GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

Course Title: Power Quality and FACTS (GR18A4071)
Following documents are available in Course File.

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

Course Coordinator

D. Karunakumar

(D Karunakumar)
Assistant Professor
EEE Department

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 help society to achieve self sufficiency.

Mission of the Department

1. To become an internationally leading department for higher learning.
2. To build upon the culture and values of universal science and contemporary education.
3. 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.
4. To develop partnership with industrial, R&D and government agencies and actively participate in conferences, technical and community activities.

GOKARAJU RANGARAJU
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Department of Electrical and Electronics Engineering

Programme Educational Objectives (PEOs):

PEO1: Graduates will have a successful technical or professional careers , including supportive and leadership roles on multidisciplinary teams.

PEO2: Graduates will be able to acquire, use and develop skills as required for effective professional practices.

PEO3: Graduates will be able to attain holistic education that is an essential prerequisite for being a responsible member of society.

PEO4: 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):

PO1: Ability to apply knowledge of mathematics, science, and engineering.

PO2: Ability to identify, formulate, analyze engineering problems using engineering sciences.

PO3: 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..

PO4: Ability to design and conduct experiments, as well as to analyze and interpret data with valid conclusions.

PO5: Ability to utilize experimental, statistical and computational methods and tools necessary for modelling engineering activities.

PO6: 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.

PO7: Ability to adapt broad education necessary to understand the impact of engineering solutions and obtain sustainability in a global, economic, environmental, and societal context.

PO8: Ability to discover ethical principles and bind to professional and ethical responsibility.

PO9: Ability to function as an individual and in multi-disciplinary teams.

PO10: Ability to communicate effectively on complex activities in engineering community and society.

PO11: Ability to develop Project management principles and apply in various disciplinary environments.

PO12: 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

Subject Allocation Sheet- Academic Year 2022-23 / II SEM

S.No.	Faculty	Designation	Faculty ID	YEAR (UG/PG)	Subject Name	No.of Sections	No. of Hours	Total (in Hrs)
1	Dr B Phaneendra Babu	Prof. & HOD	1563	II B.Tech	ACM	1	3	12
				II M.Tech	Dph 1	1	3	
				II M.Tech	DLED	1	3	
				III B.Tech	Mini Proj.	1	3	
2	Dr.D G Padhan	Prof.	1283	I M.Tech	EHV	1	3	11
				I B.Tech	DT	1	2	
				I B.Tech	BEE Lab	1	3	
				III B.Tech	SMI Lab	1	3	
3	Dr. J. Sridevi	Prof.	516	III B.Tech	HVDCTS	1	5	10
				IV B.Tech	ESG	2	5	
4	Dr T Suresh Kumar	Prof.	1494	II B.Tech	PAE	1	5	11
				I Mtech	PE Lab	1	3	
				I Mtech	MSPEC	1	3	
5	V.Vijaya Rama Raju	Asso. Prof.	361	II B.Tech	PDP	1	5	11
				II B.Tech	ACM Lab	1	6	
6	P Ravikanth	Asso. Prof.	1178	II B.Tech	PDE Lab	1	3	11
				I B.Tech	BEE	1	5	
				I B.Tech	BEE Lab	1	3	
7	A Vinay Kumar	Asso. Prof.	881	I M.Tech	PQ Lab	1	3	12
				I M.Tech	PQ	1	3	

				IV B.Tech	PW Phase-II	2	6	
8	Syed Sarfaraz Nawaz	Asso. Prof.	695	Electrical Maintenance Officer				
9	Dr Pakkiraiah B	Asso. Prof.	1593	I M.Tech	IPR	1	2	12
				III B.Tech	MPE	1	5	
				IV B.Tech	PLC	2	5	
10	Dr D Naga Mallesara Rao	Asso. Prof.	1598	I B.Tech	BEE	2	10	10
11	Dr P Sri Vidya Devi	Asso. Prof.	931	III B.Tech	SMI	1	5	11
				III B.Tech	SMI Lab	1	6	
12	Dr D Raveendhra	Asso. Prof.	1604	Long Leave				
13	P.Praveen Kumar	Asst. Prof	609	I B.Tech	BEE	2	10	16
				I B.Tech	BEE Lab	2	6	
14	R. Anil Kumar	Asst. Prof	657	I B.Tech	BEE	1	5	11
				I B.Tech	BEE Lab	2	6	
15	U Vijaya Lakshmi	Asst. Prof	692	II B.Tech	PDE Lab	1	6	15
				I B.Tech	BEE Lab	2	6	
				III B.Tech	SMI Lab	1	3	
16	**D Karuna Kumar**	**Asst. Prof**	**760**	**II B.Tech**	**CS Lab**	**1**	**6**	**17**
				I B.Tech	BEE Lab	2	6	
				IV B.Tech	PQ&FACTS	2	10	
17	M Naga Sandhya Rani	Asst. Prof	882	II B.Tech	PDE Lab	1	3	12
				III B.Tech	PS Lab	1	6	
				IV B.Tech	PW Phase-II	2	3	
18	G Sandhya Rani	Asst. Prof	888	II B.Tech	ACM	1	3	12
				III	PS Lab	1	6	

				B.Tech				
				IV B.Tech	PW Phase-II	2	3	
19	M Rekha	Asst. Prof	933	II B.Tech	ACM Lab	1	6	15
				I B.Tech	BEE Lab	3	9	
20	V Usha Rani	Asst. Prof	1045	II B.Tech	CS	1	5	11
				II B.Tech	CS Lab	1	6	
21	P Prashanth Kumar	Asst. Prof	1055	I B.Tech	BEE	1	5	16
				I B.Tech	BEE Lab	2	6	
				III B.Tech	PLC	1	5	
22	K Sudha	Asst. Prof	1211	I B.Tech	BEE	2	10	13
				I B.Tech	BEE Lab	1	3	
23	M Prashanth	Asst. Prof	1279	II B.Tech	BEEE5	1	5	11
				I B.Tech	BEE Lab	2	6	
24	D Srinivasa Rao	Asst. Prof	1540	I M.Tech	MAEM	3	3	12
				II M.Tech	IS	1	3	
				III B.Tech	NPTEL	1	3	
				III B.Tech	Mini Proj.	1	3	

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY
Department of Electrical and Electronics Engineering

Class Time Table, Individual Timetable

GRIET/PRIN/06/G/01/22-23 **Wef : 16th December 2022**

BTech - EEE - A & B **IV Year - II 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	ESG		PQ & FACTS	BREAK	PW-2		
TUESDAY	ESG		PW-2		PW-2		
WEDNESDAY	PQ & FACTS		ESG		PLC		Mentoring
THURSDAY	PLC	PQ & FACTS			PW-2		
FRIDAY	PLC		PW-2		PW-2		
SATURDAY	PW-2				PW-2		

ROOM NO	
Theory/Tutorial	4404
Lab	MP Phase - 4404
Class Incharge:	M. N. Sandhy Rani

Course Code	Course Name	Faculty Code	Faculty Name (Emp ID)
GR18A4070	Programmable Logic Controllers (PLC)	Dr PB	Dr. Pakkiraiah (1593)
GR18A4071	Power Quality & FACTS (PQ & FACTS)	DKK	D. Karuna Kumar (760)
GR18A4075	Electric Smart Grid (ESG)	Dr. JS	Dr. J. Sridevi (516)
GR18A4108	Project Work Phase-II (PW-2)	AVK/MNSR/ GSR	A. Vinay Kumar (881) /M. N. Sandhya Rani (882)/ G. Sandhya Rani (888)

Almanac	
1st Spell of Instructions	16-12 2022 t 13-02 2023
1st Mid-term Examinations	14-02 2023 t 16-02 2023
2nd Spell of Instructions	17-02 2023 t 26-04 2023
2nd Mid-term Examinations	27-04 2023 t 29-04 2023
Preparation	01-05 2023 t 13-05 2023
End Semester Examinations (Theory/ Practicals) Regular / Supplementary	15-05 2023 t 03-06 2023

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	EHV		Mentoring	BREAK	ED		HVE
TUESDAY	ED		-		EHV		-
WEDNESDAY	PS-III		-		PW-I/ED Lab		
THURSDAY	HVE		EHV		ED	PS-III	
FRIDAY	HVE		PS-III		ED Lab/PW-I		
SATURDAY	PW-I				PW-I		

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

Course Code	Course Name	Faculty Code	Faculty Name (Emp ID)
GR18A4012	Power Systems-III (PS-III)	PK	P. Prasanth Kumar (1055)
GR18A4013	Electroncis 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	Electronic 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)

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

Time Table Coordinator — HOD — DAA

Faculty Name: D Karunakumar

DAY/ HOUR	10.20-11.15	11.15-12.10	12.10-1.05	1.05-1.40	1.40-2.30	2.30 - 3.20	3:20 -4.10
MONDAY	PQ & FACTS			LUNCH			
TUESDAY					PQ & FACTS		
WEDNESDAY	PQ & FACTS						
THURSDAY	PQ & FACTS						
FRIDAY					PQ & FACTS		
SATURDAY	PQ & FACTS						

Branch: EEE	Subject Code: GR18A4071	Academic Year: 2022-23	Regulation: GR18	Year: IV Semester: II

Power Quality and FACTS **L:3 T:0 P:0 C:3**

Syllabus

Unit 1: FACTS Concepts

Transmission Interconnections, Power Flow and Dynamic Stability Considerations of a Transmission Interconnection, Relative Importance of Controllable Parameters, Basic Types of FACTS Controllers -Shunt Connected Controllers, Series Connected Controllers, Combined Shunt and Series Connected controllers.

Unit 2: Shunt Compensators

Objectives of shunt compensation, Mid-point voltage regulation, Improvement of Transient stability, power oscillation damping, Principle of operation of FC-TCR(SVC) compensator, characteristic of FC-TCR and control diagram, Basic concept of voltage source converter, principle of operation of STATCOM, characteristic of STATCOM, control diagram.

Unit 3: Series Compensators

Objectives of series compensation, Improvement of Transient stability, power oscillation damping, Principle of operation of Thyristor controlled series compensator (TCSC), operating characteristics, TCSC control diagram, Principle of operation voltage source converter type series compensator (SSSC). Basic principle of operation of UPFC, transmission control capabilities of UPFC.

Unit 4: Power Quality

Measurements Power Quality problems in distribution systems: Transient and Steady state variations in voltage and frequency. Unbalance, Sags, Swells, Interruptions, Wave-form Distortions: harmonics, noise, notching, dc-offsets, fluctuations. Flicker and its measurement. Tolerance of Equipment: CBEMA curve.

Unit 5: Working Principle of DVR, DSTATCOM

Three phase three wire and three phase four wire D STATCOM topologies description, Principle of operation of DSTATCOM, Control in UPF mode of operation and zero voltage regulation mode, Full bridge single phase DVR and Three phase three wire DVR topology description, Principle of operation of active series compensator (DVR).

Text Books:

1. N. G. Hingorani and L. Gyugyi, “Understanding FACTS: Concepts and Technology of FACTS Systems” , Wiley-IEEE Press, 1999.

2. K. R. Padiyar, “FACTS Controllers in Power Transmission and Distribution”, New Age International (P) Ltd. 2007.

Reference Books

1. Bhimsingh, Ambrishchandra and Kamal AL-Haddad, “Power Quality Problems and Mitigation Techniques” John wiley and sons Ltd 2015

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

COURSE OBJECTIVES

Academic **Y**ear : 2022-23

Semester : II

Name of the Program: B.Tech Year: IV

Course/Subject: Power Quality and FACTS Course Code: GR18A4071

Name of the Faculty: D Karunakumar Dept.: ……EEE………

Designation: Assistant Professor

On completion of this Subject/Course the student shall be able to:

S.No	**Objectives**
1	Analyze the transmission interconnections and relative importance of FACTS controllers.
2	Determine the operating characteristics of Shunt compensators.
3	Understand the working principles of Series compensators.
4	Analyze the basic concepts of Power Quality.
5	Understand the working principle of DVR, DSTATCOM

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

COURSE OUTCOMES

Academic **Y**ear : 2022-23

Semester : II

Name of the Program: B.Tech Year: IV

Course/Subject: Power Quality and FACTS Course Code: GR18A4071

Name of the Faculty: D Karunakumar Dept.: ……EEE………

Designation: Assistant Professor

The expected outcomes of the Course/Subject are:

S.No	**Outcomes**
1	Analyze the characteristics of ac transmission and know basic types of FACTS controllers.
2	Adapt FACTS devices for power-flow control and discuss the working principles of Shunt compensators and their operating characteristics.
3	Discuss the working principles of Series compensators.
4	Interpret the basic concepts of power quality.
5	Determine the working principles of devices DVR and DSTATCOM, to improve power quality.

Note: Please refer to Bloom's Taxonomy, to know the illustrative verbs that can be used to state the outcomes.

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INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

GUIDELINES TO STUDY THE COURSE /SUBJECT

Academic **Y**ear : 2022-23

Semester : II

Name of the Program: B.Tech Year: IV

Course/Subject: Power Quality and FACTS Course Code: GR18A4071

Name of the Faculty: D Karunakumar Dept.: ……EEE………
Designation: Assistant Professor
Guidelines to study the Course/ Subject: Power Quality and FACTS

<u>Course Design and Delivery System (CDD):</u>

The Course syllabus is written into number of learning objectives and outcomes.

These learning objectives and outcomes will be achieved through lectures, assessments, assignments, experiments in the laboratory, projects, seminars, presentations, etc.

Every student will be given an assessment plan, criteria for assessment, scheme of evaluation and grading method.

The Learning Process will be carried out through assessments of Knowledge, Skills and Attitude by various methods and the students will be given guidance to refer to the text books, reference books, journals, etc.

The faculty be able to –

Understand the principles of Learning

Understand the psychology of students

Develop instructional objectives for a given topic

Prepare course, unit and lesson plans

Understand different methods of teaching and learning

Use appropriate teaching and learning aids

Plan and deliver lectures effectively

Provide feedback to students using various methods of Assessments and tools of Evaluation

Act as a guide, advisor, counselor, facilitator, motivator and not just as a teacher alone

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

COURSE SCHEDULE

Academic **Y**ear : 2022-23

Semester : II

Name of the Program: B.Tech Year: IV

Course/Subject: Power Quality and FACTS Course Code: GR18A4071

Name of the Faculty: D Karunakumar Dept.: ……EEE………
Designation: Assistant Professor

S.No	Date	Description	Total No.of Periods
1	16-12-2022	Transmission Interconnections, Power Flow	2
2	17-12-2022	Dynamic Stability Considerations of a Transmission Interconnection	2
3	20-12-2022	Relative Importance of Controllable Parameters	2
4	27-12-2022	Basic Types of FACTS Controllers	2
5	30-12-2022	Shunt Connected Controllers	1
6	31-12-2022	Series Connected Controllers	2
7	03-01-2023	Combined Shunt and Series Connected controllers	2
8	07-01-2023	Revision Unit-I	2
9	13-01-2023	Objectives of shunt compensation	1
10	17-01-2023	Mid point voltage regulation, Improvement of Transient stability	2
11	20-01-2023	Power oscillation damping	1
12	21-01-2023	Principle of operation of FC-TCR(SVC) compensator	2
13	27-01-2023	Characteristic of FC-TCR(SVC)	1
14	28-01-2023	Control diagram, Basic concept of voltage source converter	1
15	31-01-2023	Principle of operation of STATCOM,	2
16	03-02-2023	Characteristic of STATCOM, control diagram	1
17	04-02-2023	Objectives of series compensation,	2
18	10-02-2023	Improvement of Transient stability, power oscillation damping	1
19	11-02-2023	Principle of operation of Thyristor controlled series compensator(TCSC)	2
20	17-02-2023	Operating characteristics, TCSC control diagram	1
21	21-02-2023	Principle of operation voltage source converter	2
22	24-02-2023	Series compensator(SSSC)	1
23	25-02-2023	Basic principle of operation of UPFC	2
24	03-03-2023	Transmission control capabilities of UPFC	1

25	04-03-2023	Power Quality problems in distribution systems	2
26	10-03-2023	Transient and Steady state variations in voltage and frequency	1
27	14-03-2023	Unbalance, Sags, Swells, Interruptions	2
28	17-03-2023	Wave-form Distortions	1
29	18-03-2023	Harmonics, noise, notching, dc-offsets, fluctuations	2
30	24-03-2023	Flicker and its measurement	1
31	25-03-2023	Tolerance of Equipment: CBEMA curve	2
32	28-03-2023	Three phase three wire and three phase four wire	2
33	31-03-2023	DSTATCOM topologies description	1
34	01-04-2023	Principle of operation of DSTATCOM	2
35	04-04-2023	Full bridge single phase DVR	2
36	18-04-2023	Three phase three wire DVR topology description	2
37	21-04-2023	Principle of operation of active series compensator(DVR)	1
38	25-04-2023	DVR Vs DSTATCOM	2

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

SCHEDULE OF INSRTUCTIONS COURSE PLAN

Academic **Y**ear : 2022-23

Semester : II

Name of the Program: B.Tech Year: IV

Course/Subject: Power Quality and FACTS Course Code: GR18A4071

Name of the Faculty: D Karunakumar Dept.: ……EEE………
Designation: Assistant Professor

Exp.No.	No. of Periods	Topics / Sub-Topics	Objectives & Outcomes Nos.	References, (Text Book, Journal…) Page Nos.: ___ _to
I	2	Transmission Interconnections, Power Flow	1	N. G. Hingorani and L. Gyugyi, “Understanding FACTS: Concepts and Technology of FACTS Systems” , Wiley-IEEE Press, 1999.
I	2	Dynamic Stability Considerations of a Transmission Interconnection	1	N. G. Hingorani and L. Gyugyi, “Understanding FACTS: Concepts and Technology of FACTS Systems” , Wiley-IEEE Press, 1999.
I	2	Relative Importance of Controllable Parameters	1	N. G. Hingorani and L. Gyugyi, “Understanding FACTS: Concepts and Technology of FACTS Systems” , Wiley-IEEE Press, 1999.
I	2	Basic Types of FACTS Controllers	1	N. G. Hingorani and L. Gyugyi, “Understanding FACTS: Concepts and Technology of FACTS Systems” , Wiley-IEEE Press, 1999.
I	1	Shunt Connected Controllers	1	N. G. Hingorani and L. Gyugyi, “Understanding FACTS: Concepts and Technology of FACTS Systems” , Wiley-IEEE Press, 1999.

I	2	Series Connected Controllers	1	N. G. Hingorani and L. Gyugyi, "Understanding FACTS: Concepts and Technology of FACTS Systems" , Wiley-IEEE Press, 1999.
I	2	Combined Shunt and Series Connected controllers	1	N. G. Hingorani and L. Gyugyi, "Understanding FACTS: Concepts and Technology of FACTS Systems" , Wiley-IEEE Press, 1999.
I	2	Revision Unit-I	1	N. G. Hingorani and L. Gyugyi, "Understanding FACTS: Concepts and Technology of FACTS Systems" , Wiley-IEEE Press, 1999.
II	1	Objectives of shunt compensation	2	N. G. Hingorani and L. Gyugyi, "Understanding FACTS: Concepts and Technology of FACTS Systems" , Wiley-IEEE Press, 1999.
II	2	Mid point voltage regulation, Improvement of Transient stability	2	N. G. Hingorani and L. Gyugyi, "Understanding FACTS: Concepts and Technology of FACTS Systems" , Wiley-IEEE Press, 1999.
II	1	Power oscillation damping	2	N. G. Hingorani and L. Gyugyi, "Understanding FACTS: Concepts and Technology of FACTS Systems" , Wiley-IEEE Press, 1999.
II	2	Principle of operation of FC-TCR(SVC) compensator	2	N. G. Hingorani and L. Gyugyi, "Understanding FACTS: Concepts and Technology of FACTS Systems" , Wiley-IEEE Press, 1999.
II	1	Characteristic of FC-TCR(SVC)	2	N. G. Hingorani and L. Gyugyi, "Understanding FACTS: Concepts and Technology of FACTS Systems" , Wiley-IEEE Press, 1999.
II	1	Control diagram, Basic concept of voltage source converter	2	N. G. Hingorani and L. Gyugyi, "Understanding FACTS: Concepts and Technology of FACTS Systems" , Wiley-IEEE Press, 1999.
II	2	Principle of operation of STATCOM,	2	N. G. Hingorani and L. Gyugyi, "Understanding FACTS: Concepts and

				Technology of FACTS Systems" , Wiley-IEEE Press, 1999.
II	1	Characteristic of STATCOM, control diagram	2	N. G. Hingorani and L. Gyugyi, "Understanding FACTS: Concepts and Technology of FACTS Systems" , Wiley-IEEE Press, 1999.
III	2	Objectives of series compensation,	3	N. G. Hingorani and L. Gyugyi, "Understanding FACTS: Concepts and Technology of FACTS Systems" , Wiley-IEEE Press, 1999.
III	1	Improvement of Transient stability, power oscillation damping	3	N. G. Hingorani and L. Gyugyi, "Understanding FACTS: Concepts and Technology of FACTS Systems" , Wiley-IEEE Press, 1999.
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IV	1	Transient and Steady state variations in voltage and frequency	4	N. G. Hingorani and L. Gyugyi, “Understanding FACTS: Concepts and Technology of FACTS Systems” , Wiley-IEEE Press, 1999.
IV	2	Unbalance, Sags, Swells, Interruptions	4	N. G. Hingorani and L. Gyugyi, “Understanding FACTS: Concepts and Technology of FACTS Systems” , Wiley-IEEE Press, 1999.
IV	1	Wave-form Distortions	4	N. G. Hingorani and L. Gyugyi, “Understanding FACTS: Concepts and Technology of FACTS Systems” , Wiley-IEEE Press, 1999.
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IV	2	Tolerance of Equipment: CBEMA curve	4	N. G. Hingorani and L. Gyugyi, “Understanding FACTS: Concepts and Technology of FACTS Systems” , Wiley-IEEE Press, 1999.
V	2	Three phase three wire and three phase four wire	5	N. G. Hingorani and L. Gyugyi, “Understanding FACTS: Concepts and Technology of FACTS Systems” , Wiley-IEEE Press, 1999.
V	1	DSTATCOM topologies description	5	N. G. Hingorani and L. Gyugyi, “Understanding FACTS: Concepts and Technology of FACTS Systems” , Wiley-IEEE Press, 1999.
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V	2	Full bridge single phase DVR	5	N. G. Hingorani and L. Gyugyi, "Understanding FACTS: Concepts and Technology of FACTS Systems" , Wiley-IEEE Press, 1999.
V	2	Three phase three wire DVR topology description	5	N. G. Hingorani and L. Gyugyi, "Understanding FACTS: Concepts and Technology of FACTS Systems" , Wiley-IEEE Press, 1999.
V	1	Principle of operation of active series compensator(DVR)	5	N. G. Hingorani and L. Gyugyi, "Understanding FACTS: Concepts and Technology of FACTS Systems" , Wiley-IEEE Press, 1999.
V	2	DVR Vs DSTATCOM	5	N. G. Hingorani and L. Gyugyi, "Understanding FACTS: Concepts and Technology of FACTS Systems" , Wiley-IEEE Press, 1999.

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2. ADDITIONAL TOPICS COVERED, IF ANY, MAY ALSO BE SPECIFIED IN BOLD

3. MENTION THE CORRESPONDING COURSE OBJECTIVE AND OUT COME NUMBERS AGAINST EACH TOPIC

GOKARAJU RANGARAJU
INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

SCHEDULE OF INSTRUCTIONS UNIT PLAN

Academic **Y**ear : 2022-23

Semester : II

Name of the Program: B.Tech Year: IV

Course/Subject: Power Quality and FACTS Course Code: GR18A4071

Name of the Faculty: D Karunakumar Dept.: ……EEE………

Designation: Assistant Professor

Lesson No.	No. of Periods	Topics / Sub - Topics	Objectives	Outcomes	References (Text Book, Journal…) Page Nos.: ____to ____
1	2	Transmission Interconnections, Power Flow	1	1	N. G. Hingorani and L. Gyugyi, "Understanding FACTS: Concepts and Technology of FACTS Systems" , Wiley-IEEE Press, 1999.
2	2	Dynamic Stability Considerations of a Transmission Interconnection	1	1	N. G. Hingorani and L. Gyugyi, "Understanding FACTS: Concepts and Technology of FACTS Systems" , Wiley-IEEE Press, 1999.
3	2	Relative Importance of Controllable Parameters	1	1	N. G. Hingorani and L. Gyugyi, "Understanding FACTS: Concepts and Technology of FACTS Systems" , Wiley-IEEE Press, 1999.
4	2	Basic Types of FACTS Controllers	1	1	N. G. Hingorani and L. Gyugyi, "Understanding FACTS: Concepts and Technology of FACTS Systems" , Wiley-IEEE Press, 1999.

5	1	Shunt Connected Controllers	1	1	N. G. Hingorani and L. Gyugyi, “Understanding FACTS: Concepts and Technology of FACTS Systems” , Wiley-IEEE Press, 1999.
6	2	Series Connected Controllers	1	1	N. G. Hingorani and L. Gyugyi, “Understanding FACTS: Concepts and Technology of FACTS Systems” , Wiley-IEEE Press, 1999.
7	2	Combined Shunt and Series Connected controllers	1	1	N. G. Hingorani and L. Gyugyi, “Understanding FACTS: Concepts and Technology of FACTS Systems” , Wiley-IEEE Press, 1999.
8	2	Revision Unit-I	1	1	N. G. Hingorani and L. Gyugyi, “Understanding FACTS: Concepts and Technology of FACTS Systems” , Wiley-IEEE Press, 1999.
9	1	Objectives of shunt compensation	2	2	N. G. Hingorani and L. Gyugyi, “Understanding FACTS: Concepts and Technology of FACTS Systems” , Wiley-IEEE Press, 1999.
10	2	Mid point voltage regulation, Improvement of Transient stability	2	2	N. G. Hingorani and L. Gyugyi, “Understanding FACTS: Concepts and Technology of FACTS Systems” , Wiley-IEEE Press, 1999.
11	1	Power oscillation damping	2	2	N. G. Hingorani and L. Gyugyi, “Understanding FACTS: Concepts and Technology of FACTS Systems” , Wiley-IEEE Press, 1999.
12	2	Principle of operation of FC-TCR(SVC) compensator	2	2	N. G. Hingorani and L. Gyugyi, “Understanding FACTS: Concepts and Technology of FACTS

					Systems" , Wiley-IEEE Press, 1999.
13	1	Characteristic of FC-TCR(SVC)	2	2	N. G. Hingorani and L. Gyugyi, "Understanding FACTS: Concepts and Technology of FACTS Systems" , Wiley-IEEE Press, 1999.
14	1	Control diagram, Basic concept of voltage source converter	2	2	N. G. Hingorani and L. Gyugyi, "Understanding FACTS: Concepts and Technology of FACTS Systems" , Wiley-IEEE Press, 1999.
15	2	Principle of operation of STATCOM,	2	2	N. G. Hingorani and L. Gyugyi, "Understanding FACTS: Concepts and Technology of FACTS Systems" , Wiley-IEEE Press, 1999.
16	1	Characteristic of STATCOM, control diagram	2	2	N. G. Hingorani and L. Gyugyi, "Understanding FACTS: Concepts and Technology of FACTS Systems" , Wiley-IEEE Press, 1999.
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LESSON PLAN

Academic **Y**ear : 2022-23

Semester : II

Name of the Program: B.Tech Year: IV

Course/Subject: Power Quality and FACTS Course Code: GR18A4071

Name of the Faculty: D Karunakumar Dept.: ……EEE………

Designation: Assistant Professor

Lesson No: 1 Duration of Lesson: 3 hrs

Lesson Title: Transmission Interconnections, Power Flow and Dynamic Stability Considerations of a Transmission Interconnection, Relative Importance of Controllable Parameters, Basic Types of FACTS Controllers -Shunt Connected Controllers, Series Connected Controllers, Combined Shunt and Series Connected controllers

INSTRUCTIONAL/LESSON OBJECTIVES:

On completion of this lesson the student shall be able to:

1. Analyze the transmission interconnections and relative importance of FACTS controllers

2. Understand FACTS controller

3. Applications of FACTS Controllers

TEACHING AIDS : OHP PROJECTOR, WHITEBOARD, MARKER, DUSTER.
TEACHING POINTS :

Assignment / Questions: Derive the equation for Deflection of PMMC.

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Department of Electrical & Electronics Engineering

ASSIGNMENT SHEET – 1

Academic **Y**ear : 2022-23

Semester : II

Name of the Program: B.Tech Year: IV

Course/Subject: Power Quality and FACTS Course Code: GR18A4071

Name of the Faculty: D Karunakumar Dept.: ……EEE………

Designation: Assistant Professor

This Assignment corresponds to Unit No. / Lesson I

1. Discuss how power flow can be controlled in parallel paths.
2. How power flow takes place in parallel paths connected in electrical power systems? Explain.
3. Describe the concept of dynamic stability considerations of a transmission interconnection
4. Explain the benefits of transmission interconnections
5. Discuss different types of FACTS controllers with their general symbolic representations.
6. Explain dynamic stability considerations and what are the benefits from FACTS controllers.

Objective Nos.: I

Outcome Nos.: I

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Department of Electrical & Electronics Engineering

EVALUATION STRATEGY

Academic **Y**ear : 2022-23

Semester : II

Name of the Program: B.Tech Year: IV

Course/Subject: Power Quality and FACTS Course Code: GR18A4071

Name of the Faculty: D Karunakumar Dept.: ……EEE………

Designation: Assistant Professor

1. TARGET:

A) Percentage for pass:

b) Percentage of class:

2. COURSE PLAN & CONTENT DELIVERY:

- OHP presentation of the Lectures
- Solving exercise problems
- Model questions

3. METHOD OF EVALUATION

3.1 Continuous Assessment Examinations (CAE-I, CAE-II)

3.2 Assignments

3.3 Seminars

3.4 Quiz

3.5 Semester/End Examination

Course Outcomes-Program Outcomes (POs) Relationship Matrix (Relationships are indicated by mark HIGH as “H” and MEDIUM as “M”)- PQ & FACTS

		P-Outcomes											
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
C-Outcomes	**1**	H	H		H	H		H	H		H	H	H
	2			M			M		M	M		M	
	3	M	H	H	H	H	H	H		H	H		H
	4		H		H	H		H	M		H	M	H
	5	H		H	M		H	M	M	H	M	M	

GOKARAJU RANGARAJU INSTITUTE OF ENGINEERING AND TECHNOLOGY
(Autonomous)
Department of Electrical and Electronic Engineering

Academic Year: **2022-23**	**Assignment – I**	
Year: **IV**	**Sub: Power Quality and FACTS**	Duration: **03 days**
Semester: **II**	**Code: GR18A4071**	Max Marks: **05**

S. No.	Question	Marks	CO	BL
1.	Discuss how power flow can be controlled in parallel paths.	01	1	2
2.	How power flow takes place in parallel paths connected in electrical power systems? Explain.	01	1	3
3.	Describe the concept of dynamic stability considerations of a transmission interconnection	01	1	3
4.	Explain the benefits of transmission interconnections	01	1	4
5.	Discuss different types of FACTS controllers with their general symbolic representations.	01	1	3

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Academic Year: **2022-23** **Assignment – II**

Year: **IV** **Sub: Power Quality and FACTS** Duration: **03 days**

Semester: **II** **Code: GR18A4071** Max Marks: **05**

S. No.	Question	Marks	CO	BL
1.	Explain with neat diagram of mid-point voltage regulation.	01	2	3
2.	What is FC-TCR(SVC)? What are its applications?	01	2	2
3.	Differentiate between STATCOM and SVC.	01	2	3
4.	Explain the transfer function and dynamic performance of SVC and STATCOM.	01	2	5
5.	Explain the concept of operating point control of Static Compensator.	01	2	3

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Academic Year: **2022-23** **Assignment – III**

Year: **IV** **Sub: Power Quality and FACTS** Duration: **03 days**

Semester: **II** **Code: GR18A4071** Max Marks: **05**

S. No.	Question	Marks	CO	BL
1.	Explain the voltage stability enhancement and power oscillation damping with series capacitive compensation.	01	3	4
2.	Explain the power oscillation damping of Series Compensation.	01	3	3
3.	Draw and explain the Thyristor-Controlled Series Capacitor (TCSC).	01	3	4
4.	Explain the operation of SSSC with necessary waveforms and characteristics	01	3	3
5.	Explain the principal operation of Unified power flow controller (UPFC).	01	3	3

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(Autonomous)
Department of Electrical and Electronic Engineering

Academic Year: **2022-23** **Assignment – IV**

Year: **IV** **Sub: Power Quality and FACTS** Duration: **03 days**

Semester: **II** **Code: GR18A4071** Max Marks: **05**

S. No.	Question	Marks	CO	BL
1.	Define voltage sag and voltage interruption. What is their impact on equipment connected? Discuss the sources of sags and interruptions.	01	5	4
2.	Explain the different terminologies used in power quality.	01	3	5
3.	Explain the need for power quality standardization and the causes for PQ deterioration. Hence Explain the methods for improving it.	01	5	5
4.	Explain Flicker and its measurement.	01	3	5
5.	Briefly Explain CBEMA curves	01	4	5

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Department of Electrical and Electronic Engineering

Academic Year: **2022-23**	**Assignment – V**	
Year: **IV**	**Sub: Power Quality and FACTS**	Duration: **03 days**
Semester: **II**	**Code: GR18A4071**	Max Marks: **05**

S. No.	Question	Marks	CO	BL
1.	Elaborate calculation of rating of DVR and DSTATCOM for voltage sag compensation.	01	5	3
2.	How do you select DC capacitor & Ripple factor for DSTATCOM? Describe.	01	5	4
3.	Discuss the principle of operation of DSTATCOM.	01	5	4
4.	Explain the control of DSTATCOM in UPF mode of operation.	01	5	4
5.	Explain the Principle of operation of active series compensator (DVR)	01	5	4

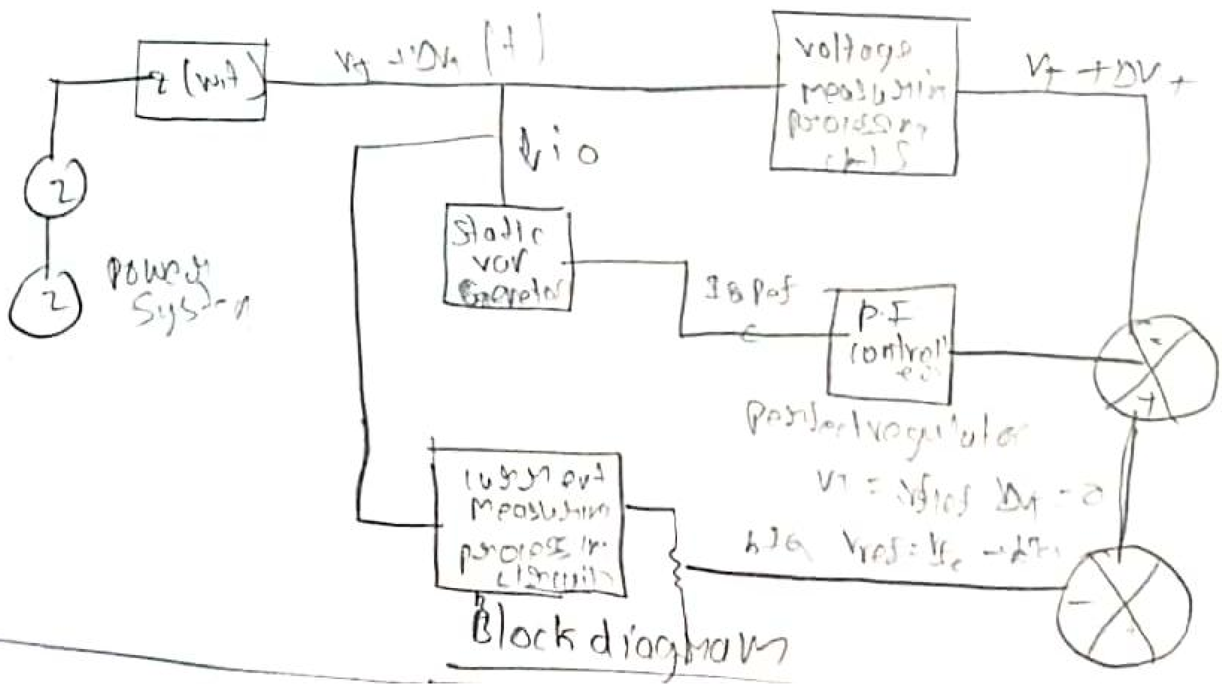
3A) var reverse operating control :-

1) static compensator is consider primarily as a fast var source to counteract rapid & unexpected voltage disturbance due to faults

2) To fullfill these applications & requirements to ensure that full compensator has sufficient var capacity to handle unpredicatable dynamic disturbance

3) This control is to limit the steady stat reactive power o/p the compensator to a given reference power o/p of the compensator transient disturbance

4) However a disturbance results in a new operating point along with steady var output.



Block diagram

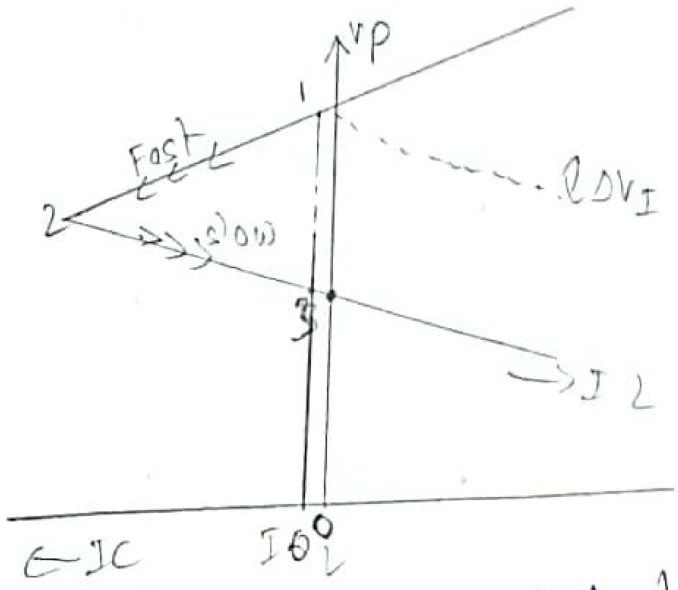
5) The var reverse control effectively changes the voltage reference in order to bring back the var o/p slowly to set value

6) let the compensator operation at point 1 ($I_Q = I_c$) on VI curve a disturbance in the form of a sudden or ~~let the~~ drop in the amplitude of the terminal voltage

7) The voltage change ΔV_T forces, via the fast voltage regulator loop

8) The o/p current increases from the steady state value I_Q and I_{Q_2} and compensator assumes working point 2 on the VI curve

9) However as $I_{C_2} > I_Q$ an error signal ΔI_Q is generated with in the var reverse control loop which via the slow integrator changes the ref. signal to the voltage regulator, forcing the compensator to reduce slowly its o/p current.



simple var reverse control

Transmission Interconnections :-

① Most of the Electric Power systems are interconnected it may be either local, region's wise (or) international connections.

