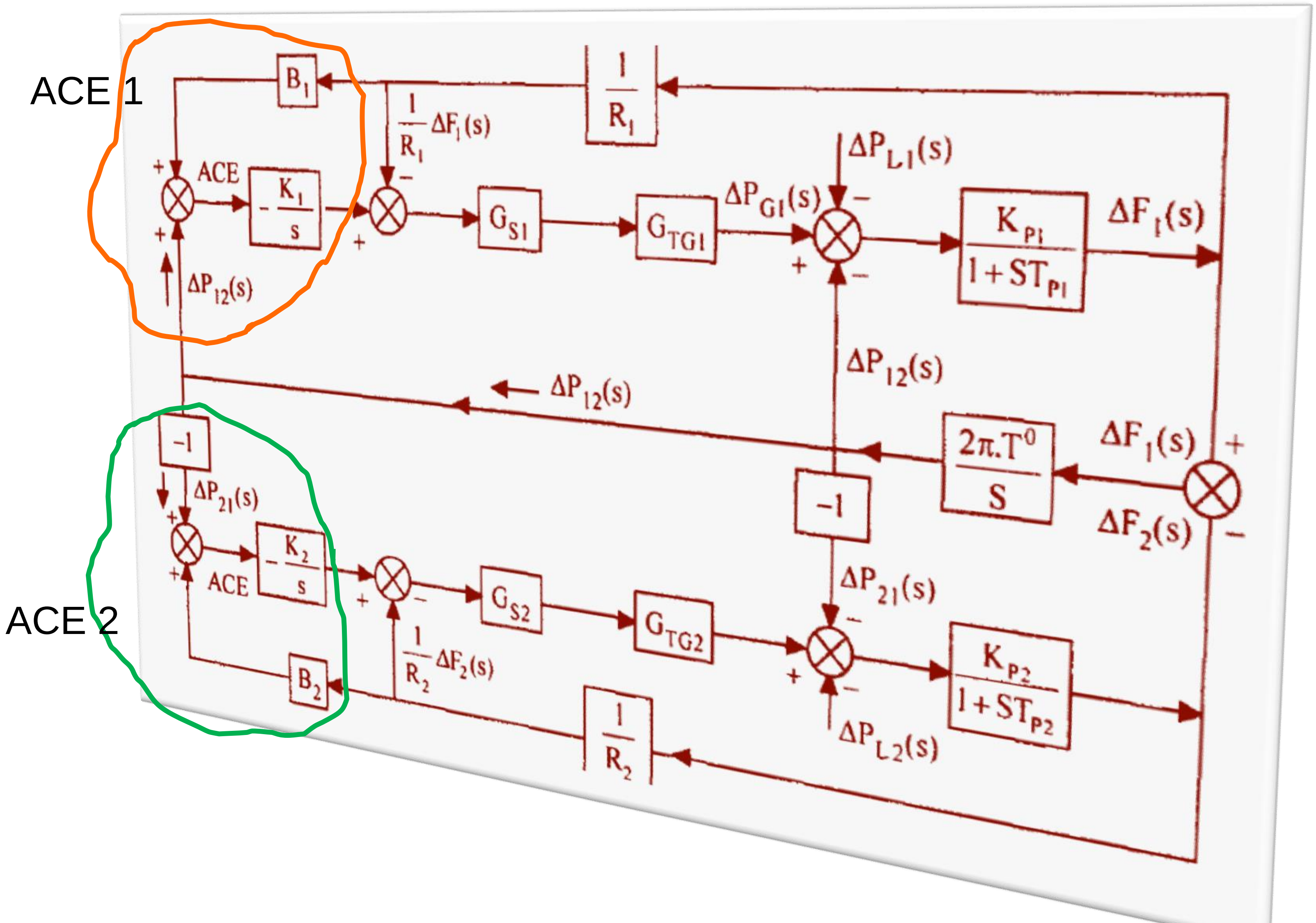
$$\Rightarrow$$

$$\Delta P_{ref\,1} = -K_1 \int (\Delta P_{12} + \beta_1 \Delta f_1) dt$$
$$\Delta P_{ref\,2} = -K_2 \int (\Delta P_{21} + \beta_2 \Delta f_2) dt$$

- Using laplace transform

$$\Delta P_{ref\,1} = -\frac{K_1}{s} (\Delta P_{12} + \beta_1 \Delta f_1)$$
$$\Delta P_{ref\,2} = -\frac{K_2}{s} (\Delta P_{21} + \beta_2 \Delta f_2)$$

- The general block diagram for a two area system can now be developed as shown below.



QV CONTROL

- Industrial and domestic loads, both, require real and reactive power. Hence, generators have to produce both real and reactive power. Reactive power is required to excite various types of electrical equipment as well as transmission network.
- Basically, the reactive power transmitted over a line a great impact on the voltage profile. Hence, by controlling the production, absorption and flow of reactive power at all levels in the system, the control of voltage levels is accomplished.
- For efficient and reliable operation of power systems, the control of voltage and reactive power should satisfy the following objectives;

(a) Voltage at the terminals of all equipment in the system are within acceptable limits.

(b) The reactive power flow is minimized so as to reduce losses to a practical minimum.

- Important generators of reactive power are
  - over-excited synchronous machines
  - capacitor banks, the capacitance of overhead lines and cables
  - Static var compensators
- Important consumers of reactive power are
  - inductive static loads, shunt reactors, inductance of overhead lines and cables
  - under-excited synchronous machines,
  - Transformer inductances, induction motors
  - Static var compensators
- For some of these, the reactive power is easy to control, while for others it is practically impossible. The most important devices for reactive power and voltage control are described hereafter.

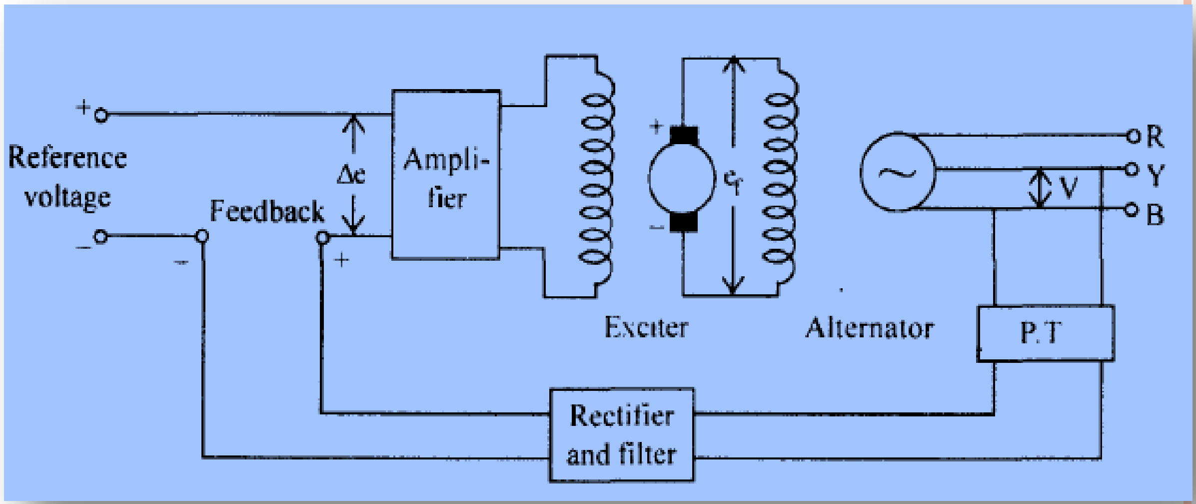
ANALYSIS OF GENERATOR VOLTAGE CONTROL

- Generators are often operated at constant voltage by using an AVR which senses the terminal voltage level and adjusts the excitation to maintain constant terminal voltage also maintain the reactive output at the required level.
- The main purpose of the excitation system of a synchronous machine which may be either DC excitation, AC excitation or Brushless excitation scheme is to feed the field winding with direct current so that the main flux in the rotor is generated. The relation between terminal voltage and induced voltage of alternator can be expressed as

$$\overline{V} = \overline{E} - \overline{I}\,\overline{Z} \approx \overline{E} - j\overline{I}X_s$$

- Under different loading conditions especially when there is constant real power and variable reactive power demand, the terminal voltage will vary.

- Consider that the current is operating at unity power factor and hence, no reactive power generation at the alternator. For there is any change in reactive power demand, the alternator acts to supply the demand, if there is no any other device to respond. If excitation is not changed depending on the condition, the terminal voltage of the alternator deviate from the desired value. This in turn, affects the voltage distribution in the system. In order to avoid this problem the excitation of the alternator has to take action accordingly.
- To understand how voltage can be maintained using excitation system, consider the following schematic diagram



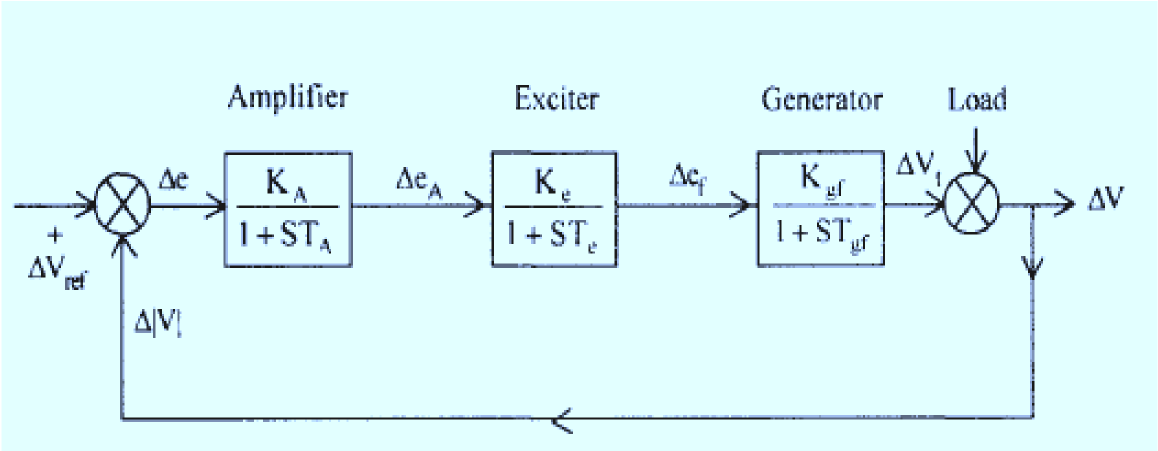
- The function of important components and their transfer function is given below

1. Potential transformer: It gives a sample of terminal voltage, V_T
2. Differencing device: at the feedback point, $V_{ref} - V_T = \Delta e$
3. Error amplifier: It demodulates and amplifies the error signal. $\Delta e_A = k_A \Delta e$, where k_A is amplifier gain.
4. SCR power amplifier and exciter field: It provides the necessary power amplification to the signal for controlling the exciter field. $\Delta e_A = R_e \Delta i_e + L_e \frac{d}{dt}(\Delta i_e)$

   where Δi_e is the change in exciter field current. If 1A change in field current produce k volt change in the output, then $\Delta e_f = k_A \Delta i_e$. The transfer function of the exciter using laplace can be expressed as $\frac{\Delta E_f}{\Delta E_A} = \frac{k_e}{R_e + sL_e} = \frac{K_e}{1 + sT_e}$
5. Alternator: Its field is excited by the main exciter voltage. Under no-load it produces a voltage proportional to field current. The input voltage signal Δe_f to the generator field, when applied to the circuit results in the following Kirchoff's voltage equation. $\Delta e_f = R_f \Delta i_f + L_f \frac{d}{dt}(\Delta i_f)$

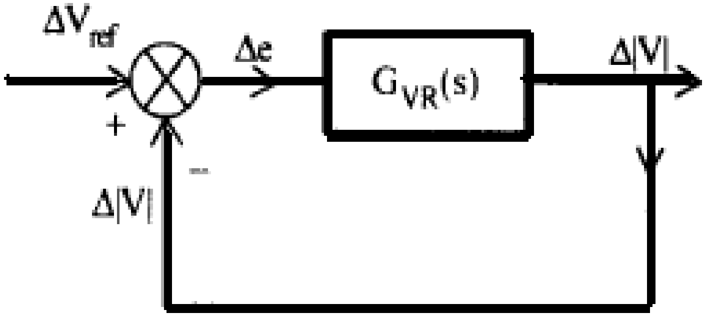
… If the output voltage changes by Δv, then $\Delta I_f = \dfrac{\sqrt{2}}{\varpi L_{fa}} \Delta V$ where L_{fa} is the mutual inductance between the field and stator phase winding. Hence, the transfer function for the generator block will be $\dfrac{\Delta V}{\Delta E_f} = \dfrac{\sqrt{2}}{\varpi R_f L_{fa}} \dfrac{1}{1+s\dfrac{L_{ff}}{R_f}} = \dfrac{K_{gf}}{1+sT_{gf}}$

- The voltage regulator loop can be represented by the following block diagram



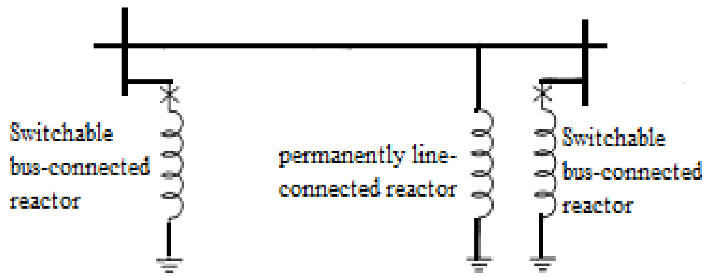
- The cascaded transfer function blocks can be combined into single block

$$G_{VR}(s) = \left[\frac{K_A}{1+sT_A}\right]\left[\frac{K_e}{1+sT_e}\right]\left[\frac{K_{gf}}{1+sT_{gf}}\right]$$

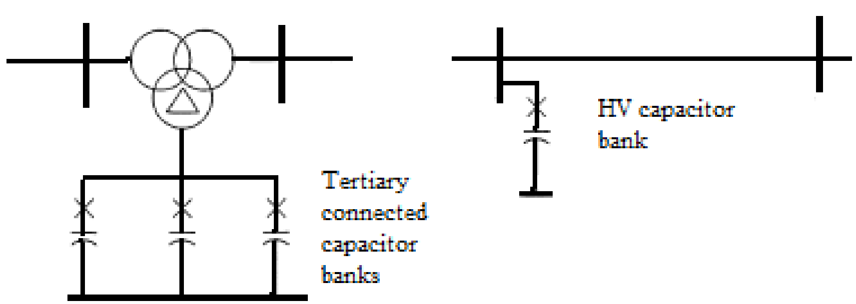


OTHER CONTROLLERS

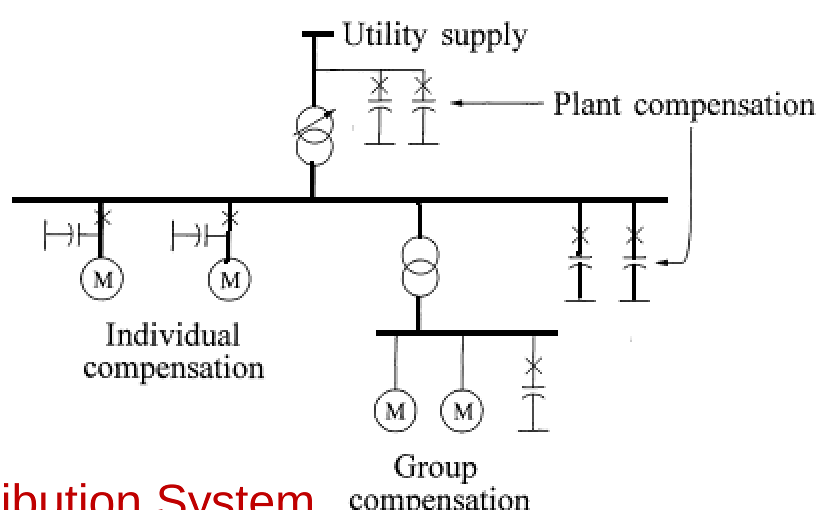
- **Shunt Reactors:** are used to compensate for the effects of line capacitance, particularly to limit voltage rise on open circuit or light load.



- **Shunt Capacitors:** supply reactive power and boost local voltages. They are used throughout the system and are applied in a wide range of sizes.



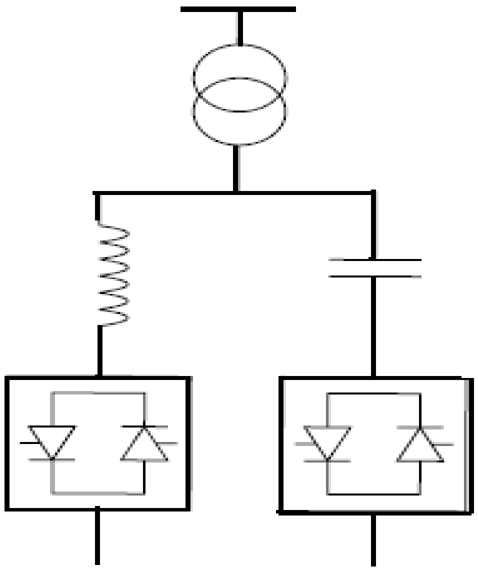
Transmission System



Distribution System

- **Synchronous condenser:** is a synchronous machine running without a prime mover or a mechanical load. By controlling the field excitation, it can be made to either generate or absorb reactive power.
- **Static var compensators (SVCs):** may be comprised of two different elements, i.e TCR and TSC. By delaying the firing of the thyristors, a continuous control of the current through the reactor can be obtained, with the reactive power consumption varying between 0 and V2/X.

- By combining the TCR with a suitable number of capacitor banks, a continuous control of the reactive power can be achieved by a combination of capacitor bank switching and control of reactor current. The control system of the SVC controls the reactive output so that the voltage magnitude Of the controlled node is kept constant.



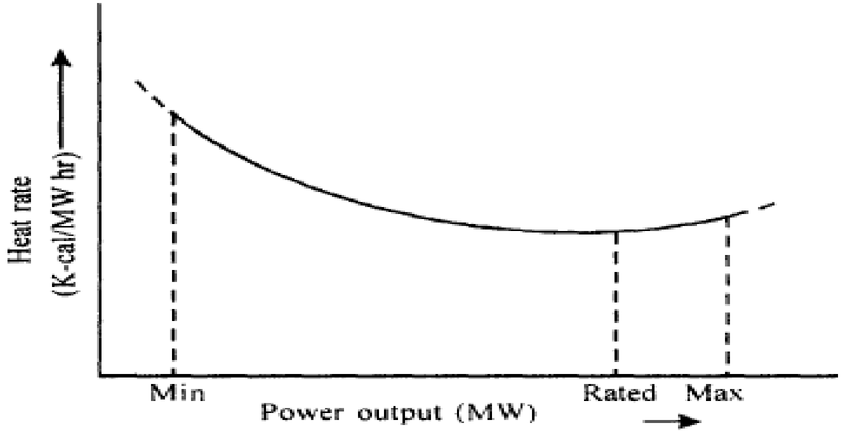
Static var compenstor

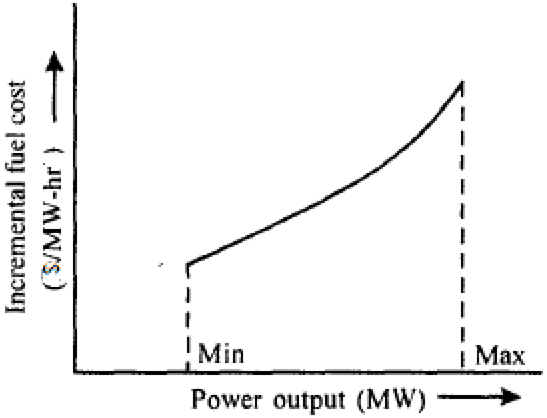
OPTIMAL POWER FLOW

ECONOMIC OPERATION /ED-ECONOMIC DISPATCH/

- The economic dispatch problem consists in allocating the total demand among generating units so that the production cost is minimized.
- Generating units have different production costs depending on the prime energy source used to produce electricity (mainly coal, oil, natural gas, uranium, and water stored in reservoirs).
- In addition to continuous decisions on how to allocate the demand among generating units, the economics of electricity generation also requires the calculation of an optimum time schedule for the start-up and shutdown costs of the generating units. (since the units' start-up or shutdown costs can be significant, on/off scheduling decisions must be optimally coordinated with the ED of the continuous generation outputs.

- Each generating unit is assigned a function, $C_i(P_{Gi})$, characterizing its generating cost in \$/h in terms of the power produced in MW, P_{Gi}, during 1hr. This function is obtained by multiplying the heat rate curve, expressing the fuel consumed to produce 1MW during 1hr, by the cost of the fuel consumed during that hour. /Note that the heat rate is a measure of the energy efficiency of the generating unit/.





- Considering n generating units, the total production cost is

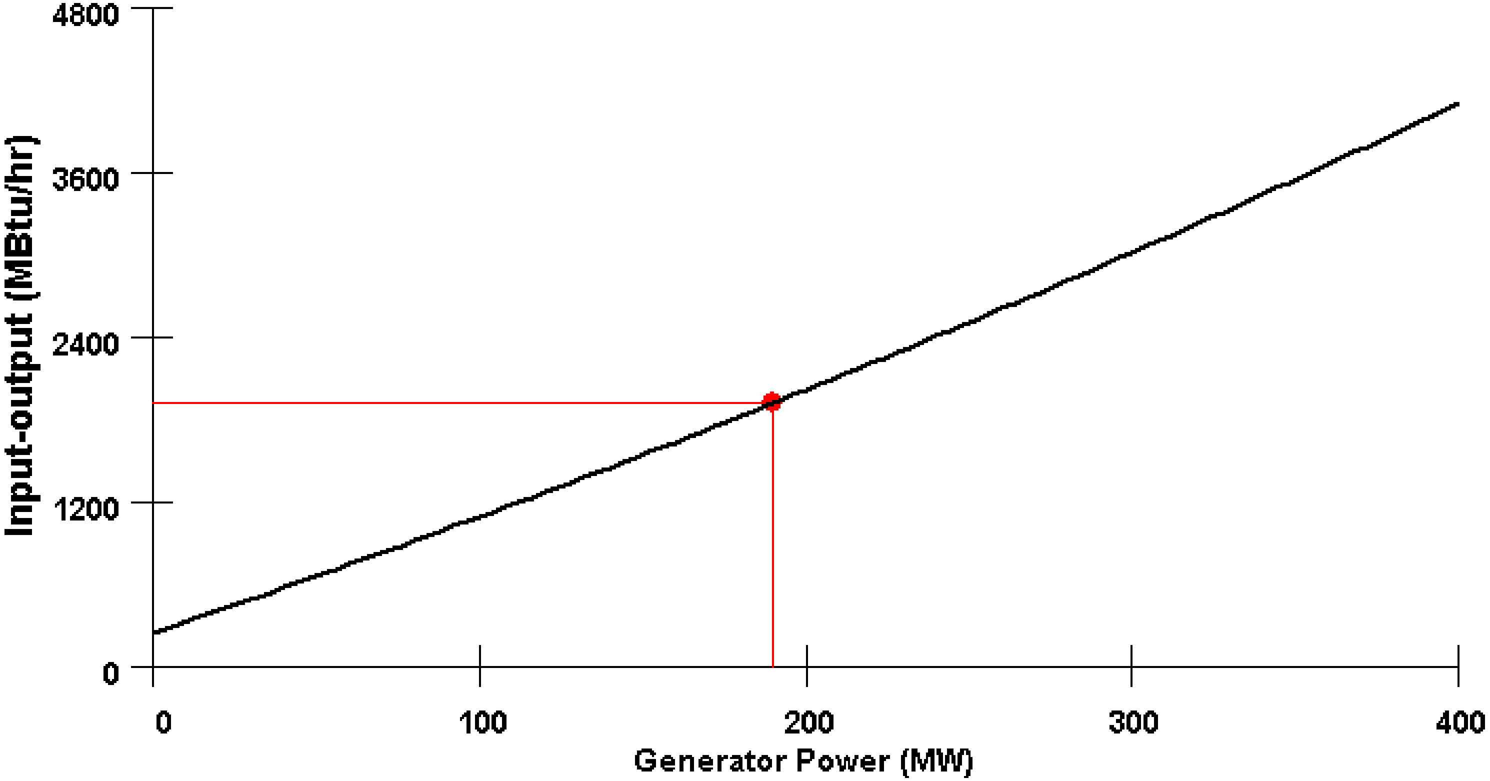
$$C(P_G) = \sum_{i=1}^{n} C_i(P_{Gi})$$ where P_{gi} is unit generation level

Thermal generator Cost Curves

- Thermal generator costs are typically represented by one or other of the following four curves
  - input/output (I/O) curve
  - fuel-cost curve
  - heat-rate curve
  - incremental cost curve
- For reference
  - 1 Btu (British thermal unit) = 1054 J
  - 1 MBtu = 1×10^6 Btu
  - 1 MBtu = 0.29 MWh

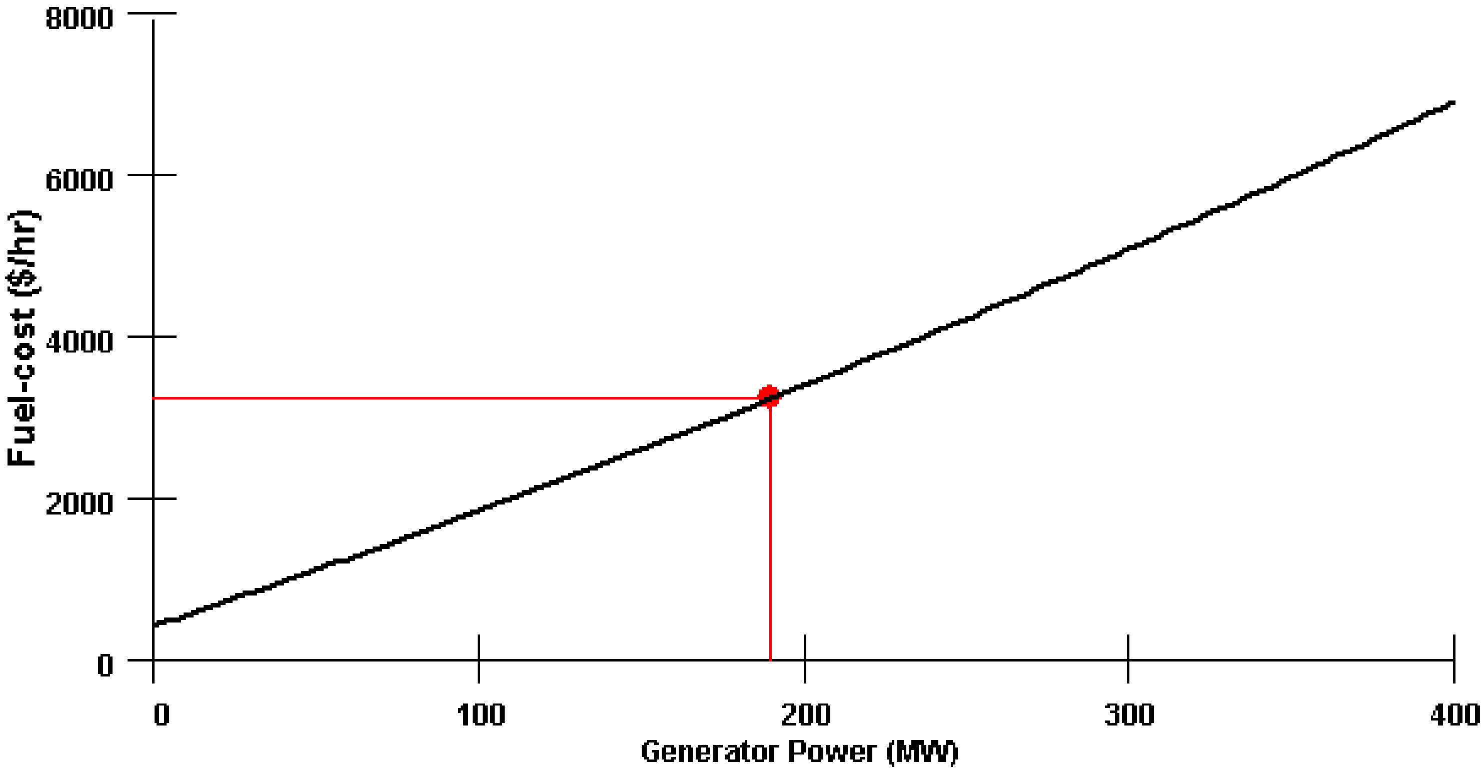
I/O Curve

- The IO curve plots fuel input (in MBtu/hr) versus net MW output.



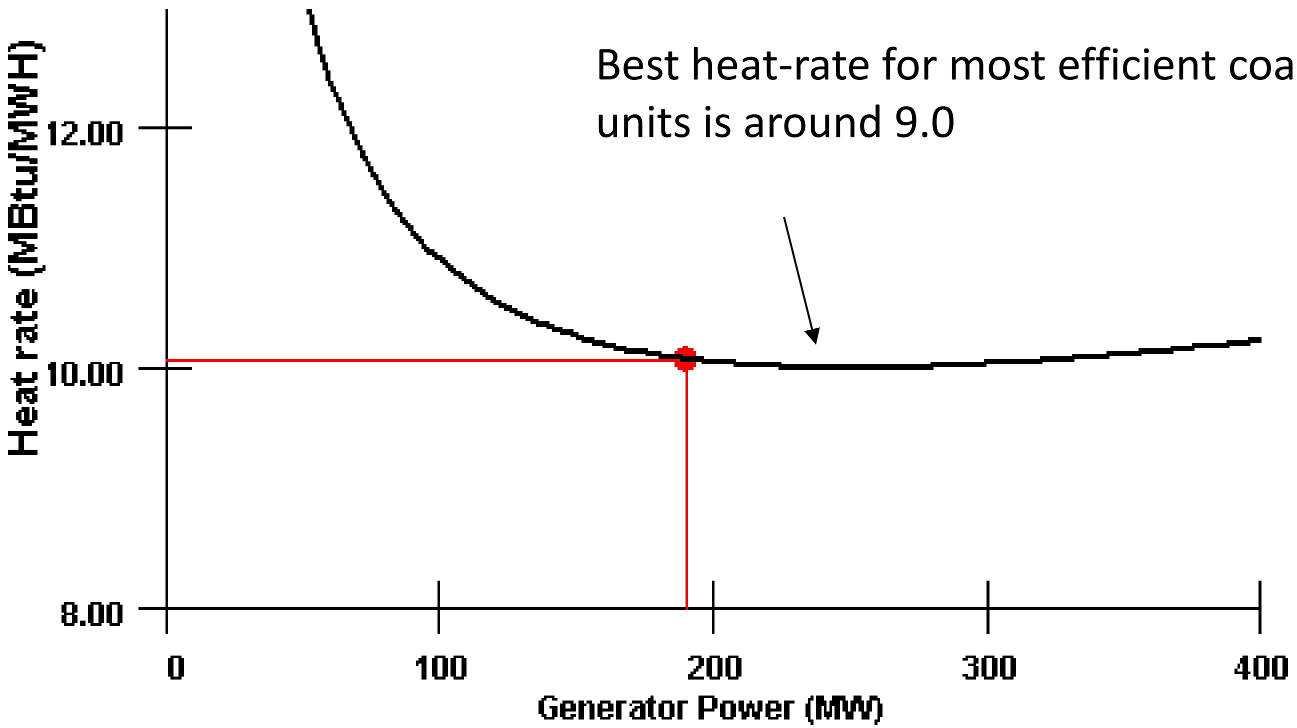
Fuel-cost Curve

- The fuel-cost curve is the I/O curve multiplied by fuel cost.
- A typical cost for coal is $ 1.70/MBtu.



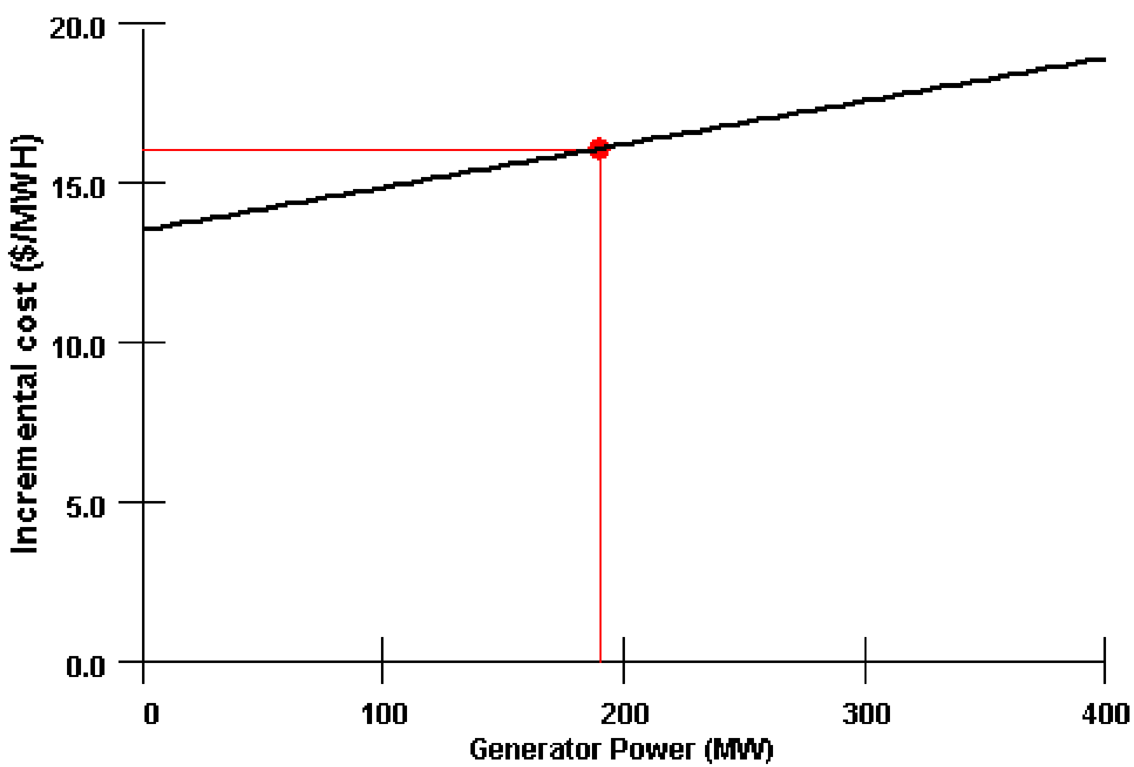
Heat-rate Curve

- Plots the average number of MBtu/hr of fuel input needed per MW of output.
- Heat-rate curve is the I/O curve divided by MW.



Incremental (Marginal) cost Curve

- Plots the incremental \$/MWh as a function of MW.
- Found by differentiating the cost curve.



- If the system total demand is $P_{D\ total}$ and all generating units contribute to supply this demand, total production or generation must be $$\sum_{i=1}^{n} P_{Gi} - (P_{Dtotal} + P_{loss}) = 0$$
- The ED problem consists of minimizing the total cost with respect to the unit generation output subject to the above power balance, and to the generating unit operational limits $P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max}$
- Using the method of Lagrange multipliers, neglecting losses and generating limits for simplicity, we have *L(P,λ) = F(P) + λG(P)* where *F(P)* is objective function for minimization and *G(P)* is equality constraint. Therefore, $$L(P_G,\lambda) = \sum_{i=1}^{n} C(P_{Gi}) - \lambda\left(\sum_{i=1}^{n} P_{Gi} - P_{Dtotal}\right)$$
- The necessary conditions are given as $$\frac{\partial L(.)}{\partial P_{Gi}} = 0$$ $$\frac{\partial L(.)}{\partial \lambda} = 0$$

- Hence, we get

$$\frac{\partial C_1(P_{G1})}{\partial P_{G1}} = \frac{\partial C_2(P_{G2})}{\partial P_{G2}} = \frac{\partial C_3(P_{G3})}{\partial P_{G3}} = \frac{\partial C_4(P_{G4})}{\partial P_{G4}} = \ldots = \frac{\partial C_n(P_{Gn})}{\partial P_{Gn}} = \lambda$$

$$\sum_{i=1}^{n} P_{Gi} - P_{Dtotal} = 0$$

- The above equation states that at the optimum all the generating stations operate the same incremental cost for optimum economy and their incremental production cost is equal to the Lagrange multiplier λ at the optimum.
- In addition to the load should be taken up always at the lowest incremental cost, it must be ensured that the generations so determined are with in their capacities. Under this circumstance, the Lagrange function becomes

$$L(P_G,\lambda) = \sum_{i=1}^{n} C(P_{Gi}) - \lambda\left(\sum_{i=1}^{n} P_{Gi} - P_{Dtotal}\right) - \sum_{i=1}^{n} \mu_i^{\max}(P_{Gi} - P_{Gi}^{\max}) - \sum_{i=1}^{n} \mu_i^{\min}(P_{Gi} - P_{Gi}^{\min})$$

where new multipliers, $\mu_i^{\max}$ and $\mu_i^{\min}$ are incorporated, corresponding to the minimum and maximum power outputs of each generating unit.

- The first-order necessary optimality conditions become

$$\frac{\partial L(.)}{\partial P_{Gi}} = IC_i(P_{Gi}) - \lambda - \mu_i^{\max} - \mu_i^{\min} = 0; i = 1,\ldots n$$

$$\frac{\partial L(.)}{\partial \lambda} = \sum_{i=1}^{n} P_{Gi} - P_{Dtotal} = 0$$

$$\mu_i^{\max} \le 0; \Leftrightarrow P_{Gi} = P_{Gi}^{\max}$$

$$\mu_i^{\max} = 0; \Leftrightarrow P_{Gi} < P_{Gi}^{\max}$$

$$\mu_i^{\min} \ge 0; \Leftrightarrow P_{Gi} = P_{Gi}^{\min}$$

$$\mu_i^{\max} = 0; \Leftrightarrow P_{Gi} > P_{Gi}^{\min}$$

- Hence, the marginal cost will be operated at equal incremental cost if the generation is with in the limits. Otherwise, the generation has to be kept constant at the capacity limit for that unit and eliminated from further optimum calculations.

ECONOMIC SCHEDULING INCLUDING LOSSES

- **Electric power transmission** or "high voltage electric transmission" is the bulk transfer of electrical energy, from generating power plants to substations located near to population centers.
- This is distinct from the local wiring between high voltage substations and customers, which is typically referred to as electricity distribution.
- In this process, some part of electric energy is lost as transmission and distribution loss.

…

…cont'd

- The size of the power systems increased enormously, with long transmission lines connecting several power generating stations extending over large geographical areas transferring power to several load centers.
- With this development, it has become necessary to consider not only the incremental fuel costs but also incremental transmission losses incurred in these line while power is transmitted.
- Here, the previous equality constraint is modified by including losses and the Lagrange function becomes $L(P_G,\lambda)=\sum_{i=1}^{n}C(P_{Gi})-\lambda\left(\sum_{i=1}^{n}P_{Gi}-P_{Dtotal}-P_{loss}\right)$
- Applying the necessary conditions for the minimum L

$$\frac{\partial L(.)}{\partial P_{Gi}}=\frac{\partial C_i(P_{Gi})}{\partial P_{Gi}}-\lambda(1-\frac{\partial P_{loss}}{\partial P_{Gi}})=0 \quad \Rightarrow \frac{\partial C_i(P_{Gi})}{\partial P_{Gi}}=\lambda(1-\frac{\partial P_{loss}}{\partial P_{Gi}}) \quad \Rightarrow \frac{\partial C_i(P_{Gi})}{\partial P_{Gi}}\underbrace{\left(\frac{1}{1-\frac{\partial P_{loss}}{\partial P_{Gi}}}\right)}_{\text{Penality factor}}=\lambda\,; \quad i=1,\ldots.n$$

- The sum of the incremental production cost of power at any plant i and the incremental transmission losses incurred due to generation P_i at bus i charged at the rate of λ must be constant for all generators and equal to λ. This constant λ is equal to the incremental cost of the received power.
- One of the most important, simple but approximate methods of expressing transmission loss as a function of generator powers is through B-coefficients. This method uses the fact that under normal operating condition the transmission loss is quadratic in the injected bus real powers.

$$P_L = \sum_i \sum_j P_i B_{ij} P_j \Rightarrow \frac{\partial P_{loss}}{\partial P_{Gi}} = \sum_j 2 B_{ij} P_j$$

where P_i and P_j are real power injection at bus i and j, and B_{ij} is loss coefficients.

- Substituting this to the previous first derivative equation, we get

$$\frac{\partial C_i(P_{Gi})}{\partial P_{Gi}} = \lambda(1-\sum_j 2B_{ij}P_j)\,; \quad i=1,\ldots.n$$

- If the incremental costs are represented by a linear relationship following a quadratic characteristics, then $IC_i(P_{Gi}) = c_iP_i + d_i$

$$c_iP_{Gi} + d_i + 2\lambda B_{ii}P_i + 2\lambda\sum_{\substack{i=1\\ i\neq j}}^{n} B_{ij}P_j = \lambda\,;$$

- Substituting $P_{Gi} = Pi + P_{di}$, and simplifying for P_i

$$P_i = \frac{1-\frac{d_i}{\lambda}+2\frac{c_i}{\lambda}P_{Di}-2\sum_{\substack{i=1\\ i\neq j}}^{n} B_{ij}P_j}{\left(\frac{c_i}{\lambda}+B_{ii}\right)}; \quad i=1,2,\ldots n$$

- For any particular value of λ, the above equation can be solved iteratively by assuming initial values of P_i . Iterations are stopped when P_is converge within a specified accuracy.

➔ It should be understood that losses can be considered not only as a constraint but also as objective function.

HYDRO-THERMAL SCHEDULING

- Most of the power systems are a mix of different modes of generating station of which thermal and hydro generating units are predominant. The hydro plants can be started easily and can be assigned load in very short time. This is not so in case of thermal plants, as it requires several hours to bring the boiler, super heater, and turbine system ready to take the load allotment. For this reason, the thermal plants are more suitable to operate as base load plants, leaving hydro plants to operate as peak load plants.

- Whatever, may be the type of plant, it is necessary to utilize the total quantity of water available in hydro development so that maximum economy is achieved.

- Considering the operation time to be T, let us divide into intervals 1,2,….J to suit the load curve so that

$$\sum_{j=1}^{J} n_j = T$$

- The equality constraint for the total volume of water available for discharge over this period is

$\sum_{j=1}^{J} n_j w_j - W = 0$ where w_j is the water rate for interval j

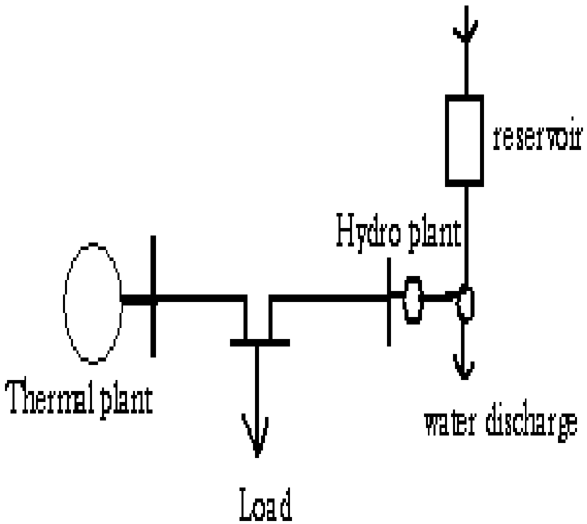
- The fuel cost required to be minimized over this period T is given as $\sum_{j=1}^{J} n_j C(P_{SGj}) = C_T$

- For load balance assuming loads are constant during this interval and head of water is also remain constant, the equality constraint is

$$P_{SGj} + P_{HGj} - P_{Di} = 0.$$

- The input-output characteristic for the equivalent hydro plant is

$$w = w(P_H)$$



- The Lagrange function for minimization subject to the above constraints is

$$L(P_{SG},P_{HG},\lambda,\gamma)=\underbrace{\sum_{j=1}^{J}n_jC(P_{SGj})}_{\text{Objective function}}-\sum_{j=1}^{J}\lambda_j\underbrace{\left(P_{SGj}+P_{HGj}-P_{Dj}\right)}_{\text{Power balance constraint}}-\gamma\underbrace{\left(\sum_{j=1}^{J}n_jw_j(P_{HGj})-W\right)}_{\text{Water balance constraint}}$$

- For any specific value of *j*, the necessary conditions are

$$\frac{\partial L(.)}{\partial P_{SGj}}=0 \qquad \frac{\partial L(.)}{\partial P_{HGj}}=0 \quad \Rightarrow \quad n_j\frac{\partial C_{Sj}}{\partial P_{SGj}}=\lambda_j \qquad \gamma n_j\frac{\partial w_j}{\partial P_{HGj}}=\lambda_j$$

- Solution to the above equations gives the economic generations at steam and hydro plants over any time interval. The incremental production cost at the steam plants must be the same as incremental production cost at the hydro plants.