② Interconnections are made mainly becoz of economic benefits like to reduce the cost of electricity & to improve reliability of power supply.

So for these interconnections, controlling power & enhancing power capacity, FACTS Technology is using now a days.

③ FACTS technology is not only a single controller, but also it is a collection of controllers which can be used individually or in coordination with others to control interrelated system parameters like series impedance
shunt impedance
current
voltage
phase angle
Active & Reactive powers

④ Advantages of FACTS technology

(i) Increase of power transfer without adding new transmission lines, by this transmission cost will be minimized.

(ii) steady state & dynamic voltage control

(iii) Improvement of system stability & voltage quality

Power flow in an AC system :-

① In AC Power systems the electrical generation ~~generating~~ and load must balance at all times.

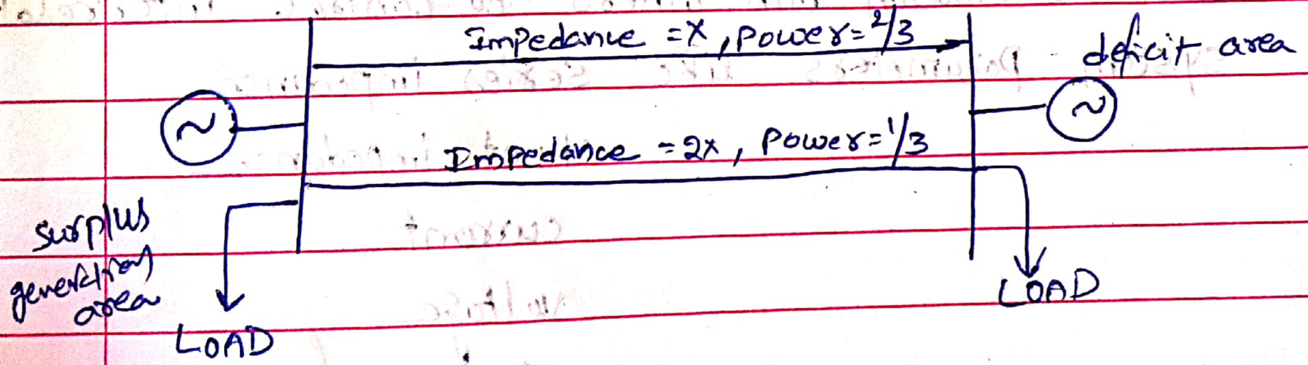
② If generation is less than the load utilization, upto some extent the electrical system is self regulating. after that the voltage & frequency drops down & system will collapse what happens?

③ when there is a adequate generation, active power flows from surplus generation areas to the deficit areas i'e high voltage levels to low voltage levels.

Mostly in AC system power flows through parallel paths.

Power flow in parallel paths :-

case (i) consider a simple case of power flow through two parallel paths.



Here power flow is based on the impedance of transmission line. It inversely related to impedance.

when impedance is X, power is 2/3

when impedance is 2X, power drops to 1/3

$$\boxed{P = \frac{V_1 V_2}{X} \sin\delta}$$

classmate

Consider when impedance is X, Assume, $P = \frac{2}{3} = \frac{V_1 V_2}{X} \sin\delta$

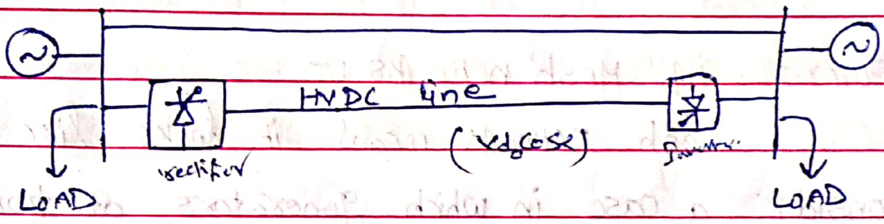
~~when impedance is~~ $P = \frac{2}{3} = \frac{1}{X}$ (inversely related)

if $P = \frac{1}{3} = \frac{1}{2X}$

So when impedance is $2X$, $P = 1/3$

So by varying impedance of transmission line, power flow will be as desired in parallel paths.

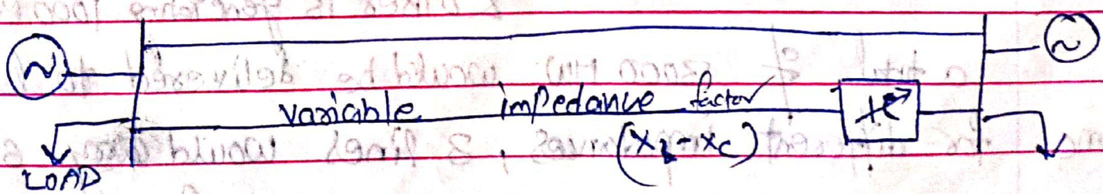
Case(ii)



This figure shows, in 2 parallel paths, one path is HVDC line. HVDC means transmission of power should be dc power.
Thats why starting of HVDC line having rectifier to convert AC to DC & again ending of HVDC line having Inverter to convert back DC to AC for utilization purpose.

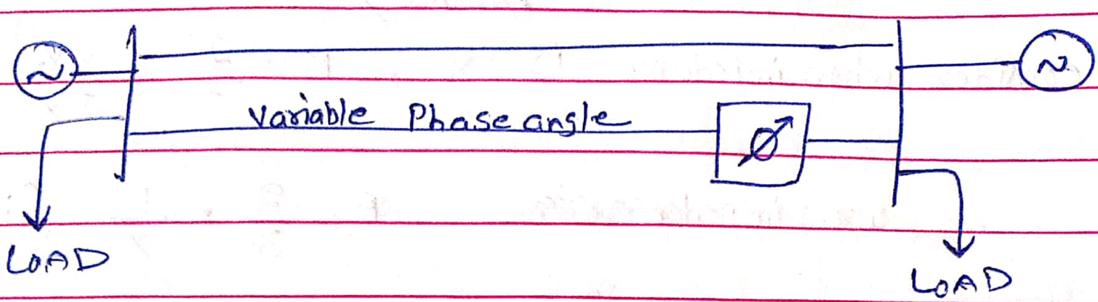
By varying these converters firing angles, power flow will be as desired in these parallel paths.

Case(iii)



By adjusting $(X_L - X_C)$ factor, we can get power flow as desired in lines.

Caleqy

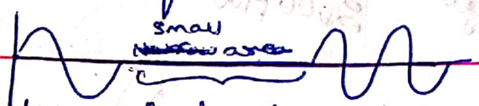


we have relation $P = \frac{V_1 V_2}{X} \sin \delta$ → Phase angle

So by adjusting this Phase angle, we can control flow of power and can get desired power in parallel paths.

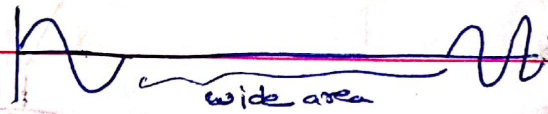
Power Quality problems :-

→ Blackouts :- It is short (or) long term loss of electric Power to an small area.



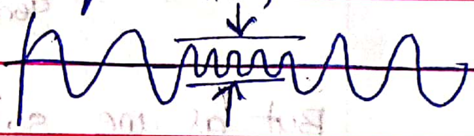
Causes :- Faults at Power stations damage of transmission lines, short ckts

→ Brown outs :- International voltage drop in electrical power supply system

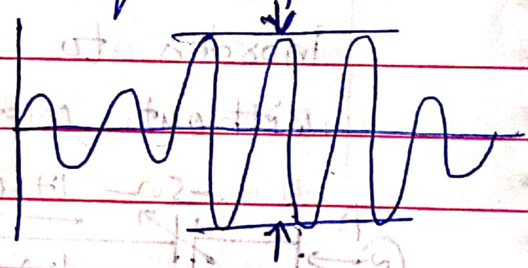


Causes :- Excessive loads

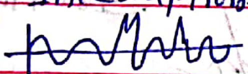
→ voltage sag (or) dip :- A decrease of voltage level b/w 10 to 90% of normal voltage for 0.5 cycle to 1 cycle of duration.



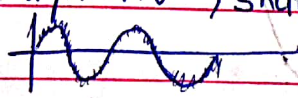
→ voltage swell (or) rise :- An Increase of voltage level b/w 10 to 90% of normal voltage for 0.5 cycle to 1 cycle of duration



→ short Interruptions & long Interruptions :-

→ voltage spikes :- 

→ voltage surges :- due to lightning, shutdown of heavy loads suddenly.

→ Harmonic distortion :- 

→ Flickering :- visible change in brightness of lamp due to rapid fluctuations in the voltage.

→ Noise :- superimposing of high frequency signals.

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Thermal
Dielectric
Steady state stability } 3/4/19

Loading capability limits :-

To improve (or) To get the maximum transmission capacity, the loading capability of transmission line must be so good & efficient.

But there are some limitations of loading capability.

Mainly "Loading capability means Power Transfer capability"

⇒ **Thermal** :- Thermal capability of a transmission line is related with (or) "it is a function of ambient temperature", wind conditions, Physical parameters of conductor, so mainly depends upon the Environmental conditions.

→ To estimate line's loading capability some computer programs can be used, these software programs can calculate loading capability based on environmental conditions & previous loading history.

→ In some cases, online monitoring devices are incorporated. These devices gives online real time loading capability values of transmission line.

→ Thus by using modern automation techniques, GPS systems, & various sophisticated communication systems, loading capability of transmission line can be monitored hour to hour & day to day i.e in regular intervals of time.

→ During design stage of transmission line only, loading capability of a transmission line is estimated by taking various loss factors into account.

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→ Dielectric :-

Dielectric property means, it is related to insulating property of Transmission lines. care should be taken while designing the insulation levels of transmission lines, that given insulation should withstand higher transient overvoltages. some examples for good insulating property devices are,

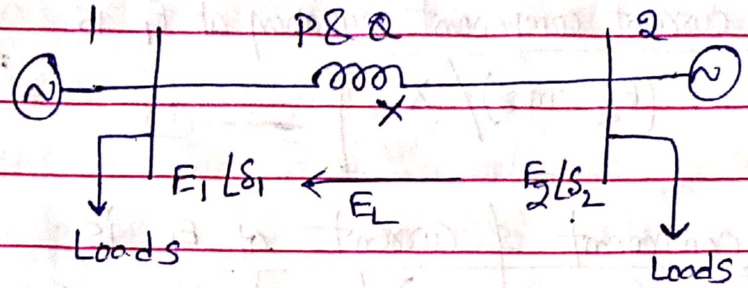
- Modern gapless arresters
- line insulators
- Powerful thyristor controlled overvoltage suppressors.

These devices give good insulation which can protect from harmful overvoltages.

→ These are some other factors which effect the transmission line loading capability, those are

- steady state stability
- Transient stability
- dynamic stability
- Frequency collapse
- Voltage collapse
- Resonance

Dynamic stability considerations :-

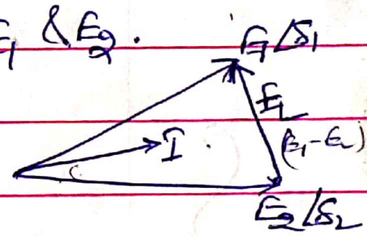


① This figure shows a simple power flow of a transmission line. Assume 1 & 2 are substations which are connected by a transmission line. These substations having corresponding loads.

② E_1 is the bus voltage at substation 1 } E_1 & E_2 are the bus voltages at 1 & 2 substa.
E_2 is the bus voltage at substation 2 }

③ The line is having an impedance of "X" (Assume it is an inductive impedance by ignoring resistance & capacitance).

④ consider E_L is the voltage difference b/w E_1 & E_2.



so

The line current is given by

$E_L \to E_1 \sim E_2$

$$\boxed{I = E_L / X}$$

E_L – resultant line voltage

Here I lags E_L by 90°, as, we assumed the line impedance is inductive nature.

⑤ By increasing ~~or~~ decreasing the impedance of a line, we can get desired power flow in the transmission line.

by varying impedance, current control can also be achieved. (so both current control as well as power flow control is possible)

Relation b/w active & Reactive current components with voltages :

The active current component equation at E_1 is

$$\boxed{I_{p_1} = (E_2 \sin\delta)/X} \quad \text{——} (1)$$

$I_{p_1} = \frac{E_1}{X} = \frac{E_2 \sin\delta}{X}$ (we can also written as E_1 & E_2 differ by δ $\therefore E_1 = E_2 \sin\delta$)

At bus 1

Reactive component of current at E_1 is

$$\boxed{I_{q_1} = (E_1 - E_2\cos\delta)/X} \quad \text{——} (2)$$

Active power at E_1 : $P_1 = E_1 I_{p_1} \Longrightarrow \boxed{P_1 = \frac{E_1 E_2 \sin\delta}{X}}$ —— (3)

Reactive power at E_1 : $Q_1 = E_1 I_{q_1} \Longrightarrow \boxed{Q_1 = \frac{E_1(E_1 - E_2\cos\delta)}{X}}$ —— (4)

similarly

Active component of current at E_2 :

$$\boxed{I_{p_2} = E_1 \sin\delta / X} \quad \text{——} (5)$$

At bus 2

Reactive component of current at E_2 :

$$\boxed{I_{q_2} = (E_2 - E_1\cos\delta)/X} \quad \text{——} (6)$$

Active power at E_2 : $P_2 = E_2 I_{p_2} \Longrightarrow \boxed{P_2 = \frac{E_1 E_2 \sin\delta}{X}}$ —— (7)

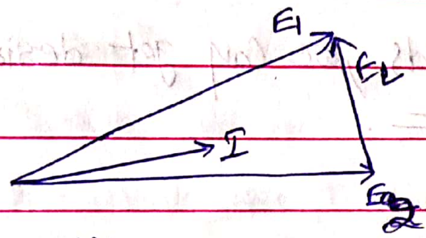
Reactive power at E_2 : $Q_2 = E_2 I_{q_2} \Longrightarrow \boxed{Q_2 = \frac{E_2(E_2 - E_1\cos\delta)}{X}}$ —— (8)

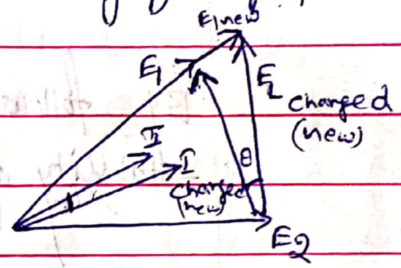
By observing the above equations, we can concluded as by adjusting E_1 & E_2, phase angle and impedance we can get control on current as well as power

Power

Eg:- ① suppose if we change the magnitude of E_1, the resultant voltage E_L magnitude may not change much but ~~differs~~ changes phase angle, let us say 'θ', by that current also changes with some phase angle.
This phase angle variation mainly influence the reactive power flow than the active power flow. Thus control on reactive power achieved.

Before changing Mag. of E_1 After changing Mag of E_1

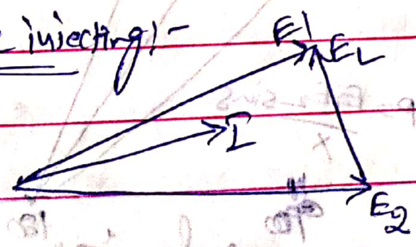




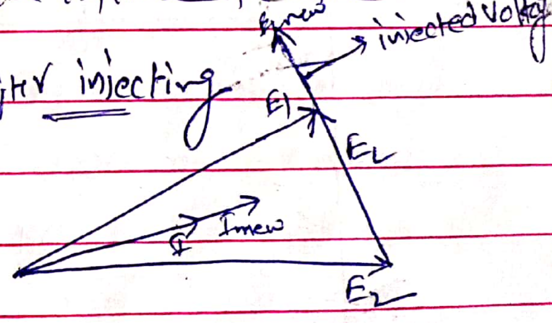
In this case mainly Reactive power can be controlled

Eg:-2 ② if some voltage is injected in series with the line, that is also effects the current flow as well as powerflow
The series injected voltage changes magnitude of current not Phase. so, by this, control on active power is achieved than the reactive power. " Magnitude variation influence the active power "

Before injecting:-



After injecting



In this case mainly Active Power can be controlled.

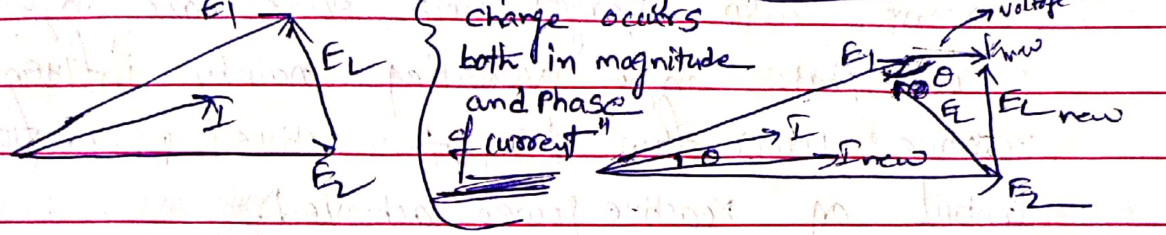
In eg① E_1 will be added by some voltage without Phase, there only reactive power can be controlled.

but in below eg ③ E_1 will be added by some voltage with some phase difference. by this both active & reactive powers can be controlled

Eg ③ :- Before adding

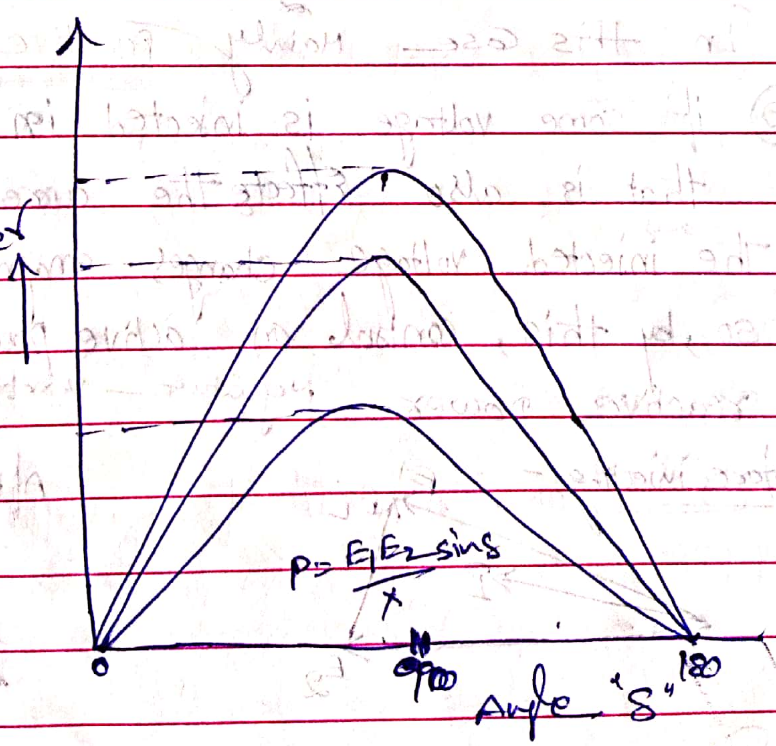
"By this adding change occurs both in magnitude and phase of current"

After adding



Note :- In Eg ① Reactive power will be controlled
In Eg ② Active Power will be controlled
In Eg ③ Both Active & reactive Powers can be Control

By following above methods, we can get desired dynamic stability of a system.



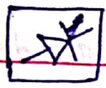
Increase & decrease of the value of 'X' will increase & decrease the height of the curves.

For a given power flow, varying "X" value corresponding vary the angle between two ends of transmission line

Basic types of FACTS controllers :-

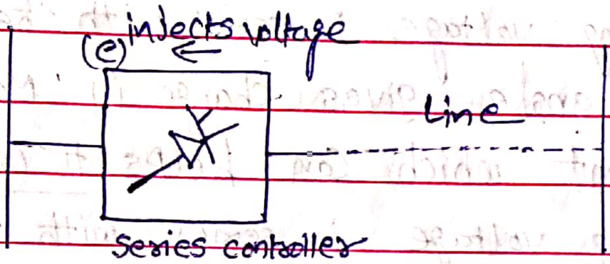
Basically FACTS controllers are divided into 4 types
- → series controllers
- → shunt controllers
- → combined series-series controllers
- → combined series - shunt controllers

General symbol for Facts controller

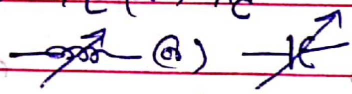


→ **series controllers :-**

series controller is connected in series with the line.



This series controller could be a variable impedance, it may be capacitance or inductance X_L (or) X_C or variable source or combination.



Principle : series controllers inject voltage in series with the line.

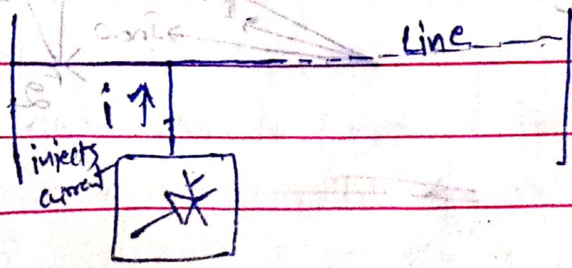
Amount of injected voltage = product of variable impedance & current.

if the phase difference b/w voltage & current is 90°, reactive power will be controlled, any other phase relationship other than 90° will give real power control also.

$Q = VI \sin\varphi$ → 90° max value
$P = VI \cos\varphi$, other than 90
if 90°, real = 0

→ **shunt controllers :-**

shunt controller is connected in ~~[illegible]~~ shunt to the line



Like series controllers, shunt controllers are also comprised with variable impedance, variable source or a combination of these.

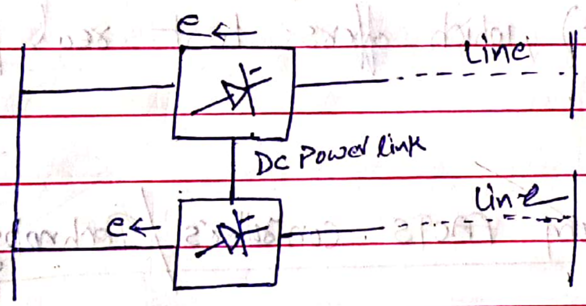
principle- shunt controllers inject current into the line @ electrical system.

$$\text{Amount of injected current} = \frac{\text{line voltage}}{\text{Variable shunt impedance connected to the line.}}$$

Like series controllers,

if injected current is in phase quadrature with the line voltage (i.e angle b/w them is 90°), reactive power can be controlled. Any other phase relationship gives real power control.

→ Combined series-series controllers :-



The name itself gives, these are a combination of separate individual series controllers, which works in a coordinated manner. These type of controllers are mainly used in multiline transmission system. ~~These can be called as unified controllers~~

Both controllers are connected through DC power link (To get minimize losses) (transferring DC power)

series controllers provide independent reactive compensation for each line, and transfer real power among the lines via the power link.

Note: These are also called as Inter line power flow controllers (IPFC) which balance both real & reactive power in the lines and improve efficiency of the transmission system.

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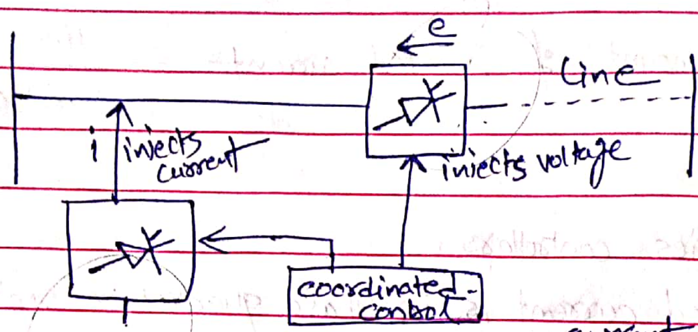
→ Combined series - shunt controllers :-

These are a combination of separate shunt & series controllers, which works in a coordinated manner.



In this, shunt controller injects ~~voltage~~ current into the line & series controller injects ~~current~~ voltage into the line.

Thus requirement of both voltage & current make use of combined series-shunt cont.

Note :- These are also referred as unified power flow controllers (UPFC), which offers best real power control in the line.

Benefits from FACTS controllers / Technology :-

1. Control of power flow as desired.
2. Increase the loading capability of transmission lines.
3. Increase the system security by limiting the short circuit currents & overloads.
4. Managing various power quality problems.
5. Provide greater flexibility to the system
6. use for upgradation of lines.
7. Reduce reactive power flows & allowing ~~the~~ lines to carry more active power.
8. Reduce internal loop flows.
9. Increase economical benefits of overall system generation & utilization. 10. Enhances Power capacity which is cost effective.

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UNIT-3
Static shunt compensation

Objectives of shunt compensation :-

① Reactive shunt compensation gives steady state transmittable Power and controlled voltage along the line.

② The main Purpose of this reactive compensation is to change the natural electrical characteristics (by adjusting some parameters) of the transmission line and make it more efficient to withstand load demand.

③ shunt connected reactors are used to minimize ↑ over voltages under light load conditions. (as it absorbs reactive power) sudden problem

④ shunt connected capacitors are used to improve voltage levels under heavy load conditions. (as it boosts reactive power)

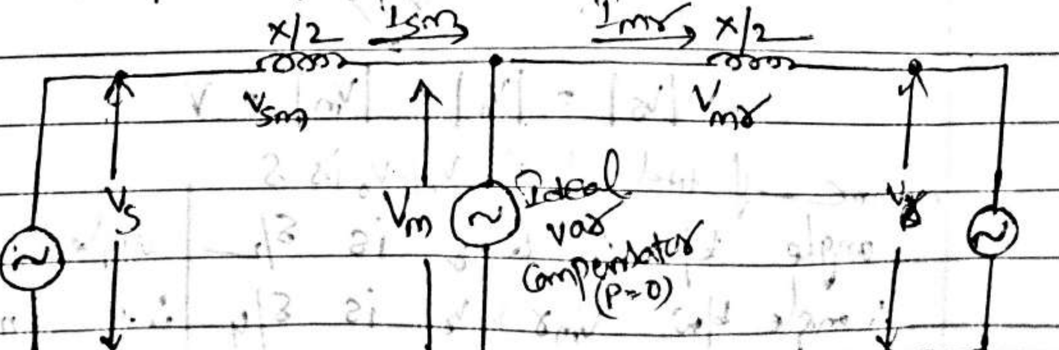
shunt capacitors : source of reactive power : boosters

shunt reactors : sink of reactive power : absorbers

⑤ Thus the main objective of shunt compensation is
→ to increase the transmittable power
→ to improve the steady state transmission characteristics as well as stability of the system.

Mid point voltage regulation :-

1. consider a simple two machine (two bus) transmission model.
2. An ideal reactive power compensator is shunt connected at the midpoint of the transmission line.



Two Bus Transmission System

3. The line is represented by series line inductance.

4. The midpoint voltage is V_m, which is equal to sending end & receiving end voltages

$$\therefore \boxed{V_m = V_s = V_r = V} \rightarrow \text{assumed}$$

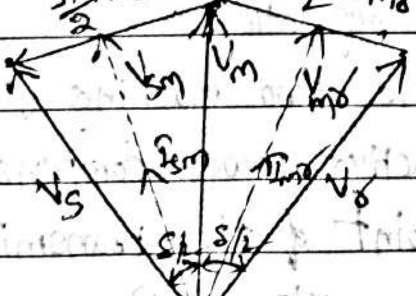
5. The midpoint compensator divides the transmission line into two equal independent parts.

6. The first segment having an impedance of $X/2$ carries power from sending end to the midpoint.

7. The second segment with impedance of $X/2$ carries power from midpoint to the receiving end.

The voltage corresponding to first segment - V_{sm}
The voltage " " second segment - V_{mr}
& corresponding line currents - I_{sm} & I_{mr}

Phasor diagram which relates above parameters is,



load is not considered
active load
no lagging current
...ve only

I_{sm} is in phase with V_{sm}
I_{mr} is in phase with V_{mr}

$$|V_s| = |V_r| = |V_m| = V$$

assume if total angle b/w V_s & V_r is δ

angle b/w V_m & V_r is $\delta/2$	angle b/w V_s & V_m is $\delta/2$
$\therefore$ angle b/w V_{mr} & V_r is $\delta/4$	$\therefore$ " " V_{sm} & V_s is $\delta/4$

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$\therefore V_{sm} = V_s \cos \delta/4$

$\Rightarrow \boxed{V_{sm} = V \cos \delta/4}$ $\because |V_s| = |V_r| = |V|$

& $V_{mr} = V_r \cos \delta/4$

$\Rightarrow \boxed{V_{mr} = V \cos \delta/4}$ $\because |V_s| = |V_r| = V$

$\therefore \boxed{V_{sm} = V_{mr} = V \cos \delta/4}$

$L = \frac{X}{2} + \frac{X}{2} = X$

similarly $\boxed{I_{sm} = I_{mr} = I} = \frac{1}{L} \int V_{sm}\, dt$

$I = \frac{1}{X/4} \int V \cos \delta/4 \; d\delta$

$\boxed{I = \frac{V}{X} \frac{\sin \delta/4}{1/4} = \frac{4V}{X} \sin \delta/4}$

Transmitted power is

$P = V_{sm} \cdot I_{sm} = V_{mr} \cdot I_{mr}$

$= V \cos \delta/4 \cdot I$

$\Rightarrow \boxed{P = VI \cos \delta/4}$ $\therefore \boxed{Q = VI \sin \delta/4}$

$P = V \cdot \frac{4V}{X} \sin \delta/4 \cdot \cos \delta/4$

$P = \frac{2V^2}{X} 2 \sin \delta/4 \cdot \cos \delta/4$ $(2 \sin A \cos A = \sin 2A)$

$P = \frac{2V^2}{X} \sin 2 \frac{\delta}{4}$

classmate

$$\Rightarrow \boxed{P = \frac{2V^2}{X} \sin \delta/2} \quad \text{—— (1)}$$

$\sin 2A = 2 \sin A \cos A$
$\cos 2A = \cos^2 A - \sin^2 A$
$= 2\cos^2 A - 1$
$= 1 - 2\sin^2 A$
$\sin^2 A = \frac{1}{2}(1 - \cos 2A)$
$\cos^2 A = \frac{1}{2}(1 + \cos 2A)$

Similarly we have $Q = VI \sin \delta/4$

$$Q = V \frac{4V}{X} \sin\delta/4 \cdot \sin\delta/4$$

$$Q = \frac{4V^2}{X} \sin^2 \delta/4$$

(since formula $\sin^2 A = \frac{1}{2}(1 - \cos 2A)$)

$$Q = \frac{4V^2}{X} \frac{1}{2}\left(1 - \cos 2\,\delta/4\right)$$

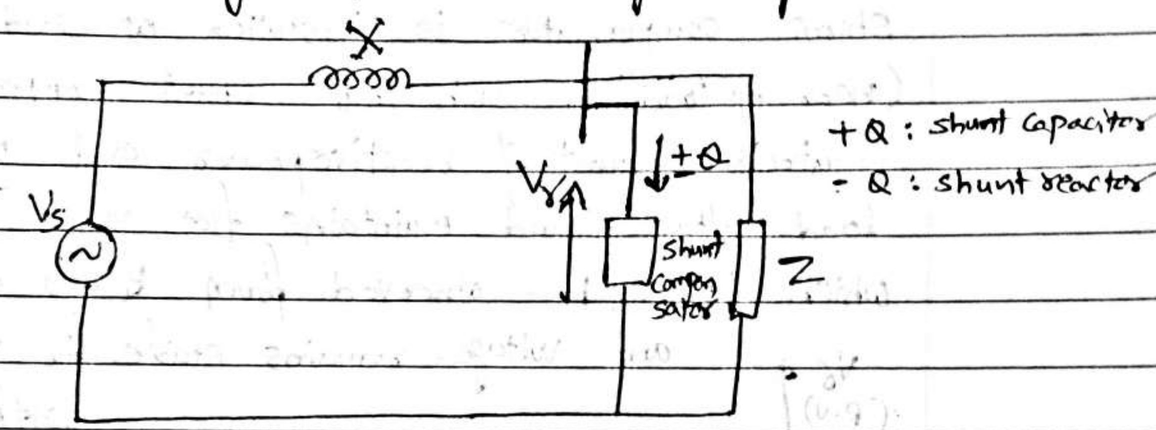
$$\boxed{Q = \frac{2V^2}{X}\left(1 - \cos\frac{\delta}{2}\right)} \quad \text{—— (2)}$$

Note :- (i) By observing the above equations (1) & (2) we can conclude that the mid point shunt compensation can significantly increase the power transfer (amost it is double). And also

(ii) mid point of the transmission line is the best location for shunt compensation & for voltage regulation, why because the voltage sag level is very high at midpoint of line, so we need to regulate that sag voltage by connecting shunt compensator at mid point of t/r line.

Voltage instability prevention :-

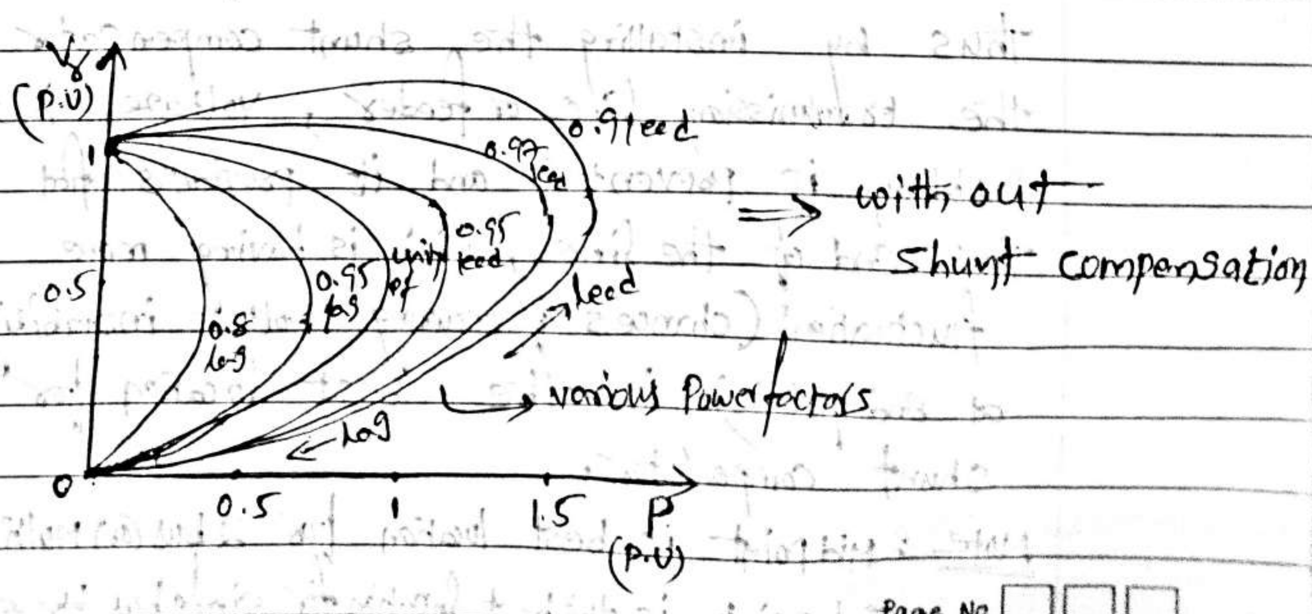
Previous mid point voltage regulation is best suitable for 2 bus transmission system. Mid point of line is best location in this case. But, if system has single bus ~~system~~, end of the line is the best location for installing shunt compensator because end of the line always experiences large voltage variations.



Single bus system

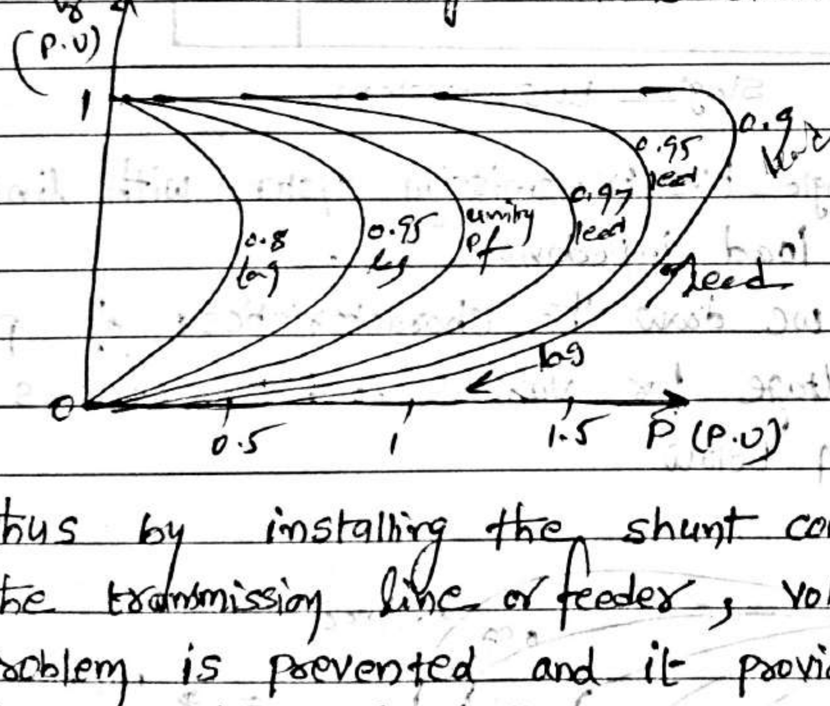
Consider single bus transmission system with line reactance "X" having ~~a~~ load impedance "Z".

If we draw the characteristics of power verses receiving voltage for various load power factors, the curves as shown below



In general if load pf varies, load voltage also varies but this variation should be in limits, load voltage should not go beyond the specified range of limits. But by observing the above characteristics, receiving end voltage or load voltage fluctuating beyond the limits, it is not at all maintaining flat voltage profile.

so to restrict the above problem, shunt compensator is installed at end of the line (near by load), such that shunt compensator provides required amount of reactive power and regulates the load voltage and maintains flat voltage profile, which it can be observed from below characteristics. and voltage remains stable for various Powerfactors.



Thus by installing the shunt compensator at End of the transmission line or feeder, voltage instability problem is prevented and it provides flat voltage profile. Thus end of the line, which is having more voltage fluctuations (chances of occurring voltage instability is more at end points) is the best location for installing shunt compensator.