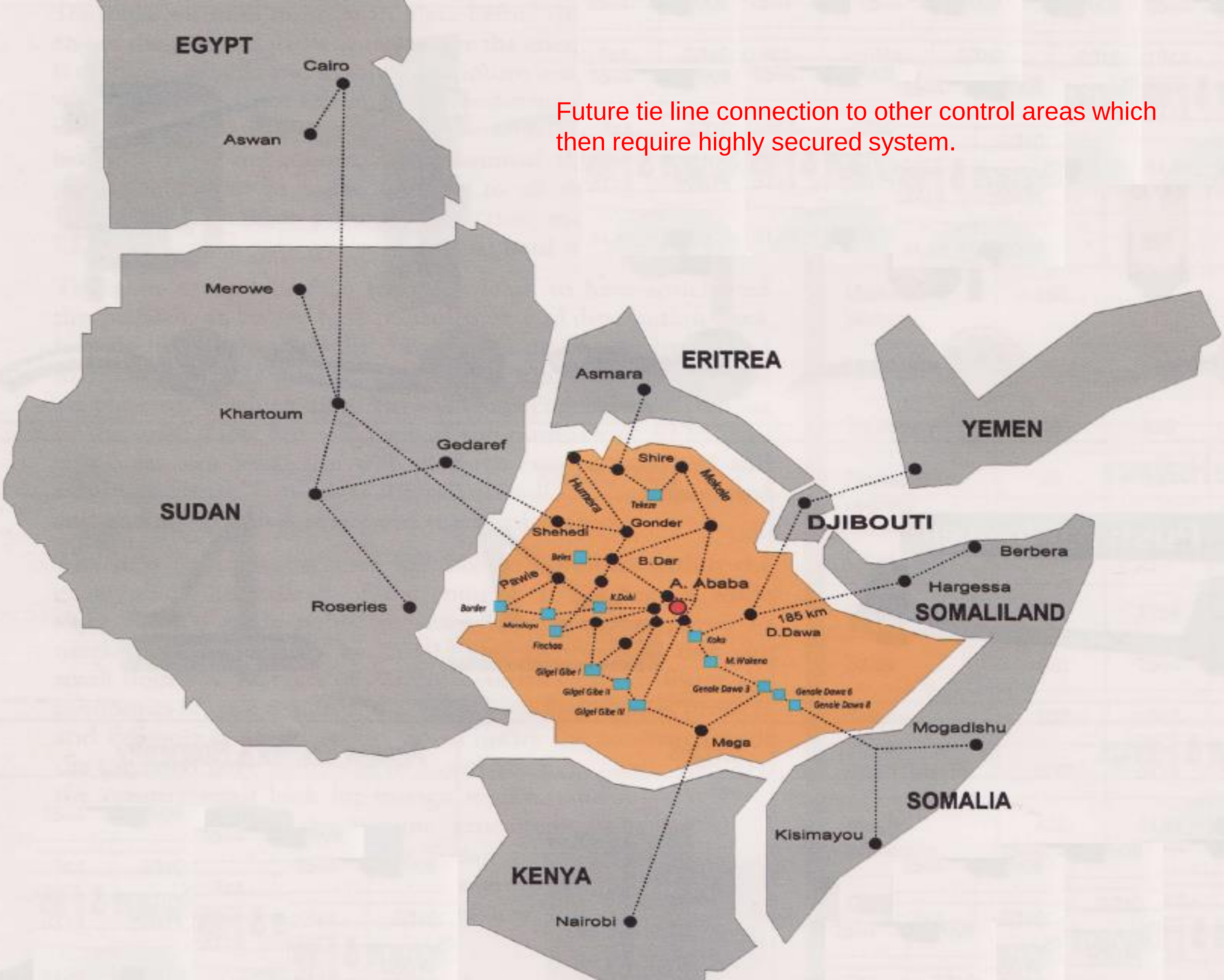
3.4 OPTIMAL POWER FLOW ANALYSIS TOOLS

- There are various optimization methods have been proposed to solve the optimal power flow problem in iterative techniques, some of which are refinements on earlier methods. These include:
  - **Gradient descent method:** is a first-order optimization algorithm. To find a local minimum of a function using gradient descent, one takes steps proportional to the negative of the gradient (or of the approximate gradient) of the function at the current point.
  - **Newton's method:** is a method for finding successively better approximations to the zeroes (or roots) of a real-valued function.
  - **Linear programming methods:** is a technique for the optimization of a linear objective function, subject to linear equality and linear inequality constraints.
  - **Quadratic programming methods:** is a special type of mathematical optimization problem. It is the problem of optimizing (minimizing or maximizing) a quadratic function of several variables subject to linear constraints on these variables.
  - **Interior point method:** are a certain class of algorithms to solve linear and nonlinear convex optimization problems.

3.5 SECURITY CONSTRAINED OPF

- So far we have been primarily concerned with the economical operation of a power system. An equally important factor in the operation of a power system is the desire to maintain system security.
- Security of supply is a measure of the power system's capacity to continue operating within defined technical limits even in the event of the disconnection of a major power system element such as an interconnector or large generator or any piece of equipment in the system due to either internal or external causes such as lightning strikes, objects hitting transmission towers, or human errors in setting relays.
- Reliability is a measure of the power system's capacity to continue to supply sufficient power to satisfy customer demand, allowing for the loss of generation capacity.
- Hence, the EMS has to operate the system at minimum cost, with the guaranteed alleviation of emergency conditions such as violations of operating limits, contingencies.

Future tie line connection to other control areas which then require highly secured system.



- System security can be said to comprise three major functions that are carried out in an energy control center:
  - **System monitoring**: supplies the power system operators with pertinent up-to-date information on the conditions of the power system. Telemetry systems measure and transmit the data, and then digital computers in a control center process and inform the operators in case of an overload or out of limit.
  - **Contingency analysis**: this model possible system troubles (outages) before they occur i.e, it carries out emergency identification and "what if" simulation. This allows the system operators to locate defensive operating states where no single contingency event will generate overloads and/or voltage violations.
  - **Corrective action analysis**: permits the operator to change the operation of the power system if a contingency analysis program predicts a serious problem in the event of the occurrence of a certain outage. Thus, this provides preventive and post-contingency control.

SECURITY ASSESSMENT: CONTINGENCY ANALYSIS

- The evaluation of the security degree of a power system is a crucial problem, both in planning and in daily operation. Without considering dynamic issues, power system security must be interpreted as security against a series of previously defined contingencies, therefore, the concept of security and its quantification are conditioned.
- Operations personnel must know which line or generation outages will cause flows or voltages to fall outside limits. To predict the effects of outages, contingency analysis techniques are used.
- Security assessment or Contingency analysis procedures model single failure events (i.e., one-line outage or one-generator outage) or multiple equipment failure events (i.e., two transmission lines, one transmission line plus one generator, etc.), one after another in sequence until "all credible outages" have been studied. For each outage tested, the contingency analysis procedure checks all lines and voltages in the network against their respective limits.

A. CONTINGENCY DEFINITION:- the list of contingencies to be processed whose probability of occurrence is high.

- The question is how to select the contingencies to analyze in detail in such a way that none of the problematic ones would be left unattended, also taking into account the required speed of response imposed by real time operation.
- One way to gain speed of solution in a contingency analysis procedure is to use an approximate model of the power system. For many systems, the use of linear sensitivity method which shows the approximate change in line flows for changes in generation on the network configuration /derived from the DC load flow method/ provides adequate capability. However, the limitation attributed to the DC power flow is that only branch MW flows are calculated and there is no knowledge of MVAR flows or bus voltage magnitudes.

- The linear sensitivity factors are basically two types:
  - Generation shift factors – change in line flow (Δf_l) due to generation outage (ΔP_i) $a_{l,i} = \frac{\Delta f_l}{\Delta P_i}$
  - Line outage distribution factors - change in line flow (Δf_l) due to line outage (f_k) $d_{l,k} = \frac{\Delta f_l}{f_k^{\,o}}$
- The flow on line *l*, under the assumption that all the generators in the interconnection participate in making up the loss, use the following

$$f_l^{'} = f_l^{0} + a_{li}\Delta P_i - \sum_{j \neq i}[a_{lj}\gamma_{ji}\Delta P_j] \text{ where } \gamma_{ji} \text{ is proportionality factor for pickup on generating unit j when unit i fails}$$

- The power flow on line *l* with line *k* out can be determined using '*d*' factors $f_l^{'} = f_l^{o} + d_{l,k} f_k^{o}$ where f^{o} are preoutage flows on lines

B. CONTINGENCY SELECTION: – these contingencies are ranked in rough order of severity employing contingency selection algorithms to shorten the list.

- The idea of performance index seems to fulfill this need. The definition for the overload performance index (PI) is as follows:

$$PI = \sum_{\substack{\text{all branches} \\ l}} \left(\frac{P_{flowl}}{P_l^{\max}} \right)^{2n}$$

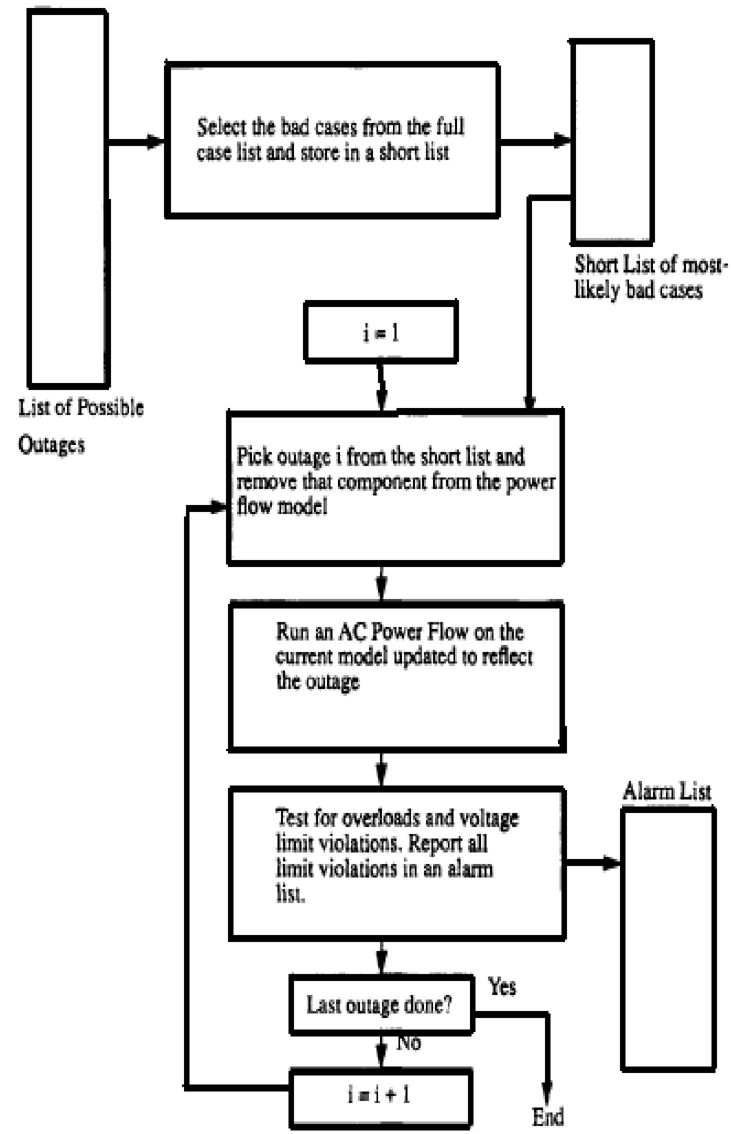
- The selection procedure then involves ordering the PI table from largest value to least. The lines corresponding to the top of the list are then candidates for the short list.

- One way to perform an outage case selection is to perform what has been called 1P1Q method. Here, a decoupled power flow is used to determine power flow through the lines and voltage at the nodes. Thus, a different PI can be used,

$$PI = \sum_{\substack{\text{all branches} \\ l}} \left(\frac{P_{flowl}}{P_l^{\max}} \right)^{2n} + \sum_{\substack{\text{all branches} \\ \text{i}}} \left(\frac{|V_i| P_{flowl}}{|V_i|^{\max}} \right)^{2m}$$

C. CONTINGENCY EVALUATION:– is then performed on the successive individual cases in decreasing order of severity. There are many power systems where voltage magnitudes are the critical factor in assessing contingencies. Hence, detail AC analysis on overloads and voltage limit violations are important.

- When an AC power flow is to be used to study each contingency case, the speed of solution and number of cases to be studied are critical. To alleviate this problem, on the selected contingencies, AC analysis will be performed. A flow chart for a process like this appears in figure below.



3.5.3 OPERATING STATES:

- The correct comprehension of the role played by the different activities involved in the system operation implies classifying of the possible system states as a function of the security degree. There are four different states:

   i. **Normal state** – all the system variables are within the normal range and no equipment is being overloaded. The system operates in a secure manner and is able to withstand a contingency without violating any of the constraints.

   ii. **Alert state** – all system variables are still within the acceptable range and all constraints are satisfied. However, the system has been weakened to a level where a contingency may cause an overloading of equipment that places the system in an emergency state. If the disturbance is very severe, the in extremis state may result directly from the alert state.

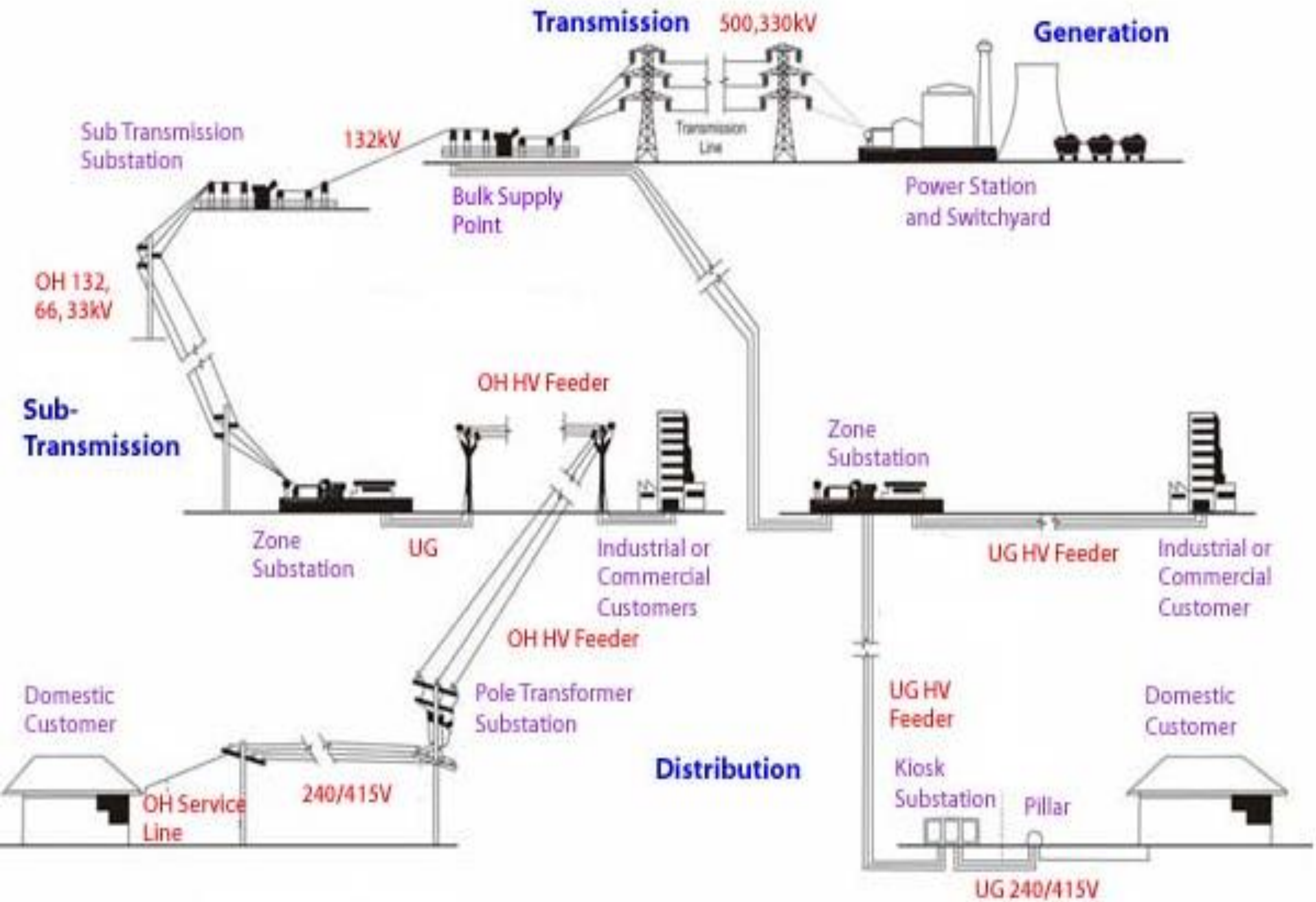
iii. **Emergency state:** – if a sufficiently sever disturbance occurs when the system is in the alert state. In this state, voltages at many buses are low and/or equipment loadings exceed short-term emergency ratings. The system is still intact and may be restored to alert state by the initiating of emergency control

iv. **Extremis:** - if measures taken are not effective, the result is cascading outages and possibly a shut-down of a major portion of the system. Control actions, such as load shedding and controlled system separation, are aimed at saving as much of the system as possible from a widespread blackout.

v. **Restorative state: -** represents a condition in which control action is being taken to reconnect all the facilities and to restore system load. The system transits from this state to either the alert state or the normal state, depending on the conditions.

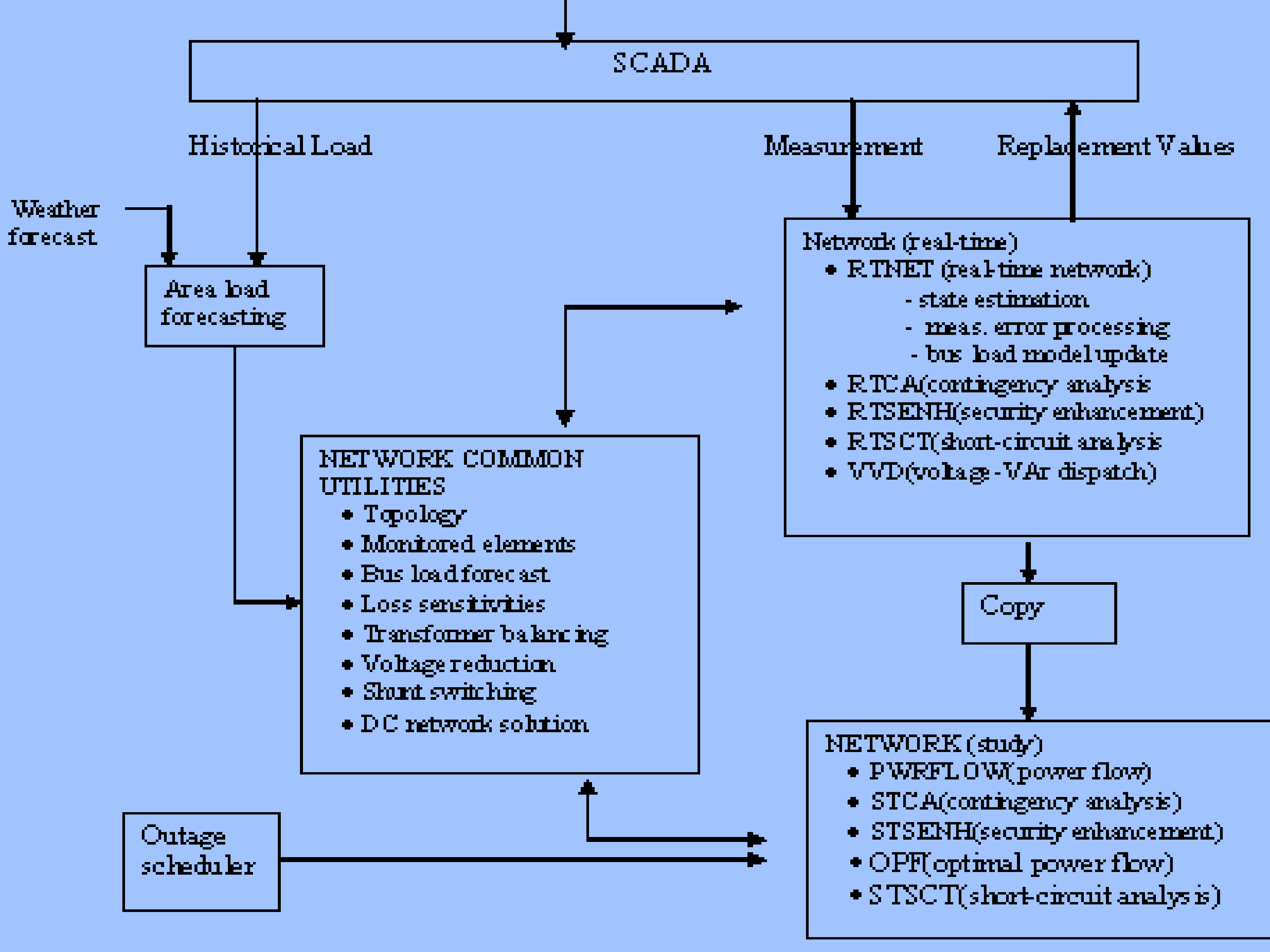
COMPUTER CONTROL OF POWER SYSTEM

- The ability to perform operations at an unattended location from an attended station or operating center and to have a definite indication that the operations have been successfully carried out can provide significant cost savings in the operation of a power system.
- Devices to control equipment remotely have been used for many years, and the need for remote indication as well as control led to the development of equipment that could perform the operations, monitor them, and report back to the control center that the desired control action had been satisfactorily affected. At the same time it is often important to transmit such information as loads and bus voltages to an operating center.


Transmission
500,330kV
Generation
Transmission Line
Sub Transmission Substation
132kV
Bulk Supply Point
Power Station and Switchyard
OH 132, 66, 33kV
Sub-Transmission
OH HV Feeder
Zone Substation
Zone Substation
UG
Industrial or Commercial Customers
UG HV Feeder
Industrial or Commercial Customer
OH HV Feeder
Pole Transformer Substation
Domestic Customer
UG HV Feeder
Domestic Customer
Distribution
Kiosk Substation
Pillar
OH Service Line
240/415V
UG 240/415V

4.1 SUPERVISORY CONTROL AND DATA AQUSITION /SCADA/

- Supervisory control: is the SCADA function used to control commands to field equipment (digital devices, set points) under the supervision of the RTUs, from the operator or from another application, through a user-callable Application Programming Interface (API).
- This allows to operate
  - two state devices, such as switching devices, with associated open/close commands
  - adjustable devises such as transformer tap changer with associated raise/lower commands
  - power units with set points, with interfacing with the AGC function


SCADA
Historical Load
Measurement
Replacement Values
Weather forecast
Area load forecasting
Network (real-time)
• RTNET (real-time network)
- state estimation
- meas. error processing
- bus load model update
• RTCA(contingency analysis
• RTSENH(security enhancement)
• RTSCT(short-circuit analysis
• VVD(voltage-VAr dispatch)
NETWORK COMMON UTILITIES
• Topology
• Monitored elements
• Bus load forecast
• Loss sensitivities
• Transformer balancing
• Voltage reduction
• Shunt switching
• DC network solution
Copy
NETWORK (study)
• PWRFLOW(power flow)
• STCA(contingency analysis)
• STSENH(security enhancement)
• OPF(optimal power flow)
• STSCT(short-circuit analysis)
Outage scheduler

- Almost all modern dispatch and operating centers of power systems are now provided with at least some SCADA system equipment.
- SCADA equipment has proven to be efficient and economical for power system operations. It is a very effective aid for station operators, making it possible for them to maintain relatively complete knowledge of conditions on the portions of the system for which they are responsible.
- The term Supervisory Control is normally applied to remote operation(control) of such devices as motors or circuit breakers, and the signalling back (supervision) to indicate that the desired operation actually has been affected where as Data Acquisition means data is collected from RTUs, substation and power plant's digital control system, other control centers, manual entries, automatic calculations, and any data from other applications.

Supervisory master units: is the heart of the system. All operator initiated operations of an RTU are made through the master unit and are reported back to the master from the RTUs. Modern supervisory master units consist of a digital computer and equipment to permit communications between the master and the RTUs.

- In addition to computer, peripheral equipment necessary for the proper operation of the system is provided. Such equipment consists of
  1. control console
  2. keyboards or other means of entering data and commands into the computer
  3. CRTs or monitors
  4. Printer to provide the operator at the master station with written messages of actions performed by the master and of data obtained from RTUs.
  5. Digital-to-Analogue converters to convert the digital data message information (on such items as line current, bus voltage, frequency, power, and reactive power flow) to analogue form that can be used to supply indicating or recording instruments.

Remote terminal units: are located at selected stations, ad are either wired to perform certain preselected functions or, in modern units, equipped with microcomputers which have memory and logic capabilities.

- The RTUs are also equipped with modems so that they can accept messages from the master and signal back to the master that messages have been received and the desired operations performed.
- Transducers in the remote units are used to convert such quantities as voltage, current, watts and vars to direct current or voltage proportional to the measured quantity, and then by means of analogue-to-digital converters convert the quantity to digital form, used by the system for transmission from the remote to the master.

SCADA system applications: in addition to the remote supervisory control, status monitoring, various other programs can be incorporated in such systems to improve operations and minimize the manual effort required of power system operators. Some of these are

a) Automatic generation control:- control systems that are responsive to frequency variations, cost factors, transmission losses, etc

b) Security monitoring:- checking the limits of loading and other quantities in order to determine whether the system is at or near at alert or emergency state.

c) Online load flow:- when sufficient information is telemetered to the master unit, a load flow program can be developed to predict loading of lines and stations under selected future conditions using actual operating data.

➔The reliability of a SCADA system is very important, and several means are used to ensure maximum reliability for such system. Most master units are dual computers, with one as a primary unit and the other on standby to take immediate control, usually automatically, if primary unit should fail.

4.2 AUTOMATIC LOAD DISPATCHING

- The Load Dispatch Department is the nerve centre for the operation, planning, monitoring and control of the power system. Electricity cannot be stored and has to be produced when it is needed. It is therefore essential that power system is planned and operated optimally & economically. This is the main objective of Load Dispatch Centre.

Major Functions of Load Dispatch Center:

- To ensure integrated operation of the power system.
- To give directions and exercise supervision and control which is required for integrated operation to achieve maximum economy and efficiency in power system operation.
- Scheduling and Re-Scheduling of available resources for optimum and economic operation of the power system.
- To coordinate shutdowns for the Generating Units and Sub-station equipment, including transmission lines taking into consideration continuity of supply with quality.
- System Restoration in a systematic manner in shortest possible duration, following Grid Disturbances.
- Accounting of Energy handled by the State System.
- Compiling & Furnishing data pertaining to Power System Operation.

THANK YOU

GOKARAJU RANGARAJU INSTITUTE OF ENGINEERING AND TECHNOLOGY
(Autonomous)
Department of Electrical and Electronics Engineering

Academic Year: **2022-23** Year: **IV** Semester: **I**	**MID Exam – I (Descriptive)** **POWER SYSTEMS-III** **GR18A4012**	Date: 05/09/2022 Duration: **90 min** Max Marks: **15**

Note: Answer any THREE questions. All questions carry equal marks.

1.	Explain the each unit in Speed Governing System with a neat diagram.	BL2	CO1
2.	Write a short notes on I. Tap-changing Transformers II. Automatic Voltage regulators	BL3	CO2
3.	a. What is the importance of Tie Line Power Sharing for Multi Area Power System. b. Write a short notes on inequality constraints with equations.	BL2	CO1
4.	Explain how power flow control happens using embedded dc links and phase-shifters for a reactive power compensation.	BL5	CO2

Academic Year: **2022-23** Year: **IV** Semester: **I**	**MID Exam – I (Objective)** **POWER SYSTEMS-III** **GR18A4012**	Date: 05/09/2022 Duration: **10 min** Max Marks: **5M**

GOKARAJU RANGARAJU INSTITUTE OF ENGINEERING AND TECHNOLOGY
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Department of Electrical and Electronics Engineering

Roll No: | | | | | | | | | | |

Note: Answer ALL questions. All questions carry equal marks.

Question No.	Unit	Option	Blooms Levels*	Course Outcome
1	Energy Management system involves (a)Monitoring (b)controlling (c) coordinating (d) all the above	[ ]	BL1 & BL2	CO1
2	Data acquisition and remote control is performed by (a)EMS (b)SCADA (c) Load Management (d) all the above	[ ]	BL1 & BL2	CO1
3	In Speed Governing System, _____ is regarded as heart of the system (a)Speed Governor (b)Turbine Generator (c) Speed changer (d) Hydraulic Amplifier	[ ]	BL1 & BL2	CO1
4	Load side management is also called as (a)Energy Management System (b)SCADA (c) Demand side Management (d) all the above	[ ]	BL1 & BL2	CO1
5	Excitation systems can be classified as (a)AC Excitation system(b) DC Excitation system (c) Static Excitation system (d) all the above	[ ]	BL3 & BL4	CO1
6	STATCOM mainly used to (a) control Bus voltage (b) eliminate harmonics ,works as a active filter (c) controls active & reactive power(d)all the above	[ ]	BL3 & BL4	CO2
7	TSC and TCR generalized form (a) STATCOM (b) SVC (c) UPSC (d)all	[ ]	BL3 & BL4	CO2
8	The common sources of reactive power are (a)synchro condensers (b)tap changing transformer (c) regulating Transformer (d)All the above	[ ]	BL3 & BL4	CO2
9	SVC is mainly used to (a) control Bus voltage (b) eliminate harmonics (c) controls reactive power(d)all	[ ]	BL3 & BL4	CO2
10	SVC comprised of two different elements (a)TSC (b)TCR (c) TCSR (d) both a & b	[ ]	BL3 & BL4	CO2

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Department of Electrical and Electronics Engineering

Academic Year: **2022-23**	**MID Exam – II (Descriptive)**	Date: 14/11/2022
Year: **IV**	**POWER SYSTEMS-III**	Duration: **90 min**
Semester: **I**	**GR18A4012**	Max Marks: **15**

Note: Answer any THREE questions. All questions carry equal marks.

1.	Explain about various electricity market models with a neat block diagram.	BL2	CO4
2.	Write a short note on I. SCADA II. Synchro Phasors	BL3	CO3
3.	a. List the applications of PMU. b. What are the functions of Electric Utility.	BL2	CO3
4.	Briefly explain Demand Side Management.	BL5	CO5

Academic Year: **2022-23**	**MID Exam – II (Objective)**	Date: 14/11/2022
Year: **IV**	**POWER SYSTEMS-III**	Duration: **10 min**
Semester: **I**	**GR18A4012**	Max Marks: **5M**

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Roll No: | | | | | | | | | | |

Note: Answer ALL questions. All questions carry equal marks.

Question No.	Unit	Option	Blooms Levels*	Course Outcome
1	PMUs provide up to _____ measurements per second (a) 6 (b) 60 (c) 24 (d) 16	[ ]	BL1 & BL2	CO1
2	The fuel cost curve specifies (a)the cost of fuel used per hour (b) the cost of fuel used per min (c) heat cost (d)None	[ ]	BL1 & BL2	CO1
3	Ancillary services include (a)scheduling and dispatch (b)frequency regulation (c)voltage control (d)all	[ ]	BL1 & BL2	CO1
4	PDC abbreviates (a)Phasor Data Collector (b)Phasor Data Concentrator (c) Power Data concentrator (d) Power Data Collector	[ ]	BL1 & BL2	CO1
5	Synchro phasors are measured with (a)PMUs (b)RTUs (c) WAMs (d) SCADA	[ ]	BL3 & BL4	CO1
6	PMU data is time-stamped using (a) previous collected data (b) programmed data (c) GPS data (d)forecasted data	[ ]	BL3 & BL4	CO2
7	Spot pricing of electricity, whereby prices (a) follows constant rise (b) change from moment to moment (c) both (d) None	[ ]	BL3 & BL4	CO2
8	The Wide Area Monitoring Systems gives control of (a) transmission and distribution networks (b) transmission networks (c) distribution networks (d) Generation and Transmission networks	[ ]	BL3 & BL4	CO2
9	Energy delivery charges include two components (a) transmission and distribution charges (b) generation and transmission charges (c) all (d) None	[ ]	BL3 & BL4	CO2
10	Synchro-phasors indicates (a)Magnitude (b)phase angle (c) both a&b (d) it does not deal magnitude	[ ]	BL3 & BL4	CO2

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Department of Electrical and Electronics Engineering

POWER SYSTEMS-III

Assignment-1

1. What is the necessity to maintain frequency constant? Give reasons.
2. Explain the each unit in Speed Governing System with a neat diagram.
3. Write short notes on inequality constraints with equations.
4. Derive Single Area Power System Transfer Function representations.
5. What is the importance of?
    a. Tie Line Power Sharing for Multi Area Power System
    b. AGC Control

Nikhila Varma
19241A0268
IV-I EEE-B

POWER SYSTEMS- III

ASSIGNMENT -1

1. What is the necessity to maintain frequency constant? Give reasons.

- Maintaining a constant electrical frequency is important because multiple frequencies cannot operate alongside each other without damaging equipment.
- Interconnected grid systems consists of two or more grids which operate in synchronism. When frequency of one grid changes, there will be no synchronism and it falls out from the grid system leading to blackout.
- The alternators and turbines in power plants are designed to operate at particular frequency. Duration of frequency beyond this band may cause gradual or immediate turbine damage.
- Any electrical equipment should be operated at rated voltage and frequency. If it is operated at different frequencies, it works ineffectively due to the variations in characteristics. This increases the chances of loads getting damaged.
- The power operation at a lower frequency than that specified maximum permissable change in frequency (0.5Hz) affects the

quality of power supply and is not allowed because:

→ Some type of steam turbines undergo excessive vibration in certain turbine rotor status resulting in metal fatigue and blade failure

→ It reduces the efficiency of auxiliary mechanisms of thermal power stations, especially feed pumps. the result of prolonged operation at lower frequency is a drop in generator output and further loss of power.

→ As frequency decreases, the generator exciters lose their speed and the generator EMF falls, the voltage in the power system unit drops. This brings the danger of a voltage avalanche.

2. Draw neatly the speed governance system. Explain each term.

The speed governance system is the main tool for load frequency control, whether the machine is used alone to feed a smaller system or whether it is a part of a more elaborate system.

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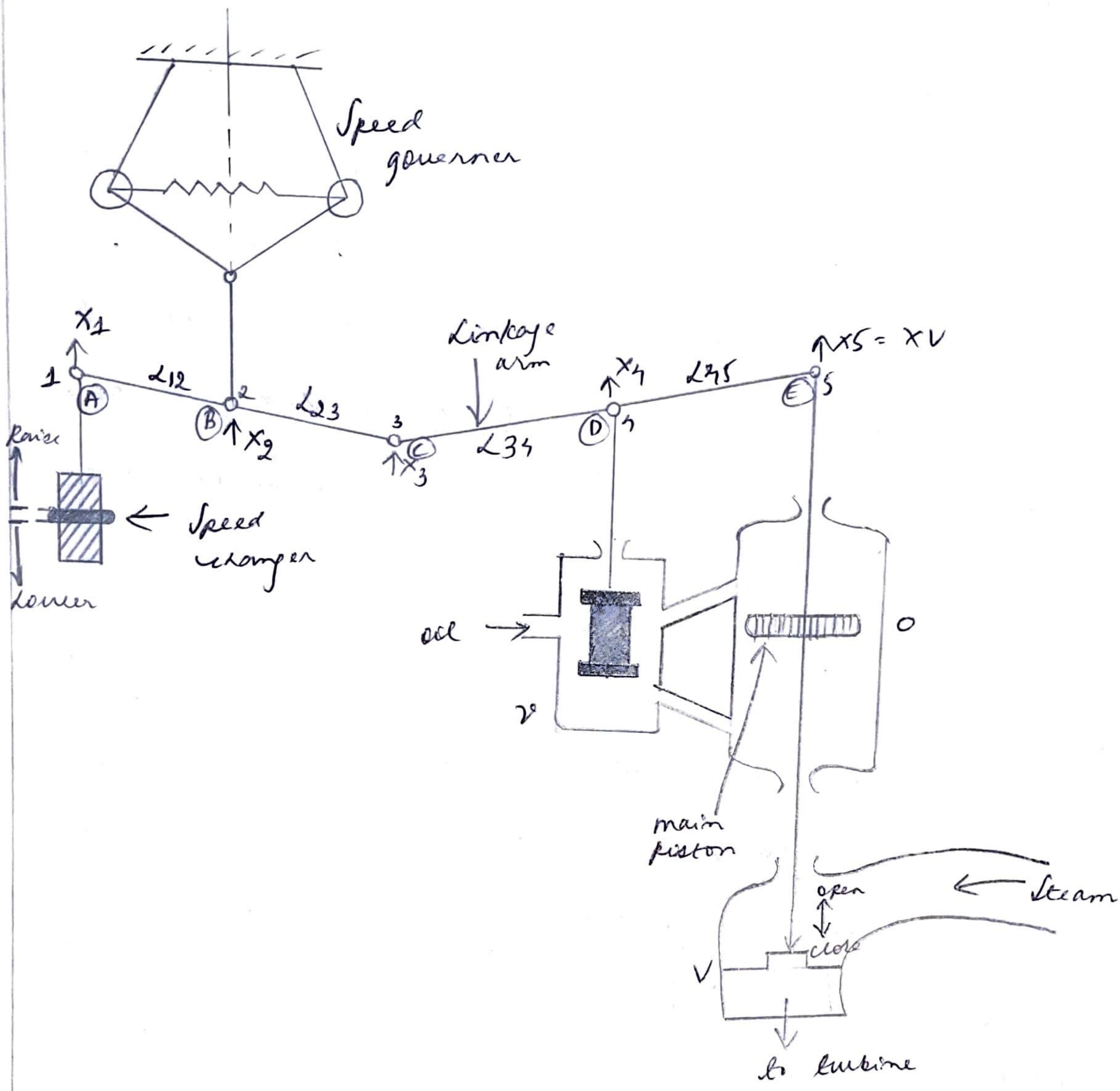

i) Centrifugal governer or speed governer:

It is a purely mechanical speed sensitive device coupled directly to and built directly on the prime mover to adjust the control value opening via the linkage system.

For example, with the increased speed, the flyballs move outwards and point 2 moves upwards and the reverse

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happens with decreased speed.

ii) Hydraulic amplifier :

It consists of pilot valve 'V' and oil servometer 'O'. With this arrangement hydraulic amplification is achieved, i.e., a lower power pilot valve movement is converted into high power level movement of oil servometer piston. Hydraulic amplification is necessary so that the steam valve could be operated against high pressure steam.

iii) Speed changer :

It makes it possible to restore the frequency to the initial value after operation of the speed governer having a steady state characteristics. Further, it provides a steady state power output setting for the turbine.

iv) Linkage mechanism:

123 is a rigid link pivoted at point 2 and 345 is another rigid link pivoteds at point 4. The function of this link mechanism is to control the steam valve V.

Only one valve V is shown in the figure, but actually steam turbines have a number of them which are opened in succession with as small an overlap as possible in order to maintain high efficiency. Via link 45, we also get feedback from V.

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3. Derive single area power system transfer function representations.

Model of speed governing system:

Assume that the system is initially operating under steady state conditions - the linkage mechanism stationary and pilot valve closed, steam valve opened by a definite magnitude, turbine running at constant speed with turbine power output balancing the generator load. Let the operating conditions be characterized by:

f° = system frequency (speed)

P_G° = generator output = turbine output (neglecting generator loss)

y_E° = steam valve setting.

Let the point A on the linkage mechanism be moved downwards by a small amount Δy_A. It is a command which causes the turbine power output to change and can therefore be written as

$$\Delta y_A = k_c \Delta P_c$$

where ΔP_c is commanded increase in power.

The command signal ΔP_C (i.e., Δy_E) sets into motion a sequence of events - the pilot valve moves upwards, high pressure oil flows on the top of the main piston moving it downwards; the steam valve

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opening consequently increases, the turbine generator speed increases, i.e; frequency goes up.

Mathematically, two events contribute to the movement of C:

i) Δy_A contributes : $(l_2/l_1)\, \Delta y_A$ or $-k_1\, \Delta y_A$ (i.e., upwards)

of $-k_1 k_c \Delta P_c$

ii) Increase in frequency Δf causes the fly balls to move outwards so that B moves downwards by a proportional amount $k_2' \Delta f$.

The consequent movement of C with A remaining fixed at Δy_A is $(l_1 + l_2/l_1)\, k_2' \Delta f = k_2 \Delta f$. (i.e, downwards)

The net movement of C is therefore

$$\Delta y_C = -k_1 k_c \Delta P_c + k_2 \Delta f \quad \text{— (1)}$$

The movement of D, Δy_D is the amount by which the pilot value opens. It is contributed by Δy_C and Δy_E and written as

$$\Delta y_D = \left[\frac{l_4}{l_3 + l_4}\right] \Delta y_C + \left[\frac{l_3}{l_4 + l_3}\right] \Delta y_E \, .$$

$$\Delta y_D = k_3 \Delta y_C + k_4 \Delta y_E \quad \text{— (2)}$$

The movement Δy_D depending upon its sign opens one of the ports of the pilot value admitting high pressure oil into the cylinder

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thereby moving the main piston and opening the steam valve by Δy_E.

The volume of oil admitted to the cylinder is thus proportional to the time integral of Δy_D. The movement Δy_E is obtained by dividing the oil volume by the area of the cross-section of the piston.

Thus, $\Delta y_E = k_5 \int_0^t (-\Delta y_D)\, dt$ — ③

Taking laplace transforms on equations ①, ② and ③ we get

$$\Delta Y_C(s) = -k_1 k_c \Delta P_c(s) + k_2 \Delta F(s)$$

$$\Delta Y_D(s) = k_3 \Delta Y_c(s) + k_4 \Delta Y_E(s)$$

$$\Delta Y_E(s) = -k_5 \frac{1}{s} \Delta Y_D(s).$$

eliminating $\Delta Y_C(s)$ and $\Delta Y_D(s)$, we get

$$\Delta Y_E(s) = \frac{k_1 k_3 k_c \Delta P_c(s) - k_2 k_3 \Delta F(s)}{k_4 + \frac{s}{k_5}}$$

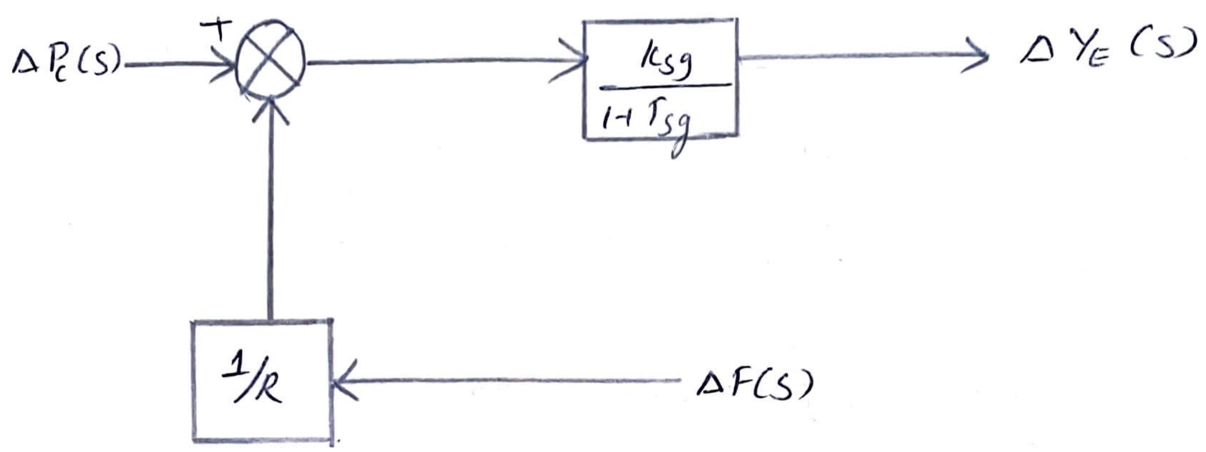
$$= \left[\Delta P_c(s) - \frac{1}{R} \Delta F(s)\right]\left[\frac{k_{sg}}{1 + T_{sg} s}\right]$$

where; $R = k_1 k_c / k_2$ = speed regulation of governer

$k_{sg} = k_1 k_3 k_c / k_4$: gain of speed governer

$T_{sg} = 1/k_4 k_5$ = time constant of speed governer

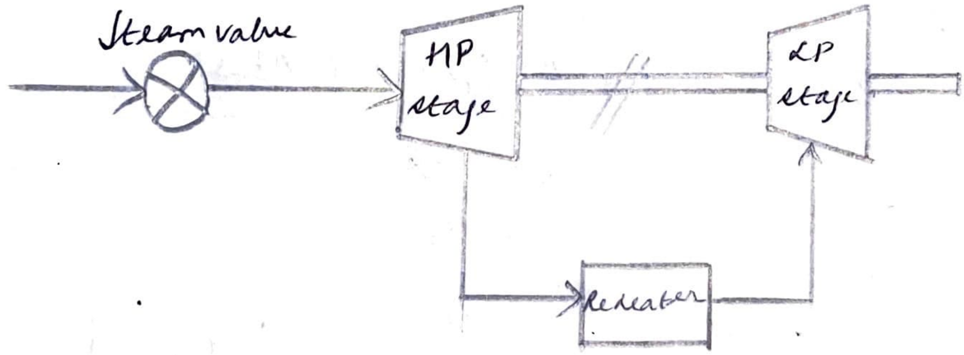
Block diagram representation of speed governer can be given as:



Turbine model:

Relating the dynamic response of a steam turbine in terms of changes in power output to changes in steam valve opening ΔY_E.