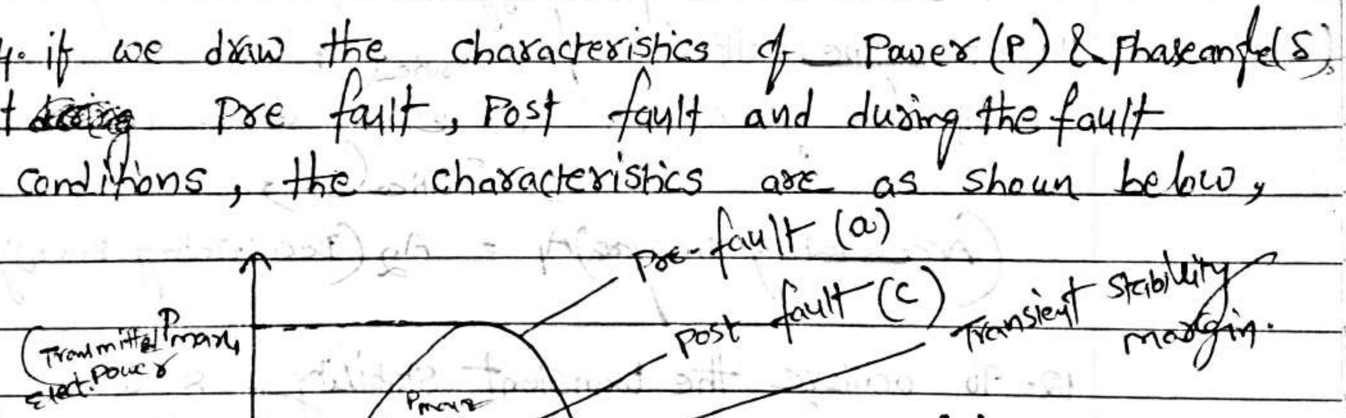
Note : Mid point is best location for 2 bus (or) Multi bus t/r system
End point is the best location for single bus t/r system.

The ability of a power system to return to its stable condition after large disturbances (like general situations like switching on & off of ckt elements (or) clearing faults) is referred as Transient stability of a power system.

Improvement of Transient stability :- (In general these disturbances happens very small period around 1 sec (or) even less)

1. Shunt compensation also improves transient stability of a system by controlling the power during fault conditions and ensures to get original characteristics of system after fault conditions.
2. This transient stability improvement can be conveniently evaluated by the concept of "equal area criterion"
3. Consider a simple two bus, two line transmission system

4. If we draw the characteristics of Power (P) & Phase angle (δ) at pre fault, post fault and during the fault conditions, the characteristics are as shown below,



Area covered b/w δ_1 to δ_2 : Accelerating area
Area " " δ_2 to δ_3 : decelerating area

5. The complete system is characterised by curve (a)
6. During the fault, system is characterised by curve (b), in this period the transmitted power decreases significantly even though the mechanical power i/p to

the sending end generator is constant/normal level.

7. As a result, the generator accelerates and transmission angle increases from δ_1 to δ_2, at this particular angle protective circuit breakers separate the faulty section from the healthy part. i.e disconnect the faulted line segment-1, then the sending end generator absorbs acceleration energy, which is represented by area "A1".

8. After fault clearing, the system is characterized by curve "c"

9. At "δ_2", the transmitted power exceeds the mechanical power (P_m) and the sending end generator decelerates and angle further increases to "δ_3".

10. This decelerating energy is represented by area (A_2).

11. At some critical angle $\delta_{critical}$, both energys are equal according to equal area criterion,

i.e at $\delta_3 = \delta_{critical}$,

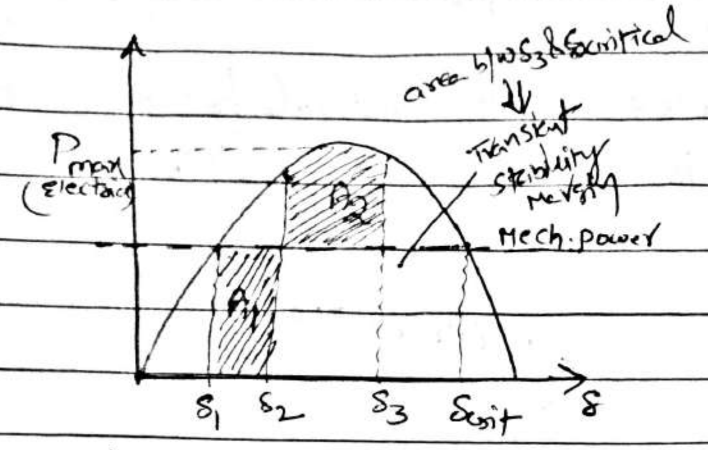
(Accelerating Energy area) $A_1 = A_2$ (Decelerating energy area)

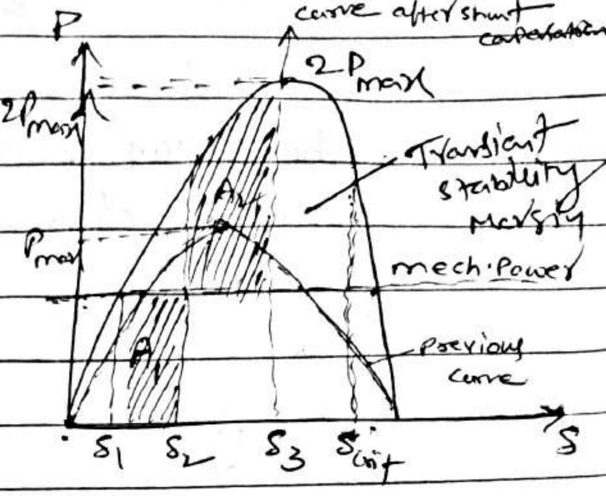
12. To achieve the transient stability δ alters from δ_3 & finally settles at $\delta_{critical}$.

So that the area b/w δ_3 and $\delta_{critical}$ is known as "transient stability margin" of the system.

After fault clearance,

13. By providing the shunt compensation, the transmission power capacity increases well and automatically enhances transient stability of the system.





Before shunt compensation — After shunt compensation, the power almost double the original power as it increases the stability margin.

Note : mech. i/p > elet. o/p : Gen. goes to acceleration mode
if elet. o/p > mech. i/p : Gen. goes to deceleration mode

During fault, transmittable o/p is significantly reduced.
(supplied)

After fault clearance again o/p is going to increase above mech. i/p
↳ if o/p is more, leads to swell of system, so inorder to restrict that gen. goes to deceleration mode.

Power oscillation damping :-

1. In the case of under-damped power system, any small disturbance can cause large variation in machine angle.
2. the lack of sufficient damping is a major problem which causes reduced transmittable power.

→ 3. Under damped system :
The system oscillates with the amplitude gradually decreasing to zero

→ over damped system :
The system returns to equilibrium without oscillating

→ critically damped system :
The system returns to equilibrium as quickly as possible without oscillating { only difference b/w critically & over damped system is critically damped system comes so fast to equilibrium than over damped. It takes less time to regain equilibrium. }
(stable state)

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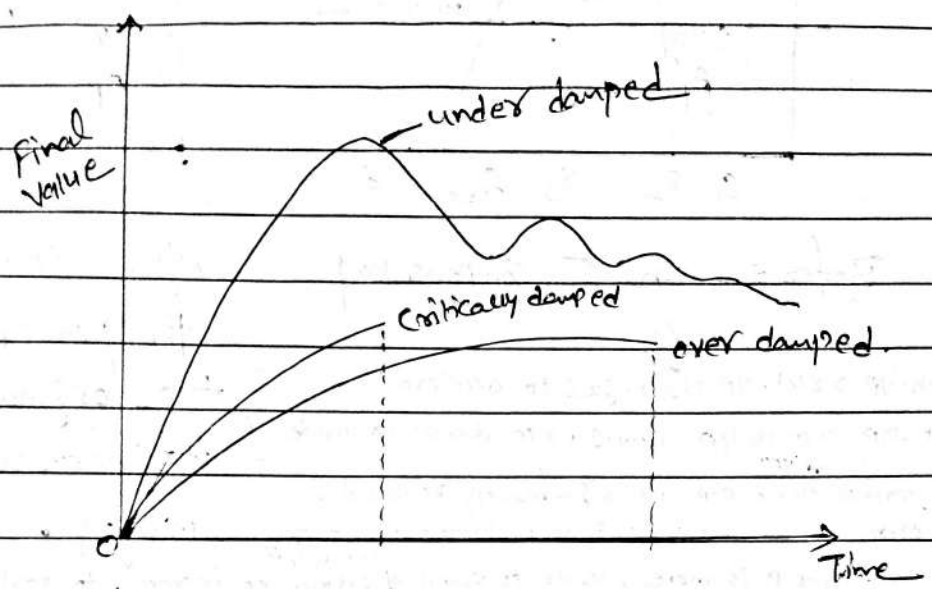
UnDamped ⟷ Damped (finally gets stable state)

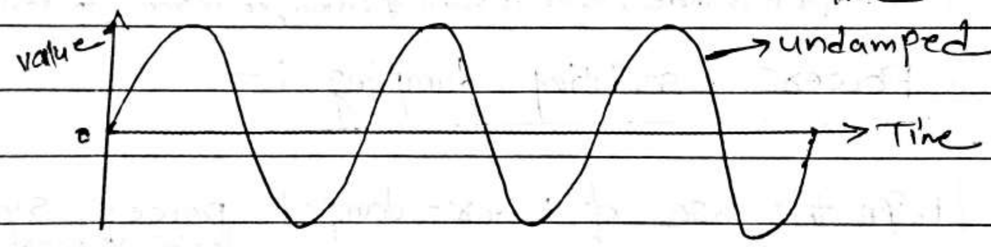
↓ does not get stable state

under damped, over damped, critically damped

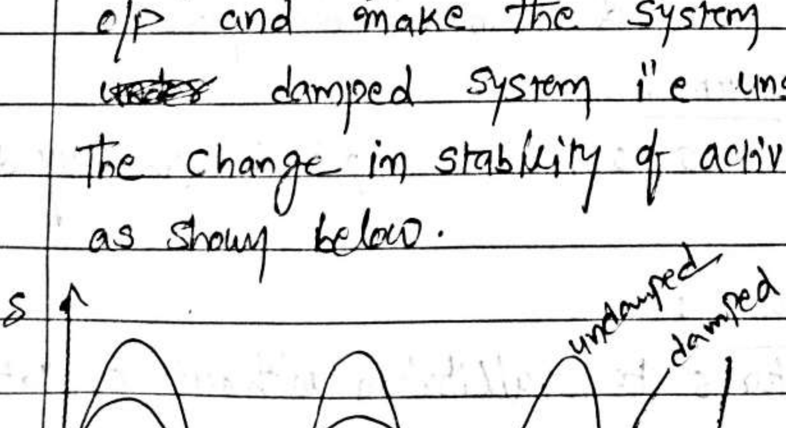
→ undamped system :

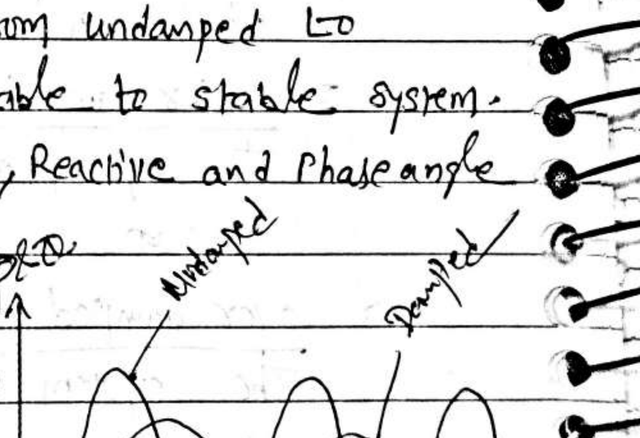
The system oscillates at it's natural frequency continuosly such that there is no return of equilibrium.





so by providing shunt compensation, it stabilizes the o/p and make the system from undamped to ~~under~~ damped system i'e unstable to stable system. The change in stability of active, Reactive and Phase angle as shown below.





Methods of controllable Var generation :- [Reactive Power Generation

1. In general capacitors are the sources of reactive power & inductors are the sinks of reactive power i.e capacitors produce reactive power and inductors absorb reactive power, when connected to A.C power source/system.
2. In olden days to control the reactive power either in generation (or) absorption, mechanical switches have been used.
3. For continuous variable reactive power compensation synchronous machines are used in earlier days, later saturating reactors in conjunction with fixed capacitors are used.
4. using appropriate switching control, the reactive power can be controlled continuously.
5. In early 1970's high power line commutated thyristors with capacitors & reactors have been introduced to produce variable reactive power.
6. Recently Gate turn off thyristors and other power semiconductors with internal turn off capability have been used to generate and absorb reactive power without using capacitors & reactors.
7. All the semi conductor power circuits with different internal control strategies collectively called as "static Var generators" "SVG" which are used to generate reactive power.
8. If o/p of "SVG" is varied by adjusting or controlling specific parameters like voltage & frequency then it is called as "static Var compensator - SVC", so SVC is sub class of SVG. Thus static var generator becomes static Var compensator if it is equipped with special external control system.

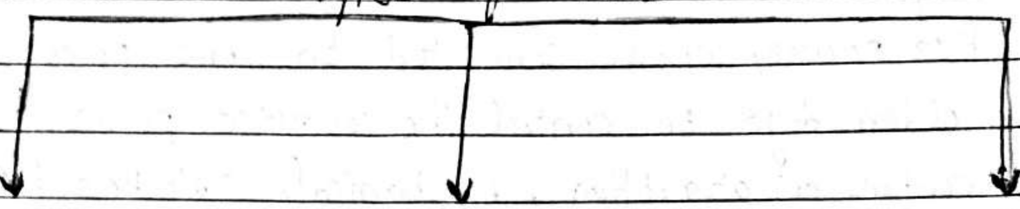
Therefore

SVC $\Longrightarrow$ SVG - with External control system

9. Modern static var generators are based on high power semiconductor switching circuits.

Basic classification of SVG $\xrightarrow{}$: Static Var Generators

Types of SVG



(i) Variable Impedance type (ii) switching converter type (iii) Hybrid var generators

Variable Impedance type static var generators :-

In this variable impedance type, there are 2 types -

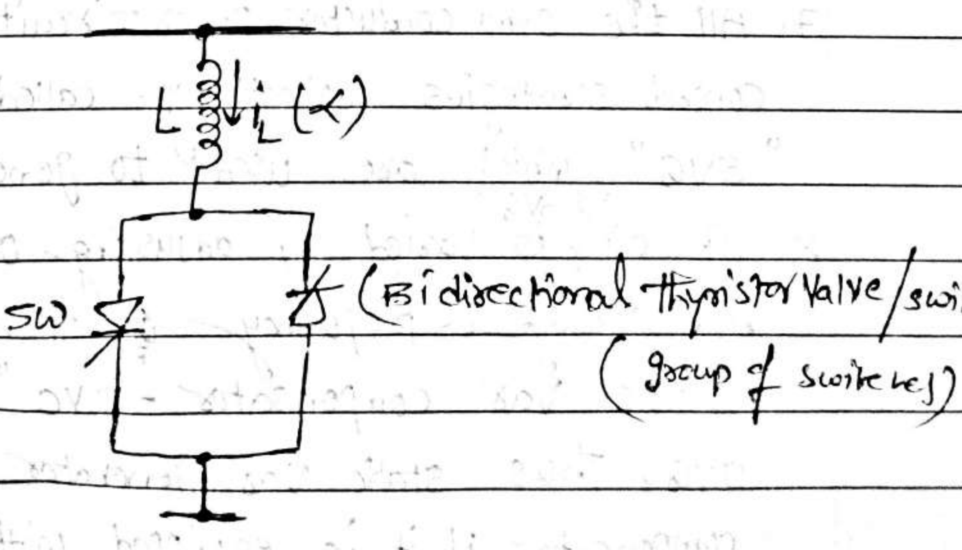
(i) TSR - Thyristor switched Reactor

(ii) TSC - Thyristor switched capacitor

(i) TSR : Thyristor switched Reactor :-

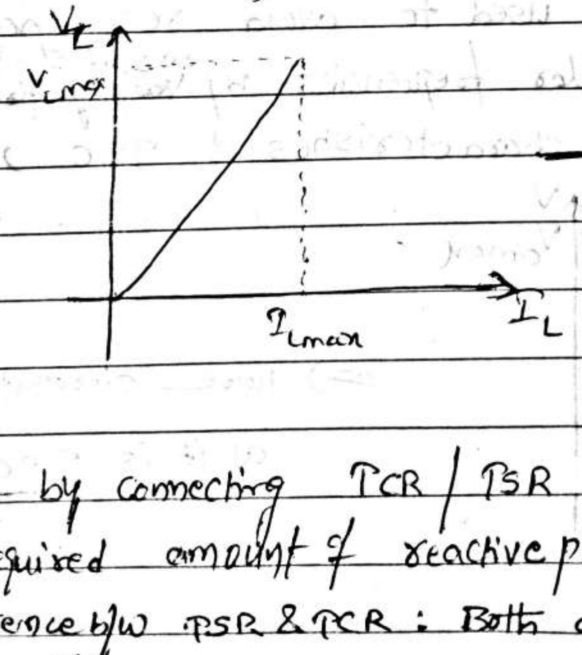
Before going to discuss "TSR", we need to know about TCR - Thyristor controlled Reactor.

TCR : Basic thyristor controlled reactor is shown below



1. It consists of a fixed reactor of inductance L and a bidirectional thyristor valve or switch (SW).
2. currently available large thyristors can block voltage upto 4000 - 9000 volts and conduct current upto 3000 to 6000 amp.
3. If required, to meet the desired blocking voltage levels, thyristors are connected in series.
4. This thyristor switch can be brought into conduction by simultaneous application of a gate pulses
5. The current in the reactor can be controlled by varying firing angle of thyristor switches with some delay.

Note:- 6. If the TCR switching is restricted to particular fixed delay angle, usually "$\alpha=0$", then it becomes thyristor switched reactor (TSR).
7. Because of fixed delay angle, TSR provides a fixed inductive admittance to the ac system. Then reactive current in TSR will be proportional to the applied voltage.
8. Thus operating characteristics of VI can be drawn as

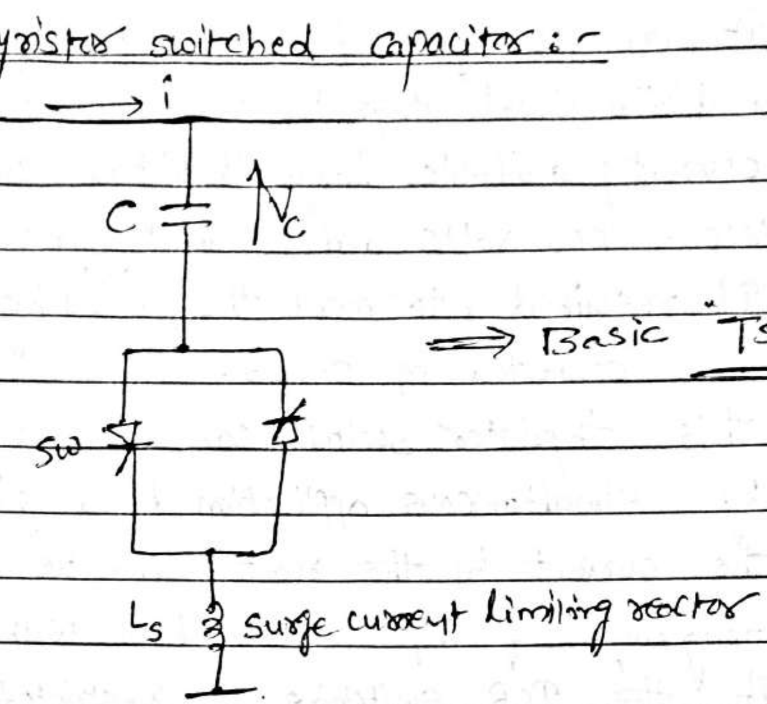


→ Here current lags voltage as it it inductor/reactor (TSR)

so by connecting TCR / TSR to the a.c system, the required amount of reactive power can be compensated.

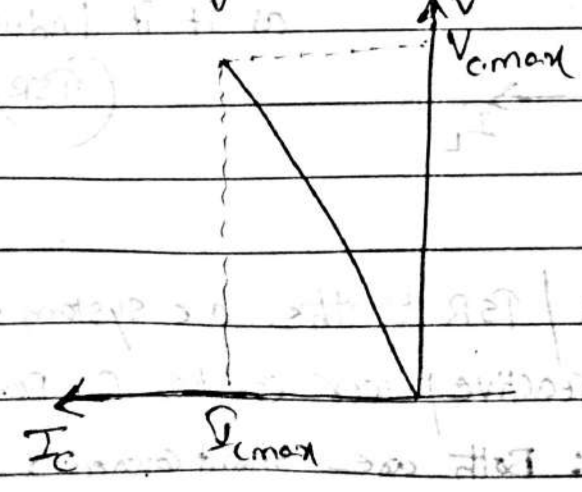
Note : Difference b/w TSR & TCR : Both are shunt connected, but TCR, whose effective reactance is varied in a continuous manner by partial conduction of of thyristor where-as TSR, whose effective reactance is varied in stepwise manner by full conduction of thyristor (or zero conduction also)

(ii) TSC - Thyristor switched capacitor :-



⟹ Basic "TSC"

1. TSC consists of a capacitor, bidirectional thyristor switches and small value of surge current limiting reactor.
2. This limiting reactor is needed initially to limit the flow of surge current in the thyristor switches under abnormal operating conditions. a thyristors are into conduction by proper gate pulses.
3. This limiting reactor also used to avoid resonance of ac system at particular frequencies. By on & off of thy. switches I_c can be controlled
4. operating V-I characteristics of TSC)



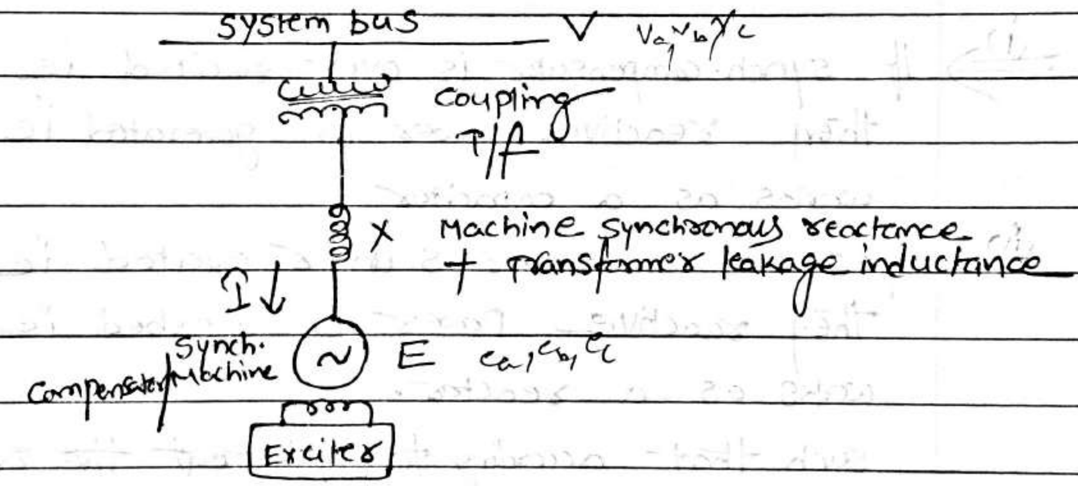
⟹ Here current leads voltage as it is TSC → capacitor

Thus by connecting "TSC" reactive power can be compensated.

Switching converter type Var generators:-

1. In static var generators, the reactive power generated/absorbed is compensated by using capacitors/reactors but without using those capacitors/reactors, reactive power is compensated in case of switching converter type var generators.
2. By using various switching power converters, reactive power is compensated.
3. These converters are either voltage sourced (or) current sourced converters. They produce essential reactive power. [But presently all are voltage sourced]
4. These converter's operation is similar to that of synchronous machines, thats why technically termed as static synchronous generators (SSG's).

BASIC OPERATING PRINCIPLE :-



1. System bus is connected to coupling T/f, which is connected by machine synch. reactance & synch. machine with exciter.
2. In a synchronous machine, for ~~generation~~ flow of pure reactive power, emf's of synchronous machine e_a, e_b & e_c are in phase with system voltages V_a, V_b & V_c.
3. The reactive current I will be drawn by synch. compensator and magnitude of I can be determined by internal voltage of compensator (E) & system voltage (V) with total reactance "X"

classmate

Therefore

reactive current $\boxed{I = \frac{V-E}{X}}$

The amount of reactive power compensated is

$Q = I \cdot V$) already it is reactive current no need to use "θ"

($Q = VI\sin\theta$ neglecting "θ" term $Q = VI$)

$$\boxed{Q = \frac{V-E}{X} \cdot V} = \frac{1-\frac{E}{V}}{X} V^2$$

By increasing or decreasing V & E, we can control the reactive power.

(i) if synch. compensator is over excited i.e if $E > V$ then reactive power is generated i.e compensator works as a capacitor

(ii) if synch. compensator is under excited i.e $E < V$, then reactive power is absorbed i.e compensator works as a reactor.

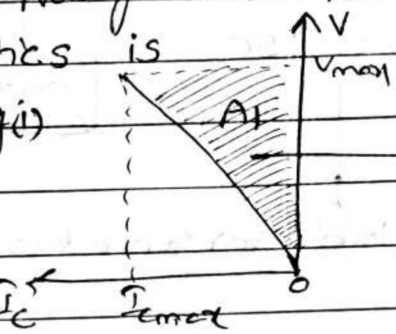
such that according to requirement the excitation must be given.

Hybrid Var Generators:-

1. The combination of Variable impedance type & switching converter type Var generators are called as Hybrid Var generators.
2. If the requirement of reactive power is ~~more~~ excess and, for some special applications this combination of both Var generators is used.
3. more reactive power is compensated by these Hybrid Var generators.
4. By single type Var generator the area associated for VI characteristics is

Capacitive :-

Fig(i)

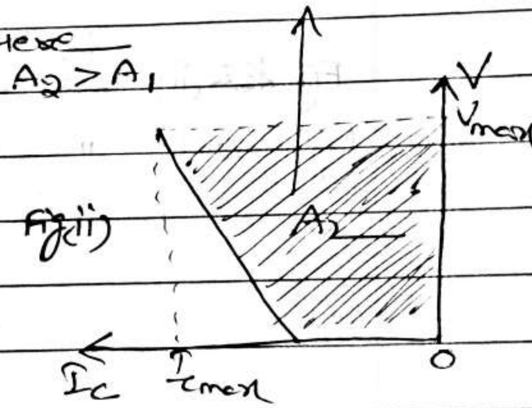


Area which resembles the reactive power compensated.

Here $A_2 > A_1$

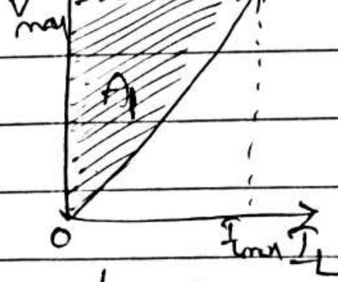
5. By using Hybrid Var generator, the amount of reactive power compensated is more.

Fig(ii)



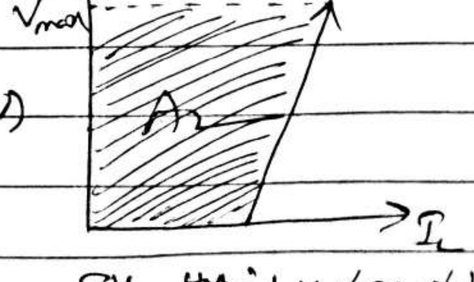
6. Inductive :-

Fig(iii)



By single var generator

Fig(iv)



By Hybrid Var generator

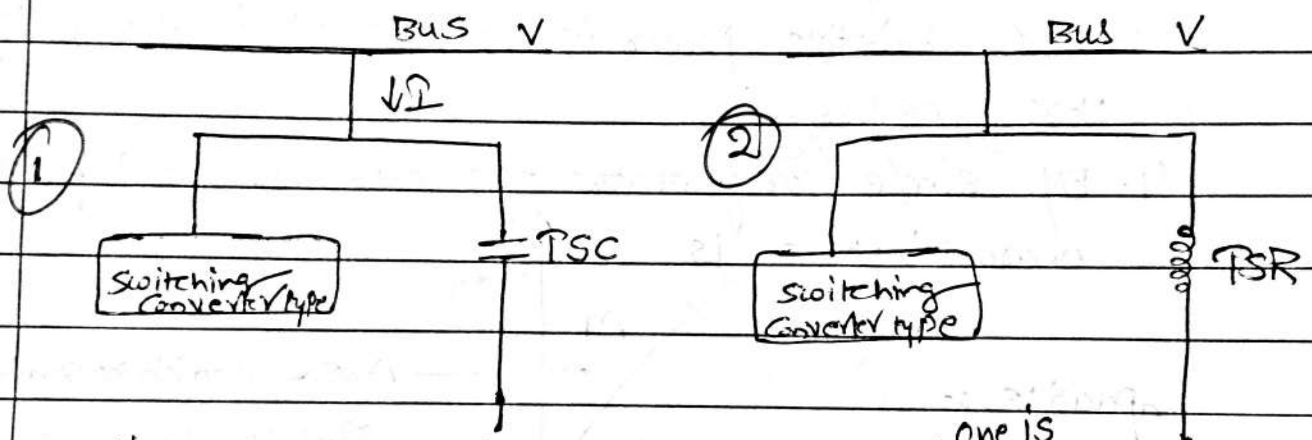
7. The areas $A_1 < A_2$ in either capacitive or inductive by using single type Var generator, if we use combination A_2 increases well ∴ The reactive power compensate

Therefore Hybrid var generator means,

$\Downarrow$

Variable Impedance Type + switching Converter type

either
Capacitive (TSC)
(or)
Inductive (TSR)



Both are Hybrid var generators with one is Combination of TSC & other is with TSR

Fig (iii) is related to ① hybrid var generator - TSC
Fig (iv) " " " ② " " - TSR

UNIT-4

SVC and STATCOM

STATCOM :- static synchronous compensator, it can be based on a voltage sourced or current sourced converter. It controls both real & reactive powers, this is static var generator used for voltage support & control, voltage fluctuation & mitigation, unsymmetrical load balancing, power factor correction, improves transient stability. It injects sinusoidal current almost 90° with line voltage. It can also absorbs system harmonics acts as active filter.

→ STATCOM gives the better results in all aspects when compared to SVC. SVC is a 1st generation FACTS device, for controlling reactive power, we need to use optimized reactive power control than the normal controlling techniques.

SVC :- static var compensator, a shunt connected static var generator or absorber whose o/p is adjusted to exchange capacitive or inductive current to maintain or control specific parameters, typically bus voltage. SVC is based on thyristors. This is a general term for TCR, TSR, TSC

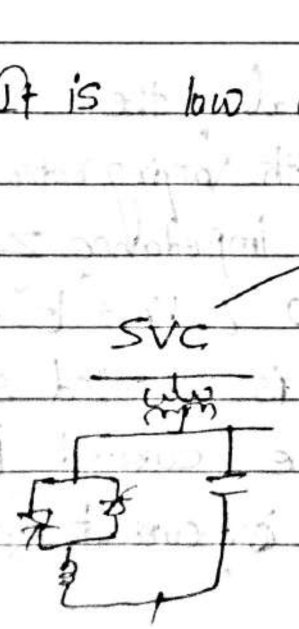
TCR, TSR ⇓ For absorbing reactive power

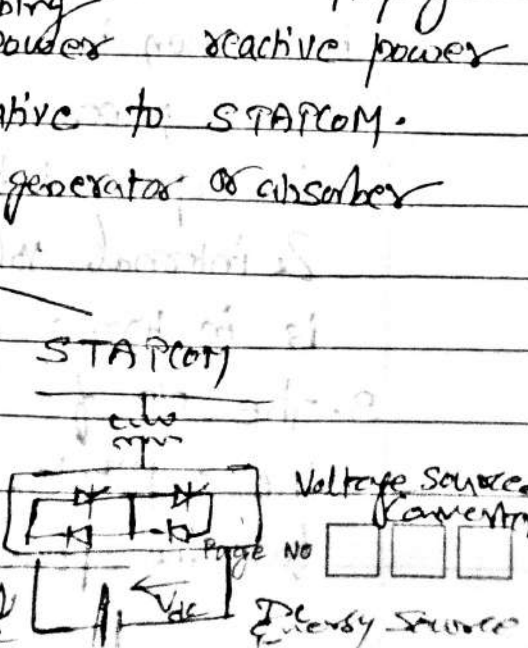
TSC ⇓ For supplying reactive power

It is low cost device, alternative to STATCOM.

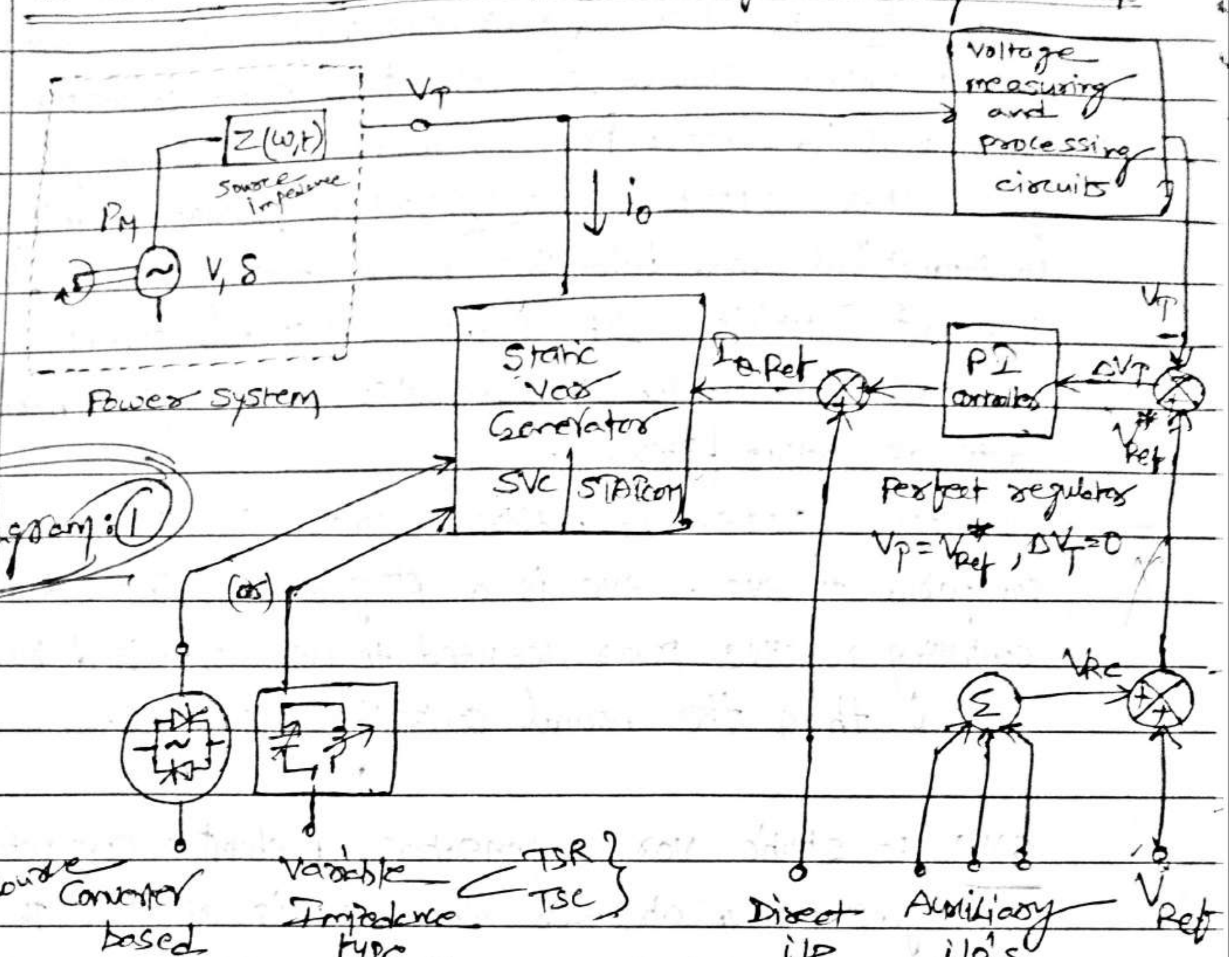
SVG - static var generator or absorber

SVC | STATCOM





General control scheme of static Var generator - SVC / STATCOM :-



1. Inorder to meet the general compensation requirements of the power system, the o/p of static var generator is to be controlled to maintain the voltage at the point of connection to the transmission line/system. The control scheme is shown in above figure
2. The power system at the terminal of the compensator is represented by a generator with varying rotor angle "δ" & internal voltage V, & source impedance Z which is in terms of angular frequency ω & time "t".
3. The o/p of static var generator is controlled so that the amplitude I_o of the reactive current i_o drawn from the power system & follows the ref current I_{oRef}

4. With the basic static compensator control, the Var generator is operated as a perfect terminal voltage regulator.
5. The amplitude V_T of the terminal voltage V_T is measured & compared with the ref. voltage V_{ref}.
6. The error ΔV_T is produced by a PI controller to provide the ref current I_{QRef} for var generator.
7. I_Q is closed loop controlled through I_{QRef}, so that V_T is maintained properly at the level of ref. voltage V_{Ref}.

Note:- If AC power system requires some specific variation in the amplitude of the terminal voltage with time or some other variable, then appropriate correcting signal V_{RC} derived from the auxiliary inputs which are summed to the fixed ref V_{Ref} inorder to obtain the desired effective reference signal V^*_{Ref}, that closed loop controls the terminal voltage V_T.

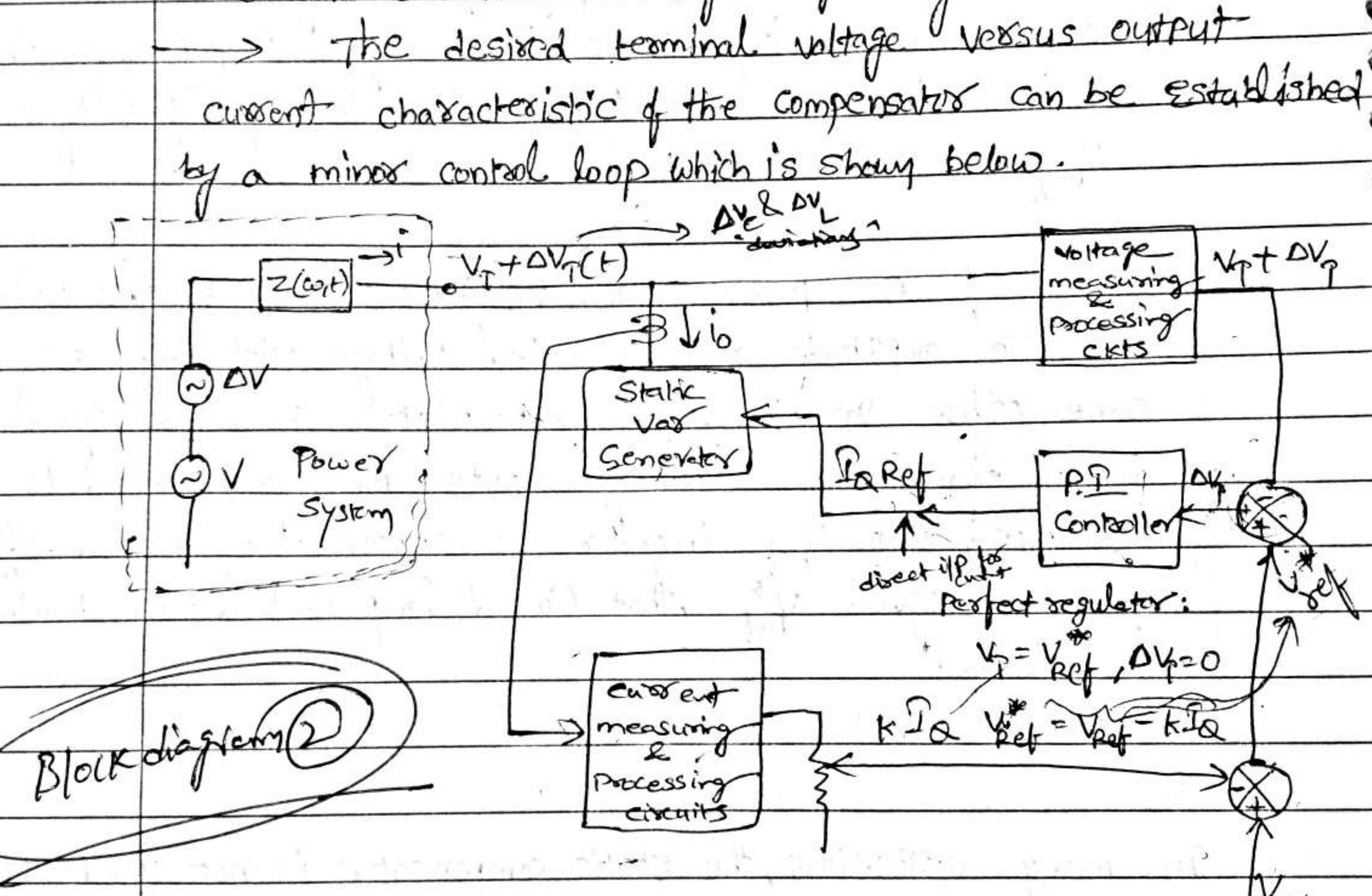
The Regulation slope :-
In many applications, the static compensator is not used as a perfect terminal voltage regulator, but the terminal voltage varies in proportion with the compensating current. There are some reasons for this :
1. The linear operating range of a compensator with given maximum capacitive & inductive ratings can be extended if a regulation "droop" is allowed. Regulation droop means that the terminal voltage is to be smaller than the nominal no load voltage at full capacitive compensation.

2. Perfect regulation (zero droop or slope) could result in poor defined operating point as

3. If the system impedance exhibited a "flat" region (low impedance) in the operating frequency range.

3. A regulation "droop" or slope tends to enforce automatic load sharing between static compensators as well as other voltage regulating devices.

→ The desired terminal voltage versus output current characteristic of the compensator can be established by a minor control loop which is shown below.



4. Above diagram gives the implementation of V-I slope by a minor control loop changing the ref voltage in proportion to the line current.

5. A signal proportional to the amplitude of the compensating current KI_Q with an ordered polarity (capacitive current is negative & inductive current is positive) is derived and summed to the ref V_{ref}.

6. The effective V^*_{Ref} controlling the terminal voltage, becomes

$$\boxed{V^*_{Ref} = V_{Ref} + K I_Q} \quad \text{——— (1)}$$

$\left\{ K I_Q \right.$: +ve for inductive current ; -ve for capacitive current

where K = The regulatory slope

& is defined as

$$\boxed{K = \frac{\Delta V_{Cmax}}{I_{Cmax}} = \frac{\Delta V_{Lmax}}{I_{Lmax}}}$$

$K = \frac{\Delta V}{I}$ $\frac{V_C}{V_L}$ $\frac{I_L}{I_C}$

→ where ΔV_{Cmax} is the (decrease) deviation of the terminal voltage from its nominal value at max. capacitive o/p current $I_{Qmax} = I_{Cmax}$

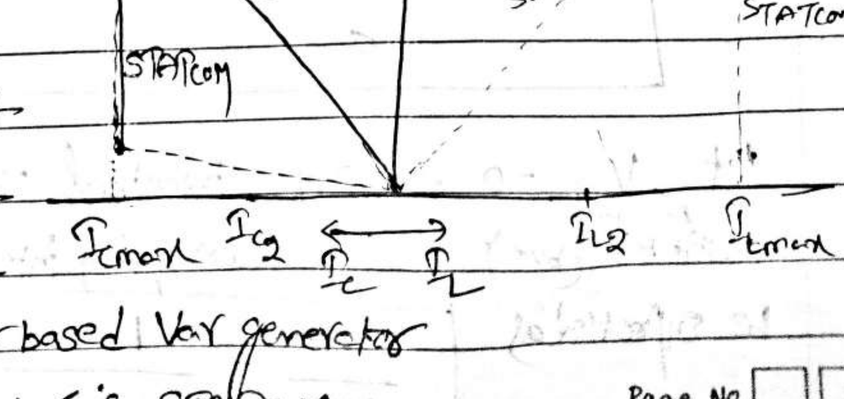
& ΔV_{Lmax} is the (Increase) deviation of the terminal voltage from its nominal value at max. inductive o/p current $I_{Qmax} = I_{Lmax}$

I_{Cmax} = maximum Capacitive Compensating current

I_{Lmax} = maximum inductive Compensating current.

Note :—

→ By observing the VI characteristics the compensator current stays at maximum capacitive (or) inductive value



✓ if it is Converter based Var generator i.e if Compensator is STATCOM

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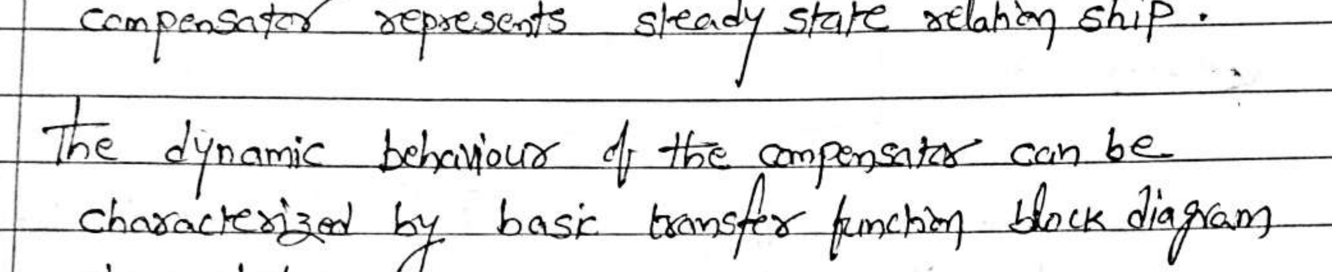
& in contrast, the compensator current will charge according to capacitor & inductor values, in the case of variable impedance type var generator i.e if compensator is SVC

Transfer function & dynamic performance :-

In previous topic, the VI characteristics of the static compensator represents steady state relationship.

The dynamic behaviour of the compensator can be characterized by basic transfer function block diagram shown below.



The terminal voltage V_T can be expressed in terms of the internal voltage V & ref. voltage V_{ref}.

$$\boxed{V_T = V \frac{1}{1+G_1G_2HX} + V_{ref} \frac{G_1G_2X}{1+G_1G_2HX}} \quad (1)$$

let $V_{ref} = 0$, then terminal voltage variation ΔV_T & Power system internal voltage variation ΔV can be expressed as

substitute in (above)

$$\boxed{\frac{\Delta V_T}{\Delta V} = \frac{1}{1+G_1G_2HX} = \frac{1}{1+GHX}} \quad (2)$$

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where $G_1 = \frac{1/K}{1+T_1 S}$
$G_2 = e^{-T_d S}$

$$\boxed{G = G_1 G_2 = \frac{1/K}{1+T_1 S} e^{-T_d S}}$$

& $$\boxed{H = \frac{1}{1+T_2 S}}$$

T_1 = main time constant of PI controller
T_2 = time constant of amplitude measuring ckt
T_d = Transport lag of Var generator

Note: The dynamic behaviour of the compensator is a function of the power system impedance, that is system impedance is an integral part of the feedback loop. that means time response & stability is dependent on the system impedance

Proof: when $(S \longrightarrow 0)$,

Eq(2) becomes

$$\frac{\Delta V_p}{\Delta V} = \frac{1}{1+GHX}$$

$$= \frac{1}{1+\left(\frac{1/K}{1+T_1(0)} e^{-T_d(0)}\right)\cdot\left(\frac{1}{1+T_2(0)}\right)X}$$

$$= \frac{1}{1+\left(\frac{1}{K}\right)X}$$

$$\boxed{\frac{\Delta V_T}{\Delta V} = \frac{1}{1+\frac{X}{K}}}$$

Transient stability Enhancement & power oscillation damping :—

Refer unit 3 for these topics

<u>Var reverse (operating point) control</u> :— Var → Reactive power

Draw the <u>block diagram (2)</u> which is in previous section.

→ Static Compensator is considered primarily, as a fast Var source to counteract rapid & unexpected voltage disturbances due to faults.

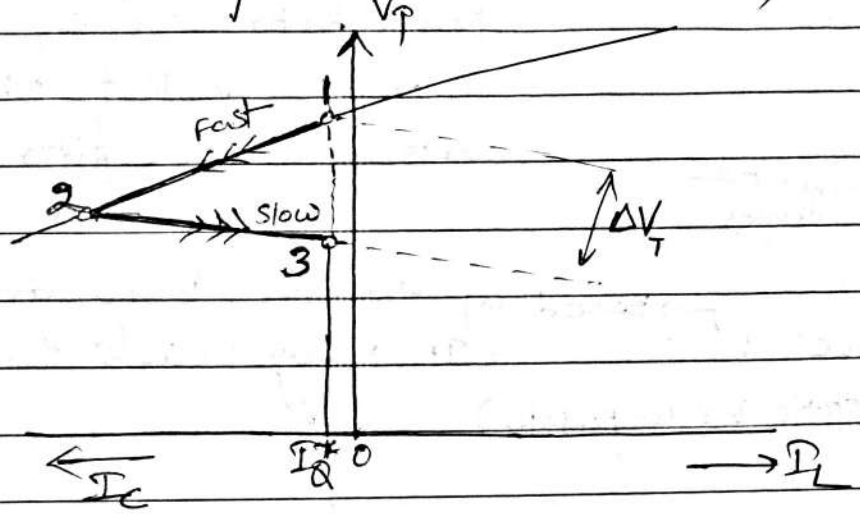
→ Inorder to fulfill these applications & requirements it is necessary to ensure that the compensator will have sufficient Var capacity to handle unpredictable dynamic disturbances.

→ The objective of this control is to limit the steady-state reactive power o/p of the compensator to a given reference Value. The basic Concept is to allow the compensator to change its o/p rapidly to counteract transient disturbances.

→ However, a disturbance results in a new operating Point, with a steady Var o/p.

→ The Var reverse control effectively changes the voltage reference in order to bring back the var o/p slowly to the set ref. value.

The operation of the simple Var reverse control is described by "below figure" shown,



→ Assume that the compensator is operating at point 1 ($I_Q = I_Q^*$) on the VI curve when a disturbance in the form of a sudden ΔV_T drop in the amplitude of the terminal voltage V_T.

→ The voltage change ΔV_T forces, via the fast voltage regula[tor] loop,

→ The o/p current increases from the steady state value I_Q^* to I_{C2} & the compensator assumes working point 2 on the VI curve.

→ However since $I_{C2} > I_Q^*$ an error signal, ΔI_Q is generated with in the Var reverse control loop, which via the slow integrator changes the ref. signal to the voltage regulator, forcing the compensator to reduce slowly its o/p current.

→ The compensator finally assumes a new steady state in working poi[nt] on V-I ...

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5.3.5 Summary of Compensator Control

The structure of static compensator control illustrating the underlying principle of superimposing auxiliary input signals on the basic voltage reference, to carry out specific compensation functions automatically as required by system conditions, is shown in Figure 5.57. With this principle, the compensator, within its MVA rating and operating frequency band, acts as a perfect amplifier forcing the magnitude of the regulated terminal voltage to follow the effective voltage reference, which is the sum of the fixed voltage magnitude reference and auxiliary signals. The effective reference thus defines the operating modes and characteristics (e.g., voltage regulation with the corresponding steady-state operating point and regulation slope) as well as the desired actions in response to dynamic changes of selected system variables (e.g., transient stability enhancement and oscillation damping).

Apart from the real-time control functions illustrated in Figure 5.57, the total control system of a modern static compensator has many other elements to manage the proper and safe operation of the equipment with high reliability and availability, as well as to accommodate proper interface with local and remote operators, as shown in a glossary manner in Figure 5.58. The main elements of this overall compensator control system include:

1. Interface between high-power, high-voltage semiconductor valves of the overall switching converter and/or TSC and TCR structure and a highly-sophisticated real-time control required for the internal operation of the var generator and for the desired system compensation functions. This interface,

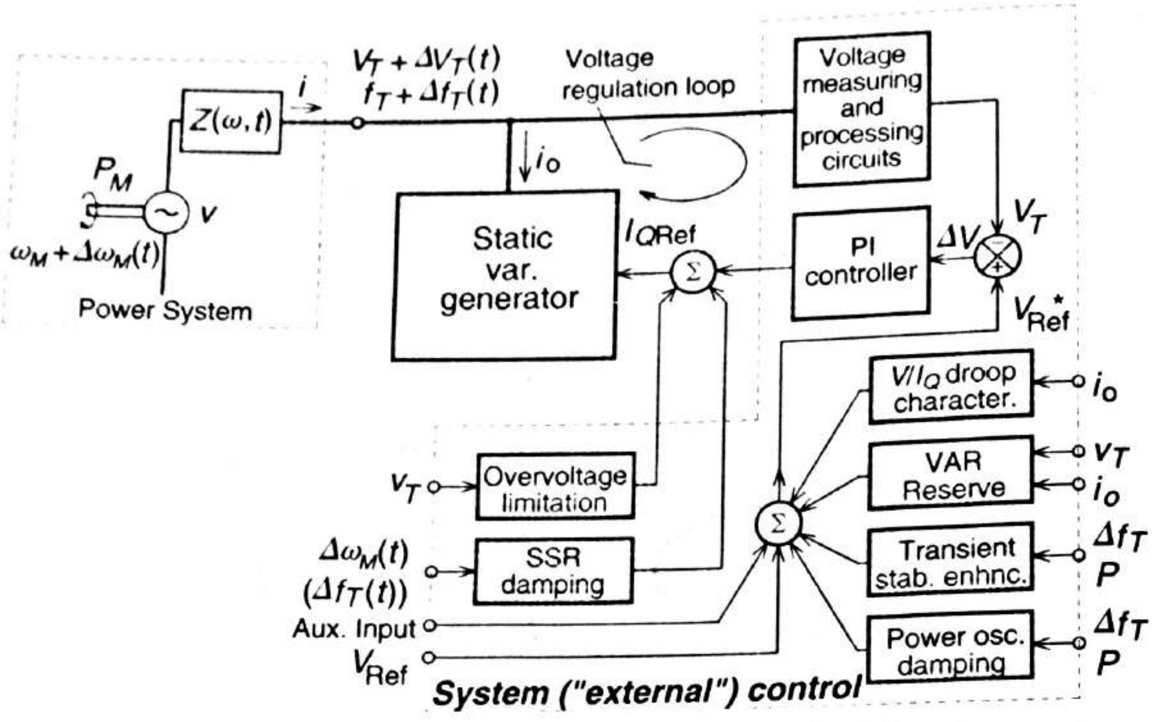


Figure 5.57 Structure of the basic compensator control for multifunctional power system compensation.

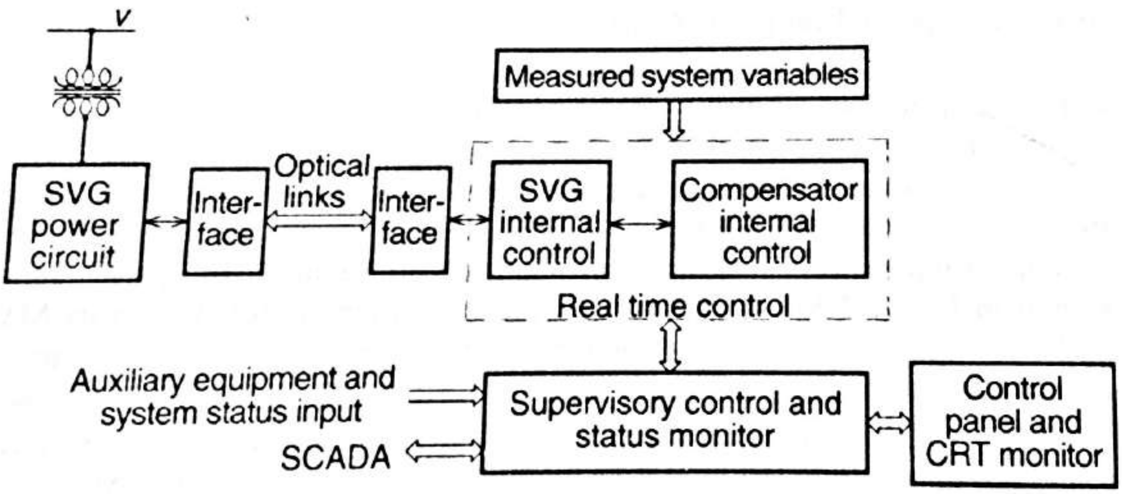


Figure 5.58 Main elements of the complete control operating a static compensator.

transmitting gating commands from the control to the valves and status information from the valves to the control is usually implemented by optical links.

2. Signal measuring and processing circuits for system and equipment variables. The real-time control and protection relays (and operator displays) need as inputs certain system variables, such as terminal voltage and compensator output current, as well as appropriate internal voltages and currents of the equipment, from which magnitude, phase, frequency, and other relevant information can be derived to follow in real-time system conditions and monitor equipment operation.
3. Supervisory control and status monitor which interfaces with the all parts of

the compensator, including all essential components of the compensator proper and its support equipment (e.g., cooling system, power supplies, breakers, switches, interlocks, etc.). It collects status information from every part of the system, usually via serial communication links, organizes and interprets the status data to determine the operational integrity of the compensator and to provide diagnostics for possible malfunctions and failures. It also carries out the start-up and shutdown sequencing and other operating routines of the compensator and provides appropriate communication links for the local and remote operators.

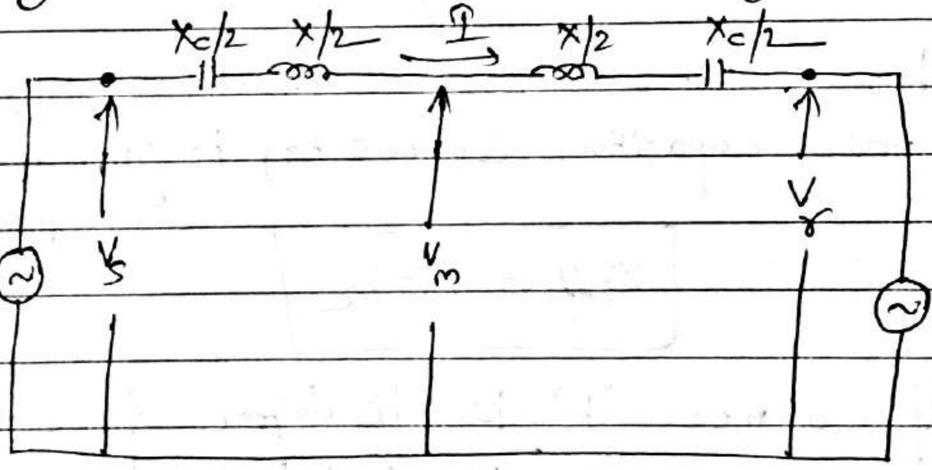
4. User interface with CRT graphical displays is usually provided by a stand-alone computer with an appropriate CRT monitor, keyboard, and pointing device for data entry. This computer usually has a serial link to the status processor and runs a graphical display and control software. Through the interface a large amount of information is available for the operation, diagnostic, and maintenance purposes in graphical and numerical form. The information includes: status information from the valves, identifying failed power semiconductors and other components and associated circuits; selected operating modes of the compensator and associated control and operational parameter settings; control operating and redundancy; and status of support equipment such as cooling system, auxiliary power supplies, breakers, switches, etc., and building climate status (temperature, humidity, etc.).

UNIT- 5

Static series Compensation

Concept of series capacitive compensation :-

① shunt compensation is ineffective in controlling the actual transmitted power at defined transmission voltage but is effectively controlled by series compensation.
② series compensation can be applied to achieve full utilization of transmission energy by controlling Powerflow in the lines, preventing loop flows & minimizing the system disturbances.
③ The uses of series compensation is maximum powertransmission, steady state power transmission, transient stability, voltage stability & power oscillation damping.



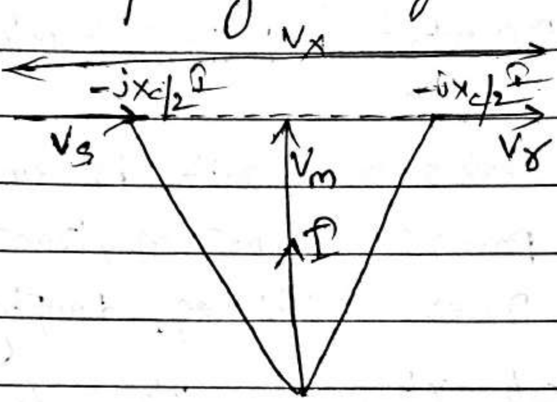
Key difference :- b/w shunt Compensation & series compensation

$$\boxed{P = \frac{V_1 V_2}{X} \sin\delta}$$ → basic Equation

→ shunt compensation improves voltage, then powertransfer Capability improved.
→ series compensation decreases overall impedance "X" then automatically power transfer Capability increases

→ The basic function of series capacitive compensation is to decrease the overall effective series compensation transmission impedance from the sending end to the receiving end.

consider the simple 2 Machine model which is shown above, having 2 identical segments, the corresponding voltage & current phasors are



The Effective transmission impedance X_{eff} with the series capacitive compensation is given by

$$\boxed{X_{eff} = X - X_c}$$

if assumes "K" is the degree of series compensation

i.e $\boxed{K = X_c / X}$ $0 \leq K \leq 1$

$\Rightarrow X_c = KX$

Then $X_{eff} = X - KX$

$$\Rightarrow \boxed{X_{eff} = (1-K)X}$$

Assuming $V_s = V_r = V$

The current in compensated line is given by

$$I = \frac{\text{voltage}}{\text{Impedance}}$$

~~voltage for total line~~ $V + V = 2V$

$$I = \frac{2V}{X_{Eff}} \sin \delta/2$$

Impedance $= X_{Eff}/2$

$$\cancel{I = \frac{2V}{X_{Eff}} \sin \delta/2}$$

$$\boxed{I = \frac{2V}{(1-K)X} \sin \delta/2}$$

$I = \frac{\text{Voltage}}{\text{Imp}} = \frac{V}{X_{Eff}}$

$= \frac{V}{(1-K)X}$

$P = VI \sin\delta = V \cdot \frac{V}{(1-K)X} \sin\delta$

$$\boxed{P = \frac{V^2}{(1-K)X} \sin\delta}$$

Then
$$\boxed{P = V_m I \sin\delta = \frac{2V^2}{(1-K)X} \sin \delta/2}$$

Therefore the reactive power supplied by series capacitor can be expressed as

$$Q_c = I^2 X_c = \left[\frac{4V^2}{(1-K)^2 X^2} (\sin \delta/2)^2\right] X_c$$

$\Rightarrow$ we have, $X_c = KX$

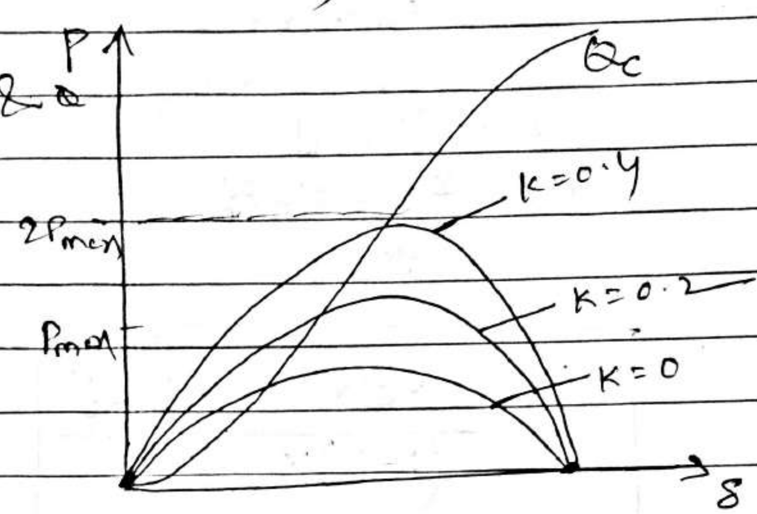
$$\therefore \cancel{Q_c = \frac{2V^2}{(1-K)^2 X^2} (\sin \delta/2)^2 \cdot K^2 X^2}$$

$\Rightarrow$ $\cancel{Q_c = 2V^2}$

classmate

$$\Rightarrow \boxed{Q_c = \frac{2V^2}{X} \frac{K}{(1-K)^2}(1-\cos\delta)}$$

for various "K" values, the plot for P & δ



voltage stability, Improvement of transient stability, power oscillation damping :- Read from 3-unit by replacing series compensation in place of shunt compensation

Add a key Note : in Improvement of Transient stability

$$\Rightarrow P = \frac{V_1 V_2}{X} \sin\delta$$

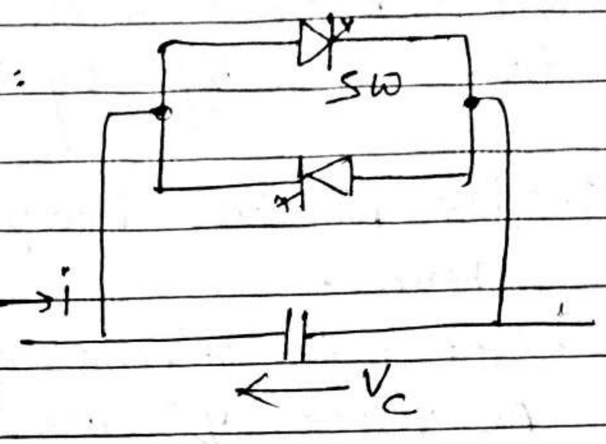
→ shunt compensation indirectly improves the transient stability by Improving voltage, then "P" increases

→ series compensation decreases overall impedance "X" then power increases which helps to improve transient stability directly. So series compensation is more Efficient than shunt compensation for improving transient stability limit.

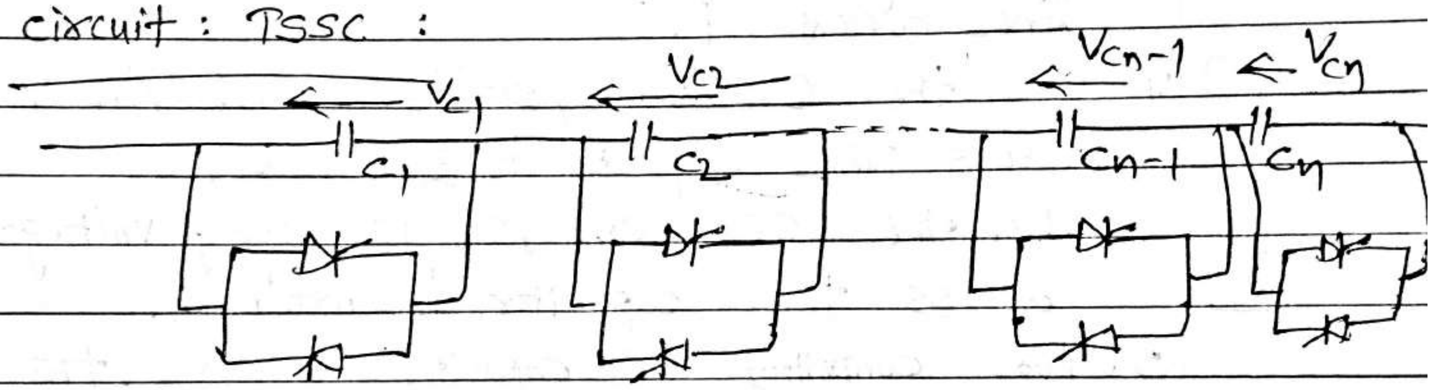
Page No

GCSC : GTO Thyristor controlled series capacitor (GCSC)
TSSC : Thyristor switched series Capacitor
TCSC : Thyristor controlled series Capacitor

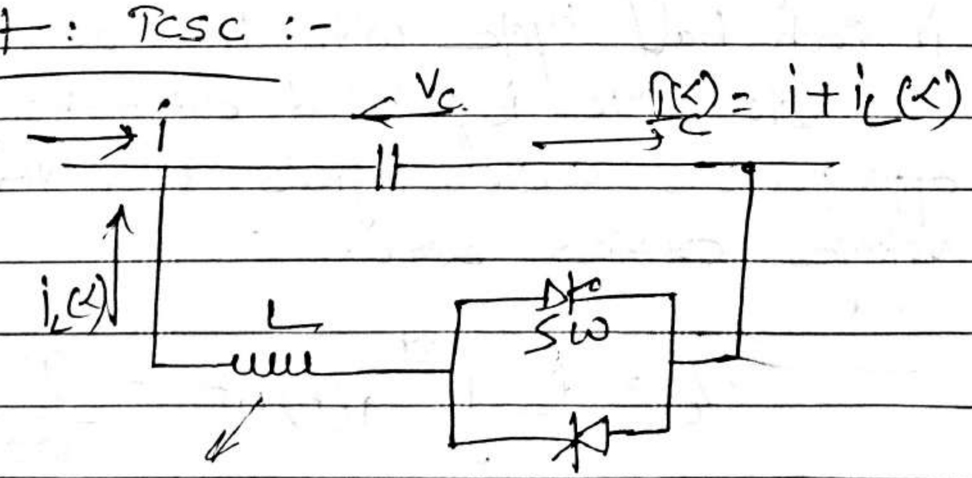
circuit : GCSC :



circuit : TSSC :



circuit : TCSC :-



Thyristor controlled reactor

$I(\alpha) = i + i_L(\alpha)$

classmate

GCSC : Theory :- Refer ckt

1. It consists of a fixed capacitor in parallel with GTO thyristor / switch which has the capability to turn on & off by taking command signals.

2. This will be incorporated into series compensation schemes.

3. The main objective of GCSC is to control the AC voltage "V_c" across the capacitor at a given line current i.

4. When the GTO valve, sw is closed, the voltage across the capacitor is zero &
When the GTO valve, sw is open, voltage across the capacitor is maximum.

5. For controlling the capacitor voltage, the closing and opening of the GTO valve is carried out in each half cycle with the ac system frequency.

6. The GTO valve is closed automatically by appropriate control signals whenever the capacitor voltage crosses zero.

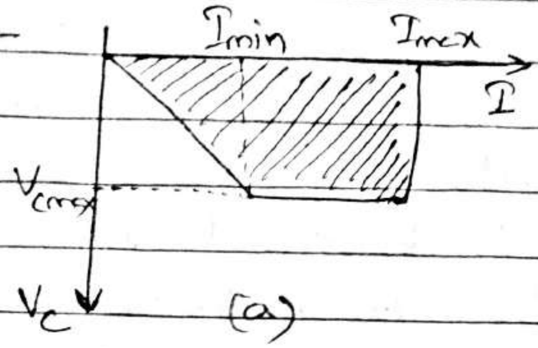
$$V_C = \frac{1}{C}\int_{\gamma}^{\omega t} i(t)\,dt = \frac{I}{\omega C}\left(\sin\omega t - \sin\gamma\right)$$

where γ = turn off delay angle.

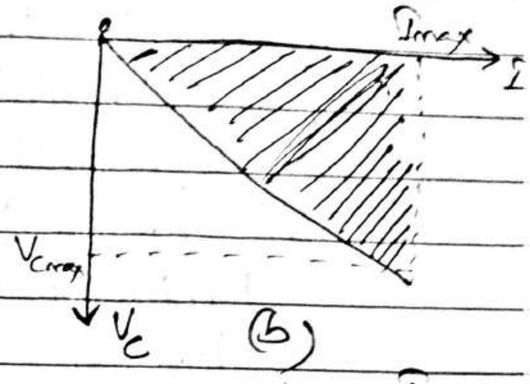
Page No

VI characteristics :-

GCSC :-

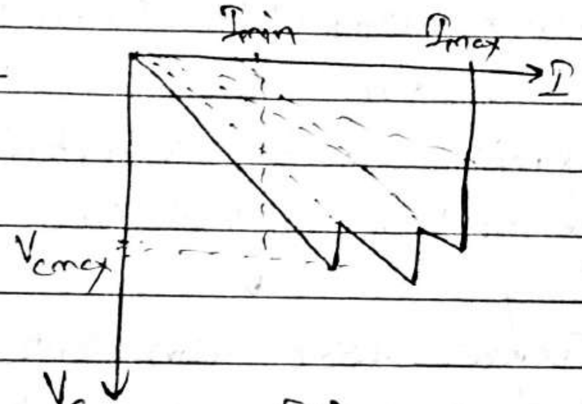


(a)

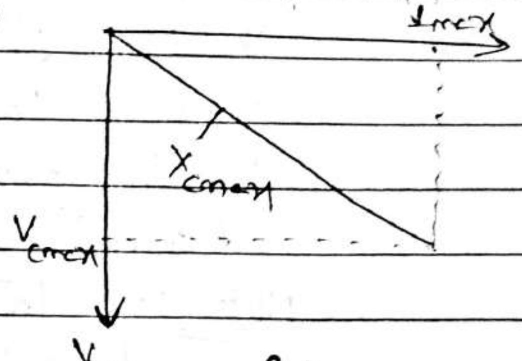


(b)

TSSC :-



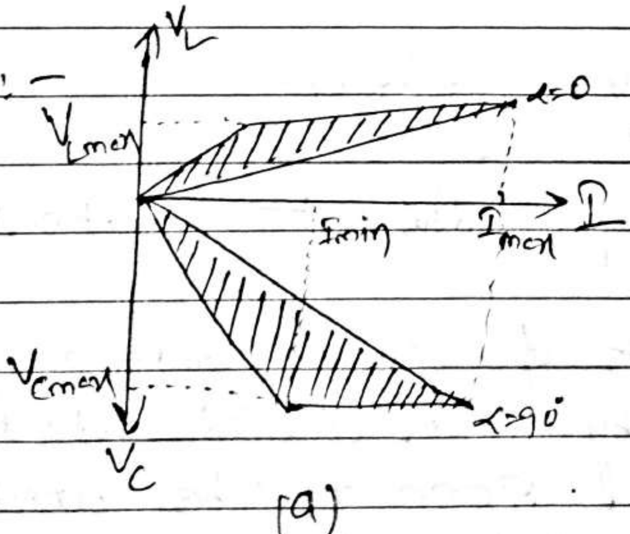
(a)



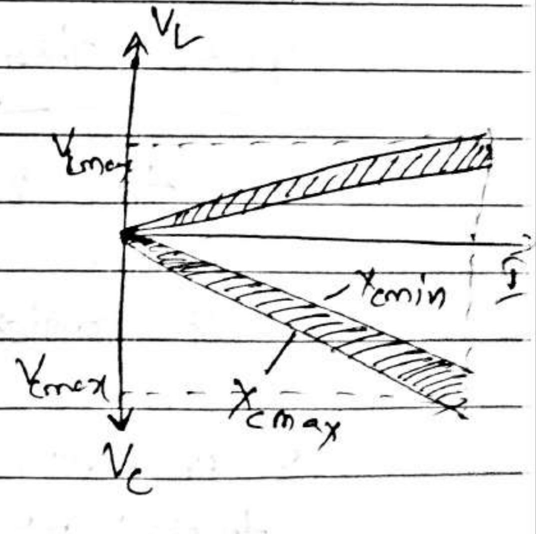
(b)

fig a ⟹ voltage control → operating mode
fig b ⟹ reactance control → operating mode

TCSC :-



(a)



TSSC : Theory :- Refer circuit

→ In this the operating principle is : series compensation is controlled in a step like manner by increasing or decreasing the no. of series capacitors inserted.

→ A capacitor is inserted by turning off & by passed by turning on the corresponding thyristor valve.

→ Thyristor valve commutates naturally, that is, it turns off when the current crosses zero.

→ Thus a capacitor can be inserted into the line by the thyristor valve only at zero crossings of line current.

Note :- Therefore TSSC can control the degree of series compensation by either inserting or bypassing series capacitors but it cannot change the natural characteristics of series capacitors compensated line.

TCSC : Theory :- Refer ckt

1. In this rapid adjustment of network impedance is done.
2. It consists of series compensating capacitor shunted by thyristor controlled reactor.
3. Practically, TCSC may be connected in series to line to obtain the desired voltage rating & operating char's.
4. This arrangement is similar to structure of TSSC, if the impedance of reactor X_L, is sufficiently smaller than that of capacitor X_C.

classmate

→ TCSC scheme is mainly used to provide a "continuous Variable capacitance".