A two stage steam turbine with a reheat unit is given as:



The dynamic response is largely influenced by two factors:

i) entrained steam between the inlet steam valve and first stage of turbine

ii) the storage action in the reheater which causes the output of the low pressure stage to lag behind that of the high pressure stage. Thus, the turbine transfer function is characterized by two time constants. For ease of analysis it will be assumed here that the turbine can be modelled to have a single equivalent time constant. Typically time constant T_t lies in the range of 0.2 to 2.5 secs.

Transfer function model of steam turbine:

$$\Delta Y_E(s) \longrightarrow \boxed{\frac{K_t}{1 + T_t(s)}} \longrightarrow \Delta P_t(s)$$

Generator load model:

The increment in power input to the generator load system is $\Delta P_G - \Delta P_D$.

where, $\Delta P_G = \Delta P_t$ incremental turbine power output

ΔP_D is the load increment.

This increment in power input to the system is accounted for in two ways:

i) Rate of increase of stored kinetic energy in the generator rotor. At scheduled frequency, f°, stored energy is

$$W^{\circ}_{ke} = H \times P_r \text{ kW}$$

where, P_r is the kW rating of the turbo-generator

H is its inertia constant

The kinetic energy being proportional to the square of speed (frequency), the kinetic energy at a frequency $(f^\circ + \Delta f)$ is given by

$$W_{ke} = W^\circ_{ke} \left[\frac{f^\circ + \Delta f}{f^\circ}\right]^2$$

$$= HP_r \left[1 + \frac{2\Delta f}{f^\circ}\right]$$

Rate of change of kinetic energy is therefore,

$$\frac{d}{dt}(W_{ke}) = \frac{2HP_r}{f^\circ}\frac{d}{dt}(\Delta f)$$

ii) As the frequency changes, the motor load changes being sensitive to speed, the rate of change of load with respect to frequency, i.e., $\delta P_D / \delta f$ can be regarded as nearly constant for small changes in frequency Δf and can be expressed as:

$$(\partial P_D / \partial f)\Delta f = B \Delta f.$$

where the constant B can be determined empirically.

B is positive for a motor load.

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Writing the power balance equation, we have

$$\Delta P_G - \Delta P_D = \frac{2HP_r}{f^\circ} \frac{d}{dt}(\Delta f) + B\Delta f$$

Dividing throughout by P_r and rearranging, we get

$$\Delta P_G(pu) - \Delta P_D(pu) = \frac{2H}{f^\circ} \frac{d}{dt}(\Delta f) + B(pu)\,\Delta f$$

Taking laplace transform, we can write $\Delta F(s)$ as

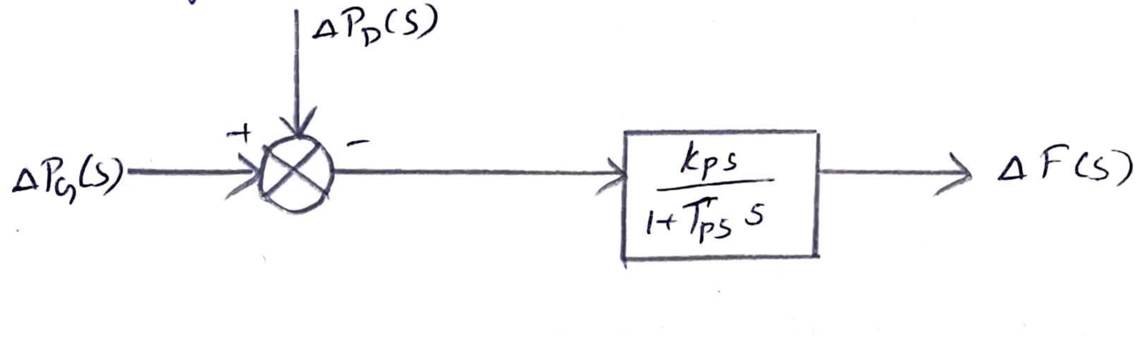
$$\Delta F(s) = \frac{\Delta P_G(s) - \Delta P_D(s)}{B + \frac{2H}{f^\circ} s}$$

$$= \left[\Delta P_G(s) - \Delta P_D(s)\right] \times \left[\frac{K_{ps}}{1 + T_{ps} s}\right]$$

where, $K_{ps} = 1/B$ = power system gain

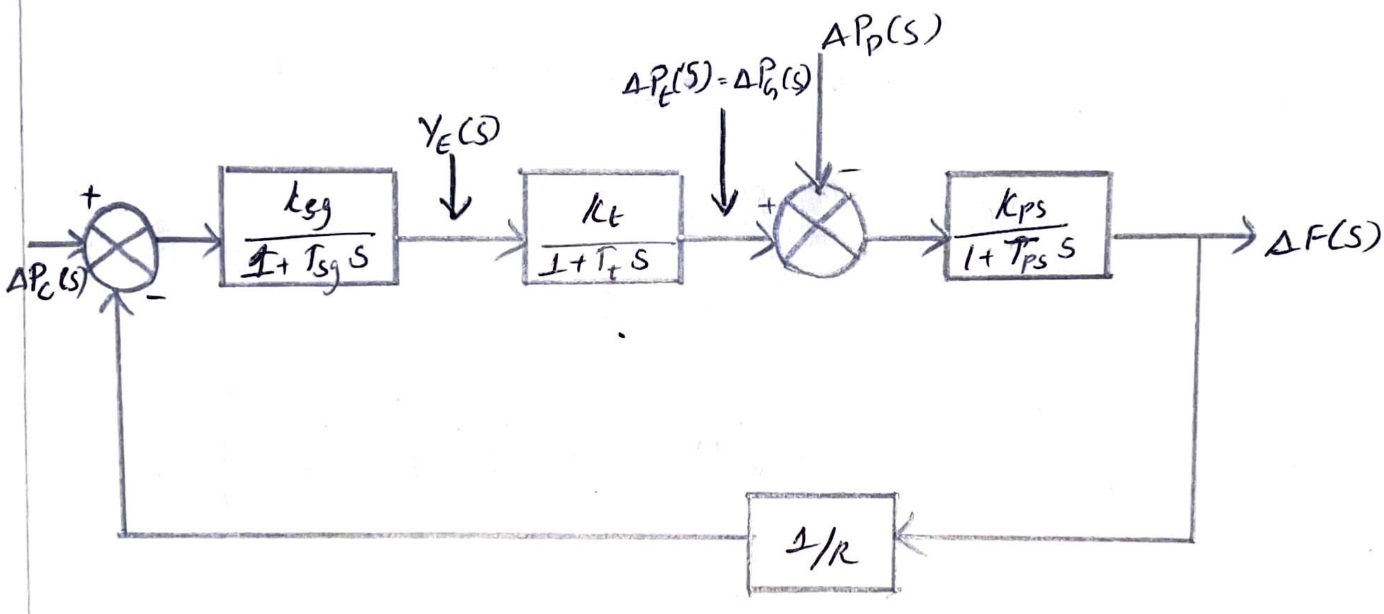
$T_{ps} = 2H/Bf^\circ$ = power system time constant.

Block diagram representation of generator-load model:



A complete block diagram representation of an isolated power system comprising turbine, generator, governer and load is easily obtained by combining individual components' block diagrams.

Hence, the block diagram for a single area power system load frequency control transfer function representation is given as:



4. What is the importance of

i) AGC control

ii) Tieline power sharing.

AGC control:

Automatic generation control (AGC) is a generator control system that adjusts the real power output of generators in response to control signals from the system operator's energy management system (EMS) within a time frame that is typically 2- 5 seconds.

The EMS monitors system frequency and sends signals to generators to adjust supply as needed to maintain the system frequency. Control signals are transmitted via telemetry to remote terminal units (RTU) at the generator. The RTUs convert the raise/lower megawatts (MW) into instructions to the generator governer, which results in change in the generator output power.

AGC is used to maintain acceptable frequency during normal operation due to fluctuations in load and variable resources, and as an early response to system contingencies such as the unexpected loss of a generator or a transmission line. AGC units are used to provide frequency response reserves.

Tie line power sharing:

Modern day power systems are divided into various areas. For examples, in India, there are five regional grids - eastern region, western region, etc. Each of these areas is generally interconnected to its neighbouring areas. The transmission lines the connects an area to its neighbouring area are called tie lines. Power sharing between two areas occurs through these tie-lines.

Power flow between different areas is regulated by holding frequency constant. All power station generators are kept in sync with each other. Small frequency deviations will result in automatic load shedding or other control actions to restore system frequency.

With a change in system frequency, there will be a change in speed of motors, change in magnetizing current will be there for transformers and induction motors will be affected with change in inductance. A huge increase will cause increase in harmonic currents and will cause heating of system and insulation failure.

The regulation mechanism is done by load frequency control. Here, tie lines, which allow bidirectional flow of power, are utilised.

5. Write a short note on inequality constraints.

In solving a constrained optimization problem, such as the ordinary power flow, there are two general classes of constraints, equality and inequality. Equality constraints are those that always have to be enforced. They are always binding. For example, in ordinary power flow, the real and reactive power balance equations at system buses must always be satisfied.

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In contrast, inequality constraints may or may not be binding. For example, a line MVA flow may or may not be at its limit, or a generator real power output may or may not be at its maximum limit.

The following classes of inequality constraints are enforced during the OPF solution:

i) Generator real power limits

ii) Generator reactive power limits

iii) Interface MW limits

iv) Transmission line MVA limits (branch)

v) Transformer (branch) MVA limits.

vi) Bus angle.

GOKARAJU RANGARAJU INSTITUTE OF ENGINEERING AND TECHNOLOGY
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Department of Electrical and Electronics Engineering

POWER SYSTEM-III

Assignment-2

1. Explain about excitation systems and how the control is related with synchronous generators.
2. List few points about the generation and absorption of reactive power of various component of power system.
3. Write a short notes on
    a. Static VAR Generators
    b. STATCOMS
    c. Tap-changing Transformers.
    d. Automatic Voltage regulators
4. Explain how power flow control happen using embedded dc links and phase-shifters for reactive power compensation.
5. Transfer Function representation and block diagram of Synchronous-generator exciter control.

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POWER SYSTEMS - III

ASSIGNMENT - 2

1. Explain about excitation system and how the control is related with synchronous generators?

Excitation system:

The system which is used for providing the necessary field current to the rotor winding of the synchronous machine, such type of system is called an excitation system.

It is a system which is used for the production of flux by passing current in the field winding. the main requirement of an excitation system is reliability under all conditions of service, a simplicity of control, ease of maintenance, stability and fast transient response.

The amount of excitation required depends on the load current, load power factor and speed of the machine. The more excitation is needed in the system when load current is large, the speed is less, and the power factor of the system becomes lagging.

The excitation system is a single unit in which each alternator has its exciter in the form of generator. The centralised excitation system has two or more exciters which feeds the bus bar. The centralised system is very cheap, but the fault in a system adversely effects the alternators in the power plant.

Excitation system for a synchronous generator:

→ To excite the field winding of the rotor of the synchronous machine, direct current is required.

→ DC is supplied to the rotor field of the small machine by a DC generator called exciter.

→ A small DC generator called pilot generator supplies the current to the exciter.

→ The exciter and the pilot exciter are both mounted on the main shaft of the synchronous motor or generator.

2. List few points about the generation and absorption of reactive power of various components of power systems.

Power system components which generate reactive power and/or absorb reactive power are:

→ Synchronous machine:

- An overexcited synchronous machine operated either as generator or motor generates kVAR and acts as a shunt capacitor as viewed from the network.

- An under-exited synchronous machine absorbs KVAR from the network and acts as a shunt reactor.

- Synchronous generators provide the cheapest means of reactive power supply or absorption.

- The KVAR required by a consumer are usually produced locally, either by static capacitor or by synchronous machine acting as motor, running idle or at increased excitation.

→ Shunt capacitor:

Apart from synchronous machines, static shunt capacitors offer the cheapest means of reactive power supply but they are not as flexible as synchronous condensers

→ Shunt reactors:

Shunt reactors offer the cheapest means of reactive power absorption and these are connected in the transmission line during light load conditions.

→ Overhead lines:

- Transmission lines can be considered as generating KVAR in their shunt capacitance and consuming KVAR in their series inductance.

- The inductive kVAR vary with the current which the line carries, whereas the capacitive kVAR vary with the system potential.

Let transmission line be loaded such that

load current - I amps

load voltage - V volts

Reactive power absorbed by the line:

$$\Delta Q_L = |I|^2 X_L = |I|^2 \omega_L$$

ω - angular frequency

L - inductance

Reactive power generated by the line,

$$\Delta Q_C = \frac{|V|^2}{X_C} = |V|^2 \omega C$$

C - shunt capacitance

In case, $\Delta Q_L > \Delta Q_C$, we find that voltage sags.

In this case, the line is said to have a light load condition. Under light load condition, the effect of shunt capacitance is predominating and line will generate reactive power.

In case, $\Delta Q_L < \Delta Q_C$, we find that voltage rises.

This means that net effect of the line will be to absorb reactive power.

→ Transformers:

Transformers always absorb reactive power.

If, X_T - transformer reactance per phase (Ω)

$|I|$ - current flowing through it (A)

then, total reactive power absorbed.

$$Q_T = 3|I|^2 X_T \text{ VAR}.$$

→ Cables:

Cables generate more reactive power than transmission lines because cables have high capacitance.

275 kV, 240 MVA cable produces 6 - 7.5 MVAR/km

132 kV cable produces 1.856 MVAR/km

33 kV cable produces 0.12 MVAR/km.

→ Loads:

- In planning a network it is desirable to assess the reactive power requirements to ascertain whether the generators are able to operate at the required power factor for the extremes of the loads to be expected.

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3. Write notes on the following with neat sketches:

i) Static VAR Generators:

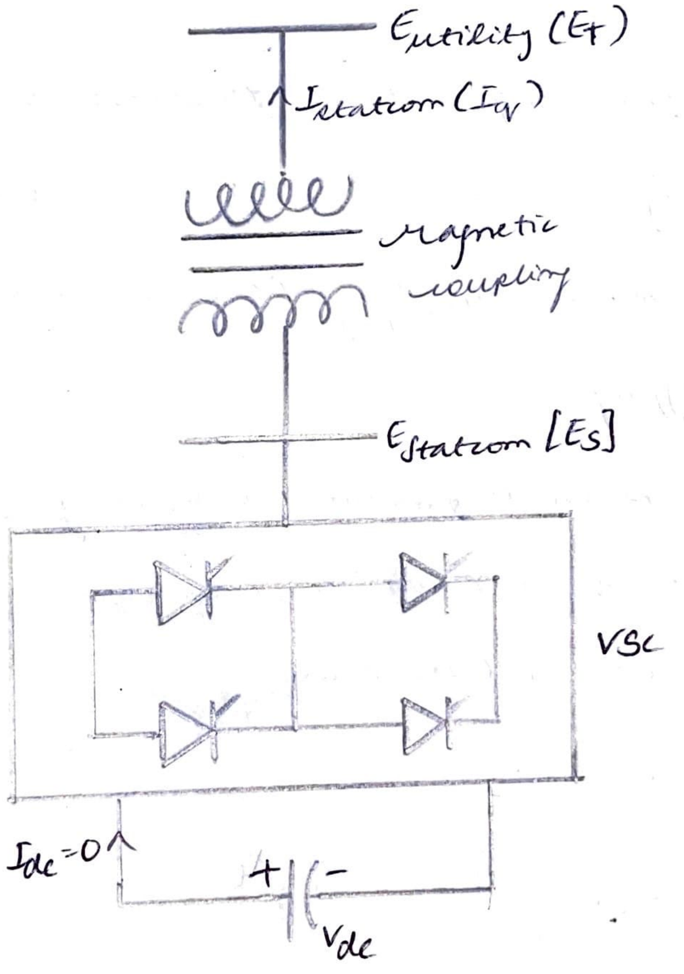
Static VAR Generator (SVG) is the new standard in reactive energy compensation. When the load is generating inductive or capacitive current, it makes load current lagging or leading the voltage.

SVG detects the phase angle difference and generator leading or lagging current into the grid, making the phase angle of current almost the same as that of voltage on the transformer side, which means fundamental power factor is unity.

features:
- It is modular in design. An SVG system consists of one or several SVG modules and an optimal liquid crystal monitor or control panel.
- Each SVG module is an independent reactive power compensation system. Users can change the SVG ratings by adding or removing SVG modules.
- SVG delivers real time inductive or capacitive reactive power compensation.
- It can rapidly and continuously compensate both inductive and capacitive reactive power, and current load imbalance.

ii) Statcoms: Static synchronous compensators

A static synchronous generator operated as shunt connected static VAR compensator whose capacitive or inductive output current can be controlled independent of the AC system voltage.



A VSC is connected to the utility bus through magnetic coupling which has an adjustable voltage source behind the reactance. This means that the capacitor banks and shunt reactors are not needed for reactive power generation and absorption, thereby giving STATCOM compact design, small foot print, low noise, and low magnetic impact

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The exchange of reactive power between the converter and AC system can be controlled by varying the amplitude of 3ϕ output voltage, E_s. If $E_s > E_t$, it supplies Q

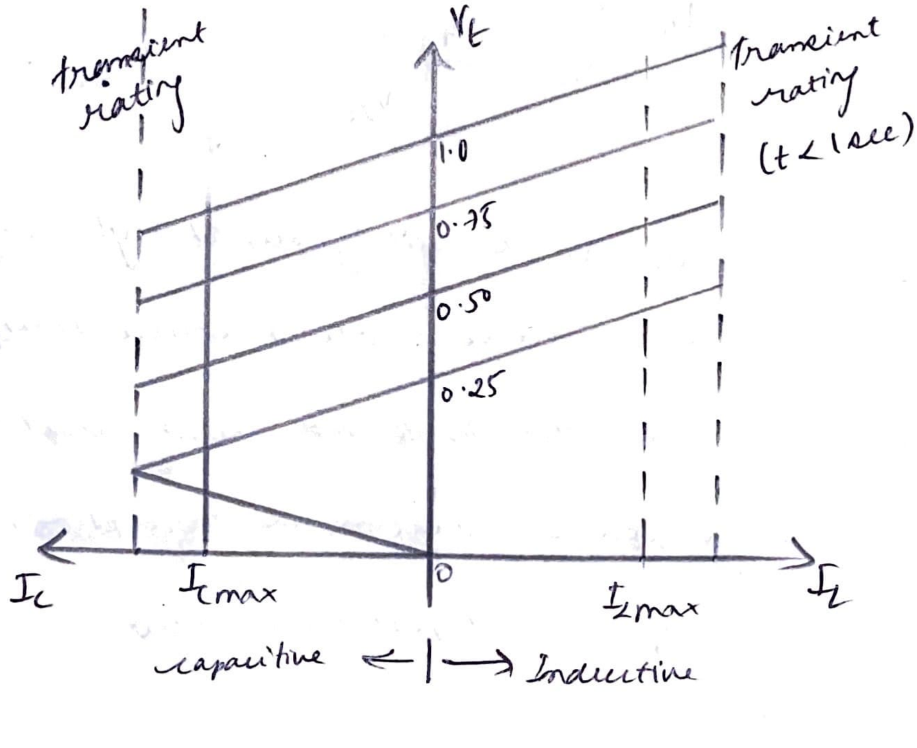
If $E_t > E_s$, it absorbs Q

If $E_t = E_s$, it is in floating state.

Adjusting phase shift between the converter output voltage and AC system voltage can control real power exchange between converter and AC system, by supplying AC power if leading and absorb real power if lagging.

The reactive power is generated internally by the action of converter switches. The DC capacitor is connected to provide a circulating path as well as a voltage source.

VI characteristics:



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iii) Tap changing transformers:

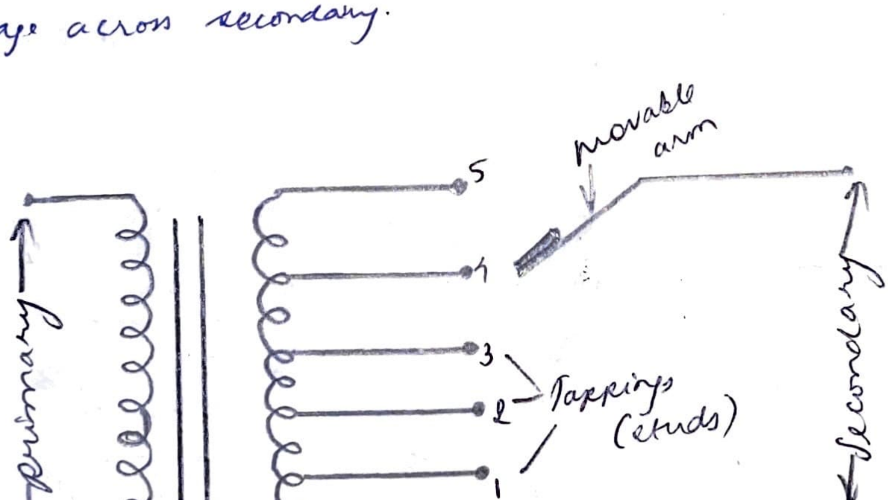
In order to maintain a constant voltage or to maintain within prescribed limits, transformer tap changing is used. In tap-changing, the tappings of the coils of the transformer are placed so that by varying the turn-ratio, voltage induced can be varied.

There are two types of tap-changing transformers:

1. Off-load tap-changing transformer:

Off-load tap-changing transformers are provided with tappings on the secondary winding.

In the figure the secondary windings have tapping 1 to 5. The position of movable arm on the first stud will give minimum secondary voltage and on the fifth stud will give maximum voltage across secondary.