The steady state impedance of the TCSC which consisting fixed capacitive impedance "X_C" & variable inductive impedance $X_L(\alpha)$ is given by

$$\boxed{X_{TCSC}(\alpha) = \frac{X_C X_L(\alpha)}{X_L(\alpha) - X_C}}$$

⟹ overall Impedance of TCSC

Basic operating control scheme for SCSC, PSSC & TCSC:-

Refer Block diagrams in page No: 240 → SCSC
241 → TCSC
(or) PSSC

6.2.5 Basic Operating Control Schemes for GCSC, TSSC, and TCSC

The function of the operating or "internal" control of the variable impedance type compensators is to provide appropriate gate drive for the thyristor valve to produce the compensating voltage or impedance defined by a reference. The internal control operates the power circuit of the series compensator, enabling it to function in a self-sufficient manner as a variable reactive impedance. Thus, the power circuit of the series compensator together with the internal control can be viewed as a "black box" impedance amplifier, the output of which can be varied from the input with a low power reference signal. The reference to the internal control is provided by the "external" or system control, whose function it is to operate the controllable reactive impedance so as to accomplish specified compensation objectives of the transmission line. Thus the external control receives a line impedance, current, power, or angle reference and, within measured system variables, derives the operating reference for the internal control.

As seen, the power circuits of the series compensators operate by rigorously synchronized current conduction and blocking control which not only define their effective impedance at the power frequency but could also determine their impedance characteristic in the critical subsynchronous frequency band. This synchronization function is thus a cornerstone of a viable internal control. Additional functions include the conversion of the input reference into the proper switching instants which result in the desired valve conduction or blocking intervals. The internal control is also responsible for the protection of the main power components (valve, capacitor, reactor) by executing current limitations or initiating bypass or other protective measures.

Structurally the internal controls for the three variable impedance type compensators (GCSC, TCSC, TSSC) could be similar. Succinctly, their function is simply to define the conduction and/or the blocking intervals of the valve in relation to the

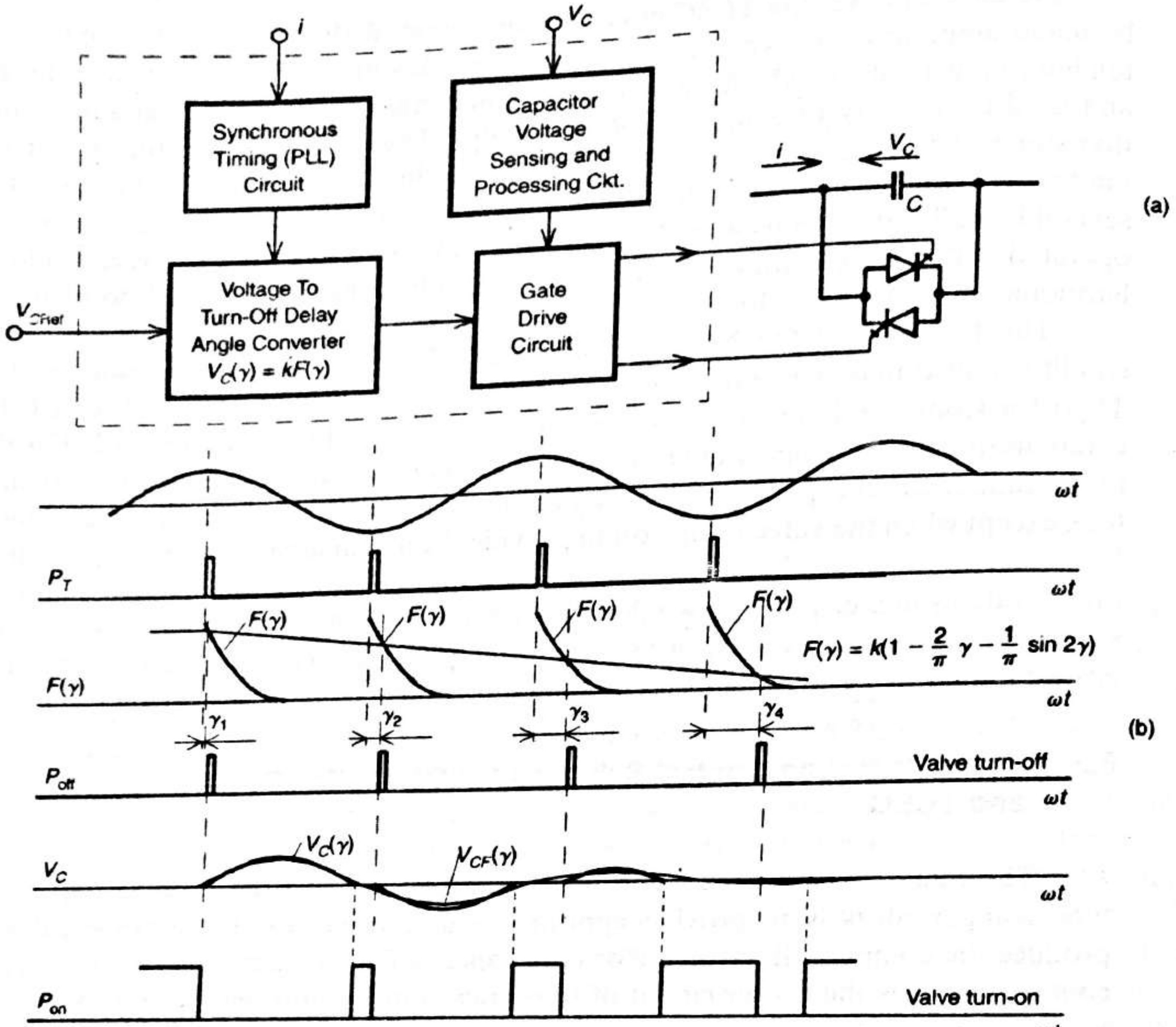


Figure 6.26 Functional internal control scheme for the GCSC (a) and associated waveforms illustrating the basic operating principles (b).

fundamental (power frequency) component of the line current. This requires the execution of three basic functions: synchronization to the line current, turn-on or turn-off delay angle computation, and gate (firing) signal generation. These functions obviously can be implemented by different circuit approaches, with differing advantages and disadvantages. In the following, three possible internal control schemes are functionally discussed: one for the GCSC, and the other two for the TCSC power circuit arrangements. Either of the TCSC schemes could be adapted for the TSSC if subsynchronous resonance would be an application concern.

An internal control scheme for the GTO-Controlled Series Capacitor scheme of Figure 6.5 is shown in Figure 6.26(a). Because of the duality between the shunt-connected GCSC and the series-connected TCR arrangements, this control scheme is analogous to that shown for the TCR in Figure 5.19(a). It has four basic functions.

The *first function* is synchronous timing, provided by a phase-locked loop circuit that runs in synchronism with the line current.

The *second function* is the reactive voltage or impedance to turn-off delay angle conversion according to the relationship given in (6.8a) or (6.8b), respectively.

The *third function* is the determination of the instant of valve turn-on when the capacitor voltage becomes zero. (This function may also include the maintenance of a minimum on time at voltage zero crossings to ensure immunity to subsynchronous resonance.)

The *fourth function* is the generation of suitable turn-off and turn-on pulses for the GTO valve.

The operation of the GCSC power circuit and internal control is illustrated by the waveforms in Figure 6.26(b). Inspection of these waveforms show that, with a "black box" viewpoint, the basic GCSC (power circuit plus internal control) can be considered as a controllable series capacitor which, in response to the transmission line current, will reproduce (within a given frequency band and specified rating) the compensating impedance (or voltage) defined by the reference input. The dynamic performance of the GCSC is similar to that of the TCR, both having a maximum transport lag of one half of a cycle.

10.14 STATIC SERIES SYNCHRONOUS COMPENSATOR (SSSC) (*UPTU 2011-12*)

This can vary the effective impedance of the trans-mission line by injecting a voltage containing appropriate phase angle in relation to the line current. It can exchange both real power and reactive power with in the transmission system. For instance injected voltage in phase with the line real power is exchanged. Injected voltage is in quadrature to the line current, then reactive power either absorbed or generated-exchanged with the line. The SSSC is better than TCSC in its ability to control power swings.

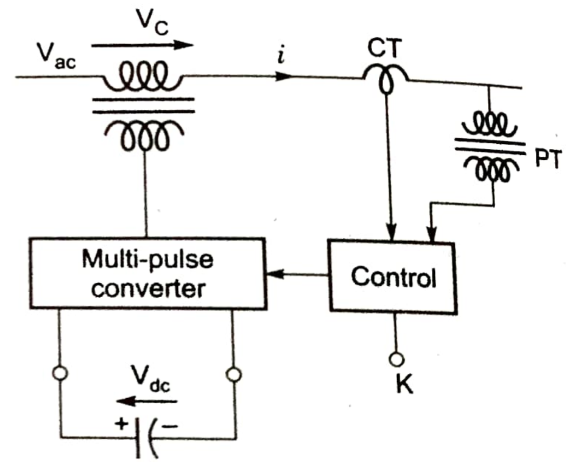


Fig. 10.10

Normally the SSSC output voltage lags behind the line current by 90° to provide effective compensation. The schematic of SSSC is shown in Fig. 10.10. The SSSC can also be gated to produce voltage that leads the line current by 90°, which provides additional inductive reactance in the line. This feature used for damping power swings and for limiting short circuit currents.

The controller scheme given in Fig. 10.10 has a VSC in which its coupling transformer is connected in series with the transmission line. The valve side rating of the coupling transformer is higher than the line side rating to reduce the current flow in the GTOs. The valve side winding is delta connected to provide path for 3^{rd} harmonics.

Solid state switches are provided on the valve side to by-pass VSC during periods of very large current flow or where VSC is in operative.

The capacitor is provided to for DC to AC conversion and to filter out ripples. The pulse width modulation technique is used to convert DC to AC. An MOV is installed across the DC capacitor to limit its voltage and provide protection to the valves.

Applications of SSSC : (*i*) Power flow control, (*ii*) sub synchronous resonance mitigation.

Fig. 10.11

10.16 UNITED POWER FLOW CONTROLLER (UPFC)

(*UPTU 2007-08; 2009-10*)

The UPFC is the most versatile FACTS controller, encompassing capabilities of voltage regulation, series compensation and phase shifting. It can independently control both real and reactive power in a transmission line. The configuration is shown in Fig. 10.12 and consists of two converters (VSCs) coupled through a common DC terminal.

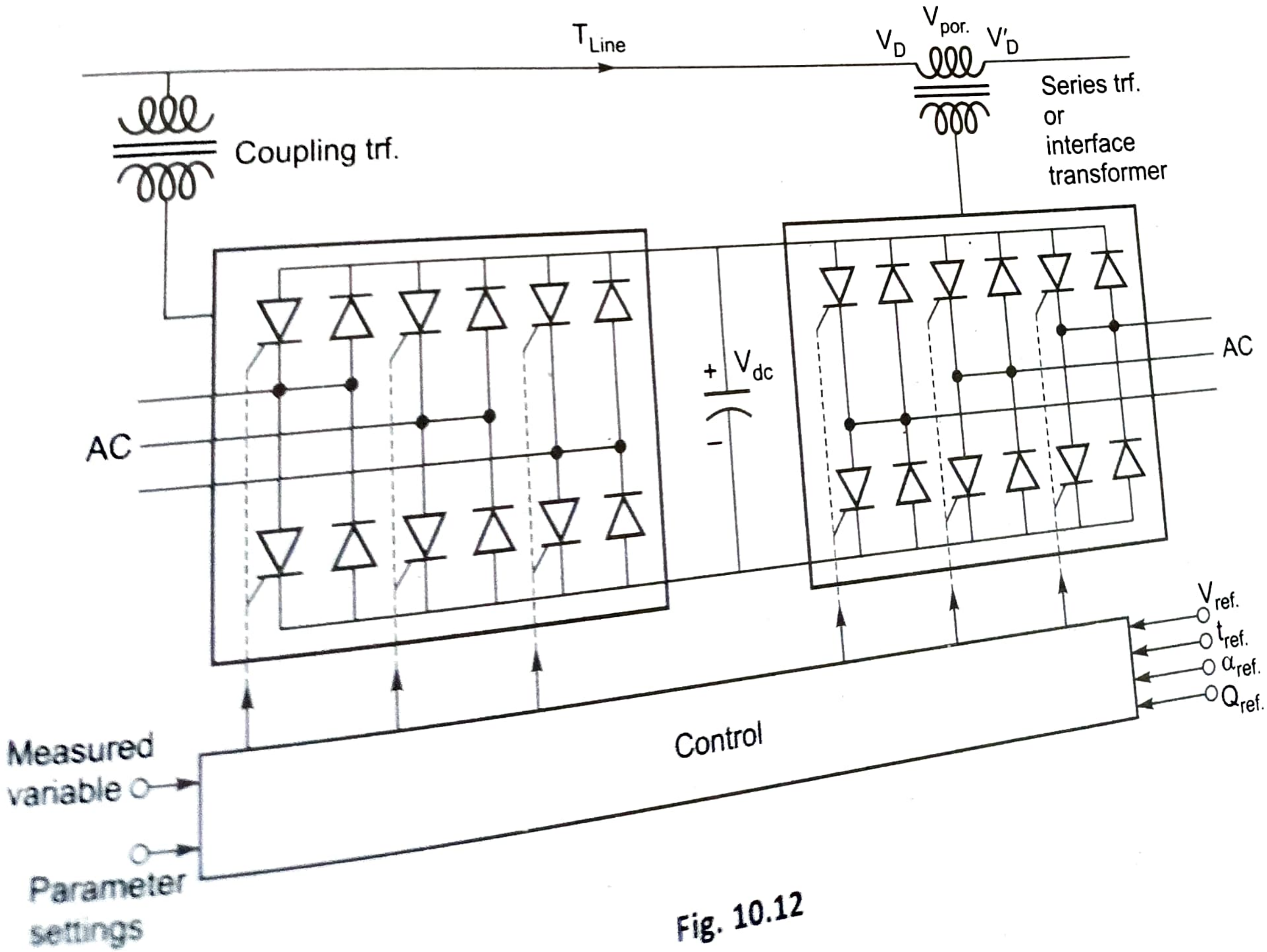


Fig. 10.12

VSC 1 is connected in shunt with the line through a coupling transformer and VSC 2 is connected in series with line through an interface transit. The DC voltage for both the converters is provided by a common capacitor bank.

A series converter is controlled to inject a voltage phasor, V_{pq} in series with the line, which can be varied from 0 to $V_{pq\ max}$.

The phase angle of V_{pq} can be independently controlled to vary from 0 to 360°. In this process the series controller exchanges both real power and reactive power with the transmission line.

Reactive power is internally generated and absorbed but active power generation and absorption is feasible by the DC energy storage device-capacitor.

The shunt connected converter 1 is used mainly to supply the real power demand of converter 2, which it gets power from the transmission line itself. The shunt converter maintains constant voltage of the DC bus. Thus the net real power drawn on from the AC system is equal to the losses of the two converters and their coupling transformers. In addition the shunt converter functions like a STATCOM and independently regulates the terminal voltage of the interconnected system by generating or sorting a requisite amount of reactive power.

The concepts of various power flow control using UPFC are shown in Fig. 10.13 (*a*) – (*e*).

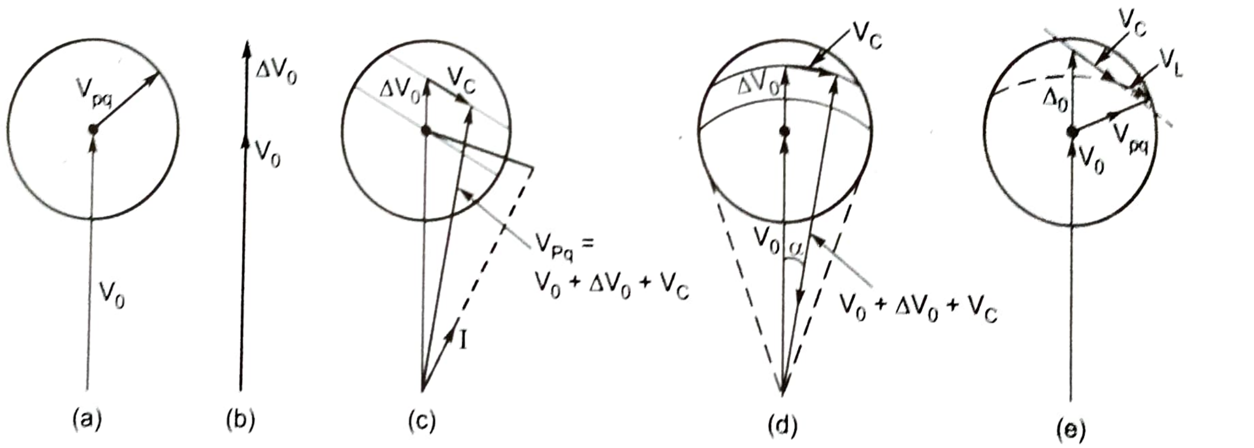


Fig. 10.13

Figure 10.13 (*a*) Depicts the addition of general phasor voltage V_{pq} to the existing bus voltage V_0, at an angle that varies from 0 to 360°.

Figure 10.13 (*b*) Voltage regulation is effected if V_{pq} $(= \Delta V_0)$ is generated in phase with V_0.

Figure 10.13 (*c*) A combination of voltage regulation and series compensation is implemented, where V_{pq} is the sum of voltage regulating component ΔV_0 and a series component V_C, that lags behind line current by 90°.

Figure 10.13 (*d*) is the phase shifting process. The UFFC generated voltage V_{pq} is the combination of regulating voltage ΔV_0 and phase shifting voltage component V_α. The function of V_α is to change the phase angle of the regulated voltage phasor $V_0 + \Delta V_0$, by an angle α.

Figure 10.13 (*e*) A simultaneous attainment of all the three foregoing power flow control is depicted in this figure.

TOPIC : INTRODUCTION TO POWER QUALITY

AIM: The quality of electrical power may be described as a set of values of parameters, such as:

- Continuity of service (Whether the electrical power is subject to voltage drops or overages below or above a threshold level thereby causing blackouts or brownouts)
- Variation in voltage magnitude
- Transient voltages and currents
- Harmonic content in the waveforms for AC power

It is often useful to think of power quality as a compatibility problem: It is the equipment connected to the grid compatible with the events on the grid, and is the power delivered by the grid, including the events, compatible with the equipment that is connected.Compatibility problems always have at least two solutions: in this case, either clean up the power, or make the equipment tougher.The tolerance of data-processing equipment to voltage variations is often characterized by the CBEMA curve, which give the duration and magnitude of voltage variations that can be tolerated. This unit describes the definition os electric power quality,its causes and classification.It describes the impact of poor power quality on power system and guidelines of various IEEE and IEC standards.

OBJECTIVES :

Introduces the definition of electric power quality, its causes and classification: transients, short-duration voltage variations, interruptions, sags, swells, long-duration voltage variations, sustained interruption, under- and over-voltage, voltage imbalance, waveform distortion, DC offset, harmonics, inter-harmonics, non-integer harmonics, triplen harmonics, sub-harmonics, time and space harmonics, characteristic and uncharacteristic harmonics, positive-negative- and zero-sequence harmonics, notching, electric noise, voltage fluctuation and flicker, and power-frequency variations. The formulations and measures used for power quality; impacts of poor power quality on power system and end-use devices; most important IEEE and IEC guidelines/recommendations/standards referring to power quality are presented.

PRE TEST-MCQ TYPE:

1. Most of the power quality problems are related to ______

(a) Transmission Issue (b) **Grounding Issue** (c) Distribution Issue (d) all of the above

2. Which of the following is not considered as good power quality voltage

(a) **Power Supply is more compared to demand** (b) Constant sine wave (c) Constant Velocity (d) Constant RMS Value unchanged with time

3. Grounding is done (i) for safety (ii) to provide a low-impedance path for the flow of fault current in case of a ground fault (iii) to create a ground reference plane for sensitive electrical equipment

(A) Only (i)

(B) Only (ii)

(C) (i) & (ii)

(D) (i), (ii), (iii)

4. _________________ refers to the interaction between electric and magnetic fields and sensitive electronic circuits and devices.

(A) Radio frequency interference

(B) Power frequency disturbances

(C) Electromagnetic interference

(D) Power system harmonics

5. All electrical devices are prone to failure or malfunction when exposed to one or more power quality problems

(A) True

(B) False

Introduction to Power Quality

Terms and definitions: Overloading - under voltage - over voltage. Concepts of transients - short duration variations such as interruption - long duration variation such as sustained interruption. Sags and swells - voltage sag - voltage swell - voltage imbalance - voltage fluctuation - power frequency variations. International standards of power quality. Computer Business Equipment Manufacturers Associations (CBEMA) curve

1.1 Introduction

- ✓ Power quality is any abnormal behavior on a power system arising in the form of voltage or current, which affects the normal operation of electrical or electronic equipment.
- ✓ Power quality is any deviation of the voltage or current waveform from its normal sinusoidal wave shape.
- ✓ Power quality has been defined as the parameters of the voltage that affect the customer's supersensitive equipment.
- ✓ Power quality problems are
    - Voltage sag
    - Voltage swell
    - Voltage Flicker
    - Harmonics
    - Over voltage
    - Under voltage
    - Transients
- ✓ Voltage sags are considered the most common power quality problem. These can be caused by the utility or by customer loads. When sourced from the utility, they are most commonly caused by faults on the distribution system. These sags will be from 3 to 30 cycles and can be single or three phase. Depending on the design of the distribution system, a ground fault on 1 phase can cause a simultaneous swell on another phase.
- ✓ Power quality problems are related to grounding, ground bonds and neutral to ground voltages, ground loops, ground current or ground associated issues.

- ✓ Harmonics are distortions in the AC waveform. These distortions are caused by loads on the electrical system that use the electrical power at a different frequency than the fundamental 50 or 60 Hz.

1.2 Terms and Definitions:

1.2.1 Power Quality:

It is any deviation of the voltage or current waveform from its normal sinusoidal wave shape.

1.2.2 Voltage quality:

Deviations of the voltage from a sinusoidal waveform.

1.2.3 Current quality:

Deviations of the current from a sinusoidal waveform.

1.2.4 Frequency Deviation:

An increase or decrease in the power frequency.

1.2.5 Impulsive transient:

A sudden, non power frequency change in the steady state condition of voltage or current that is unidirectional in polarity.

1.2.6 Oscillatory transients:

A sudden, non power frequency change in the steady state condition of voltage or current that is bidirectional in polarity.

1.2.7 DC Offset:

The presence of a DC voltage or current in an AC power system.

1.2.8 Noises:

An unwanted electric signal in the power system.

1.2.9 Long duration Variation:

A variation of the RMS value of the voltage from nominal voltage for a time greater than 1 min.

1.2.10 Short Duration Variation:

A variation of the RMS value of the voltage from nominal voltage for a time less than 1 min.

1.2.11 Sag:

A decrease in RMS value of voltage or current for durations of 0.5 cycles to 1min.

1.2.12 Swell:

A Temporary increase in RMS value of voltage or current for durations of 0.5 cycles to 1 min.

1.2.13 Under voltage:

10% below the nominal voltage for a period of time greater than 1 min.

1.2.14 Over voltage:

10% above the nominal voltage for a period of time greater than 1 min.

1.2.15 Voltage fluctuation:

A cyclical variation of the voltage that results in flicker of lightning.

1.2.16 Voltage imbalance:

Three phase voltages differ in amplitude.

1.2.17 Harmonic:

It is a sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental power frequency.

1.2.18 Distortion:

Any deviation from the normal sine wave for an AC quantity.

1.2.19 Total Harmonic Distortion:

The ratio of the root mean square of the harmonic content to the RMS value of the fundamental quantity.

$$\mathrm{THD} = \frac{\sqrt{\sum_{h>1}^{h_{\max}} {M_h}^2}}{M_1}$$

1.2.20 Interruption:

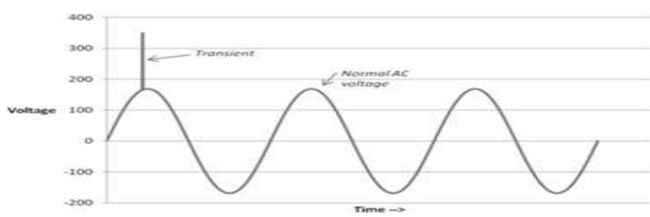
The complete loss of voltage on one or more phase conductors for a time greater than 1 min.

1.3 Concepts of transients:

- ✓ Transient over voltages in electrical transmission and distribution networks result from the unavoidable effects of lightning strike and network switching operations.
- ✓ Response of an electrical network to a sudden change in network conditions.
- ✓ Oscillation is an effect caused by a transient response of a circuit or system. It is a momentary event preceding the steady state (electronics) during a sudden change of a circuit.
- ✓ An example of transient oscillation can be found in digital (pulse) signals in computer networks. Each pulse produces two transients, an oscillation resulting from the sudden rise in voltage and another oscillation from the sudden drop in voltage. This is generally considered an undesirable effect as it introduces variations in the high and low voltages of a signal, causing instability.
- ✓ Types of transient:
  - o Impulsive transient
  - o Oscillatory transient

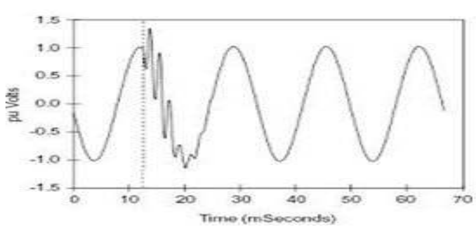
1.3.1 Impulse transient:

A sudden, non power frequency change in the steady state condition of voltage or current that is unidirectional in polarity.



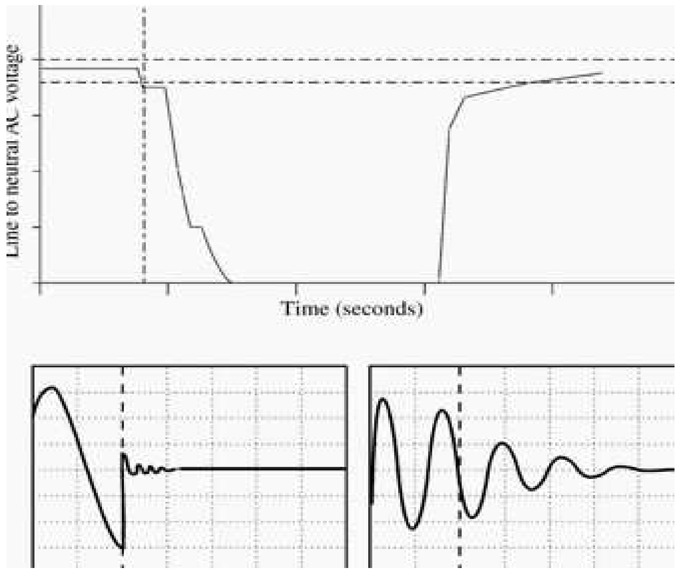
1.3.2 Oscillatory transient:

A sudden, non power frequency change in the steady state condition of voltage or current that is bidirectional in polarity.



1.3.3 Short duration variations – Interruption

The complete loss of voltage on one or more phase conductors for a time less than 1 min.

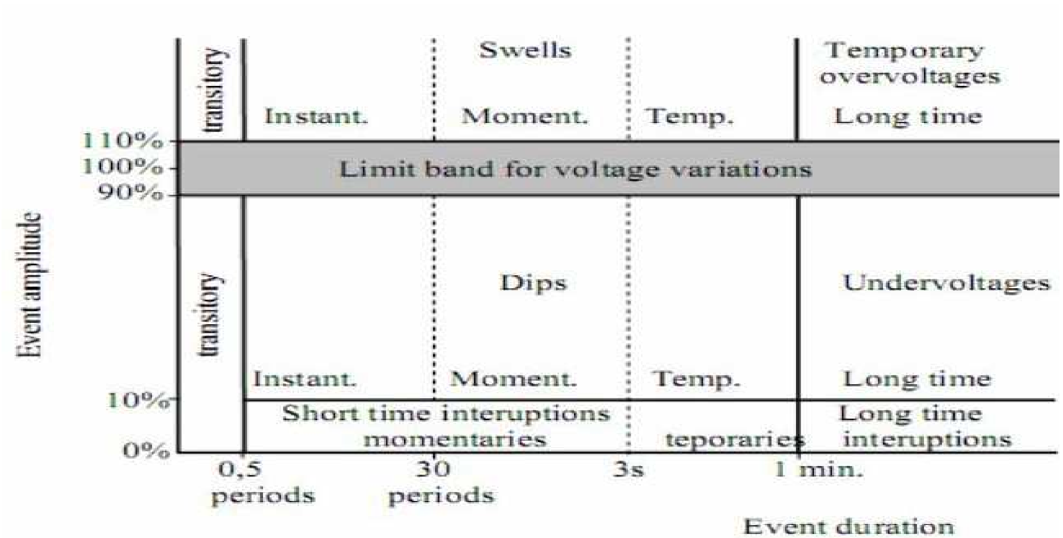


1.3.3.1 Types of Short Duration interruption:

- ✓ Momentary Interruption < 1 min , <0.1 pu
- ✓ Temporary Interruption < 1 min , <0.1 pu

1.3.4 Long duration variations – Sustained interruption

The complete loss of voltage on one or more phase conductors for a time greater than 1 min.



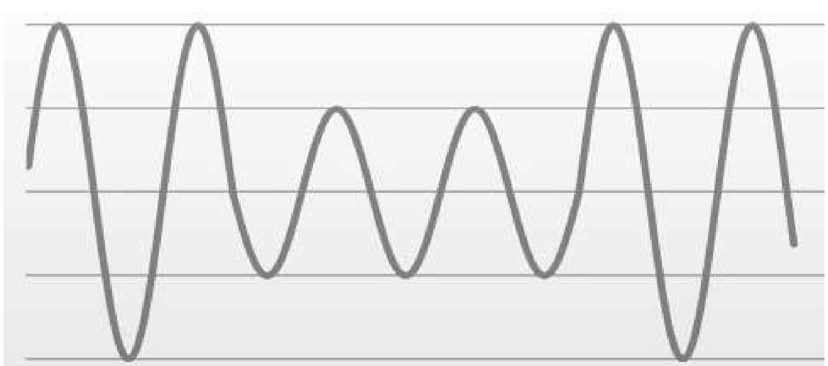
1.4 Sags and Swells:

1.4.1 Voltage sag:

- ✓ A **voltage sag** or **voltage dip** is a short duration reduction in RMS voltage which can be caused by a short circuit, overload or starting of electric motors.
- ✓ Voltage sag happens when the RMS voltage decreases between 10 and 90 percent of nominal voltage for one-half cycle to one minute.
- ✓ Some references define the duration of sag for a period of 0.5 cycles to a few seconds, and longer duration of low voltage would be called “sustained sag".

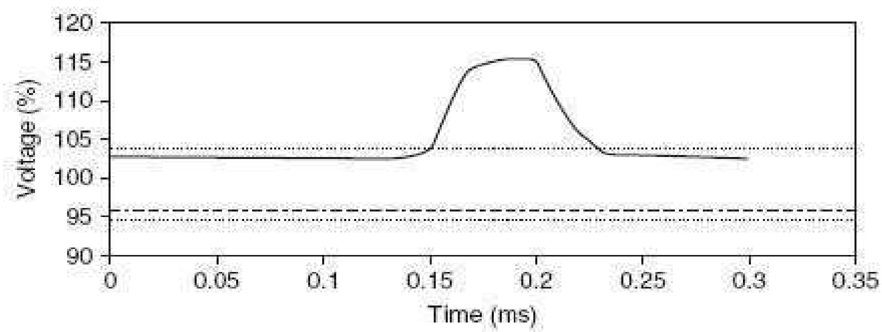
There are several factors which cause voltage sag to happen:

- ✓ Since the electric motors draw more current when they are starting than when they are running at their rated speed, starting an electric motor can be a reason of voltage sag.
- ✓ When a line-to-ground fault occurs, there will be voltage sag until the protective switch gear operates.
- ✓ Some accidents in power lines such as lightning or falling an object can be a cause of line-to-ground fault and voltage sag as a result.
- ✓ Sudden load changes or excessive loads can cause voltage sag.
- ✓ Depending on the transformer connections, transformers energizing could be another reason for happening voltage sags.
- ✓ Voltage sags can arrive from the utility but most are caused by in-building equipment. In residential homes, we usually see voltage sags when the refrigerator, air-conditioner or furnace fan starts up.



1.4.2 Voltage Swell:

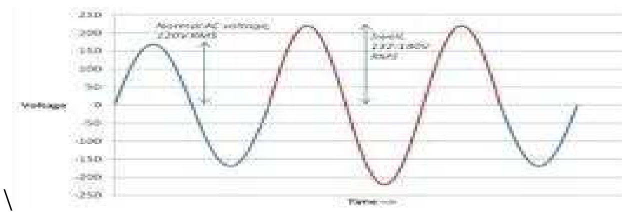
- ✓ Swell - an increase to between 1.1pu and 1.8 pu in rms voltage or current at the power frequency durations from 0.5 to 1 minute
- ✓ In the case of a voltage swell due to a single line-to-ground (SLG) fault on the system, the result is a temporary voltage rise on the un faulted phases, which last for the duration of the fault. This is shown in the figure below:



Instantaneous Voltage Swell Due to SLG fault

- ✓ Voltage swells can also be caused by the deenergization of a very large load.
- ✓ It may cause breakdown of components on the power supplies of the equipment, though the effect may be a gradual, accumulative effect. It can cause control problems and hardware failure in the equipment, due to overheating that could eventually result to shutdown. Also, electronics and other sensitive equipment are prone to damage due to voltage swell.

Voltage Swell	Magnitude	Duration
Instantaneous	1.1 to 1.8 pu	0.5 to 30 cycles
Momentary	1.1 to 1.4 pu	30 cycles to 3 sec
Temporary	1.1 to 1.2 pu	3 sec to 1 min



1.4.3 Voltage unbalance:

- ✓ In a balanced sinusoidal supply system the three line-neutral voltages are equal in magnitude and are phase displaced from each other by 120 degrees (Figure 1). Any differences that exist in the three voltage magnitudes and/or a shift in the phase separation from 120 degrees is said to give rise to an unbalanced supply (Figure 2)

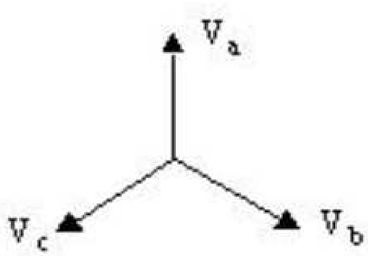


Figure 1 A balanced system

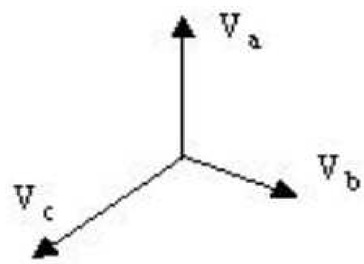
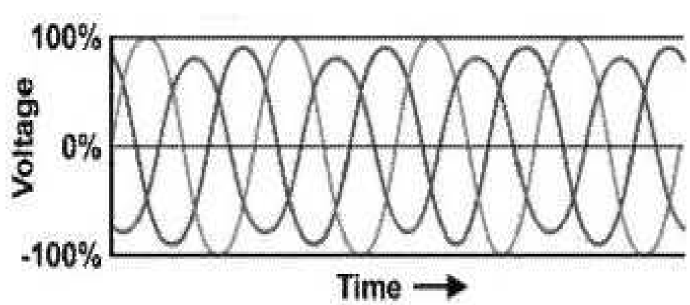


Figure 2 An unbalanced system

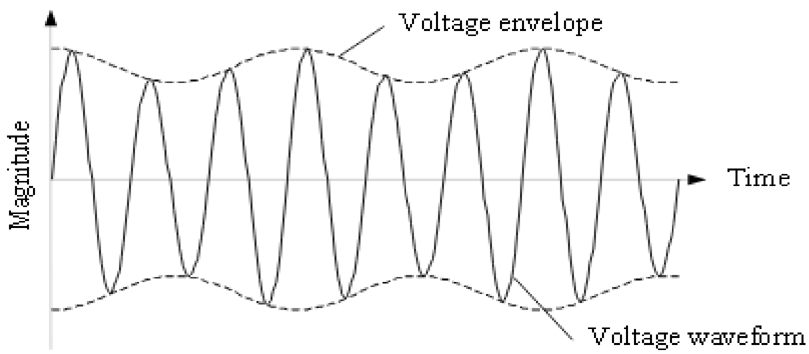


- ✓ The utility can be the source of unbalanced voltages due to malfunctioning equipment, including blown capacitor fuses, open-delta regulators, and open-delta transformers. Open-delta equipment can be more susceptible to voltage unbalance than closed-delta since they only utilize two phases to perform their transformations.
- ✓ Also, voltage unbalance can also be caused by uneven single-phase load distribution among the three phases - the likely culprit for a voltage unbalance of less than 2%. Furthermore, severe cases (greater than 5%) can be attributed to

single-phasing in the utility's distribution lateral feeders because of a blown fuse due to fault or overloading on one phase.

1.4.4 Voltage Fluctuation:

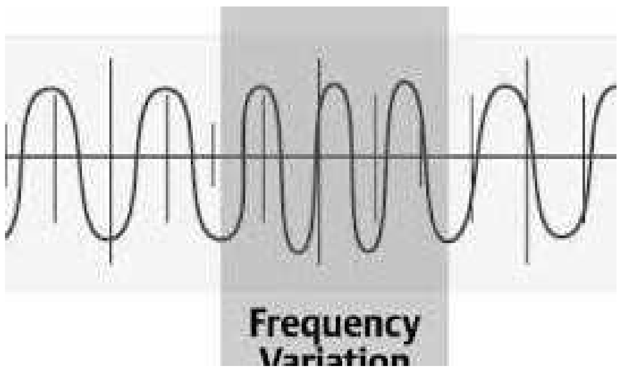
- ✓ Voltage fluctuations can be described as repetitive or random variations of the voltage envelope due to sudden changes in the real and reactive power drawn by a load. The characteristics of voltage fluctuations depend on the load type and size and the power system capacity.
- ✓ Figure 1 illustrates an example of a fluctuating voltage waveform. The voltage waveform exhibits variations in magnitude due to the fluctuating nature or intermittent operation of connected loads.
- ✓ The frequency of the voltage envelope is often referred to as the flicker frequency. Thus there are two important parameters to voltage fluctuations, the frequency of fluctuation and the magnitude of fluctuation. Both of these components are significant in the adverse effects of voltage fluctuations.



- ✓ Voltage fluctuations are caused when loads draw currents having significant sudden or periodic variations. The fluctuating current that is drawn from the supply causes additional voltage drops in the power system leading to fluctuations in the supply voltage. Loads that exhibit continuous rapid variations are thus the most likely cause of voltage fluctuations.
- ✓ Arc furnaces
- ✓ Arc welders
- ✓ Installations with frequent motor starts (air conditioner units, fans)
- ✓ Motor drives with cyclic operation (mine hoists, rolling mills)
- ✓ Equipment with excessive motor speed changes (wood chippers, car shredders)

1.5 Power frequency variations:

- ✓ Power frequency variations are a deviation from the nominal supply frequency. The supply frequency is a function of the rotational speed of the generators used to produce the electrical energy.
- ✓ At any instant, the frequency depends on the balance between the load and the capacity of the available generation.
- ✓ A frequency variation occurs if a generator becomes un-synchronous with the power system, causing an inconsistency that is manifested in the form of a variation.
- ✓ The specified frequency variation should be within the limits $\pm 2.5\%$ Hz at all times for grid network.