During light load period, the movable arm is placed on the first stud and with an increase in load, the movable arm is taken

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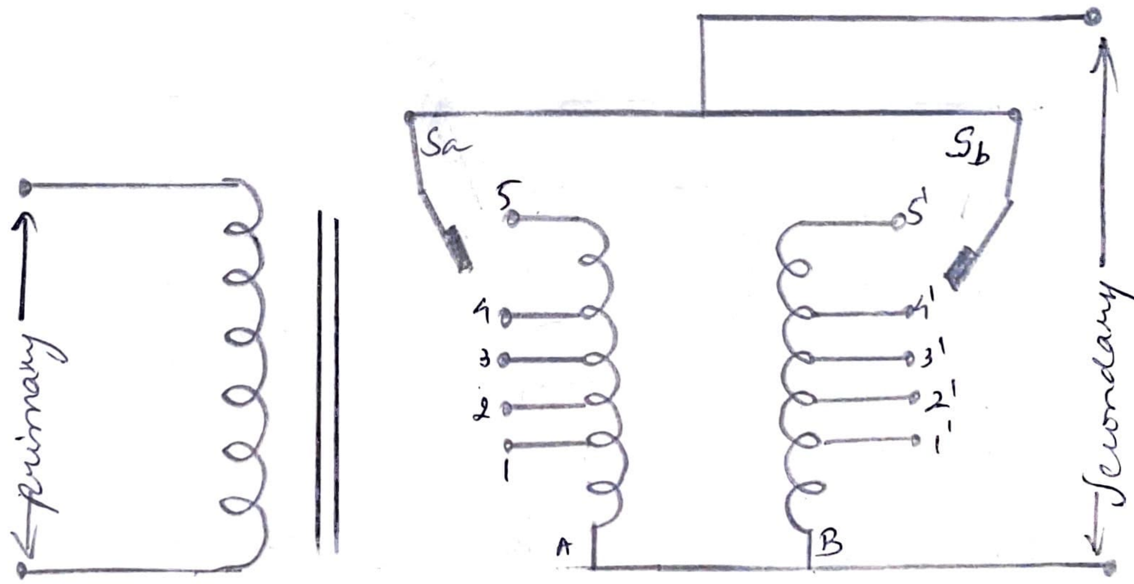
to a stud (3, 4, 5) giving higher turns-ratio so that voltage drop in the line is compensated and the output secondary voltage is maintained.

The disadvantage of this scheme is whenever the tapping is to change, load must be disconnected from the transformer, thus, giving it the name off-load tap-changing. This type cannot be used where constant power supply is a main priority and it is limited where there will be a need for only slight changing in turn-ratio.

2. On-load tap-changing transformer:

The drawback of off-load tap-changing can be overcome by using a special arrangement of coil connections to the transformer known as on-load tap-changing of the transformer.



The coils of the winding in which tappings are to be done are divided into two equal parallel sections. This forms the two windings A & B. Under normal conditions, both ~~A&B~~ switches S_A & S_B are closed with identical tappings (1 and 1').

When tapping is to be changed, to maintain constant supply, the process in made in such a way that:

- First A is disconnected, its tapping is changed and reconnected, while B is kept connected
- This causes an imbalance in load sharing due to difference in turns ratio
- Now, with A connected to the new tapping, B is disconnected and connected back to the tapping similar to that of A.

This way, continuity is maintained and more turn-ratio of tap-changing can be achieved.

iv) Automatic Voltage Regulators (AVR):

The AVR can maintain the generator terminal voltage at a constant value. It is done by changing the excitation current to the generator field.

The AVR gives the required DC supply to the generator field depending on the load, powerfactor, terminal voltage. The input of AVR is a 3-ϕ supply.

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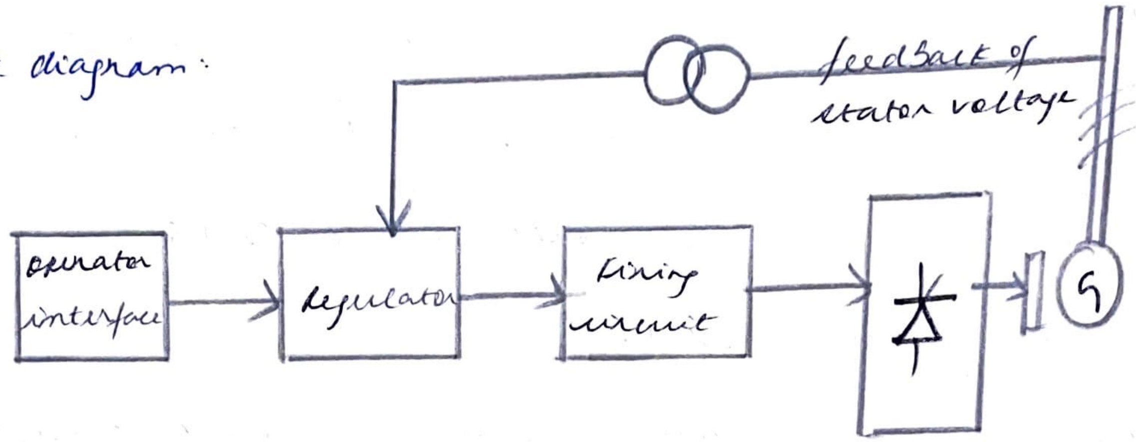
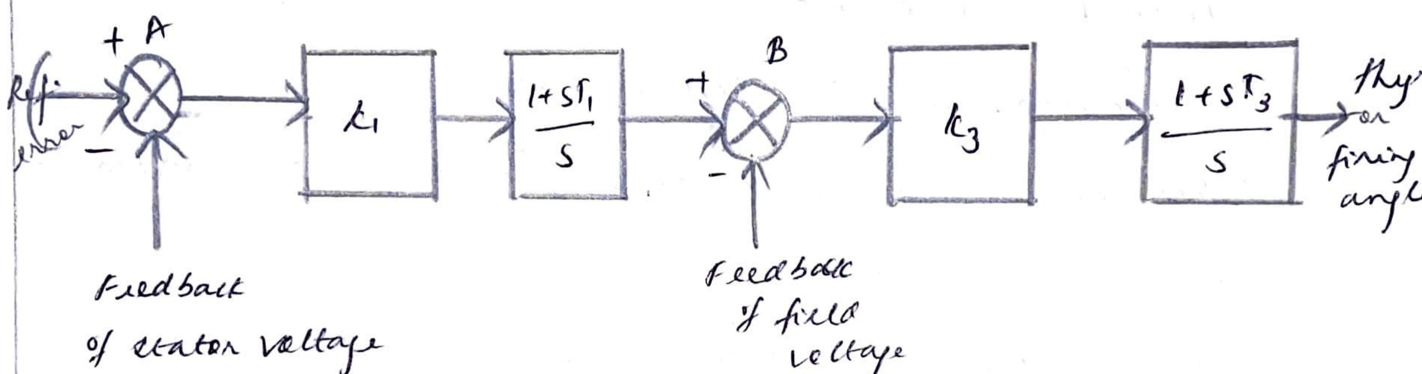
Block diagram:



Transfer function:



Voltage drop can be controlled by AVR. The real purpose of AVR is to deal ~~with~~ ~~when~~ with the voltage drop when an extra load is connected. It can restore the rated voltage without undue overshooting and regeneration.

There are three basic parts of AVR: error detection element, correcting element and stabilizing element.

AVR can sense the DC output voltage and it can act to filter the field current to maintain the output voltage at the rated value.

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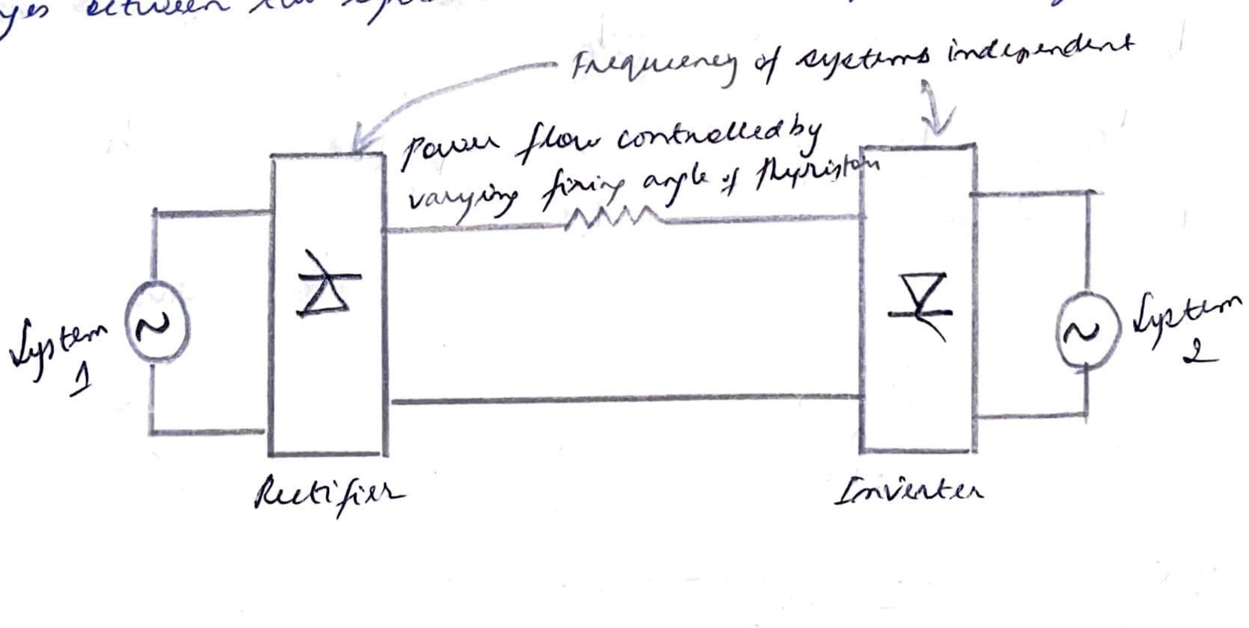
4. Explain how power flow control using embedded DC links and phase shifters for a reactive power compensation.

→ Power flow control using D.C embedded links:

Power flow can be controlled by converting AC to DC by thyristor bridges or voltage source converters and reconverting DC to AC (at another bus) again by the same means. The converters are connected in shunt with the AC transmission system at 2 buses. If a substantial distance between the two buses is involved, then high voltage DC transmission is done. The power flow is a function of the converter firing angles and is practically independent of the voltage phase angle and frequency at either end.

- Normally, DC links embedded in an AC system are mainly used to transfer power over long distances which is difficult with AC lines.
- DC links are also used to allow for controlled power interchanges between two systems which are not synchronously connected.



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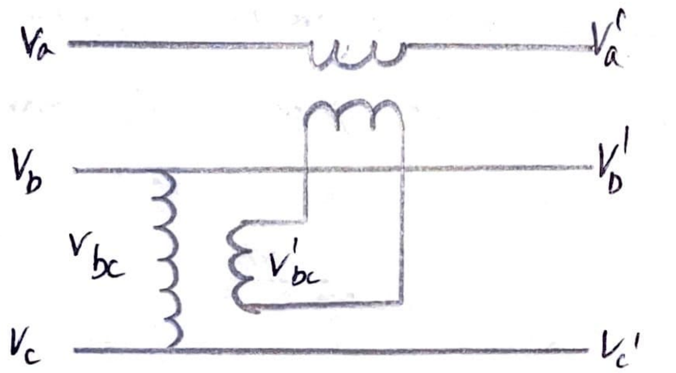
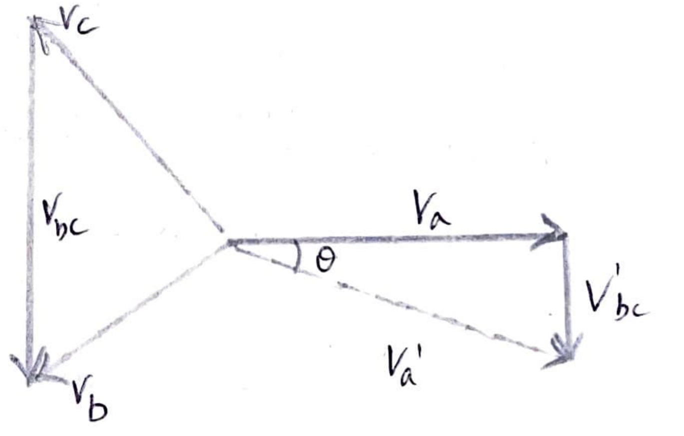
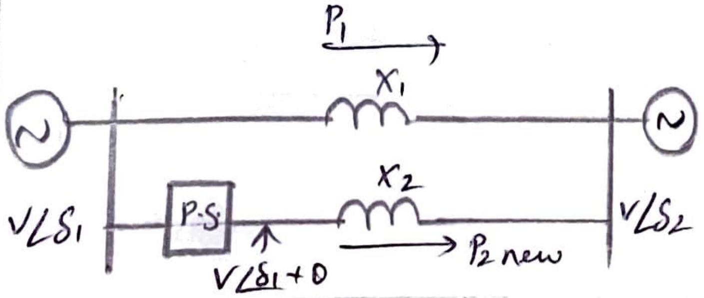
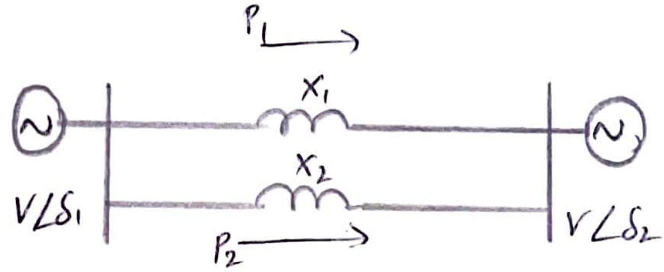
→ Power flow control using phase shifters:

Another method of changing power flow through a transmission line is by using a phase shifter. A phase shifter introduces a small phase shift in the voltage at its two terminals by injecting a series voltage. The series voltage injected in one phase is in phase with the line voltage across the other 2 phases. This implies that the voltage injected in one phase is in quadrature with the bus voltage at one terminal of that phase. This small quadrature voltage injection mainly affects the bus voltage angle at the other terminal. The magnitude is not much affected if the series injected voltage is small. In the phasor diagram, the mechanism of obtaining a phase shift of 'θ' is shown. Similarly, a phase shift of -θ can be obtained by reversing injected voltage.









A phase shifter can alter the power flows in a transmission system. In the figure shown, for the given phasor angles at both ends, the power flow in line 2 can be altered.

Thus, ~~total~~ the sharing of total power flow = $\dfrac{P_{2new}}{P_{2new} + P_1}$

The expression for power flow in line 2 is given by

$$P_{2new} = \frac{V^2 \sin(\delta_1 + \theta - \delta_2)}{X_2}$$

5. Transfer function representation and block diagram of synchronous generator excitor control.

For the sake of convenience, we neglect the effect of saturation and also remove the stabilizing transformer from the excitation system.

The system transfer function is written as

$$\frac{V_t(s)}{V_{ref}(s)} = \frac{G(s)}{1 + G(s)H(s)}$$

where $G(s)$ - feed forward transfer function

$H(s)$ - feedback transfer function.

We have,
$$G(s) = \frac{K_A K_G}{(1+sT_A)(K_E + sT_E)(1+sT_A)}$$

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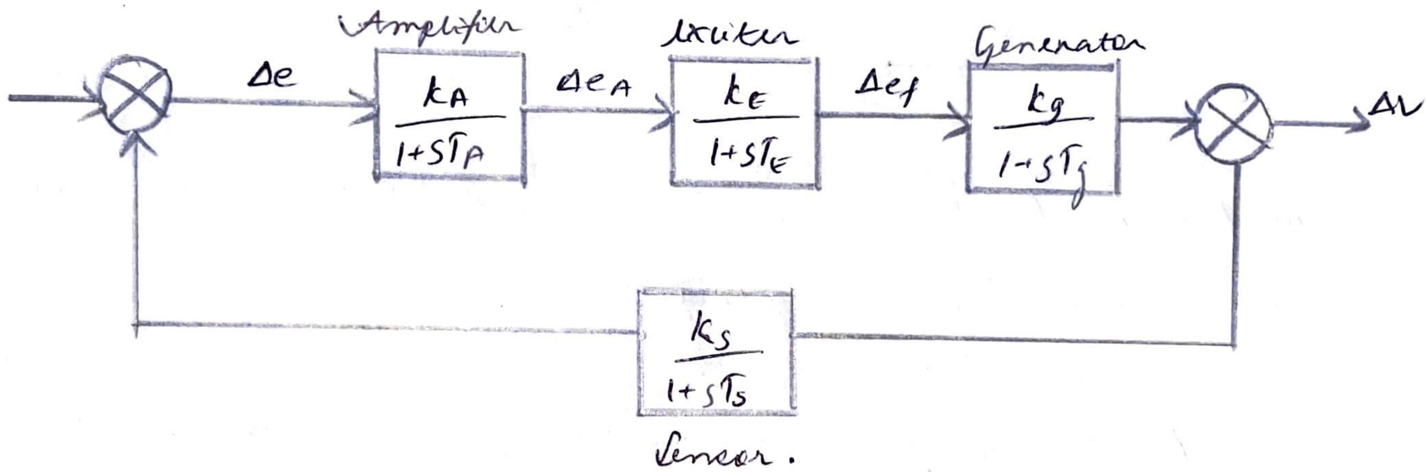
$$H(s) = \frac{k_R}{1 + sT_R}$$

we get, $$\frac{V_t(s)}{V_{ref}(s)} = \frac{k_A k_G (1 + sT_R)}{(1+sT_A)(k_E + sT_E)(1+sT_G)(1+sT_R) + k_A k_G k_R}$$

knowing the mathematical values of different constants, we can analyse the response of system.



UNIT- 3

1) Write a Short notes on

   1. SCADA
   2. Synchro phasors.
   3. WAMS
   4. System Security Assesment

2) What are the functions of SCADA.

3) How feeder voltage & End User Load Control automation Can be done by SCADA.

4) List Application of PMU.

5) How Various Power System networks are Connected with PMUs

6) with neat flow Chart Explain the procedure of Security Assesment

7) what are the Various operating States of Power System

8). Explain State Estimation in Power System

Assignment - 3

1.) Write a short note on

1. SCADA
2. Synchrophasors
3. WAMS
4. System Security Assesment.

A.) 1. SCADA :- SCADA performs automatic monitoring, protecting and controlling of various equipments in power systems with the use of Intelligent Electronic Devices.

* It restores the power service during fault condition and also maintains the desired operating conditions.

* SCADA improves the reliability of supply by reducing duration of outages and also gives the cost-effective operation of power system.

2. Synchro-phasors :-

* Synchro-phasors are time-synchronized numbers that represent both magnitude and phase angle of the sine waves found in Electricity or any power system network.

* They are measured by high-speed monitors called "phasor Measurment Units (PMU's)".

* Synchro-phasors provide a real-time measurement of electrical quantities across the power system.

Applications

* wide-area control
* System model validation
* Determining stability margins
* Maximizing stable system loading
* System-wide disturbance recording
* Visualization of dynamic system response.

* PMU :- PMU is a device used to estimate the magnitude and phase angle of an electrical quantity (such as voltage & current) in the Electric grid or power system using a common time source for synchronization.

* The resultant magnitude + phase angle = Synchro. phasor.

3. WAMS (wide area monitoring system) :-

* WAMS is a advanced new data acquisition technology of phasor measurement and allow "monitoring various conditions of power system over large areas in view of detecting faults" and further counteracting grid instabilities.

* The WAMS gives control of transmission and distribution networks.

* Used for network stability, ampacity of lines and detection of critical network conditions.

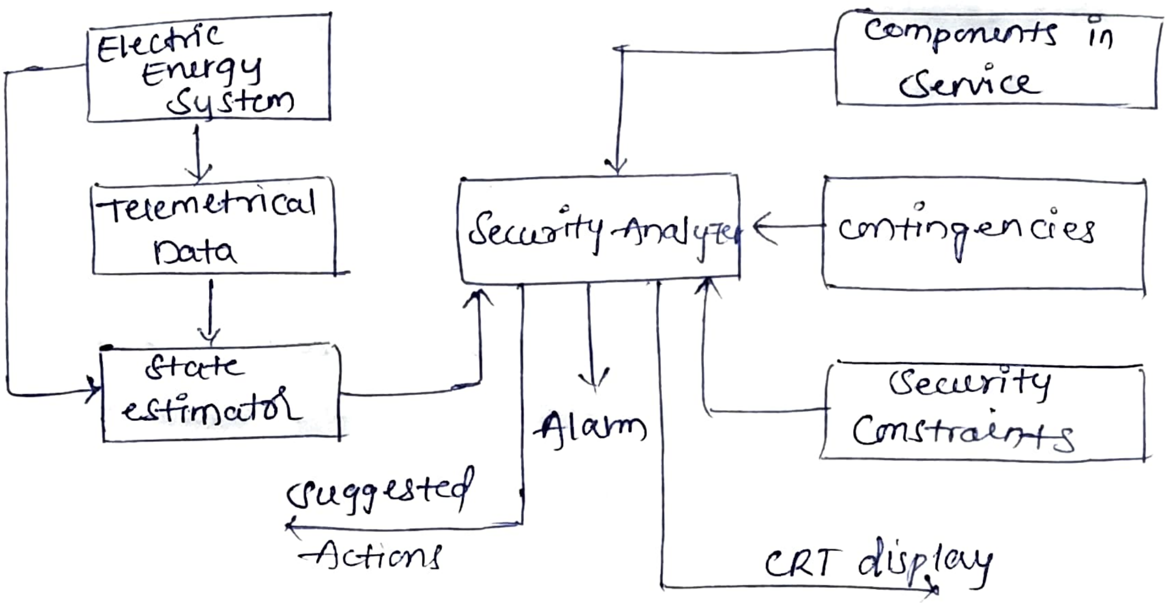
Applications

* Active & Reactive power Monitoring
* System Condition Monitoring
* Network stability monitoring.
* Estimating Short Ckt Capacity
* Line parameter Estimation.
* Controlling the Network.

4. System Security Assessment :-

* Security monitoring is the on line identification of the actual operating conditions of a power system.

It requires system wide instrumentation to gather the system data as well as a means for the on line determination of network topology involving an open or closed position of ckt breakers.



2) What are the functions of SCADA ?

A) * Control & indication of position of a two & three - position device, for example : a motor-driven switch or a ckt Breaker.

* State indication without control, for example : Transformer fans on or off.

* Control without indication, for example : Capacitors switched in or out.

* Alarm sensing, for example : Fire or the performance of a noncommanded function.

* permit operators to initiate operations at remote stations from a central control station.

* Initiation and recognition of sequences of events, for example: routing power around a bad transformer by opening and closing ckt Breakers, or sectionalizing a bus with a fault on it.

3.) How feeder voltage & End user load control automation can be done by SCADA ?

A.) * This automation includes feeder voltage or VAR control and feeder automatic switching.

Feeder voltage control preforms voltage regulation and ~~ca~~ capacitor placement operations while feeder switching deals with remote switching of various feeders, detection of faults, identifying fault location, isolating operation and restoration of service.

* In this system, SCADA architecture continuously checks the faults and their location by using wireless faults detector units deployed at various feeding stations.

In addition, it facilitates of feeder parameters and their status.

End user load control Automation

* It provides the energy consumption by the large consumers and appropriate pricing on demand or time slots wise. Also detects energy meter tampering and theft and accordingly disconnects the remote service. Once the problem resolved, it reconnects the service.

* In this, Smart meters with a communication unit extract the energy consumption information and made it available to a central control room as well as local data storage unit.

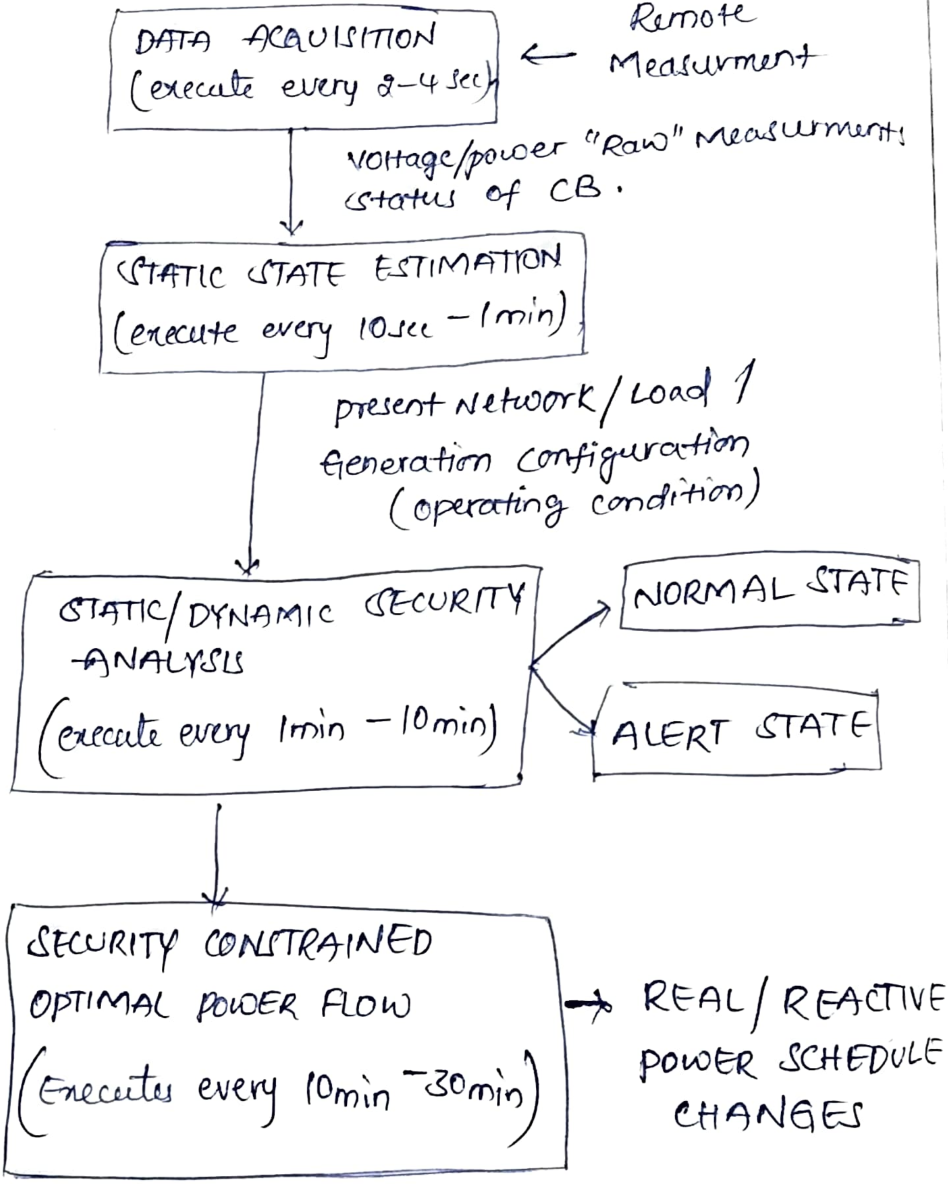
* Modems or Communication devices at each meter provide secure two-way communication b/w central control & monitoring room and remote sites.

4.) List applications of PMUs?

A) * Network state estimation
* Dynamic supervision
* Instability predicition and control
* protection.
* Finding fault location.
* power Quality monitoring.

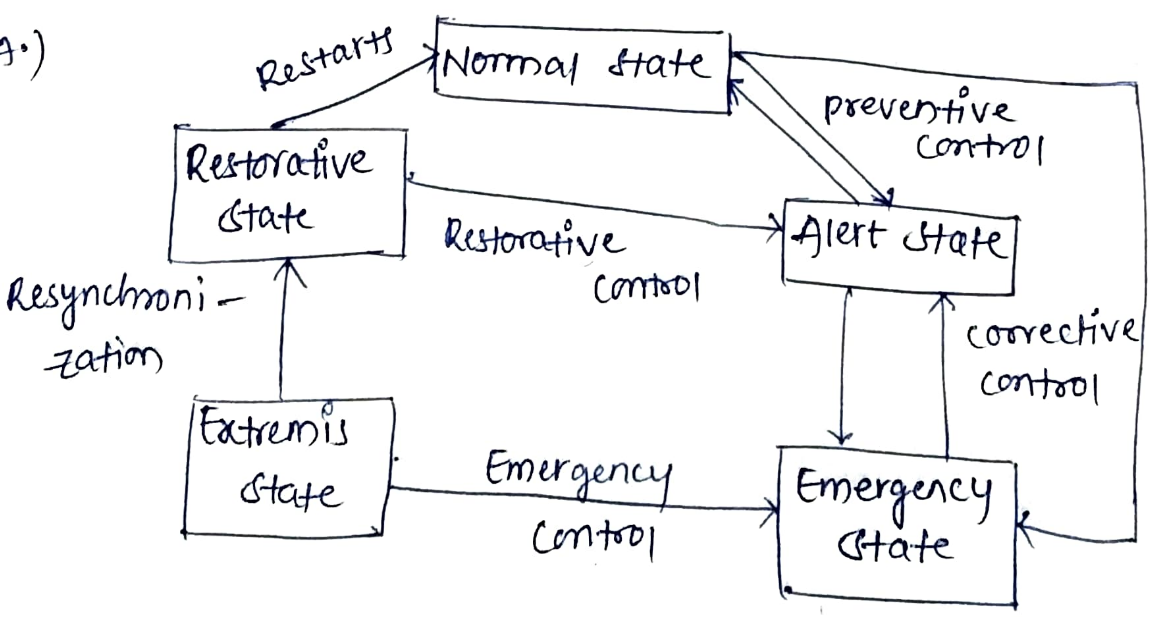
5.) with neat flow chart Explain security Assessment procedure ?

A.)



6.) what are various operating states of power System ?

A.)



Normal State : A system is said to be in normal if both load and operating constraints are satisfied.

Alert State : when the system security level falls below a certain level or the probability of disturbance increases, the system is said to be alert state.

Emergency State : If several disturbance occurs, the system will push into emergency state.

Extremis State : when the system is in emergency, if no proper corrective action is taken in time, then it goes to extremis state.

Restorative State : From this state, the system may be brought back either to alert state (or) Secure State.

In certain cases, first the system is brought back to alert state and then to the Secure State.

This is done using restorative control action.

7.) Explain state estimation in power system ?

A.) The main goal of the power systems state estimator is to find a robust estimate for the unknown complex voltage at every bus in the network.

This introduces the problem of how to devise a "best" estimate for the voltages given the available measurement.

Of the many ~~certain~~ criteria used to devolop a robust state estimator, the following three are regarded as the most common :

* Maximum Likelihood : Maximizes the probability that the estimated state variable is near the true value.

* Weighted Least - Square (WLS) : Minimizes the sum of the squared weighted residuals b/w the estimated and actual measurment.

* Minimum Variance :- Minimizes the expected values of the sum of the squared residuals b/w ~~(the estimated and actual measurments.)~~ components of the estimated state variable and the true state variable.

UNIT - IV

1. Explain about Power System Economics.

2. Draw the following Curves w.r.t Power plants.

   a) Generation Cost Curves.

   b) Generation heat rate Curves.

3. what are functions of Electric Utility

4. Give brief about Power Exchanges. & Spot pricing

5. with neat block diagram explain about Various Electricity Market Models.

6. Write a Short notes on

   a) whole Sale Competition Model

   b) Retail Competitive model.

UNIT - V

1. Explain how Demand Side Management can be acheived.

2. Illustrate the following terms

   ⓐ Transmission pricing

   ⓑ Ancillary Services. & its functions

   ⓒ Regulatory frame work

3. What are EMC Standards for Power supplies.

POWER SYSTEMS-III

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ASSIGNMENT-5

1. Explain how demand side management can be achieved.

Demand side management is used to describe the actions of a utility. beyond the customer's meter. with the objective of altering the end-use of electricity - whether it be to increase demand, decrease it, shift it between high and low peak periods, or manage it when there are intermittent load demands - in the overall interests of reducing utility costs.

Demand side Management (DSM) can be achieved through:

- Improving efficiency of various end-users through better housekeeping such as correcting energy leakages, system conversion losses, etc.
- Developing and promoting energy efficient technologies
- By adopting soft options like higher prices during peak hours, concessional rates during off peak hours, seasonal tariffs, interruptible tariffs, etc

DSM also includes options such as renewable energy sources, combined heat and power systems, independent power purchase, etc., to meet the consumer's demand at the lowest possible cost Hence, DSM can be achieved through energy efficiency by reducing energy consumption on one hand and on the other hand by managing the load demand itself. The first may be achieved through awareness on the use of energy efficiently on part of consumers. Thus, leading to conservation of energy. The latter calls for reducing power demand or shifting it to off-peak hours. This can be achieved by utility providing incentives like time-of-use tariff giving rebate during off-peak hours.

Utility has a leading role through its actions that effect quantity or pattern of energy consumption by the consumer through reduction of drawl during peak period. This in turn helps the utility to reduce investment for generation vis-à-vis transmission and distribution

2. Illustrate the following terms:

a) Transmission pricing:

The Federal Energy Regulatory Commission (FERC) recognized that transmission grid is the key issue to competition, and issued guidelines to price the transmission. The guidelines are summarized such that transmission pricing would:

→ Meet traditional revenue requirements of transmission owners.

→ Reflect comparability i.e., a transmission owner would charge itself on the same basis that it would charge others for the same service.

→ Promote economic efficiency.

→ Promote fairness

→ Be practical.

→ Even though transmission costs are small compared to power production expenses and represent a small percentage of major investor owned utilities' expenses, a transmission system is the most important key to competition because it would provide price signals that can create efficiencies in the power generation market.

There are two methods of transmission pricing:

1. Contract path method
2. MW- mile method

b) Ancillary services and its functions:

Ancillary services: are defined as services which are required to support the transmission of capacity and energy from resources to loads while keeping a reliable operation of the transmission system of a provider with good utility practice.

Ancillary services are the speciality services and functions provided by the electric grid that facilitate and support the continuous flow of electricity so that supply will continuously meet demand. The term ancillary services are used to define the variety of operations beyond transmission and ~~distribution~~ generation that are required to maintain grid stability and security.

Traditionally ancillary services have been provided by generators. However, the integration of intermittent generation and the development of smart grid technologies have prompted a shift in the equipment that can be used to provide ancillary services. A large number of activities on the interconnected grid can be termed as ancillary services. However, in order to remove large discrepency, the North American Electric Reliability council (NREC) along with the Electric Power Research Institute (EPRI) has identified 12 functions as ancillary services. These are:

1. Regulation - the use of generation or load to maintain minute-to-minute generation-load balance with the control area.

2. Load following - This refers to load-generation balance towards the end of the scheduling period.

3. Energy Imbalance - The use of generation to meet hour-to-hour or daily imbalance/variations in load.

4. Operating Reserve (Spinning) - the provision of unloaded generating capacity that is synchronised to the grid and can immediately respond to correct generation-load imbalances, caused by generation and/or transmission outages and that is fully available for several minutes

5. Operating reserve (Supplemental) - the provision of generating capacity and curtailable load to correct generation-load imbalances. Supplemental reserve is not required to respond immediately.

6. Backup Supply – This service consists of supply guarantee contracted by generators with other generators or with electrical systems, to ensure they are able to supply their consumers in case of scheduled or unscheduled unavailability

7. System Control – System control is about control area operations functions that schedule generation and transactions and control generation in real time to maintain generation load balance.

8. Dynamic Scheduling – It includes real-time metering, tele-metering along with computer software and hardware to virtually transfer generator's output or consumer's load from one control area to another.

9. Reactive Power and Voltage Control Support – The injection or absorption of reactive power from generators or capacitors to maintain system voltages within required range.

10. Real power transmission losses – This service is necessary to compensate for the difference existing between energy supplied to the network by the generator and energy taken from the network by the consumer.

11. Network stability services from generation sources – Maintenance and use of special equipment to maintain secure transmission system.

12. System black start capability – The ability of generation unit to proceed from a shutdown condition into an operating condition without assistance from the grid and then to energize the grid to help other units start after blackout occurs.

c) Regulatory framework:

Regulatory standards must be met because international and domestic standards are required for power management section of the end-item equipment. These standards vary from one country to another, so the power subsystem manufacturer and the end-item system manufacturer must adhere to these standards where the system will be sold. Design engineers must understand these standards even though they may not perform standards certification. Understanding these standards usually poses problems for power management subsystem designers.

- Many standards are technically complex, requiring an expert to be able to decipher them.
- Standards are written in a form that is difficult for the uninitiated to interpret because there are usually exclusions and exemptions that are not clear.
- Several different agencies may be involved, so some may be specific to one country or group of countries and not others.
- Standard requirements vary and sometimes conflict from one jurisdiction to another.
- Standards are usually evolving, with new ones introduced periodically, so it is difficult to keep pace with them.

3. What are EMC standards for power supplies?

The most commonly used international standard for emissions is C.I.S.P.R. 22 "Limits and Methods for measurement of Emissions from ITE". Most of the immunity standards are contained in various sections of EN61000. As of January 1996, EC directive 89/336/EEC on EMC requires the manufacturer to make a declaration of conformity if the product is sold in the European community.

Sections EN61000 for EMC include:

EN61204-3 : Covers the EMC requirements for power supply with a DC output upto 200V at power levels upto 30 kW and operating from AC to DC sources upto 600V.

EN61000-2-12 : Compatability levels for low frequency conducted disturbances and signaling in public medium-voltage power supply systems.

EN61000-3-12 : Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16A and <75A per phase.

EN61000-3-2 : Limits for harmonic currents injected by equipment connected to public ~~low voltage~~ supply systems.

EN61000-4-1 : Test and measurement techniques for electric and electronic equipment in electromagnetic environment.

EN61000-4-11: measurement techniques for voltage dips, short interruptions, and voltage variations.

EN61000-4-12: Testing for non-repetitive damped oscillatory transients occurring in low-voltage power, control and signal lines

EN61000-4-3: Testing ~~for coverage~~ and measurement techniques for immunity requirements for electric and electronic equipment to radiate electromagnetic energy.

EN61000-4-4: Testing and measurement for electrical fast transient/bursting immunity test

EN61000-4-5: Recommended test levels for equipment to unidirectional surges caused by overvoltage from switching and lightening.

EN61000-6-1: Electromagnetic compatibility (EMC) immunity for residential, commercial, and light-industrial environments

EN61000-6-2: Generic standards for EMC immunity in industrial environment.

EN61000-6-3: EMC emission requirement for electrical and electronic apparatus intented for use in residendial, commercial, and light-industrial environment

EN61000-6-4: Generic EMC standards for industrial environments intended for use by test laboratories, industrial/medical product designers, and system installers.

Gokaraju Rangaraju Institute of Engineering & Technology

(Autonomous)

Results

Year: IV B.Tech - I Sem Academic Year : 2022 - 2023

Dept: EEE

S.No	Roll No	GR18A2068	GR18A4012	GR18A4013	GR18A4014	GR18A4021	GR18A4022	GR18A4061	GR18A4079	GR18A6004	GR18A6012	SGPA	Credits
1	19241A0254	6	5	7	8	6	9	6		6	7	6.41	27
2	19241A0252		9	8	10	8	10	9	9	9		8.96	24
3	19241A0236		9	9	7	9	10	10	8	8		8.79	24
4	19241A0250	7	8	9	9	8	9	10		8		8.63	24
5	19241A0227		8	9	9	8	8	9	9	8		8.58	24
6	20245A0202	8	8	9	9	8	10	8		7		8.17	24
7	20245A0203	7	8	9	9	7	10	9		7		8.17	24
8	19241A0217		7	8	7	6	7	9	9	8		7.83	24
9	19241A0262	7	7	8	8	7	10	9			7	7.83	24
10	19241A0201		7	7	8	6	9	9	8	7		7.71	24
11	19241A0270		6	7	6	7	10	9	8	8		7.63	24
12	19241A0228		6	8	7	7	7	8	9	8		7.58	24
13	19241A0238	6	7	8	8	7	8	8		8		7.50	24
14	19241A0275		6	8	7	6	10	8	8	7		7.33	24
15	19241A0272	5	6	8	7	7	10	8		7		7.08	24
16	19241A0282	5	6	8	7	8	10	7		8		7.08	24
17	19241A0224		7	7	7	6	8	7	8	7		7.04	24
18	19241A0294		6	6	6	5	9	8	8	8		7.00	24
19	20245A0210	6	6	7	7	7	10	7		7		6.88	24
20	19241A0265	6	5	6	6	7	10	8		7		6.79	24
21	19241A0209		6	6	7	6	8	7	7	6		6.58	24
22	19241A0210		9	9	10	9	10	10	10			9.62	21
23	19241A0235		9	9	10	8	10	10	10			9.48	21
24	19241A0287	8	9	10	9	10	10	10				9.43	21
25	19241A0204		10	9	10	8	10	9	10			9.33	21
26	19241A0253		9	9	10	9	10	9	10			9.33	21
27	19241A0213	9	9	10	10	9	10	9				9.29	21
28	19241A0269		9	9	10	9	10	8	10			9.05	21
29	19241A0298	8	8	9	9	9	10	10				9.05	21
30	19241A0206		9	9	10	7	8	9	10			8.95	21
31	19241A0292		8	10	9	8	9	9	10			8.95	21
32	19241A0215		8	9	10	8	10	9	9			8.90	21
33	19241A0240	8	9	9	9	9	10	9				8.90	21
34	19241A0258		9	9	8	9	10	9	9			8.90	21
35	19241A0221		8	9	9	8	9	9	10			8.86	21
36	19241A0251	7	8	9	9	9	9	10				8.86	21
37	19241A0285		8	10	9	9	10	8	10			8.86	21
38	19241A0214		7	8	10	7	10	10	9			8.81	21
39	19241A0205		8	9	9	8	10	9	9			8.76	21
40	19241A02A5	8	8	9	9	9	10	9				8.76	21
41	19241A0257	8	8	9	10	8	9	9				8.71	21
42	20245A0213		8	8	8	8	10	9	10			8.67	21
43	19241A0261		8	8	8	9	10	8	10			8.52	21
44	19241A0290		7	8	7	8	10	10	9			8.52	21
45	19241A0274		8	9	7	9	10	8	10			8.48	21
46	19241A0286		7	9	7	7	10	10	9			8.48	21
47	19241A0202		8	8	9	7	8	9	9			8.43	21
48	19241A0211		8	8	7	7	10	10	8			8.38	21
49	19241A0229		7	8	8	7	9	10	8			8.33	21
50	19241A0255		7	9	7	6	10	10	9			8.33	21
51	19241A0284	6	8	9	8	9	10	9				8.33	21

S.No	Roll No	GR18A2068	GR18A4012	GR18A4013	GR18A4014	GR18A4021	GR18A4022	GR18A4061	GR18A4079	GR18A6004	GR18A6012	SGPA	Credits
52	19241A0203	7	7	8	8	7	10	10				8.24	21
53	20245A0207		8	8	7	7	10	9	9			8.24	21
54	20245A0217		7	8	7	7	10	10	8			8.24	21
55	19241A0220		7	8	8	7	9	9	9			8.19	21
56	19241A0267		7	9	8	8	10	8	9			8.19	21
57	19241A0295	7	8	9	7	8	10	9				8.19	21
58	20245A0211	7	8	9	9	8	10	8				8.19	21
59	20245A0212	6	8	9	9	7	10	9				8.19	21
60	19241A0247	7	8	9	8	9	9	8				8.14	21
61	20245A0216	7	8	9	8	9	9	8				8.14	21
62	19241A0241	7	8	8	7	8	9	9				8.05	21
63	19241A0278		7	9	7	9	10	8	8			8.05	21
64	20245A0204		8	7	7	7	8	9	9			8.05	21
65	20245A0215	6	7	9	8	8	10	9				8.05	21
66	20245A0218	6	7	9	8	8	10	9				8.05	21
67	19241A0268		6	7	7	7	10	10	8			8.00	21
68	20245A0205	7	7	8	8	8	8	9				8.00	21
69	19241A0218	8	9	8	8	8	10	7				7.95	21
70	20245A0201		8	9	7	8	8	8	8			7.95	21
71	19241A0243		8	9	9	9	10	9	10			7.92	21
72	19241A0225		7	8	8	6	6	9	9			7.90	21
73	19241A0276	7	8	9	7	8	10	8				7.90	21
74	19241A02A4	6	8	8	7	8	9	9				7.90	21
75	20245A0220	7	7	9	8	8	10	8				7.90	21
76	19241A0239	7	8	9	7	6	9	9				7.86	21
77	19241A0288	7	7	9	7	7	9	9				7.86	21
78	20245A0219	6	8	7	8	7	10	9				7.86	21
79	19241A0222		8	8	8	6	7	8	9			7.81	21
80	19241A0280	7	7	8	7	7	10	9				7.81	21
81	20245A0208		6	8	8	7	10	8	9			7.81	21
82	19241A0234		6	8	7	6	9	9	9			7.76	21
83	19241A0271	6	7	9	7	7	10	9				7.76	21
84	19241A0296	6	8	8	7	8	10	8				7.67	21
85	19241A0277	6	6	8	7	8	9	9				7.62	21
86	19241A0207	6	7	8	7	7	8	9				7.57	21
87	19241A0223		6	8	8	7	8	8	8			7.57	21
88	20245A0209	6	7	7	8	6	10	9				7.57	21
89	19241A0208		6	7	8	6	9	9	7			7.52	21
90	19241A0264	7	7	8	8	6	10	8				7.52	21
91	19241A0249	7	7	8	7	7	9	8				7.48	21
92	19241A0256	6	7	7	7	7	8	9				7.48	21
93	19241A0281	6	7	9	7	7	10	8				7.48	21
94	19241A02A7	6	7	9	7	7	10	8				7.48	21
95	19241A0232		5	7	8	6	7	9	8			7.43	21
96	19241A0293	6	7	9	7	7	9	8				7.43	21
97	19241A0291	6	6	8	7	8	10	8				7.38	21
98	19241A0244		8	8	7	8	9	9	9			7.29	21
99	19241A0246	7	6	8	7	7	7	8				7.24	21
100	19241A0279	6	7	8	8	8	10	6				7.10	21
101	19241A02A1	5	6	8	7	7	10	8				7.10	21
102	19241A0231		6	7	8	7	8	7	7			7.05	21
103	20245A0224	6	7	8	6	6	8	8				7.00	21
104	19241A0233		6	9	7	7	6	6	8			6.86	21
105	19241A0283	6	6	7	6	6	10	8				6.86	21
106	20245A0225	5	7	8	5	6	10	8				6.81	21
107	19241A0212	5	6	7	6	7	8	8				6.76	21
108	19241A0289		5	7	7	6	10	7	7			6.71	21
109	19241A0216	0	7	8	8	5	9	9		7		6.67	21
110	20245A0222	6	6	8	6	6	9	7				6.62	21
111	20245A0223	6	5	8	7	6	9	7				6.62	21