1.6 International Standards of power quality:

1.6.1 IEEE Standards:

- ✓ IEEE power quality standards: Institute Of Electrical and Electronics Engineer.
- ✓ IEEE power quality standards: International Electro Technical Commission.
- ✓ IEEE power quality standards: Semiconductor Equipment and Material International.
- ✓ IEEE power quality standards: The International Union for Electricity Applications
- ✓ IEEE Std 519-1992: IEEE Recommended practices and requirements for Harmonic control in Electric power systems.
- ✓ IEEE Std 1159-1995: IEEE Recommended practices for monitoring electrical power
- ✓ IEEE std 141-1993, IEEE Recommended practice for electric power distribution for industrial plants.
- ✓ IEEE std 1159-1995, IEEE recommended practice for Monitoring electrical power quality.

1.6.2. IEC Standards:

- ✓ Definitions and methodology 61000-1-X
- ✓ Environment 61000-2-X
- ✓ Limits 61000-3-X
- ✓ Tests and measurements 61000-4-X
- ✓ Installation and mitigation 61000-5-X
- ✓ Generic immunity and emissions 61000-6-X

1.7 CBEMA and ITI Curves:

- ✓ One of the most frequently employed displays of data to represent the power quality is the so-called CBEMA curve.
- ✓ A portion of the curve adapted from IEEE Standard 4469 that we typically use in our analysis of power quality monitoring results is shown in Fig. 1.5.
- ✓ This curve was originally developed by CBEMA to describe the tolerance of mainframe computer equipment to the magnitude and duration of voltage variations on the power system.
- ✓ While many modern computers have greater tolerance than this, the curve has become a standard design target for sensitive equipment to be applied on the power system and a common format for reporting power quality variation data.
- ✓ The axes represent magnitude and duration of the event. Points below the envelope are presumed to cause the load to drop out due to lack of energy. Points above the envelope are presumed to cause other malfunctions such as insulation failure, overvoltage trip, and over excitation.
- ✓ The upper curve is actually defined down to 0.001 cycle where it has a value of about 375 percent voltage.
- ✓ We typically employ the curve only from 0.1 cycles and higher due to limitations in power quality monitoring instruments and differences in opinion over defining the magnitude values in the sub cycle time frame.
- ✓ The CBEMA organization has been replaced by ITI, and a modified curve has been developed that specifically applies to common 120-V computer equipment (see Fig. 1.6). The concept is similar to the CBEMA curve. Although developed for 120-V

computer equipment, the curve has been applied to general power quality evaluation like its predecessor curve.

- ✓ Both curves are used as a reference in this book to define the withstand capability of various loads and devices for protection from power quality variations.
- ✓ For display of large quantities of power quality monitoring data, we frequently add a third axis to the plot to denote the number of events within a certain predefined cell of magnitude and duration.

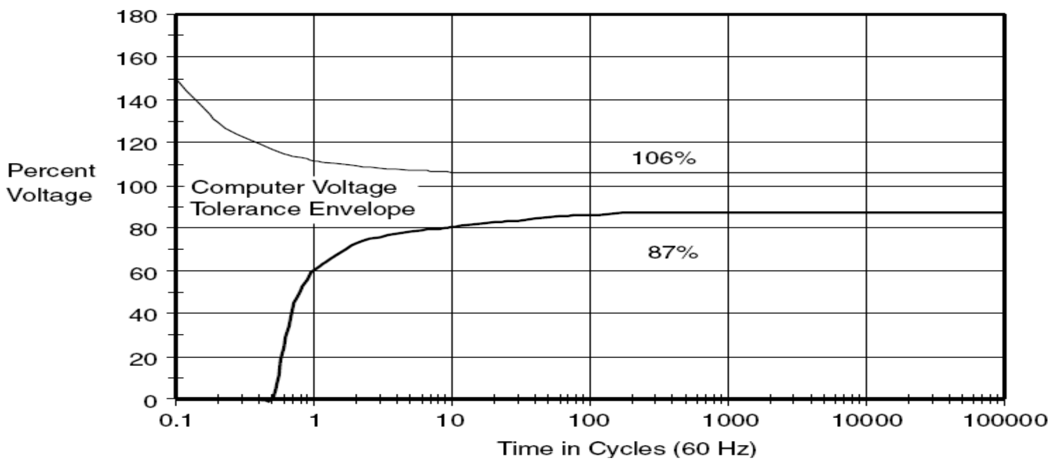


Fig 1.5 A portion of the CBEMA curve commonly used as a design target for equipment And a format for reporting power quality variation data.

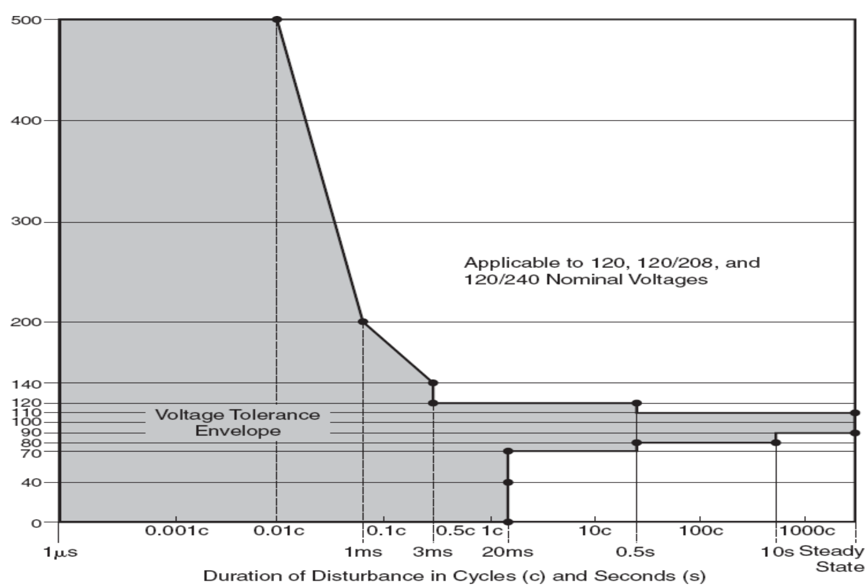


Fig 1.6 ITI curve for susceptibility of 120-V computer equipment.

APPLICATIONS:

- ❖ Active line filters (power quality management)

Operators of industrial facilities and rail networks, in particular, use active line filters with IGBT modules to meet the requirements of energy suppliers in terms of low mains feedback. The applications cover a wide range of outputs, from 1 kVA to several MW with parallel power converters. Active line filters are controlled power sources that can feed current into the network with any amplitude, frequency or phasing to compensate for harmonics and reactive power caused by the load. Their topology is that of an inverter with DC bus voltage, which is connected to the network via a filter.
Constant comparison of the actual value of the current in the network against the target value determines the energy that must be fed from the DC link capacitors via the inverter into the network, separately for each phase. In order to achieve good control dynamics, the highest possible pulse frequencies must be used.

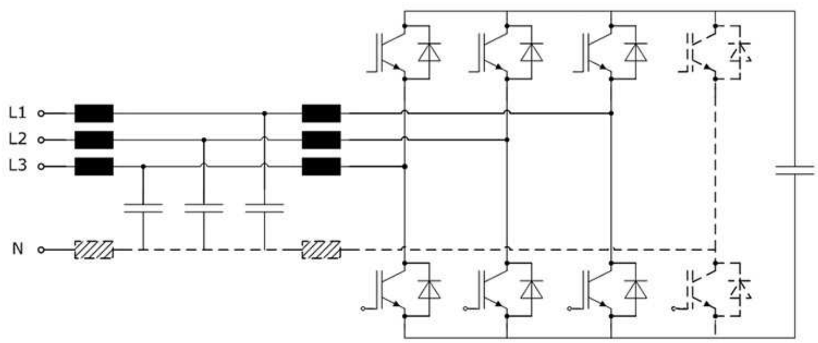


Figure 1.Block diagram of an active filter

- ❖ Energy Storage

The application "Energy Storage" includes very diverse fields of application, e.g.:

- Back-up of power failures to protect sensitive consumers with UPS systems (Uninterruptible Power Supplies)
- Electric energy storage for short-term support of wind energy and PV solar systems during grid faults and compensate for short-term production deficits
- Storing large amounts of energy for long term support in a limited supply network or to integrate producers into the grid with non-predictable, uneven power generation.

Depending on the storage volume and discharge time, today electric energy storage systems either store directly (e.g. battery storage or capacitor storage, superconducting magnetic storage) as mechanical energy (flywheel energy storage, pump storage, compressed air storage), or in the form of electrolytically produced hydrogen.

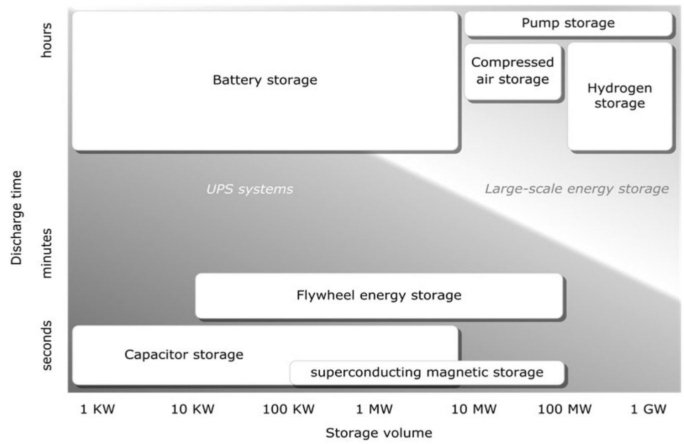


Figure 2.

MCQ POST TEST:

1. Lightening and Tree striking on a live conductor is an example________ Power Quality issue.

(a) Voltage Sag (b) **Voltage Swell** (c) Interruption (d) Surge

2. Interruption is

(a) complete loss of power (b) **complete loss of voltage** (c) complete loss of current (d) all the above

3. The Transients in the power system occurs for

a) less than two complete cycles b) exact two complete cycles c**) less than one complete cycles** d) exact one complete cycles

4. The most common cause of long interruption is ______ (a) Faults (b) Outages **(c) Both (a) & (b)**

(d) none of the above

5. Outage is the

(a) Removal of Primary Component (b) No Power Generation (c) Transmission Faults (d) None of the above

6.Single Phase Tripping is generally used in _________________.

(a) Transmission System (b) Distribution System (c) Low Voltage System (d) Generation System

7. The Short Interruptions occurs for

(a) Less than two complete cycles (b) exact two complete cycles **(c) less than one complete cycles** (d) exact one complete cycles

8. Most electrical equipment is designed to operate within a voltage of ± _____ of nominal with marginal decrease in performance.

(A) 5 %

(B) 1 %

(C) 10 %

(D) 0.5 %

9. Which of the following equipment has low immunity index?

(A) electronic medical equipment

(B) adjustable speed drives

(C) transformers

(D) electromechanical relays

10. As per the power quality indices, which of the following applications face low power quality problems?

(A) HVAC power panels

(B) lighting power distribution panel

(C) elevators

(D) large motors

CONCLUSION:

Power quality maintenance is an important aspect in the economic operation of a system. Various power quality problems may lead to another undesirable problem. Proper mitigation devices may be used to maintain the level of power quality as desired. Power-quality standards address limits to harmonics and power-quality events at the point of common coupling in power systems. Emphasis is given to causes and effects of current harmonics on different power system components.

REFERENCES :

1. Dugan, Roger C.; Mark McGranaghan; Surya Santoso; H. Wayne Beaty (2003). Electrical Power Systems Quality. McGraw-Hill Companies, Inc. ISBN 978-0-07-138622-7.
2. Meier, Alexandra von (2006). Electric Power Systems: A Conceptual Introduction. John Wiley & Sons, Inc. ISBN 978-0471178590.
3. Heydt, G.T. (1991). Electric Power Quality. Stars in a Circle Publications. Library Of Congress 621.3191. Bollen, Math H.J. (2000). Understanding Power Quality Problems: Voltage Sags and Interruptions. New York: IEEE Press. ISBN 0-7803-4713-7.
4. Sankaran, C. (2002). Power Quality. CRC Press LLC. ISBN 978-0-8493-1040-9.

5. Baggini, A. (2008). Handbook of Power Quality. Wiley. ISBN 978-0-470-06561-7.

ASSIGNMENTS :

1. What do you understand about power quality issues? Discuss all the power quality issues in brief.

2. Explain the cause and effect with respect to power quality point of view? What is an immunity of the equipment? Discuss the treatment criteria for a machine.

3. Define and technically describe following terms: (1)Linear loads (2)Inrush current (3)Power factor(displacement) (4)Voltage swell (5)Transient

4. What are the power quality standards? Discuss responsibilities of supplier and user of electrical power with respect to power quality

5. Define the following terms 1. Displacement Power Factor 2. Flicker 3. Nonlinear load

6. Explain following terms related to power quality. (1) Grounding (2) Noise (3) Notch.

7. Explain all power quality concerns in brief.

8. What are CBEMA and ITIC graphs? Draw and discuss the ITIC graph in detail

9. Explain different power quality solution techniques in detail.

10. Define the term “Power Quality”. Discuss the common power frequency disturbances with suitable examples.

4.1 Introduction

Present-day AC distribution systems are facing a number of power quality problems, especially due to the use of sensitive equipment in most of the industrial, residential, commercial, and traction applications. These power quality problems are classified as voltage and current quality problems in distribution systems. The custom power devices (CPDs), namely, DSTATCOMs (distribution static compensators), DVRs (dynamic voltage restorers), and UPQCs (unified power quality conditioners), are used to mitigate some of the problems depending upon the requirements. Out of these CPDs, DSTATCOMs are extensively used for mitigating the current-based power quality problems. There are a number of current-based power quality problems such as poor power factor, or poor voltage regulation, unbalanced currents, and increased neutral current. Therefore, depending upon the problems, the configuration of the DSTATCOM is selected in the practice. With the objective of mitigating the current-based power quality problems especially in distribution systems, this chapter focuses on the configurations, design, control algorithms, modeling, and illustrative examples of DSTATCOMs.

These problems further aggravate in the presence of harmonics either in the voltage or in the currents. The shunt active compensators are also reported with some modifications as cost-effective shunt active power filters to eliminate harmonic currents in nonlinear loads. Of course, the main objective of shunt active power filters has been to eliminate harmonic currents at the PCC (point of common coupling) voltage normally created by nonlinear loads. In view of the additional applications of the shunt compensators as shunt active power filters, a separate chapter (Chapter 9) is devoted to the shunt active power filters to deal with the elimination of harmonics in currents along with some specific applications and case studies.

4.2 State of the Art on DSTATCOMs

The DSTATCOM technology is now a mature technology for providing reactive power compensation, load balancing, and/or neutral current and harmonic current compensation (if required) in AC distribution networks. It has evolved in the past quarter century with development in terms of varying configurations, control strategies, and solid-state devices. These compensating devices are also used to regulate the terminal voltage, suppress voltage flicker, and improve voltage balance in three-phase systems. These objectives are achieved either individually or in combination depending upon the requirements and the control strategy and configuration that need to be selected appropriately. This section describes the history of development and the current status of the DSTATCOM technology.

In AC distribution systems, current-based power quality problems have been faced for a long time in terms of poor power factor, poor voltage regulation, load unbalancing, and enhanced neutral current.

Classical technology of using power capacitors and static VAR compensators using TCRs (thyristor-controlled reactors) and TSCs (thyristor-switched capacitors) has been used to mitigate some of these power quality problems. However, DSTATCOM technology is considered the best technology to mitigate all the current-based power quality problems.

DSTATCOMs are basically categorized into three types, namely, single-phase two-wire, three-phase three-wire, and three-phase four-wire configurations, to meet the requirements of three types of consumer loads on supply systems. Single-phase loads such as domestic lights and ovens, TVs, computer power supplies, air conditioners, laser printers, and Xerox machines cause power quality problems. Single-phase two-wire DSTATCOMs have been investigated in varying configurations and control strategies to meet the needs of single-phase systems. Starting from 1984, many configurations have been developed and commercialized for many applications. Both current source converters (CSCs) with inductive energy storage and voltage source converters (VSCs) with capacitive energy storage are used to develop single-phase DSTATCOMs.

A major amount of AC power is consumed by three-phase loads. A substantial work has been reported on three-phase three-wire DSTATCOMs, starting from 1984. Many configurations and control strategies such as instantaneous reactive power theory, synchronous frame d–q theory, and synchronous detection method are used in the development of three-phase DSTATCOMs.

The problem of increased neutral current in addition to poor power factor and load unbalancing is observed in three-phase four-wire systems mainly due to unbalanced loads such as computer power supplies and fluorescent lighting. The problems of neutral current and unbalanced load currents can be resolved by using four-wire DSTATCOMs in four-wire distribution systems, which cause reduction of neutral current, load balancing, reactive power compensation, and/or harmonic compensation (if required).

The problems of reactive power and load unbalancing have been recognized long ago and they have got aggravated in the presence of nonlinear loads. Many publications are reported on solid-state compensators for voltage flicker, reactive power, and balancing the reactive loads such as arc furnaces and traction loads. Many more terminologies such as static VAR compensators, static flicker compensators, and static VAR generators have been used in the literature.

One of the major factors in advancing the DSTATCOM technology is the advent of fast, self-commutating solid-state devices. In the initial stages, BJTs (bipolar junction transistors) and power MOSFETs (metal-oxide semiconductor field-effect transistors) have been used to develop DSTATCOMs; later, SITs (static induction thyristors) and GTOs (gate turn-off thyristors) have been employed to develop DSTATCOMs. With the introduction of IGBTs (insulated gate bipolar transistors), the DSTATCOM technology has got a real boost and at present it is considered as an ideal solid-state device for DSTATCOMs. The improved sensor technology, especially Hall effect current and voltage sensors, has also contributed to the enhanced performance of DSTATCOMs. The availability of Hall effect sensors and isolation amplifiers at reasonable cost and with adequate ratings has improved the performance of DSTATCOMs.

The next breakthrough in DSTATCOM development has resulted from the microelectronics revolution. Starting from the use of discrete analog and digital components, the progression has been to microprocessors, microcontrollers, and DSPs (digital signal processors). Now it is possible to implement complex algorithms online for the control of DSTATCOMs at a reasonable cost. This development in DSPs has made it possible to use different control algorithms such as PI (proportional-integral) controller, variable structure control, fuzzy logic control, and neural network control for improving the dynamic and steady-state performance of DSTATCOMs. With these improvements, the DSTATCOMs are capable of providing fast corrective action even with dynamically changing loads such as furnaces and traction.

4.3 Classification of DSTATCOMs

DSTATCOMs can be classified based on the type of converter used, topology, and the number of phases. The converter used in the DSTATCOM can be either a current source converter or a voltage source converter. Different topologies of DSTATCOMs can be realized by using transformers and various

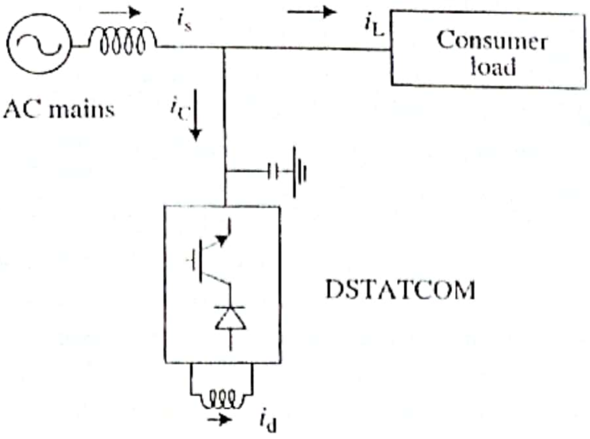


Figure 4.1 A CSC-based DSTATCOM

circuits of VSCs. The third classification is based on the number of phases, namely, single-phase two-wire, three-phase three-wire, and three-phase four-wire systems.

4.3.1 Converter-Based Classification

Two types of converters are used to develop DSTATCOMs. Figure 4.1 shows a DSTATCOM using a CSC bridge. A diode is used in series with the self-commutating device (IGBT) for reverse voltage blocking. However, GTO-based DSTATCOM configurations do not need the series diode, but they have restricted frequency of switching. They are considered sufficiently reliable, but have high losses and require high values of parallel AC power capacitors. Moreover, they cannot be used in multilevel or multistep modes to improve the performance of DSTATCOMs in higher power ratings.

The other converter used in a DSTATCOM is a voltage source converter shown in Figure 4.2. It has a self-supporting DC voltage bus with a large DC capacitor. It is more widely used because it is light, cheap, and expandable to multilevel and multistep versions, to enhance the performance with lower switching frequencies.

4.3.2 Topology-Based Classification

DSTATCOMs can also be classified based on the topology, for example, VSCs without transformers, VSCs with non-isolated transformers, and VSCs with isolated transformers. DSTATCOMs are also used as advanced static VAR generators (STATCOMs) in the power system network for stabilizing and improving the voltage profile. Therefore, a large number of circuits of DSTATCOMs with and without transformers are evolved for meeting the specific requirements of the applications.

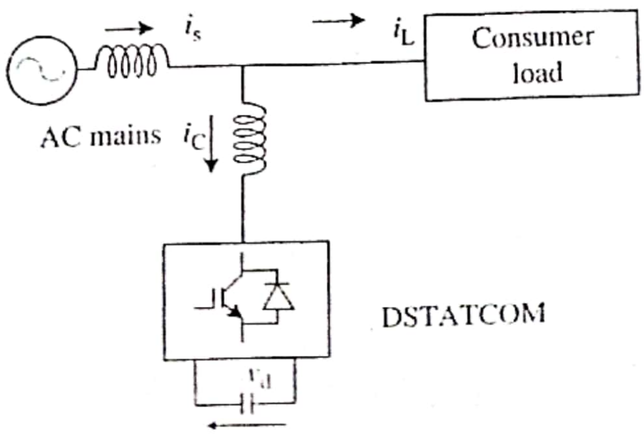


Figure 4.2 A VSC-based DSTATCOM

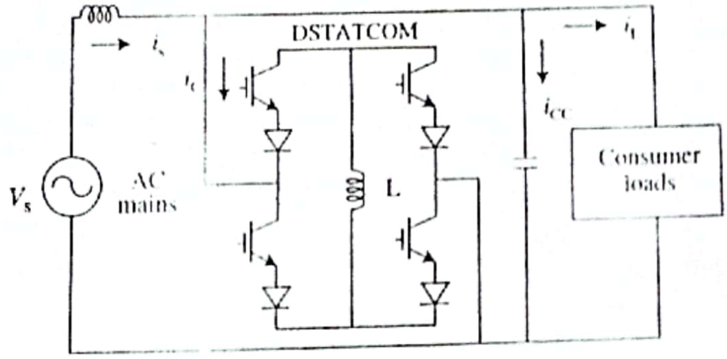


Figure 4.3 A two-wire DSTATCOM with a CSC

4.3.3 *Supply System-Based Classification*

This classification of DSTATCOMs is based on the supply and/or the load system, for example, single-phase two-wire, three-phase three-wire, and three-phase four-wire systems. There are many varying loads such as domestic appliances connected to single-phase supply systems. Some three-phase loads are without neutral terminals, such as traction, furnaces, and ASDs (adjustable speed drives) fed from three-wire supply systems. There are many single-phase loads distributed on three-phase four-wire supply systems, such as computers and commercial lighting. Hence, DSTATCOMs may also be classified accordingly as two-wire, three-wire, and four-wire DSTATCOMs.

4.3.3.1 Two-Wire DSTATCOMs

Two-wire (single-phase) DSTATCOMs are used in both converter configurations, a CSC bridge with inductive energy storage elements and a VSC bridge with capacitive DC bus energy storage elements, to form two-wire DSTATCOM circuits.

Figure 4.3 shows a configuration of a DSTATCOM with a CSC bridge using inductive energy storage elements. A similar configuration based on a VSC bridge with capacitive energy storage at its DC bus is obtained by considering only two wires (phase and neutral terminals) as shown in Figure 4.4.

4.3.3.2 Three-Wire DSTATCOMs

There are various configurations of capacitor-supported DSTATCOMs based on the type of VSC used and auxiliary circuits. The classification of three-phase three-wire DSTATCOMs is shown in Figure 4.5, consisting of isolated and non-isolated VSC-based topologies of DSTATCOMs. The non-isolated configurations include three-leg VSC-based DSTATCOMs and two-leg VSC-based DSTATCOMs; these circuit configurations are shown in Figures 4.6 and 4.7, respectively. The two-leg VSC-based DSTATCOM has the advantage that it requires only four switching devices, but there are two capacitors

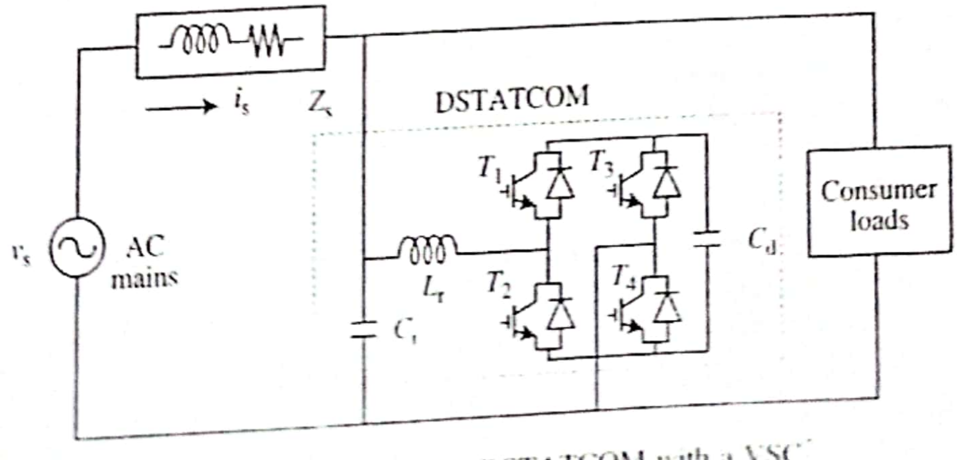


Figure 4.4 A two-wire DSTATCOM with a VSC

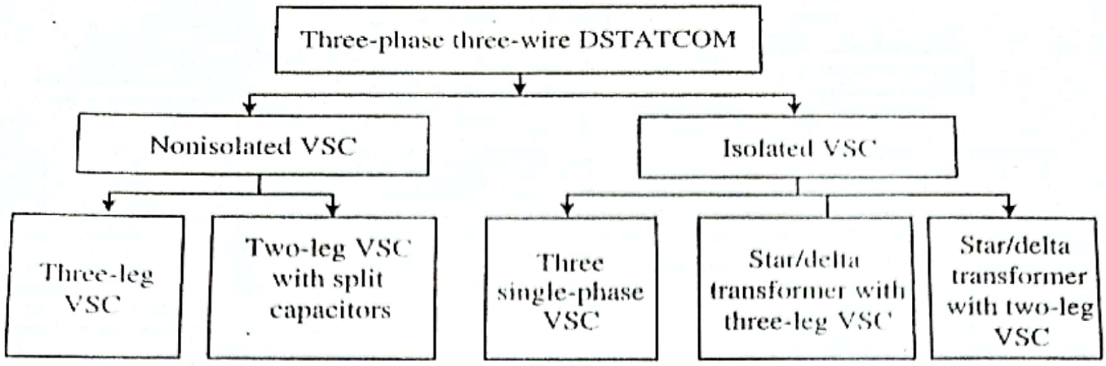


Figure 4.5 Topology classification of three-phase three-wire DSTATCOMs

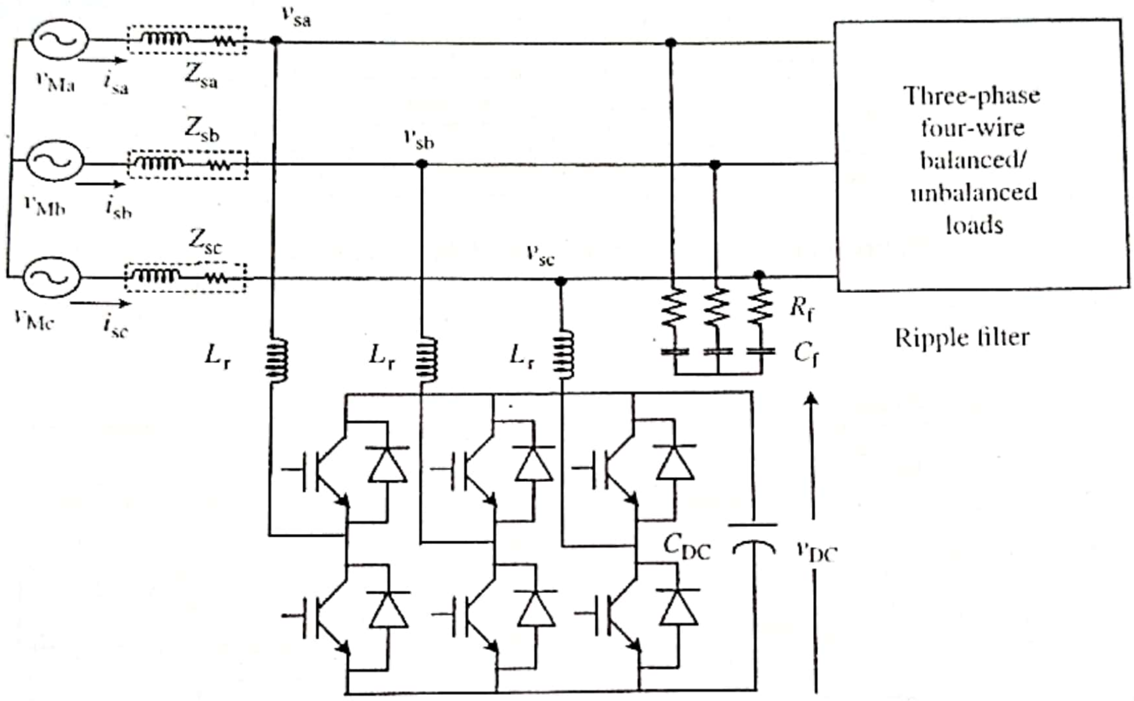


Figure 4.6 A three-leg VSC-based three-phase three-wire DSTATCOM

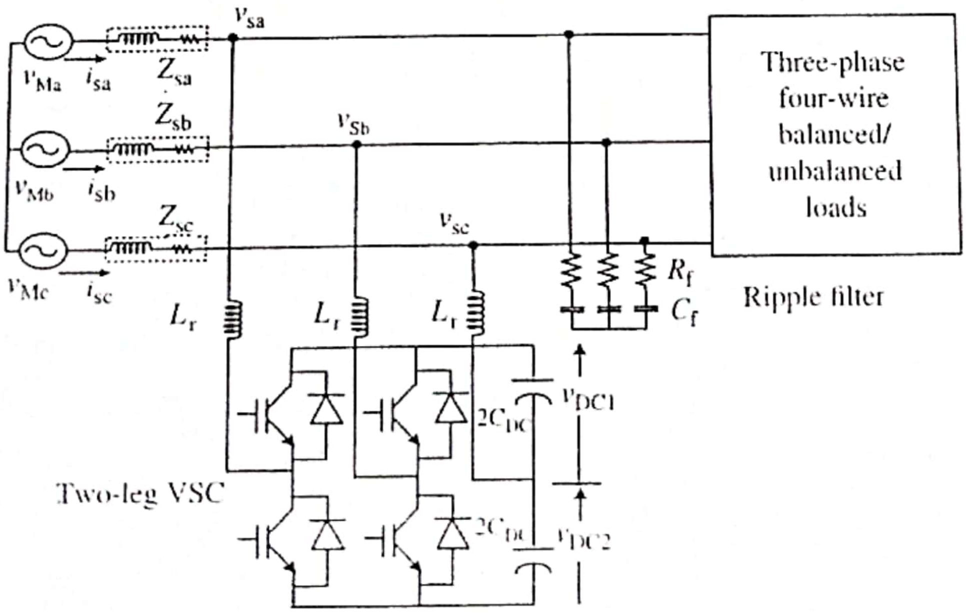


Figure 4.7 An H-bridge VSC and midpoint capacitor-based three-phase three-wire DSTATCOM

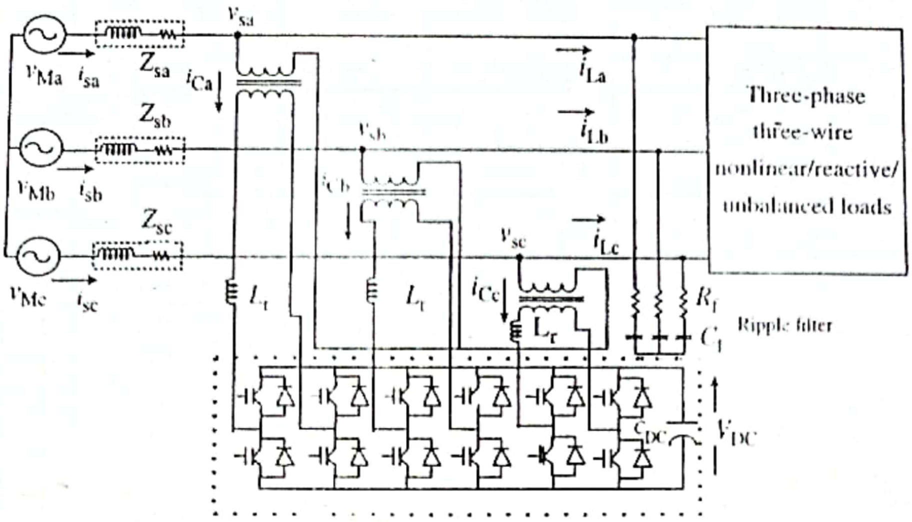
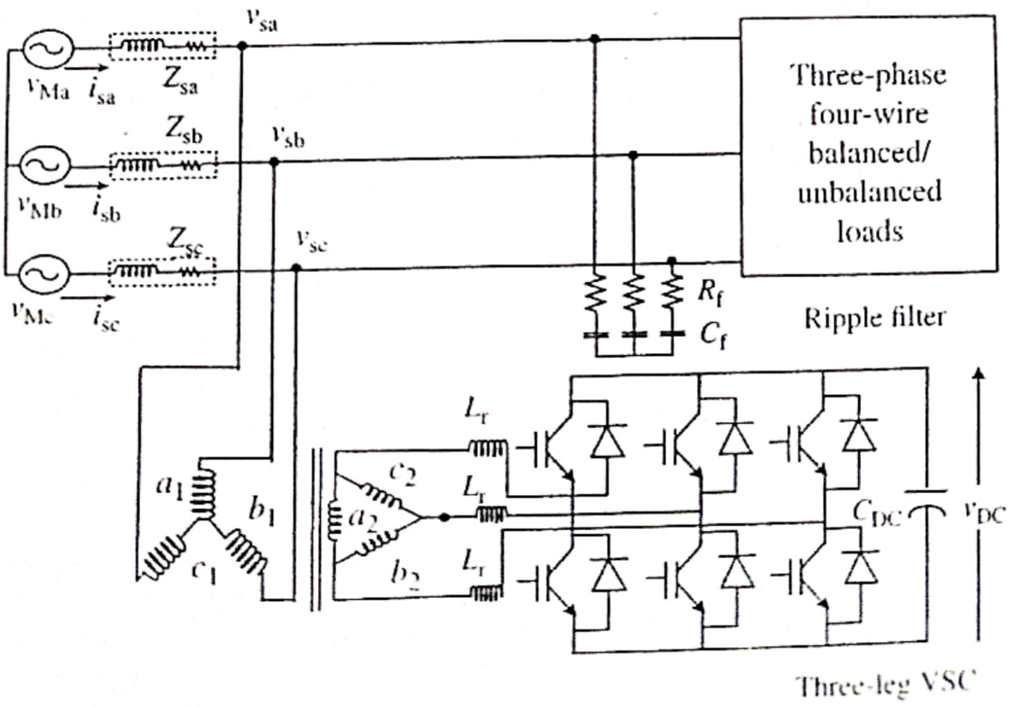


Figure 4.8 A three single-phase VSC-based three-phase three-wire DSTATCOM

connected in series and the total DC capacitor voltage is twice the DC bus voltage of the three-leg VSC topology. The isolated configurations include three single-phase VSC-based DSTATCOMs, three-leg VSC-based DSTATCOMs, and two-leg VSC-based DSTATCOMs; these configurations are shown in Figures 4.8–4.10, respectively. The advantage of the isolated VSC-based DSTATCOM topology is that the voltage rating of the VSC can be optimally designed as there is an interfacing transformer. Three single-phase VSC-based DSTATCOMs require 12 semiconductor switches, whereas in three-leg VSC-based DSTATCOMs there are only 6 switches. However, two-leg VSC-based DSTATCOMs require only four switches.

4.3.3.3 Four-Wire DSTATCOMs

In a three-phase four-wire distribution system, there are three-phase loads and single-phase loads depending upon the consumers' demands. This results in severe burden of unbalanced currents along with the neutral current on the distribution feeder. To prevent the unbalanced currents from being drawn from the distribution bus, a shunt compensator, also called DSTATCOM, can be used. It ensures that the



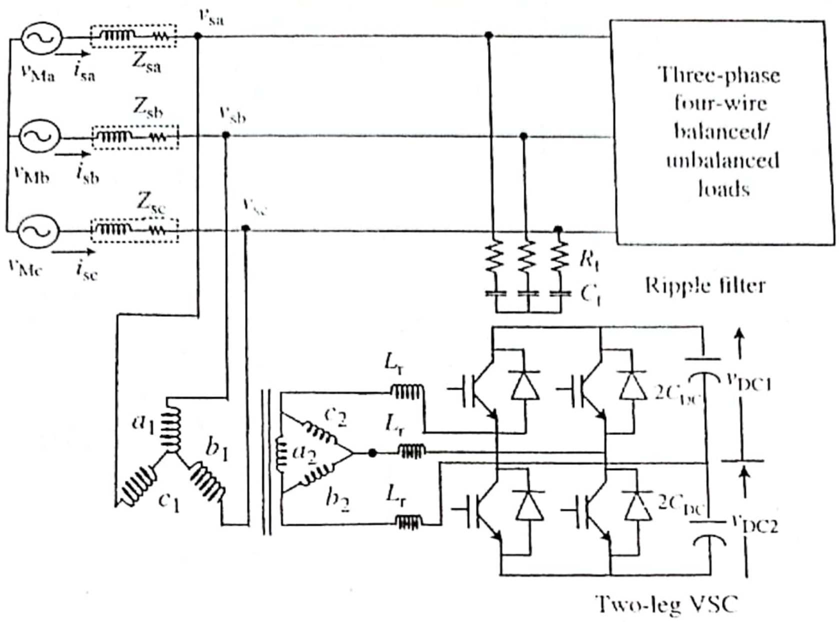


Figure 4.10 An isolated H-bridge VSC and midpoint capacitor-based DSTATCOM

currents drawn from the distribution bus are balanced and sinusoidal and, moreover, the neutral current is compensated.

A DSTATCOM is a fast-response, solid-state power controller that provides power quality improvements at the point of connection to the utility distribution feeder. It is the most important controller for distribution networks. It has been widely used to precisely regulate the system voltage and/or for load compensation. It can exchange both active and reactive powers with the distribution system by varying the amplitude and phase angle of the voltage of the VSC with respect to the PCC voltage, if an energy storage system (ESS) is included into the DC bus. However, a capacitor-supported DSTATCOM is preferred for power quality improvement in the currents, such as reactive power compensation for unity power factor or voltage regulation at PCC, load balancing, and neutral current compensation.

4.4 Principle of Operation and Control of DSTATCOMs

The basic function of DSTATCOMs is to mitigate most of the current-based power quality problems such as reactive power, unbalanced currents, neutral current, and harmonics (if any) and to provide sinusoidal balanced currents in the supply with the self-supporting DC bus of the VSC used as a DSTATCOM.

A fundamental circuit of the DSTATCOM for a three-phase three-wire AC system with balanced/unbalanced loads is shown in Figure 4.6. An IGBT-based current-controlled voltage source converter (CC-VSC) with a DC bus capacitor is used as the DSTATCOM. Using a control algorithm, the reference DSTATCOM currents are directly controlled by estimating the reference DSTATCOM currents. However, in place of DSTATCOM currents, the reference supply currents may be estimated for an indirect current control of the VSC. The gating pulses to the DSTATCOM are generated by employing hysteresis (carrierless PWM (pulse-width modulation)) or PWM (fixed frequency) current control over reference and sensed supply currents resulting in an indirect current control. Using the DSTATCOM, the reactive power compensation and unbalanced current compensation are achieved in all the control algorithms. In addition, zero voltage regulation (ZVR) at PCC is also achieved by modifying the control algorithm suitably.

4.4.1 Principle of Operation of DSTATCOMs

The main objective of DSTATCOMs is to mitigate the current-based power quality problems in a distribution system. A DSTATCOM mitigates most of the current quality problems, such as reactive power, unbalance, neutral current, harmonics (if any), and fluctuations, present in the consumer loads or otherwise in the system and provides sinusoidal balanced currents in the supply with its DC bus voltage regulation.

In general, a DSTATCOM has a VSC connected to a DC bus and its AC sides are connected in shunt normally across the consumer loads or across the PCC as shown in Figures 4.6–4.8. The VSC uses PWM control; therefore, it requires small ripple filters to mitigate switching ripples. It requires Hall effect voltage and current sensors for feedback signals and normally a DSP is used to implement the required control algorithm to generate gating signals for the solid-state devices of the VSC of the DSTATCOM. The VSC is normally controlled in PWM current control mode to inject appropriate currents in the system. The DSTATCOM also needs many passive elements such as a DC bus capacitor, AC interacting inductors, injection and isolation transformers, and small passive filters.

4.4.2.1.1 *Control of DSTATCOMs in UPF Mode of Operation*

Figure 4.21 shows the unit template-based control algorithm of DSTATCOMs for power factor correction (PFC) at PCC. In this control algorithm, three-phase voltages at PCC along with the DC bus voltage of the DSTATCOM are used for implementing this control algorithm. In real-time implementation of DSTATCOMs, a band-pass filter (BPF) plays an important role. Three-phase voltages are sensed at PCC and are conditioned in a band-pass filter to filter out any distortion. The three-phase load voltages are inputs and three-phase filtered voltages (v_{sa}, v_{sb}, v_{sc}) are outputs of band-pass filters.

For the control of the DSTATCOM, the self-supporting DC bus is realized using a PI voltage controller over the sensed (v_{DC}) and reference (v_{DC}^*) values of the DC bus voltage of the DSTATCOM. The PI voltage controller on the DC bus voltage of the DSTATCOM provides the amplitude (I_{spp}^*) of in-phase components (i_{sa}^*, i_{sb}^*, i_{sc}^*) of reference supply currents. The three-phase unit current vectors (u_{sa}, u_{sb}, u_{sc}) are derived in phase with the filtered supply voltages (v_{sa}, v_{sb}, v_{sc}). The multiplication of the in-phase amplitude with in-phase unit vectors results in the in-phase components of three-phase reference supply currents (i_{sa}^*, i_{sb}^*, i_{sc}^*). Hence, for fundamental unity power factor supply currents, the in-phase reference supply currents, which are estimated in the above-described procedure, become the reference supply currents.

The amplitude of reference supply currents is computed using a PI voltage controller over the average value of the DC bus voltage (v_{DCa}) of the DSTATCOM and its reference value (v_{DC}^*). A comparison of average and reference values of the DC bus voltage of the DSTATCOM results in a voltage error, which is fed to a PI voltage controller:

$$v_{DCe}(n) = v_{DC}^*(n) - v_{DCa}(n). \tag{4.1}$$

This voltage error is fed to a PI voltage controller, and the output of the PI voltage controller is

$$I_{spp}(n) = I_{spp}(n-1) + K_{pd}\{v_{DCe}(n) - v_{DCe}(n-1)\} + K_{id}v_{DCe}(n), \tag{4.2}$$

where $v_{DCe}(n) = v_{DC}^*(n) - v_{DC}(n)$ is the error between the reference (v_{DC}^*) and the sensed (v_{DC}) DC voltage at the nth sampling instant, and K_{pd} and K_{id} are the proportional and integral gain constants of the DC bus voltage PI controller, respectively.

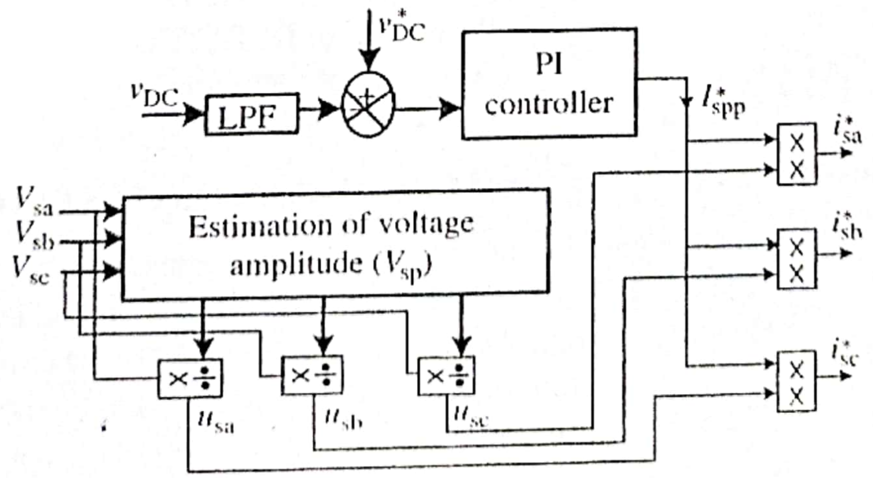


Figure 4.21 Unit template-based control algorithm of DSTATCOMs for power factor correction mode of operation

Here, proportional (K_{pd}) and integral (K_{id}) gain constants are chosen such that a desired DC bus voltage response is achieved. The output of the PI controller is taken as the amplitude (I^*_{spp}) of the reference supply currents. Now, in-phase components of the three-phase reference supply currents are computed using their amplitude and in-phase unit vectors derived in phase with the PCC voltages, and are given as

$$i^*_{sa} = I^*_{spp}u_{sa}, \quad i^*_{sb} = I^*_{spp}u_{sb}, \quad i^*_{sc} = I^*_{spp}u_{sc}, \tag{4.3}$$

where u_{sa}, u_{sb}, and u_{sc} are in-phase unit templates and are derived as

$$u_{sa} = v_{sa}/V_{sp}, \quad u_{sb} = v_{sb}/V_{sp}, \quad u_{sc} = v_{sc}/V_{sp}, \tag{4.4}$$

where V_{sp} is the amplitude of the PCC voltage and is computed as

$$V_{sp} = \{2/3(v^2_{sa} + v^2_{sb} + v^2_{sc})\}^{1/2}. \tag{4.5}$$

4.4.2.1.2 *Control of DSTATCOMs in ZVR Mode of Operation*

The DSTATCOM can compensate the reactive power and negative-sequence currents of the loads. However, because of finite (nonzero) internal impedance of the utility, which is represented by Z_s (L_s, R_s), the voltage waveforms at PCC to other loads are not regulated and result in a voltage drop. The DSTATCOM should regulate the PCC voltages so that other loads connected at PCC are not affected by this voltage drop. The voltage drops are caused by many loads such as inrush currents by the direct-on line starting of motors. Thus, it is necessary to switch the operating mode of the DSTATCOM to a voltage regulator.

As mentioned earlier, in addition to load balancing, the DSTATCOM can also be operated to maintain constant voltage at PCC. For this purpose, the DSTATCOM takes normally a leading current component (in general) due to lagging power factor loads and it is explained using phasor diagrams shown in Figure 4.22. When the system is operating without a DSTATCOM, the voltage at PCC (V_s) is less than the supply voltage (V_M) due to the drop in the supply impedance Z_s (L_s, R_s) as shown in Figure 4.22a. Now with a DSTATCOM connected in the system and drawing a leading current component, the supply current and hence the drop across the supply impedance can be controlled so that the magnitudes of the PCC voltage and supply voltage become equal ($|V_s| = |V_M|$) as shown in Figure 4.22b. By controlling the DSTATCOM current, the amplitude and phase of the supply current may be changed to maintain the desired load voltage. Hence, at the same time, both UPF and ZVR functions cannot be achieved.

The control algorithm to maintain the desired PCC voltage, the DSTATCOM for ZVR operation at PCC, is shown in Figure 4.23. Using this algorithm, one can achieve AC voltage regulation at load terminals (at PCC) and load balancing of unbalanced loads. For regulation of voltage at PCC, the three-phase reference supply currents (i^*_{sa}, i^*_{sb}, i^*_{sc}) have two components. The first component (i^*_{sad}, i^*_{sbd}, i^*_{scd}) is in phase with the voltages at PCC to feed active power to the loads and the losses of the DSTATCOM. The second component (i^*_{saq}, i^*_{sbq}, i^*_{scq}) is in quadrature with the voltages at PCC to feed reactive power to the loads and to compensate the line voltage drop by reactive power injection at PCC. For power factor correction to unity and balancing of unbalanced loads, the quadrature component of reference supply

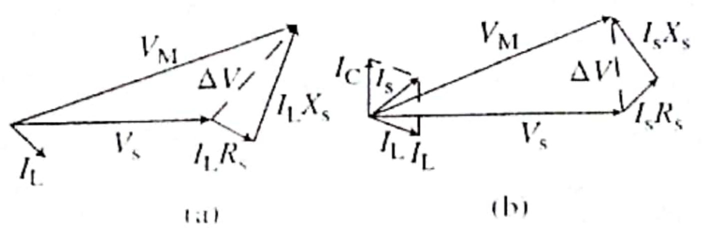


Figure 4.22 Phasor diagrams for ZVR mode of operation: (a) without a DSTATCOM and (b) with a DSTATCOM

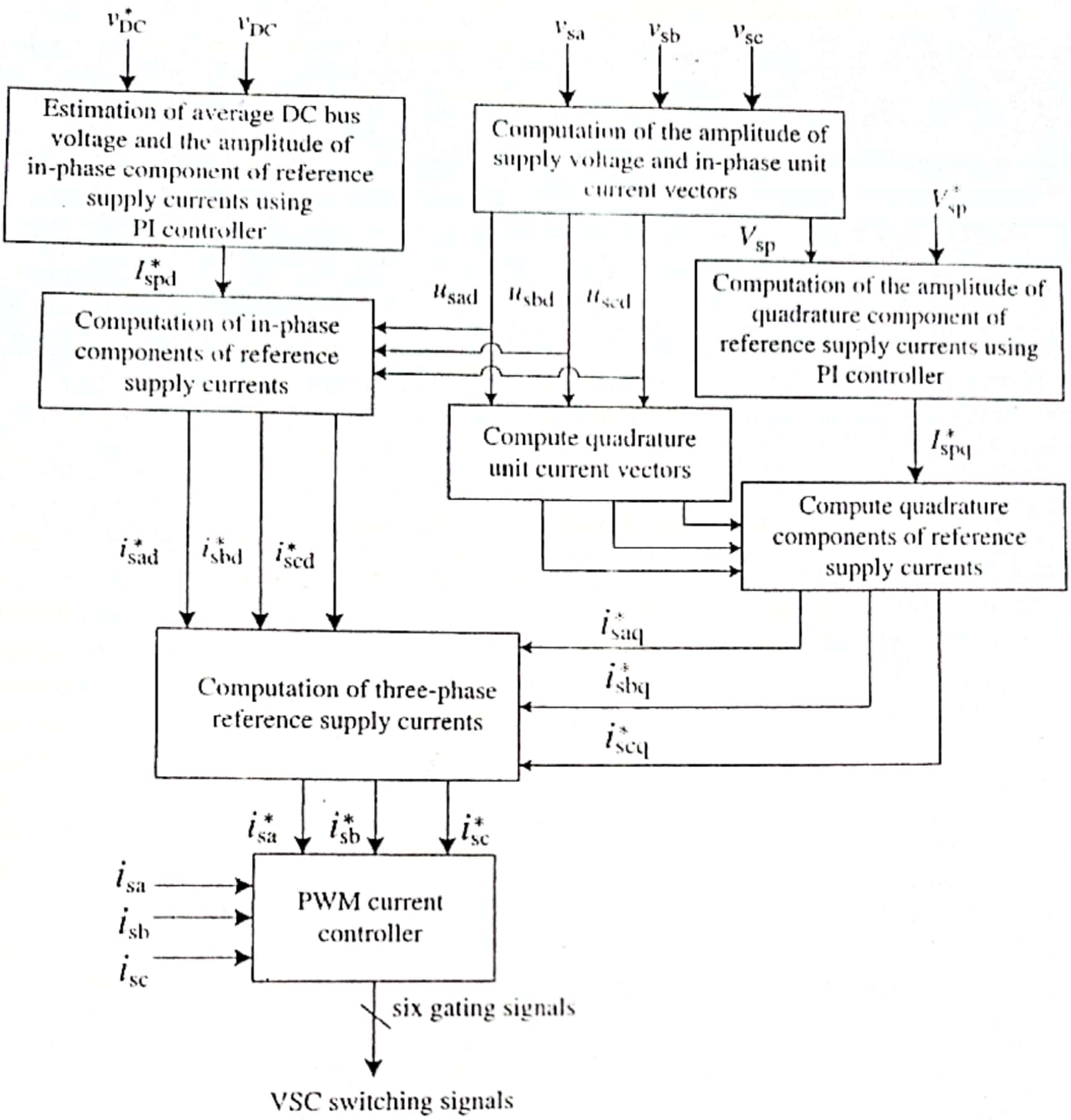


Figure 4.23 Unit template-based control algorithm of DSTATCOMs for ZVR mode of operation

currents is set to zero. For voltage regulation at PCC, the supply currents should lead the supply voltages for lagging PF loads, while for the power factor control to unity, the supply currents should be in phase with the supply voltages. These two conditions, namely, voltage regulation at PCC and power factor control to unity, cannot be achieved simultaneously. Therefore, the control algorithm of the DSTATCOM is made flexible to achieve either voltage regulation or power factor correction to unity and load balancing. The operation of DSTATCOMs in UPF mode is already explained in the previous section. Therefore, the three in-phase components of supply currents are the quantities estimated in Equation 4.3.

The amplitude (I^*_{spq}) of the quadrature component of reference supply currents is estimated using another PI controller over the filtered amplitude (V_{sp}) of the PCC voltage and its reference value (V^*_{sp}). A comparison of the reference value with the amplitude of the PCC voltage results in a voltage error (V_{spe}). This voltage error signal is processed in a PI controller. The output signal of the PI voltage controller $I^*_{spq}(n)$ for maintaining the PCC terminal voltage at a constant value at the nth sampling instant is expressed as

$$I^*_{spq}(n) = I^*_{spq}(n-1) + K_{pi}\{v_{spe}(n) - v_{spe}(n-1)\} + K_{ii}v_{spe}(n). \tag{4.6}$$

where K_{pi} and K_{ii} are the proportional and integral gain constants of the AC bus voltage PI controller, respectively, $v_{spe}(n)$ and $v_{spe}(n-1)$ are the voltage errors at the nth and $(n-1)$th instants, respectively, and

$I^*_{spq}(n-1)$ is the required reactive power at the $(n-1)$th instant. The term $I^*_{spq}(n)$ is considered as the amplitude (I^*_{spq}) of the quadrature component of reference supply currents. Three-phase quadrature components of reference supply currents are estimated using their amplitude and quadrature unit current templates as

$$i^*_{saq} = I^*_{spq}u_{saq}, \quad i^*_{sbq} = I^*_{spq}u_{sbq}, \quad i^*_{scq} = I^*_{spq}u_{scq}, \tag{4.7}$$

where u_{saq}, u_{sbq}, and u_{scq} are quadrature unit current templates and are derived as

$$\begin{aligned} u_{saq} &= (-u_{sbd} + u_{scd})/\sqrt{3}, \\ u_{sbq} &= (3u_{sad} + u_{sbd} - u_{scd})/2\sqrt{3}, \\ u_{scq} &= (-3u_{sad} + u_{sbd} - u_{scd})/2\sqrt{3}, \end{aligned} \tag{4.8}$$

where $u_{sad} = u_{sa}$, $u_{sbd} = u_{sb}$, $u_{scd} = u_{sc}$ are in-phase unit templates of phase voltages.

Three-phase instantaneous reference supply currents are estimated by adding in-phase and quadrature components expressed in Equations 4.3 and 4.7. For power factor correction and load balancing, the amplitude of quadrature components is set to zero and in this condition the in-phase components of reference supply currents become the total reference supply currents. These estimated three-phase reference supply currents and sensed supply currents are given to the hysteresis/PWM current controller to generate the switching signals for switches of the VSC of the DSTATCOM.

)9

5.2 State of the Art on Active Series Compensators DVR

The custom power device technology is now mature enough for providing compensation for voltage-based power quality problems in AC distribution systems. It has evolved in the last decade of development with varying configurations, control strategies, and solid-state devices. Active series compensators are used to eliminate voltage spikes, sags, swells, notches, and harmonics, to regulate terminal voltage, to suppress voltage flicker, and to mitigate voltage unbalance in the three-phase systems. These wide range of objectives are achieved either individually or in combination depending upon the requirements, control strategy, and configuration, which have to be selected appropriately. This section describes a chronological development and present status of the active series compensator technology.

Since 1971, many configurations of active series compensators have been reported in the literature such as DVRs and static synchronous series compensators (SSSCs) for transmission systems, series compensation for furnaces, and many other fluctuating loads. The concepts based on both the CSC with inductive energy storage and the VSC with capacitive energy storage are used to develop single-phase SSSCs.

One of the major factors in the advancement of SSC technology is the advent of fast, self-commutating solid-state devices. In the initial stages, BJTs and power MOSFETs were used for DVR development; later, SITs and GTOs were employed to develop DVRs. With the introduction of IGBTs, the SSSC technology has got a real boost and at present it is considered an ideal solid-state device for SSCs. The improved sensor technology has also contributed to the enhanced performance of the SSC. The availability of Hall effect sensors and isolation amplifiers at a reasonable cost and with adequate ratings has improved the SSC performance substantially.

Another breakthrough in the development of SSC has resulted from the microelectronics revolution. From the initial use of discrete analog and digital components, the SSSCs are now equipped with microprocessors, microcontrollers, and DSPs. Now it is possible to implement complex algorithms online for the control of the SSC at a reasonable cost. This development has made it possible to use different control algorithms such as proportional–integral (PI) control, variable structure control, fuzzy logic control, and neural nets-based control for improving the dynamic and steady-state performance of the SSC. With these improvements, the SSCs are capable of providing fast corrective action even under dynamically changing loads.

5.3 Classification of Active Series Compensators

Active series compensators can be classified based on the power converter type, topology, and the number of phases. The type of power converter can be either CSC or VSC. The topology can be half-bridge VSC, full-bridge VSC, and so on. The third classification is based on the number of phases such as single-phase two-wire and three-phase three- or four-wire systems.

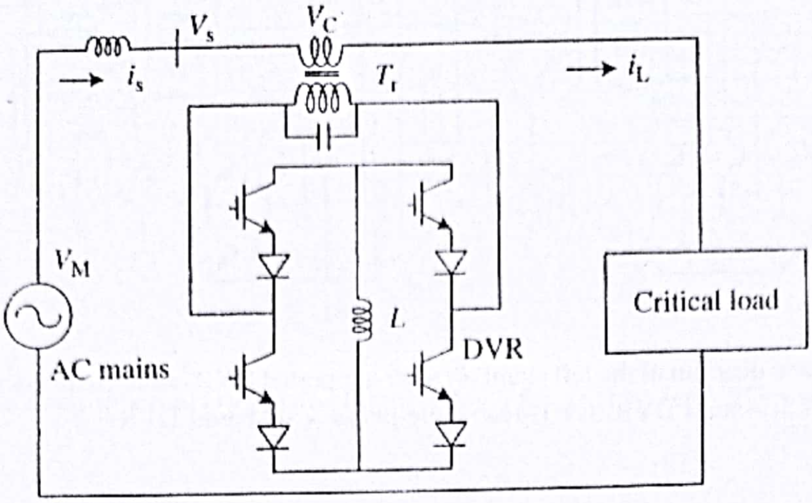


Figure 5.1 CSC-based single-phase DVR

5.3.1 *Converter-Based Classification*

Two types of power converters are used in the development of active series compensators. Figure 5.1 shows single-phase SSC (DVR) based on current source converter. In this CSC-based DVR, a diode is used in series with the self-commutating device (IGBT) for reverse-voltage blocking. However, GTO-based DVR configurations do not need the series diode, but they have restricted switching frequency. Although CSCs are considered sufficiently reliable, they cause high losses and require high-voltage parallel AC power capacitors. Moreover, they cannot be used in multilevel or multistep modes to improve performance in higher ratings.

The other power converter used in SSC is a VSC, as shown in Figure 5.2. It has a self-supporting DC voltage bus with a large DC capacitor. It has become more dominant since it is lighter, cheaper, and expandable to multilevel and multistep versions, to enhance the performance with lower switching frequencies. It is more popular in UPS-based applications because in the presence of AC mains, the same power converter can be used as an active series compensator for series compensation of critical and sensitive loads.

5.3.2 *Topology-Based Classification*

Active series compensators can be classified based on the topology used as half-bridge, full-bridge, and transformerless configurations. Figures 5.3–5.5 show the basic block of active series compensators. It is connected before the load in series with AC mains, using a matching transformer, to balance and regulate the terminal voltage of the load or line. It has been used to reduce negative sequence voltage and to regulate the voltage in three-phase systems. It can be installed by electric utilities to damp out harmonic propagation caused by resonance with line impedances and passive shunt compensators.

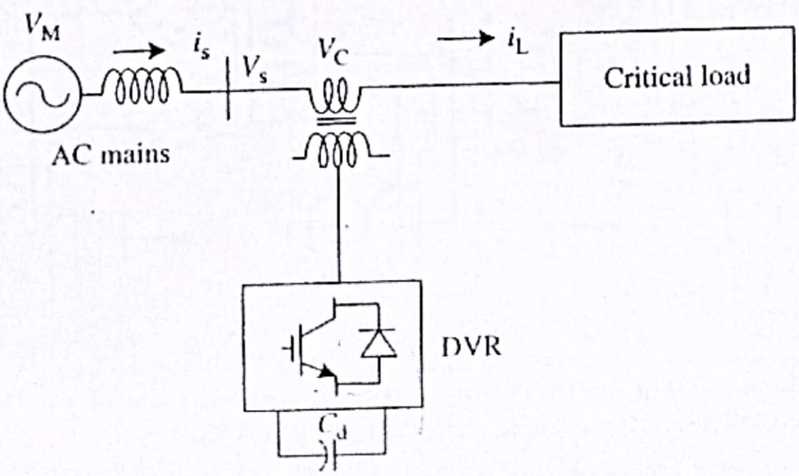


Figure 5.2 VSC-based single-phase DVR

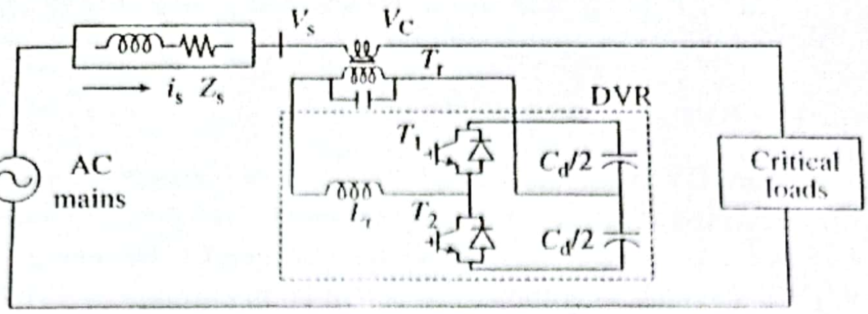


Figure 5.3 Half-bridge topology of VSC-based single-phase DVR

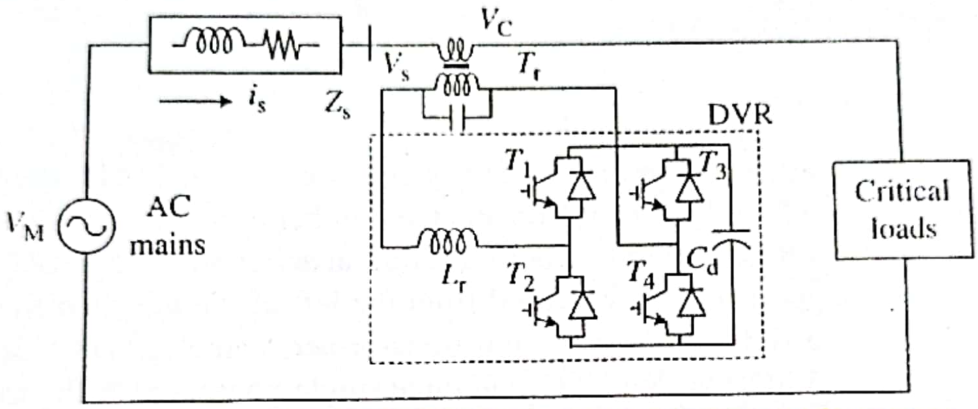


Figure 5.4 Full-bridge topology of VSC-based single-phase DVR

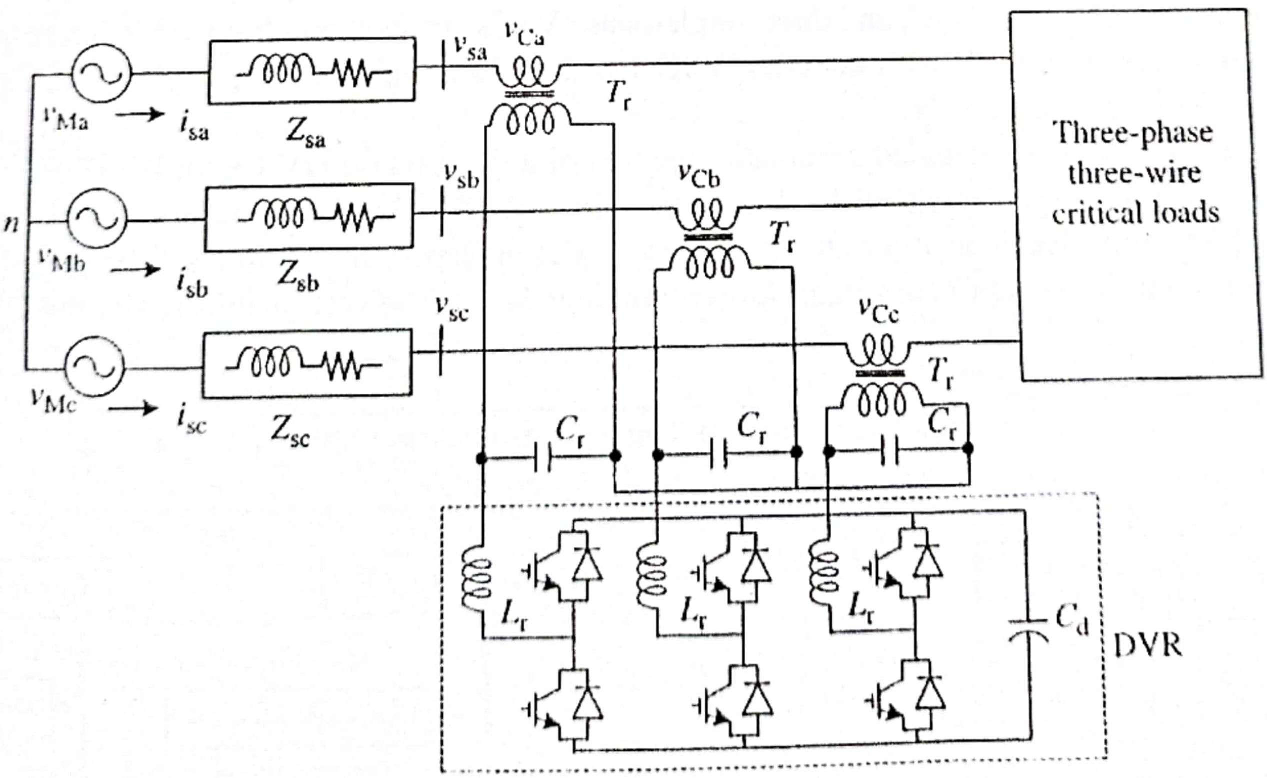


Figure 5.5 Three-phase three-wire DVR

5.4 Principle of Operation and Control of Active Series Compensators (DVR)

The fundamental circuit of the active series compensators for a three-phase, three-wire AC system is shown in Figure 5.12. An IGBT-based VSC with a DC bus capacitor is used as the DVR. Using a control algorithm, the injected voltages are directly controlled by estimating the reference injected voltages. However, in place of injected voltages, the reference load voltages may be estimated for an indirect voltage control of its VSC. The gate pulses for the DVR are generated by employing hysteresis (carrierless PWM) or PWM (fixed frequency) voltage control over reference and sensed load voltages, which result in an indirect voltage control. Using the DVR with a proper control algorithm, the voltage spikes, surges, flickers, sags, swells, notches, fluctuations, waveform distortion, voltage imbalance, and harmonics compensation are achieved. The detailed principle of operation and control of active series compensators are given in the following sections.

DVR Principle of Operation of Active Series Compensators

The active series compensators are based on the principle of injecting a voltage in series with the supply and this is implemented in two ways. This compensator inserts a voltage of required waveform so that it can protect sensitive consumer loads from supply disturbances such as sag, swell, surges, spikes, notches, unbalance, harmonics, and so on in supply voltage and is known as dynamic voltage restorer.

Figure 5.14a shows a single line diagram of the DVR for power quality improvement in a distribution system. A voltage (V_C) is injected such that the load voltage (V_L) is constant in magnitude and undistorted, although the supply voltage (V_S) is not constant in magnitude or may be distorted. Figure 5.14b shows the phasor diagram of different voltage injection schemes of the DVR. A $V_{L(pre\text{-}sag)}$ is the voltage across the critical load prior to voltage sag condition. During the sag, the voltage is reduced to V_S with a phase lag angle of θ. Now the DVR injects a voltage so that the load voltage magnitude is maintained at the pre-sag condition. According to the phase angle of the load voltage, the injection of voltages can be realized in four ways. V_{C1} represents the voltage injected in-phase with the supply voltage. With the injection of V_{C2}, the load voltage magnitude remains the same, but it leads V_S by a small angle. In V_{C3}, the load voltage retains the same phase as that of the pre-sag condition, which may be an optimum angle considering the energy source at DC bus of the VSC used as a DVR. V_{C4} is the condition where the injected voltage is in quadrature with the current and this case is suitable for a capacitor-supported DVR as this injection involves no active power except small losses in the DVR. However, the minimum possible rating of the power converter is achieved by V_{C1} where the voltage injected is in-phase with the supply voltage. The DVR is operated in this scheme with a BESS, as shown in Figure 5.14a.

5.4.2 Control of Active Series Compensators

The control algorithms for the DVR are based on the estimation of either injected voltages or the reference load voltages for power quality improvement in a distribution system. The terminal voltages, source currents, load voltages, and the DC bus voltage are generally used as feedback signals and the reference load voltages are estimated using the control algorithms. There are many control algorithms reported in the literature for the control of DVR similar to other custom power devices such as

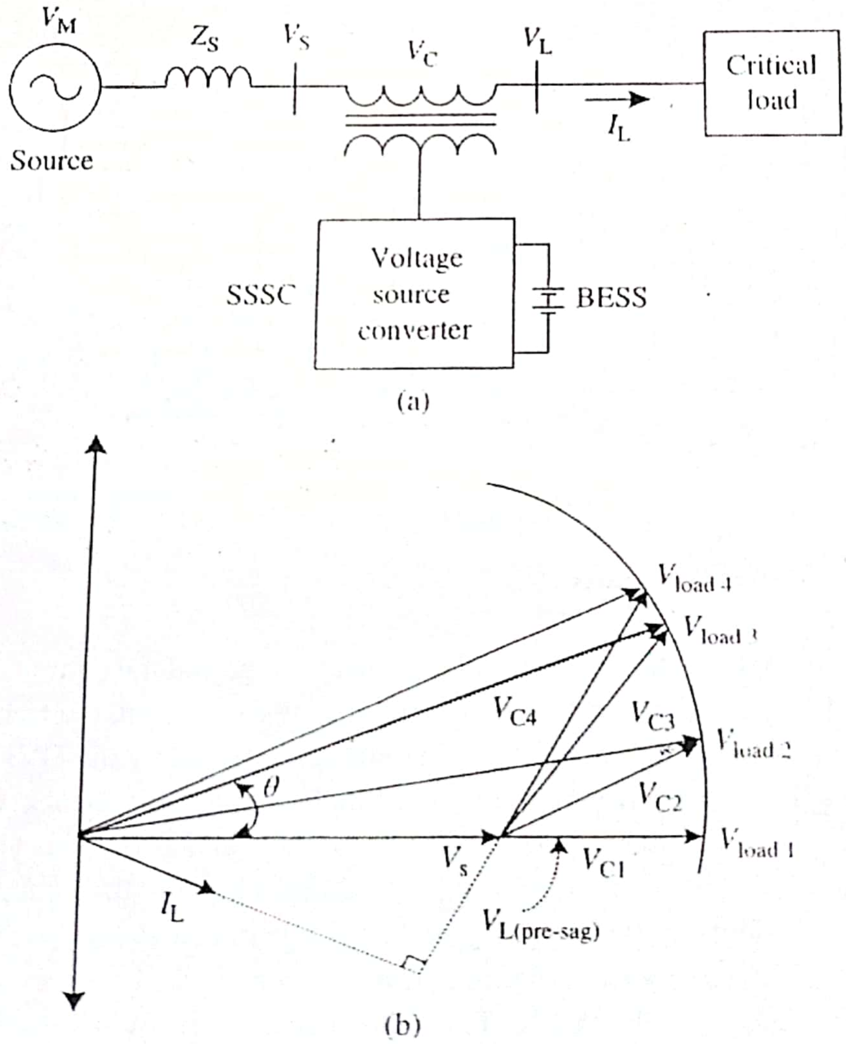


Figure 5.14 (a) Single line diagram of DVR. (b) Phasor diagram of the DVR voltage injection schemes

CODE: GR18A4071 | GR 18 | SET - 3

IV B.Tech II Semester Regular Examinations, May 2023

POWER QUALITY AND FACTS

(Electrical and Electronics Engineering)

Time: 3 hours

Max Marks: 70

Instructions:

1. Question paper comprises of Part-A and Part-B
2. Part-A (for 20 marks) must be answered at one place in the answer book.
3. Part-B (for 50 marks) consists of five questions with internal choice, answer all questions.
4. CO means Course Outcomes. BL means Blooms Taxonomy Levels

PART – A

(Answer ALL questions. All questions carry equal marks)

10 * 2 = 20 Marks

1. a.	What is the need for FACTS Controllers?	[2]	CO1	BL1
b.	Write some of the applications of FACTS controllers.	[2]	CO1	BL1
c.	Write objectives of shunt compensation.	[2]	CO2	BL1
d.	Draw the control diagram of STATCOM.	[2]	CO2	BL2
e.	Draw the V-I characteristics of TCSC.	[2]	CO3	BL2
f.	List the any three applications of SSSC.	[2]	CO3	BL1
g.	What is power quality? Why we are concern about power quality?	[2]	CO4	BL1
h.	What is voltage sag?	[2]	CO4	BL1
i.	List the application of DSTATCOM.	[2]	CO5	BL1
j.	What is DVR explain it?	[2]	CO5	BL1

PART – B

(Answer ALL questions. All questions carry equal marks)

5 * 10 = 50 Marks

2.	(a) Discuss various limitations on the loading of a transmission line.	[10]	CO1	BL3
	(b) Explain relative importance of controllable parameters in details.		CO1	BL2
	OR			
3.	(a) Explain about the basic types of FACTS controllers.	[10]	CO1	BL2
	(b) Briefly explain about the series connected controllers with neat diagram.		CO1	BL3

4. (a) Briefly describe the way by which the transient stability is enhanced with staticVAR compensator. [10] CO2 BL3

(b) Explain the series capacitor connected at the mid-point of the line. CO2 BL2

OR

5. (a) Explain the operation of STATCOM with a block diagram. [10] CO2 BL2

(b) Explain working principle of FC-TCR, characteristic and control diagram in details. CO2 BL3

6. (a) Explain the basic operating principles of UPFC with a conceptual representation. [10] CO3 BL3

(b) Explain the basic control schemes of TCSC and its applications in details. CO3 BL2

OR

7. (a) Explain power oscillation damping in details. [10] CO3 BL2

(b) Explain SSSC Operating principles and control schemes? CO3 BL3

8. (a) Explain briefly about various harmonic characterization on power systems. [10] CO4 BL2

(b) Write a short note on:
i) Notching ii) Voltage imbalance iii) Voltage fluctuations. CO4 BL2

OR

9. (a) Explain flicker and its measurement in details with neat diagram. [10] CO4 BL2

(b) Explain different sources of voltage sags and interruptions. CO4 BL2

10. (a) Explain three phase three wire DVR topology description in details. [10] CO5 BL2

(b) List the advantages and disadvantages of DSTATCOM. CO5 BL2

OR

11. (a) Briefly explain full bridge single phase DVR with neat diagram. [10] CO5 BL3

(b) Explain three phase four wire DSTATCOM topologies description. CO5 BL2

*****

(1)

IV B.Tech II Sem – Regular Exam, May 2023

Power Quality and FACTS

(EEE)

Id.No-760

Scheme of Evaluation

D. Karunakumar

EEE

1)

10×2 = 20M

a)

A:- → The FACTS devices are used to control the amount of flow of power through the transmission line. 2M

→ FACTS enhance the overall grid capacity & performance

→ they also increase the reliability and efficiency of your power system.

b)

A:- Application of FACTS Controller —2M

1. power flow control

2. Increase of transmission capacity

3. Voltage control, reactive power compensation

4. Stability improvement

5. power quality improvement.

c)

A:- objectives of shunt compensation:— 2M

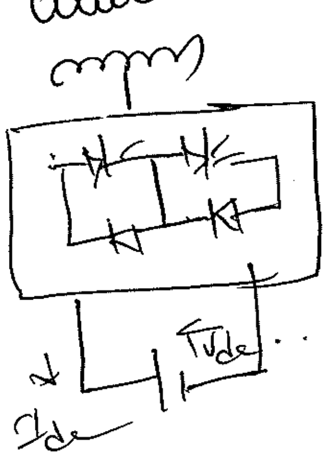
1. Reactive shunt compensation gives steady state transmittable power and controlled voltage along the line

→ shunt connected ... to minimize over voltage under light under loading

→ shunt connected capacitor are used to improve voltage levels under heavy load condition

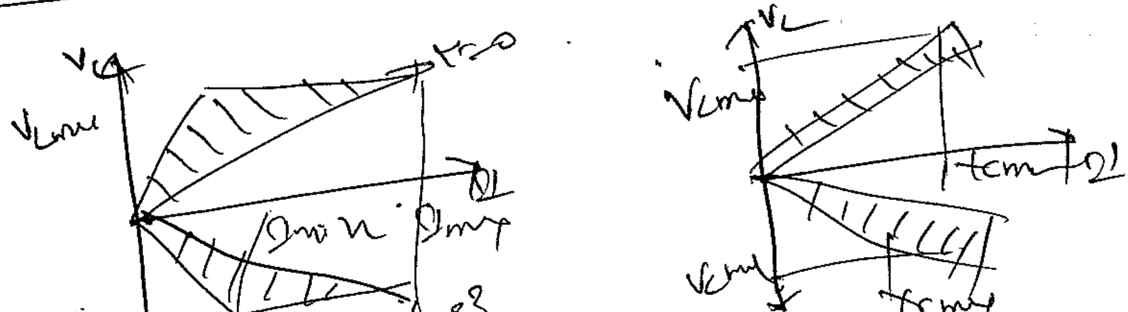
d) Draw the control diagram of STATCOM :- — 2M

A)



e) Draw the V-I characteristics of TCR — 2M

A) —



f) Application of SSSC :- — 2M

A) → It can be used to reduce or increase the equivalent line impedance & enhance the active power transfer capability of the line

→ Highly controlled device

②

a)

A:- power quality:- ← 2M

→ power quality is the measurement of how close to perfect an electrical voltage is at any given time & point

→ It allows the equipment to run in optimised energy consumption

b)

A: Voltage sag:- ← 2M

→ voltage sag are considered the most common power quality problem

→ these can be caused by the utility by customer loads

c) Application of DSTATCOM:- ← 2M

A- → It is used to solve all power quality problem which connected in parallel with system

→ It is generated & absorb the reactive power at point of common coupling.

j)
A:- DVR (Dynamic Voltage Restorer) — 2M

→ DVR is device that can be used in distribution networks to inject 3 phase voltage in series and synchronism with the distribution feeder voltage to correct short voltage reduction

2) — 5M

a)
A:- → the loading limit for a transmission line shall be its thermal loading limit

→ the thermal loading limit of a line is determined by design parameters based on ambient temperature

→ the power feeding load to power transmission lines by installing the necessary equipment.