S.No	Roll No	GR18A2068	GR18A4012	GR18A4013	GR18A4014	GR18A4021	GR18A4022	GR18A4061	GR18A4079	GR18A6004	GR18A6012	SGPA	Credits
112	19241A0260		6	6	6	6	6	7	8			6.57	21
113	19241A02A3		5	6	5	6	10	7	8			6.48	21
114	19241A0297	6	6	8	6	7	8	6				6.43	21
115	19241A0230		6	6	6	5	8	7	7			6.38	21
116	19241A0219	6	6	8	7	6	6	6				6.33	21
117	20245A0221	5	6	7	6	5	10	7				6.29	21
118	20245A0214	5	5	7	5	5	8	8				6.19	21
119	19241A0226		6	6	6	5	8	6	6			5.95	21
120	19241A0299		5	6	5	5	8	7	6			5.95	21
121	19241A02A6	0	8	9	8	8	10	9				7.33	18
122	19241A0266	0	6	7	7	7	10	9				6.57	18
123	19241A0263	0	6	8	6	7	10	9				6.52	18
124	19241A0242	0	6	7	7	6	7	8				6.00	18
125	19241A0273	0	6	7	5	5	10	6				5.14	18
126	19241A02A2	0	0	7	0	5	9	6				3.52	12
127	19241A0259		0	5	0	0	6	6	6			3.33	12
128	19241A0237	0	0	0	5	0	8	7				3.10	10
129	20245A0206	0	0	0	0	0	10	9				3.05	7

GR18A2068 Database Management Systems
GR18A4012 Power Systems - III
GR18A4013 Electronics Design
GR18A4014 Electrical and Hybrid Vehicles
GR18A4021 High Voltage Engineering
GR18A4022 Electronics Design Lab
GR18A4061 Project Work (Phase-I)
GR18A4079 Robotics
GR18A6004 Introduction to Internet of Things (through MOOCs)
GR18A6012 Cloud Computing (through MOOCs)

HOD,EEE

	9	4	2	3	3	0	0	0	0	0
	0	1	4	11	1	71	16	13	0	0
	1	12	45	17	18	26	52	21	1	0
	7	37	47	32	32	21	37	17	9	0
	19	35	22	47	41	6	15	5	9	2
	27	32	8	13	25	5	9	3	2	0
	7	8	1	6	9	0	0	0	0	0

Summation of Teacher's Appraisal by Students

Name of the Instructor	P. Prasanth Kumar
Branch	Electrical and Electronics Engineering
Class and Semester	IV B -I Semester
Academic Year	2022-23
Subject Title	Power Systems-III
Total No. of Responses/class strength	45/67

Average rating on a scale of 4 for the responses considered: 3.55

S.No.	Questions	Average
1	How does the teacher explain the subject?	3.51
2	The teacher pays attention to	3.73
3	The language and communication skills of the teacher is	3.60
4	Is the session interactive	3.49
5	Rate your teacher's explanation in clearing doubts	3.53
6	Rate your teacher's commitment in completing the syllabus	3.58
7	Rate your teacher's punctuality	3.51
8	Rate your teachers use of teaching aids	3.51
9	Rate your teachers guidance in other activities like NPTEL,MOODLE,Swayam, projects	3.47
10	What is the overall opinion about the teacher?	3.56

Net Feedback on a Scale of 1 to 4 **3.55** Pral

Remarks by HOD:

Remarks by Principal:

Remarks by Director:

GOKARAJU RANGARAJU INSTITUTE OF ENGINEERING AND TECHNOLOGGY
Approved By AICTE, Affiliated to JNTUH, Autonomous Under UGC
Nizampet Road, Bachupally, Kukatpally, Hyderabad - 500090, Telangana, India
Tel: 7207344440, Email:info@griet.ac.in, www.griet.ac.in

STUDENT FEEDBACK

Faculty : POKKULA. PRASANTH KUMAR
Subject : Power Systems – III (B.Tech, IV/IV B.Tech I Semester, EEE Sec-B)
Academic Year : 2022 - 2023
Phase : Phase-2

Sl.No	Question	Excellent	Good	Average	Poor	Q.Wise Total	Q.Wise %
1	Preparation and delivery of the lessons by the teacher	25	18	3	1	161	86.00
2	Subject Knowledge	24	19	3	1	160	85.00
3	Clarity in Communication	25	18	3	1	161	86.00
4	Using Modern Teaching Aids of ICT	24	19	3	1	160	85.00
5	Creating interest on the course in the class	24	19	3	1	160	85.00
6	Maintaining discipline in the class	23	20	3	1	159	85.00
7	Encouraging and clearing doubts in the class	24	19	3	1	160	85.00
8	Punctuality	24	19	3	1	160	85.00
9	Accessibility of the teacher	24	19	3	1	160	85.00
10	Overall grading of the teacher	24	20	2	1	161	86.00
	Total	241	190	29	10		
	Total Points	964	570	58	10	1602	85.00

No.Of Students Posted	47
Total Percentage Awarded to The Faculty	85.00
Grade of Faculty	Good

*Excellent (4) : >=90 % *Good (3) : >=75 & <90%
*Average (2) : >=60 & <75 % *Poor (1) : Below 60 %

Formula: Total Obtained Points/(Max Points(i.Excellent-4) * No.Of.Students * NoOfQuestions)

Prabal

Gokaraju Rangaraju Institute of Engineering and Technology

(Autonomous)

Bachupally, Kukatpally, Hyderabad – 500 090

Direct Internal CO Attainments

Academic Year	2022-23	Department	Electrical and Electronics Engineering	Name of the Programme	B.Tech		
Year - Semester	IV-I	Course Name :	Power Systems-III	Course Code	GR18A4012	Section	B

	Mid -I									Mid -II									Assignment Marks					Assessment
	Q.No 1	Q.No 2	Q.No 3	Q.No 4					Objective Marks	Q.No 1	Q.No 2	Q.No 3	Q.No 4					Objective Marks	I	II	III	IV	V	Marks
Enter CO Number → 1,2,3,4,5,6,7	CO1	CO2	CO1	CO2					CO1,CO2	CO4	CO3	CO3	CO5					CO1,CO2	CO1	CO2	CO3	CO4	CO5	CO1,CO2,CO3,CO4,CO5
Marks →	5	5	5	5					5	5	5	5	5					5	5	5	5	5	5	5
S.No/Roll No.	*Note :* Enter Marks Between Two Green rows. *Another Note :* Additional Columns if Required should be inserted after column H and appropriately rename the Q. Nos. For Calculations consult Departments CO-PO Incharge																							
19241A0261	4	4		2					5	4	4		5					4	5	5	5	5	5	5
19241A0262	4	4		4					3	5	4	4						4	5	5	5	5	5	4
19241A0263	5	4		3					3	3		3	3					4	5	5	5	5	5	4
19241A0264	3	2	3						3	3	4		3					3	5	5	5	5	5	4
19241A0265	2								2	1								1	5	5	5	5	5	4
19241A0266	2	2							3	2	1							4	5	5	5	5	5	4
19241A0267	5	4		4					4	4	4		3					3	5	5	5	5	5	4
19241A0268	3	2	3						5	3	2	3						5	5	5	5	5	5	5
19241A0269	5	5		4					2		4	4	4					5	5	5	5	5	5	5
19241A0270	3		2	3					2									AB	5	5	5	5	5	4
19241A0271	2		2	3					3		3	3	4					4	5	5	5	5	5	4
19241A0272	2	2		1					3	1								3	5	5	5	5	5	4
19241A0273	2	1							2	2			4					2	5	5	5	5	5	4
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19241A0275	2	1		1					2		2		2					3	5	5	5	5	5	4
19241A0276	3	2	2						4	3	4		4					5	5	5	5	5	5	4
19241A0277	4	3		3					2			1	2					4	5	5	5	5	5	4
19241A0278	4	5		4					3	2		2	2					2	5	5	5	5	5	5
19241A0279	2		2	3					4	2	2		4					3	5	5	5	5	5	4
19241A0280	3	2		3					3		4	3	2					4	5	5	5	5	5	4
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19241A0282	2	2		3					3	3	3		4					3	5	5	5	5	5	4
19241A0283	4	3		2					2		2	2	4					4	5	5	5	5	5	5
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19241A0285	4	3		3					4	5	5		4					3	5	5	5	5	5	5
19241A0286	2		2	1					4			3	3					3	5	5	5	5	5	4
19241A0287	5	5		5					4	4	4		5					5	5	5	5	5	5	5
19241A0288	2	3		2					4	2		3	2					5	5	5	5	5	5	4
19241A0289									AB		3		2					3	5	5	5	5	5	4
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19241A0291	4	4		2					3		2		4					4	5	5	5	5	5	4
19241A0292	2	3		4					4	4	4		5					4	5	5	5	5	5	4
19241A0293	3	2		1					4	2		2	3					4	5	5	5	5	5	4
19241A0294	3	3	1						4	3	2	2						4	5	5	5	5	5	4
19241A0295	4	5		3					4	4	4	4						5	5	5	5	5	5	4
19241A0296	3	2		3					3		5	4	3					3	5	5	5	5	5	4
19241A0297	3	2	3						4	2		2	4					4	5	5	5	5	5	5
19241A0298	5	5		4					4	4	5	4						5	5	5	5	5	5	4
19241A0299	2	1							4			2						5	5	5	5	5	5	4
19241A02A0									AB									AB	5	5	5	5	5	4
19241A02A1	3	3							3		2		2					4	5	5	5	5	5	4
19241A02A2									AB			1						4	5	5	5	5	5	4
19241A02A3									AB		2		3					4	5	5	5	5	5	4
19241A02A4	5	3		2					2	4		4	4					5	5	5	5	5	5	4
19241A02A5	5	5		4					3	4		4	5					5	5	5	5	5	5	5
19241A02A6	5	3		4					4	4	5	4						5	5	5	5	5	5	5
19241A02A7	4		4	4					4		3	3	4					5	5	5	5	5	5	4
20245A0206	2	2							4									AB	5	5	5	5	5	4
20245A0207	5	3		3					4	4	4	4						5	5	5	5	5	5	4
20245A0208	3	2		1					3		3	3	3					5	5	5	5	5	5	4
20245A0209	4	4	2						4	2	3	2						4	5	5	5	5	5	5
20245A0210	3	2	1						3		1		2					4	5	5	5	5	5	4
20245A0211		4	4	4					5	5		4	4					4	5	5	5	5	5	5
20245A0212	4	3		3					3	4	4		4					5	5	5	5	5	5	4
20245A0213	5	4		4					5		5	4	4					5	5	5	5	5	5	4

20245A0214	2	2							4		1								4		5	5	5	5	5	4
20245A0215	3		2						3			3	3	3					5		5	5	5	5	5	4
20245A0216	4	3		3					4		4		4	4					5		5	5	5	5	5	4
20245A0217	3	4	3						5			3	3	4					4		5	5	5	5	5	4
20245A0218	4	2		2					4		4		3	3					3		5	5	5	5	5	4
20245A0219	3	4		3					3		4	4	4						5		5	5	5	5	5	5
20245A0220	3	4		4					3			2		3					3		5	5	5	5	5	4
20245A0221									AB		4		2	3					5		5	5	5	5	5	4
20245A0222	2								2			2	3						4		5	5	5	5	5	4
20245A0223	0								5			2		2					4		5	5	5	5	5	4
20245A0224	4	3		2					4		2	4	2						3		5	5	5	5	5	4
20245A0225	2	2							4			2		1					5		5	5	5	5	5	5
if your class strength is > 60 then ***insert rows*** ***above the green row(last record)*** , Similarly ***delete the empty rows above green row*** if the class strenght is < 60)																										
Total number of students appeared for the examination (NST)	67	67	67	67					67		67	67	67	67					67		67	67	67	67	67	67
Total number of students attempted the question (NSA)	61	52	17	42					62		38	43	40	47					64		67	67	67	67	67	67
Attempt % (TAP) = (NSA/NST)*100	91.04	77.61	25.37	62.69					92.54		56.72	64.18	59.70	70.15					95.52		100.00	100.00	100.00	100.00	100.00	100.00
Total number of Students who got more than 60% marks (NSM)	43	32	6	30					44		26	28	28	37					56		67	67	67	67	67	67
Attainment % (TMP) = (NSM/NSA)*100	70.49	61.54	35.29	71.43					70.97		68.42	65.12	70.00	78.72					87.50		100.00	100.00	100.00	100.00	100.00	100.00
Score(S)	3	3	1	3					3		3	3	3	3					3		3	3	3	3	3	3
Note : CO attainment is considered to be zero if the attempt % is less than 30%																										
CO Validation	**CO1**	**CO2**	**CO1**	**CO2**					**CO1,CO2**		**CO4**	**CO3**	**CO3**	**CO5**					**CO1,CO2**		**CO1**	**CO2**	**CO3**	**CO4**	**CO5**	**CO1,CO2,CO3,CO4,CO5**
Course Outcome	**COCO1**	**COCO2**	**COCO1**	**COCO2**					**COCO1,CO CO2**		**COCO4**	**COCO3**	**COCO3**	**COCO5**					**COCO1,CO CO2**		**COCO1**	**COCO2**	**COCO3**	**COCO4**	**COCO5**	**COCO1,COCO2,COCO3,COCO4,COCO5**
Marks (Y)	**5**	**5**	**5**	**5**					**5**		**5**	**5**	**5**	**5**					**5**		**5**	**5**	**5**	**5**	**5**	**5**
No. of COs Shared (Z)	**1**	**1**	**1**	**1**					**2**		**1**	**1**	**1**	**1**					**2**		**1**	**1**	**1**	**1**	**1**	**5**
Y/Z	**5**	**5**	**5**	**5**					**2.5**		**5**	**5**	**5**	**5**					**2.5**		**5**	**5**	**5**	**5**	**5**	**1**
S*Y/Z	**15**	**15**	**5**	**15**					**7.5**		**15**	**15**	**15**	**15**					**7.5**		**15**	**15**	**15**	**15**	**15**	**3**
CO1	**1**	**0**	**1**	**0**					**1**		**0**	**0**	**0**	**0**					**1**		**1**	**0**	**0**	**0**	**0**	**1**
CO2	**0**	**1**	**0**	**1**					**1**		**0**	**0**	**0**	**0**					**1**		**0**	**1**	**0**	**0**	**0**	**1**
CO3	**0**	**0**	**0**	**0**					**0**		**0**	**1**	**1**	**0**					**0**		**0**	**0**	**1**	**0**	**0**	**1**
CO4	**0**	**0**	**0**	**0**					**0**		**1**	**0**	**0**	**0**					**0**		**0**	**0**	**0**	**1**	**0**	**1**
CO5	**0**	**0**	**0**	**0**					**0**		**0**	**0**	**0**	**1**					**0**		**0**	**0**	**0**	**0**	**1**	**1**
CO6	**0**	**0**	**0**	**0**					**0**		**0**	**0**	**0**	**0**					**0**		**0**	**0**	**0**	**0**	**0**	**0**
CO7	**0**	**0**	**0**	**0**					**0**		**0**	**0**	**0**	**0**					**0**		**0**	**0**	**0**	**0**	**0**	**0**

Weighted Average for Attainment relevance (Internal CODn)	CO1	CO2	CO3	CO4	CO5	CO6	CO7
	2.52	3.00	3.00	3.00	3.00		

!!

!! Caution !! For CO Values < 2.1 should be justified with Remidial Action Report.

Gokaraju Rangaraju Institute of Engineering and Technology

(Autonomous)

Bachupally, Kukatpally, Hyderabad – 500 090

Indirect CO Attainments

Academic Year	2022-23	Department	Electrical and Electronics Engineering	Name of the Programme	B.Tech		
Year - Semester	IV-I	Course Name :	Power Systems-III	Course Code	GR18A4012	Section	B

Course Outcomes survey on Scale 1 (Low) to 5 (High)

Enter Course Outcomes →	List methods to control the voltage, frequency and power flow.	Summaries about Reactive Power compensation	Compose monitoring and control of a power system.	Recall the basics of power system economics.	Write about Demand Side-management		
CO Number → 1,2,3,4,5,6,7	1	2	3	4	5		
Marks →	5	5	5	5	5		
S.No/Roll No.	Note : Enter Marks Between Two Green rows.						
19241A0261	3	4	5	4	2		
19241A0262	3	5	5	4	5		
19241A0263	5	4	2	5	4		
19241A0264	2	2	4	3	3		
19241A0265	5	3	2	2	2		
19241A0266	2	2	2	4	3		
19241A0267	3	2	2	4	5		
19241A0268	5	4	3	3	4		
19241A0269	3	5	5	5	5		
19241A0270	5	2	4	5	2		
19241A0271	3	4	4	4	3		
19241A0272	2	4	2	3	3		
19241A0273	3	5	5	4	2		
19241A0274	3	5	3	5	3		
19241A0275	5	3	5	4	2		
19241A0276	3	4	5	4	3		
19241A0277	4	3	5	5	5		
19241A0278	2	2	5	3	5		
19241A0279	3	5	3	3	3		
19241A0280	4	4	3	3	2		
19241A0281	2	4	5	4	5		
19241A0282	5	3	3	2	5		
19241A0283	2	3	4	2	3		
19241A0284	4	4	3	3	2		
19241A0285	3	5	5	3	4		
19241A0286	3	2	2	4	4		

19241A0287	4	4	4	2	4		
19241A0288	3	3	2	3	4		
19241A0289	4	5	3	3	5		
19241A0290	3	5	4	5	2		
19241A0291	2	2	5	5	5		
19241A0292	5	5	4	5	4		
19241A0293	2	4	2	5	4		
19241A0294	2	4	5	4	5		
19241A0295	5	4	5	2	3		
19241A0296	4	5	5	5	3		
19241A0297	5	5	5	5	4		
19241A0298	2	3	2	2	3		
19241A0299	5	3	4	5	2		
19241A02A0	3	2	3	4	2		
19241A02A1	5	3	3	5	2		
19241A02A2	2	5	4	5	4		
19241A02A3	3	4	2	5	3		
19241A02A4	4	5	3	4	2		
19241A02A5	3	4	4	4	4		
19241A02A6	3	4	3	4	2		
19241A02A7	2	3	5	2	3		
20245A0206	2	3	3	3	3		
20245A0207	3	3	3	4	2		
20245A0208	3	5	4	3	3		
20245A0209	3	5	2	4	5		
20245A0210	4	5	3	5	4		
20245A0211	4	2	4	2	3		
20245A0212	5	2	4	2	2		
20245A0213	2	4	5	5	3		
20245A0214	3	3	4	5	3		
20245A0215	5	2	3	4	5		
20245A0216	4	3	3	3	5		
20245A0217	2	2	2	3	5		
20245A0218	3	3	2	4	2		
20245A0219	5	3	3	2	4		
20245A0220	2	3	5	4	3		
20245A0221	2	3	4	3	2		
20245A0222	4	4	2	5	2		
20245A0223	2	4	5	4	5		
20245A0224	4	3	5	5	2		

20245A0225	4	4	5	4	5		
if your class strength is > 60 then *insert rows above the green row(Last Record)* , Similarly *delete the empty rows above green row* if the class strenght is < 60)							
Total number of students appeared for the examination (NST)	67	67	67	67	67		
Total number of students attempted the question (NSA)	67	67	67	67	67		
Attempt % (TAP) = (NSA/NST)*100	100.00	100.00	100.00	100.00	100.00		
Total number of Students who got more than 60% marks (NSM)	49	55	53	57	48		
Attainment % (TMP) = (NSM/NST)*100	73.13	82.09	79.10	85.07	71.64		
Score(S)	3	3	3	3	3		

CO attainment is considered zero if the attempt % is less than 30%

Indirect CO (COIn)	CO1	CO2	CO3	CO4	CO5		
	3	3	3	3	3		

!! Caution !! For CO Values < 2.1 should be justified with Remidial Action Report.

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Summary Sheet CO Attainments

Academic Year:	2022-23
Course/Subject:	Power Systems-III
Department:	Electrical and Electronics Engineering
Section	B

Name of the Program:	B.Tech
Course Code:	GR18A4012
Year - Semester :	IV-I

Attainment/CO	CO1	CO2	CO3	CO4	CO5	
Attainment for Direct Internal CO (Mid I & II, Assignments, Tutorials, Assessments, etc.)	2.52	3.00	3.00	3.00	3.00	
Attainment for Direct External CO (End Semester Exam)						
Direct CO (0.3*Internal + 0.7*External)						
Indirect CO	3.00	3.00	3.00	3.00	3.00	
Final CO (COFn) = (0.9 x Direct CO + 0.1 x Indirect CO)						

CO	Course Outcome	Remedial Action for COs Less than 70% (2.1)
CO1	List methods to control the voltage, frequency and power flow.	
CO2	Summaries about Reactive Power compensation	
CO3	Compose monitoring and control of a power system.	
CO4	Recall the basics of power system economics.	
CO5	Write about Demand Side-management	

ID No.	Name of the Faculty	Department	Signature

HOD **DAA**

Copy to: IQAC