→ the load test script requires knowledge of the tool

(3)

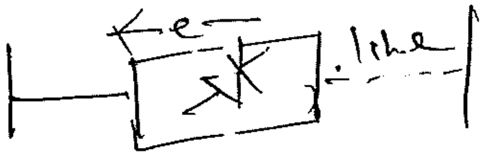
2)
b)
A:- Relative importance of Controllable parameter — 5M

1. Control of the line impedance X
2. Control of angle
3. Injecting a voltage in series with the line
4. Injecting voltage in series with the line and with any phase angle with respect to driving voltage
5. Combination of the line impedance control with a series control and voltage

3)
a)
A:- ~~Types of FACTS Controller~~:- — 5M

→ Series Controller
→ Shunt Controller
→ Combined series - series Controller
→ Combined series - shunt Controller

3)
b)
A) Series Connected Controllers



— 2M

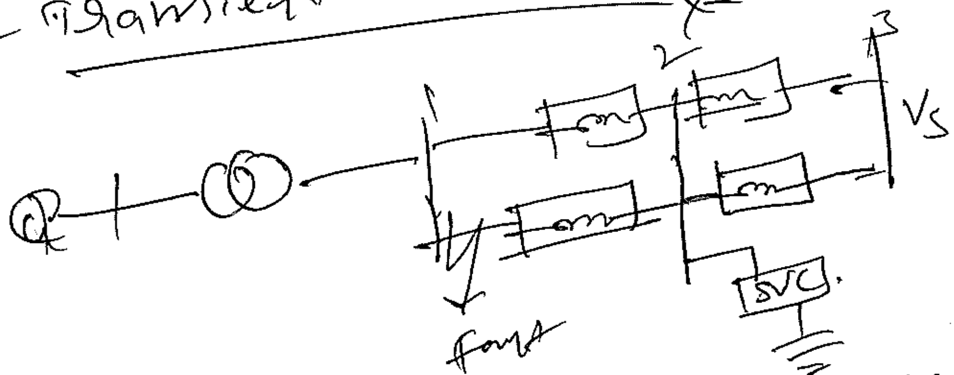
— 3M

→ Series Controller is connected in series with the line

→ this series Controller could be a variable impedance, it may be capacitance & inductance

→ Series Controller inject voltage in series with line

4)
a)
A:- Transient stability is enhanced with SVC



— 2M

— 3M

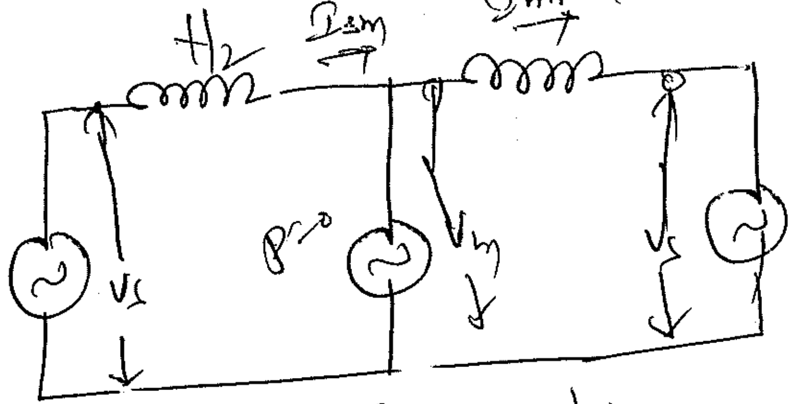
→ Transient stability maintain model to maintain the stability of power under sudden and large disturbancy

→ the transient stability analysis is performed for considering a stability of the power ...

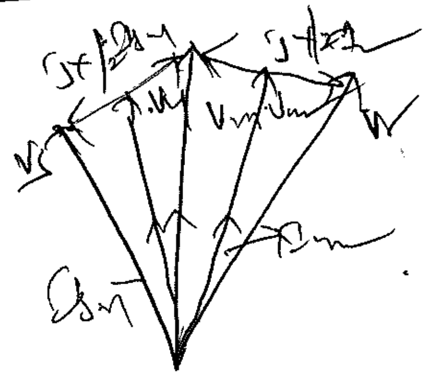
(4)

4)
b)

A:- Series Capacitor Connected at mid-point



— 2M



— 1M

$|V_s| = |V_r| = |V_m| = V$

— 2M

→ Consider the simple two-machine (two-bus) transmission Model in which an ideal Var Compensator

→ the Compensator is deployed by the voltage in phase with the mid-point voltage

$V_m = V_s = V_r = V = V \cos \delta/4$

power = $V_{sm} I_{sm} = V_{mr} I_{mr} = V_m I_{sm} \cos \delta/4$

$p = 2V^2/X \sin \delta/2$

5)
a)

A:- operation of STATCOM:-

— 3M

→ Static Synchronous Compensator it can be based on a voltage sourced & current sourced converter

→ It Controls both real & reactive power

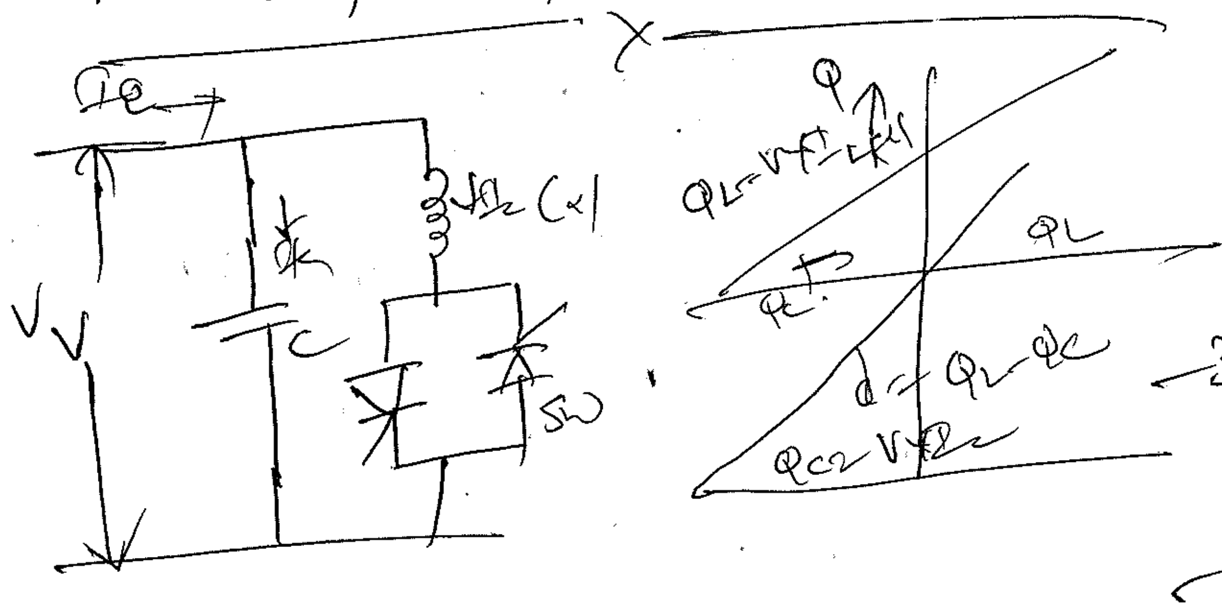
→ STATCOM gives the better results than

speeds when compared to SVC. SVC are

generating FACTS device

5) b)

A:- Working principle of FC-TCR:-



-3M

2M

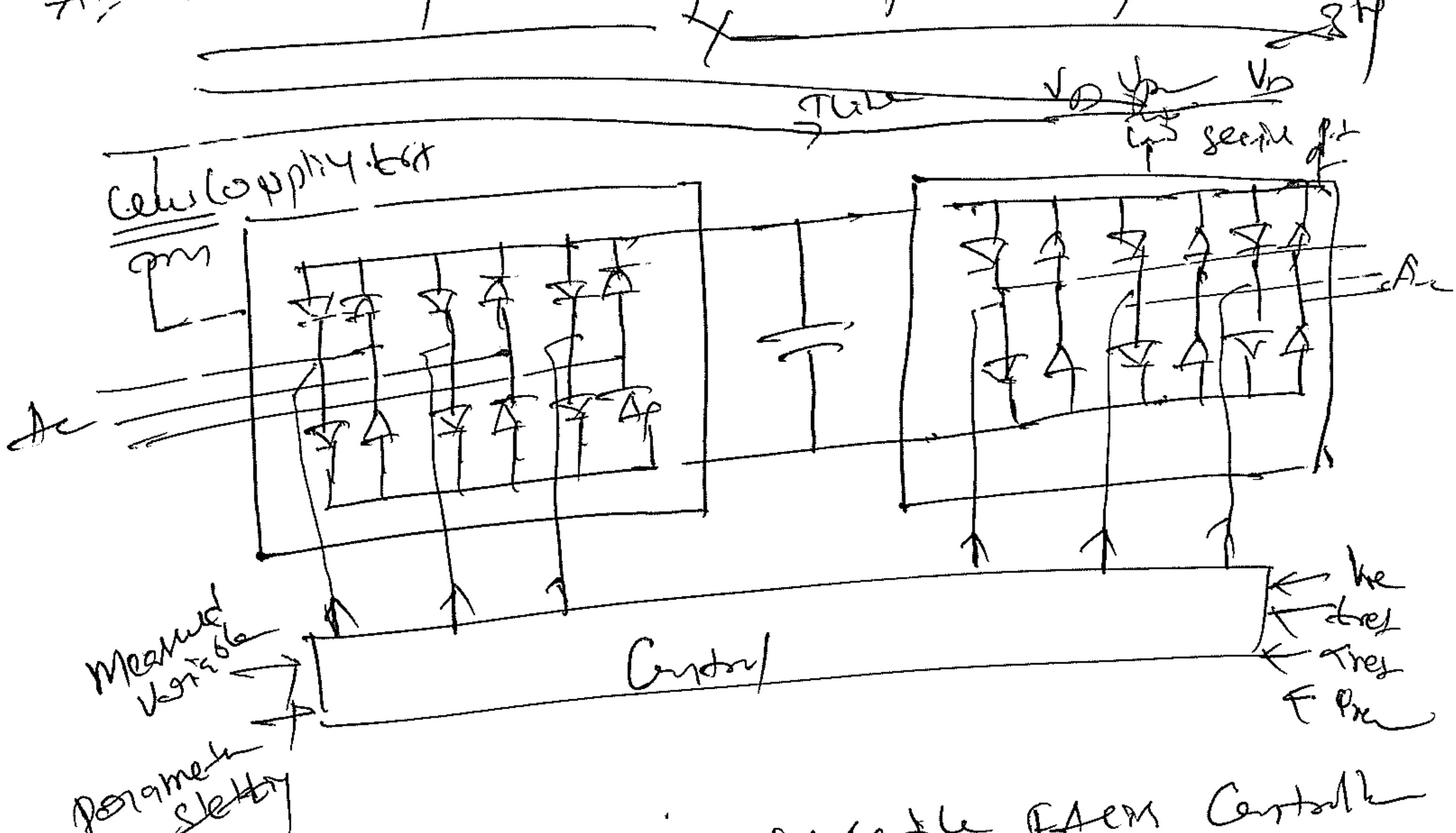
→ The basic var generated arrangement are fixed capacitor with thyristor controlled reactor

→ the current in the reactor is varied by the previously discussed method of firing delay angle control

→ FC-TCR may be connected variable reactor and fixed capacitor.

5) 6) a)

A) Basic operating principles of UPFC:— 8M



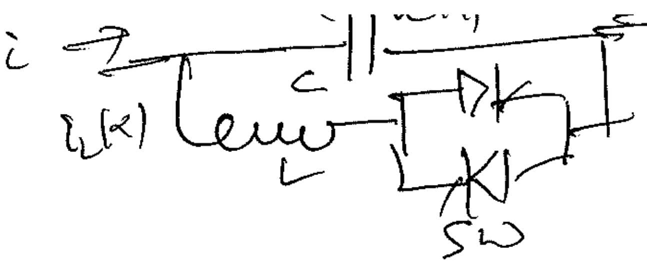
→ UPFC is the most versatile FACTS controller encompassing capabilities of voltage regulation —2M

→ series compensation & phase shift by independently control both real and reactive power transm line

6) b)

A) Control scheme of TCSC :— 5M

→ the TCSC scheme, ~~PAT~~ can compensating capacitor shunted by the thyristor controlled reactor



→ the fundamental system frequency reactance Variable Reactive impedance controllable by delay angle α, the steady state impedance of the TCSC is that parallel LC circuit

→ $$X_{TCSC}(\alpha) = \frac{X_C X_L(\alpha)}{X_L(\alpha) - X_C}$$

$$X_L(\alpha) = X_L \frac{\pi}{\pi - 2\alpha - \sin\alpha} \quad X_L \le X_L(\alpha) \le \infty$$

7)
a)
A:- power oscillation damping:-

→ Considered series compensation can be applied effectively to damp power oscillation

→ power oscillation damping it is necessary to vary the applied compensation so as to

→ angle δ increase (dδ/dt > 0). the electric power transmitted must to be increased to compensate for the excess mechanical input power

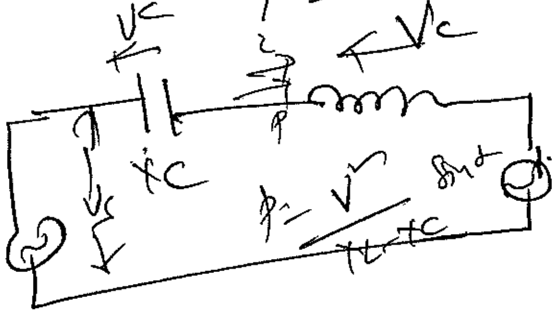
(6)

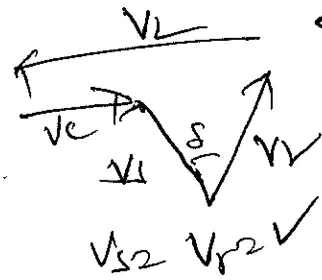
6) b)
A) Operating principle of SSSC:- —2M

→ The voltage sourced converter based series compensator called static synchronous series compensator (SSSC)

→ Series capacitive compensation works by increasing the voltage across the impedance of the given physical line

$V_q = V_C = -jX_C I = -jkXI$



 —3M

—5M

8) a)
A) → The EPS, a harmonic in a voltage wave at a multiple of the fundamental frequency of the ...

→ Harmonics can best be described as the shape & characteristics of voltage & current waveforms relative to its fundamental frequency

8)
b)
(i) Notching:- — 2M

→ Notching is periodic voltage disturbance caused by the normal operating of power electronic devices.

(ii) Voltage imbalance:- — 2M

→ It is maximum deviation from the average of the 3-φ voltage & currents divided by the average of the 3-φ voltage & currents.

(iii) Voltage fluctuations:- — 1M

→ It is systematic variations of the voltage envelope & series of random voltage changes the magnitude of which does not normally exceed the voltage range 0.9 to 1.1 pu

9)
a) Flicker and its measurement:- — 5M

A:-

→ the term is derived from the impact of the voltage fluctuating on lamps such that.

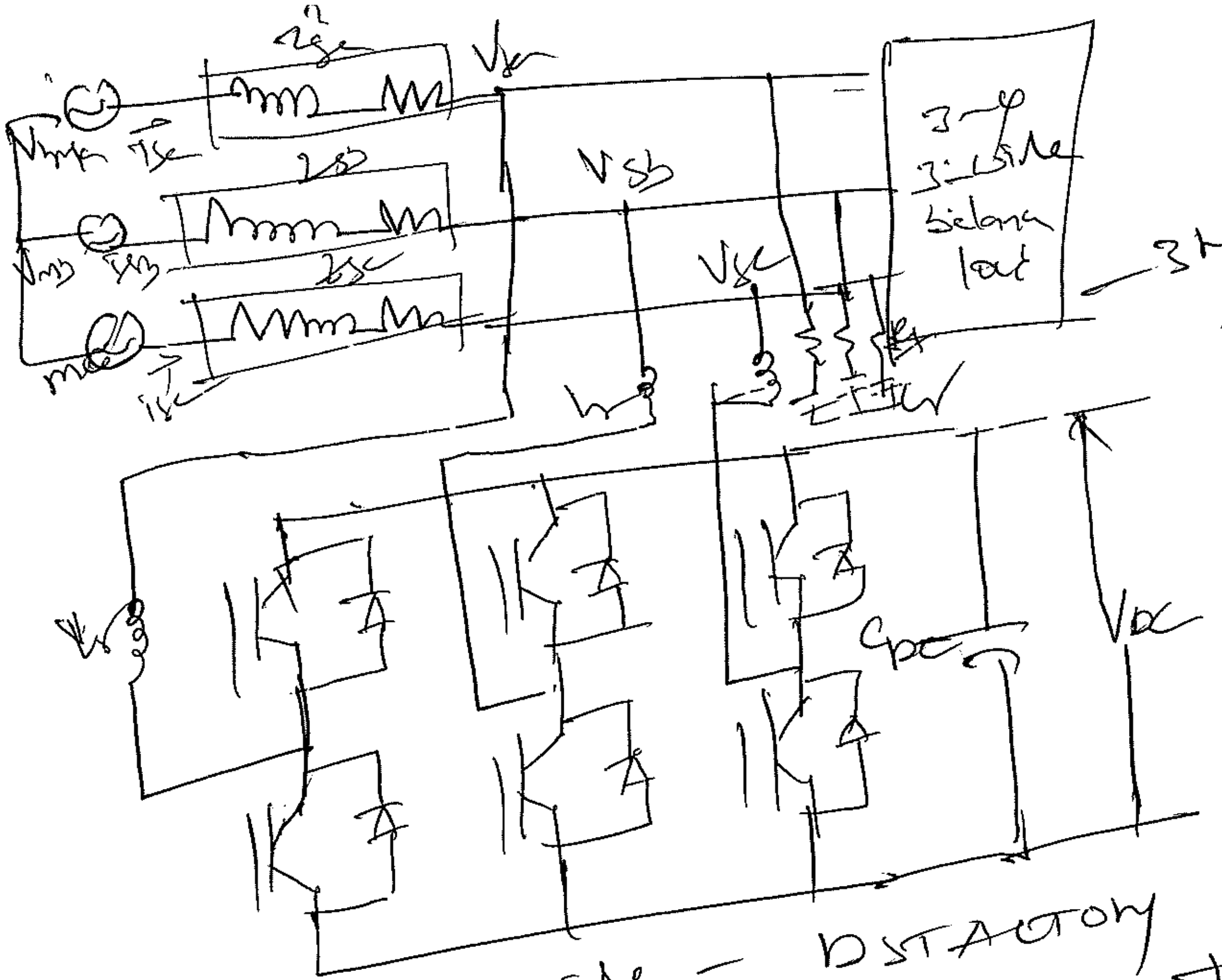
(7)
→ they are perceived by the human eye - flicker
→ Voltage fluctuation is an electromagnetic phenomenon
while flicker is an undesirable result of
the voltage fluctuation in some loads

9)
b) Source of Voltage Sags and interruptions
A:-

→ Voltage sags and interruptions are generally caused
by faults in the utility system
→ Consider a customer that is supplied from the
feeder supplied by the circuit breaker
feeder supplied by the circuit breaker
→ If there is fault on the same feeder the
customer will experience a voltage sag due
the fault followed by a interruption
→ stay the breaker open to clear the fault
→ If the fault temper ... the fault

10)
a) 3-φ - three wire DVR topology
A:-

→ capacitors are connected in series and
the total DC capacitor voltage



— 3M

3-φ – 3-wire – DSTATCOM — 2M

twice the DC bus voltage of the above topology.

VSC topology

→ the isolated configuration included 3-1-φ VSC based DSTATCOM.

→ 3, 1-φ. VSC-based DSTATCOM require 12 semiconductor switches.

10)b) Ans:- Advantages of DSTATCOM:- — 2M

→ Require single dc source

→ Does not require auxiliary capacitors

(8)

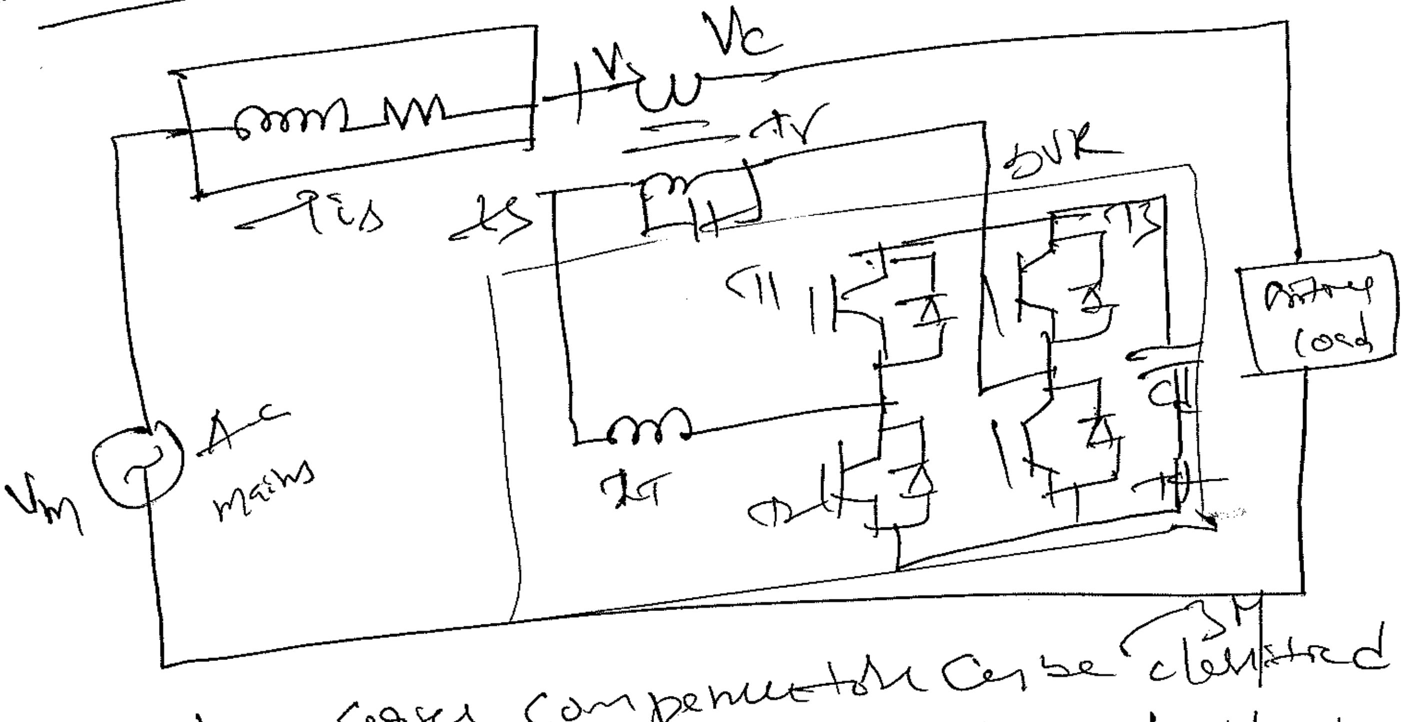
Disadvantages of DSTATCOM:- — 3M

→ unequal power distributing among switches

→ Balancing problems while delivering real power above 3 level

→ Requires a large no of diodes which is quadratic function of the no of level

11)
a)
A:- Full bridge 1-φ-DVR :- — 2M



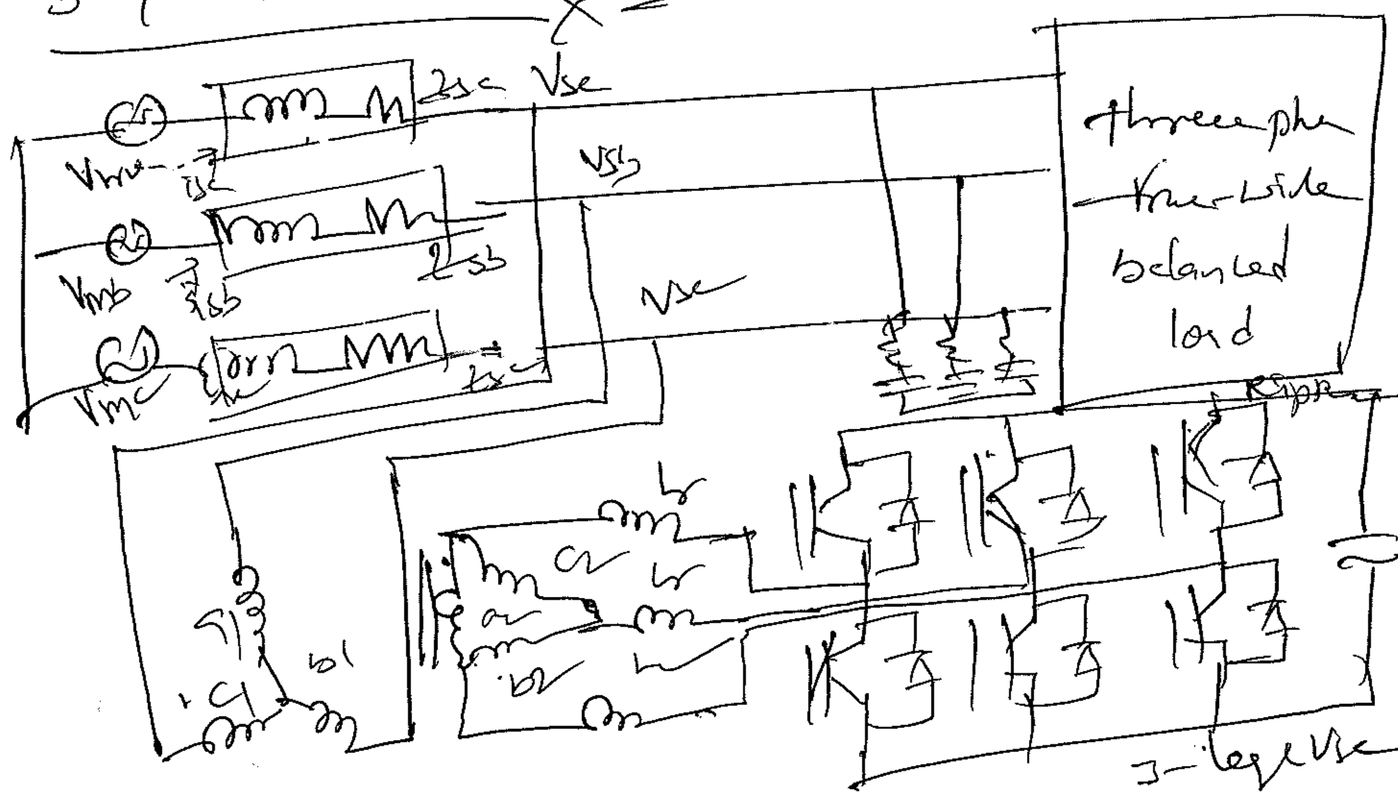
— 3M

→ Active series compensation can be classified based on the topology used as full bridge

→ Basic block of active series compensation

→ It has been used to reduce negative sequence voltage and to regulate the voltage 1φ-3φ

11) b) A:- 3-φ four-wire DSTATCOM:- 3M



2M

Sol:-

→ In a 3-φ four wire distribution system there are 3-φ loads and 1-φ loads depending upon the customer demands

→ To compensate the unbalanced current from being drawn from the distribution bus, a shunt compensator is called DSTATCOM can be used

→ It ensures that current drawn from the di) distribution bus are balanced sinu

CODE: GR15A4032 | GR 15 | SET - 2

IV B. Tech II Semester Advanced Supplementary Examinations, June 2019
Flexible AC Transmission Systems
(Electrical and Electronics Engineering)

Time: 3 hours **Max Marks: 70**

PART – A
Answer ALL questions. All questions carry equal marks.
*****

10 * 2 Marks = 20 Marks

1). a List out the advantages of transmission interconnections. **[2]**

b Write the advantages of FACTS controllers. **[2]**

c Write the basic principle of current source converter. **[2]**

d List out the differences between VSC and CSC. **[2]**

e Write the basic objectives of shunt compensation. **[2]**

f List out various variable impedance type Static Var Generators. **[2]**

g Write the slope transfer function of SVC. **[2]**

h List out the advantages of STATCOM. **[2]**

i Draw the functional circuit diagram of TCSC. **[2]**

j Write the objectives of Series Compensation. **[2]**

PART – B
Answer any FIVE questions. All questions carry equal marks.
*****

5 * 10 Marks = 50 Marks

2. a) Explain basic types of FACTS controllers. **[10]**

b) Explain the importance of various controllable parameters.

3. Explain briefly the three phase transformer connections for 12-pulse operation with neat wave forms. **[10]**

4. Explain how the regulation of a transmission line can be improved using mid-point shunt compensation. **[10]**

5. a) Explain the operation of switching converter type shunt compensator. **[10]**

b) Differentiate between STATCOM and SVC.

6. a) Explain the basic objectives of series compensation. **[10]**

b) Enumerate the working of TCSC in detail.

7. a) Compare voltage source converter with current source converter. **[10]**

b) Discuss the working of various hybrid var generators.

8. a) Discuss the working of variable impedance type series compensators. **[10]**

b) How transient stability can be improved using static series compensation?

*****

SET - 3 **GR 11** **CODE: GR11A4041**

IV B. Tech II Semester Regular Examinations, May/June 2016

FLEXIBLE AC TRANSMISSION SYSTEMS

(Electrical and Electronics Engineering)

Time: 3 hours **Max Marks: 75**

Answer any FIVE questions
All questions carry equal marks

*****

1). a		Explain the importance of Transmission Inter Connection.	**[8]**
	b	Briefly describe the basic types of FACTS Controllers.	**[7]**
2). a		Explain briefly the three phase transfer connections for 12-pulse operation.	**[8]**
	b	With a neat diagram explain the operation of Pulse width Modulation Converter.	**[7]**
3). a		What are the objectives of Shunt Compensation?	**[8]**
	b	Explain the operation of Hybrid Var Generator for controllable Var Generation.	**[7]**
4). a		Compare STATCOM and SVC.	**[8]**
	b	Explain the transfer function and dynamic performance of SVC and STATCOM.	**[7]**
5). a		Describe how static series compensation can improve the transient stability.	**[8]**
	b	Draw and explain the Thyristor-Controlled Series Capacitor (TCSC).	**[7]**
6). a		Explain the possible benefits from FACTS Controllers.	**[8]**
	b	Explain the fundamental and harmonic voltage for a Three-Level Converter.	**[7]**
7). a		Explain the variable impedance type static Var generator for controllable Var generation.	**[8]**
	b	Draw and explain the GTO Thyristor-Controlled Series Capacitor (GCSC).	**[7]**

*****

CODE: GR14A4032 | GR 14 | SET - 3

IV B. Tech II Semester Regular Examinations, Apr/May 2018

Flexible AC Transmission Systems

(Electrical and Electronics Engineering)

Time: 3 hours **Max Marks: 70**

PART – A

Answer ALL questions. All questions carry equal marks.

****

10 * 2 Marks = 20 Marks

1). a Define FACTS Controller and give its basic types. **[2]**

b Write short notes on importance of controllable parameters in AC System. **[2]**

c Write the basic principle of voltage source converter. **[2]**

d Differentiate between current sources converter and voltage source converter. **[2]**

e What are the objectives of shunt compensation? **[2]**

f List out the variable impedance type Static Var Generators. **[2]**

g What are the advantages of STATCOM? **[2]**

h What is Power Oscillation Damping? **[2]**

i List out the merits of TCSC. **[2]**

j What are the objectives of Series Compensation? **[2]**

PART – B

Answer any FIVE questions. All questions carry equal marks.

****

5 * 10 Marks = 50 Marks

2. (a) Explain the power flow in an AC System. **[10]**

(b) Explain the possible benefits from FACTS Controllers.

3. Explain briefly the three phase transfer connections for 12-pulse operation with neat wave forms. **[10]**

4. (a) Explain how to prevent voltage instability by using shunt compensating at receiving end. **[10]**

(b) Explain the operation of Hybrid Var Generator for Controllable Var Generation.

5. (a) Differentiate between STATCOM and SVC. **[4]**

(b) Explain the concept of operating point control of Static Compensator. **[6]**

6. (a) Explain the power oscillation damping of Series Compensation. **[10]**

(b) Draw and explain the Thyristor-Controlled Series Capacitor (TCSC).

7. (a) What are the basic types of FACTS Controllers? Write short notes on each of them. **[10]**

(b) Explain the fundamental and harmonic voltage for a Three-Level Converter.

8. (a) Write short notes on Switching Converter type Var Generator. **[10]**

(b) Draw and explain the GTO Thyristor-Controlled Series Capacitor (GCSC).

*****

Code No: 137FV **R16**

JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY HYDERABAD
B. Tech IV Year I Semester Examinations, December - 2019
POWER QUALITY
(Electrical and Electronics Engineering)

Time: 3 Hours **Max. Marks: 75**

Note: This question paper contains two parts A and B.
Part A is compulsory which carries 25 marks. Answer all questions in Part A. Part B consists of 5 Units. Answer any one full question from each unit. Each question carries 10 marks and may have a, b as sub questions.

PART – A

(25 Marks)

1.a) What are the causes for interruptions? [2]
b) Write the remedies to improve power quality. [3]
c) Write the causes of short duration voltage variations. [2]
d) Explain the ways of comparing the observations and the results of reliability evaluation. [3]
e) What do meant by phase angle jumps? [2]
f) What is voltage sag? [3]
g) What are the P-Q considerations with synchronous motor? [2]
h) Explain the impact of voltage sag on process control equipment. [3]
i) What is the European voltage characteristics standard? [2]
j) What are the key standards of IEC Electromagnetic Compatibility? [3]

PART – B

(50 Marks)

2. What is the impact of transient on power quality? Classify the transients that occur in power systems. [10]

OR

3 Write a short note on:
a) Notching b) Voltage imbalance c) Voltage fluctuations. [10]

4 Explain characteristics of power quality events in short and long duration voltage variations. [10]

OR

5.a) What are the causes of long interruptions.
b) What are the limits of duration of interruptions? [10]

6. Explain how the sag magnitudes were calculated for meshed systems. [10]

OR

7. How Voltage Sag types are classified? Write the factors that affect the voltage sag types. [10]

8 Explain the behavior of computers and consumer electronics due to voltage sag. [10]

OR

9 Explain the overview of mitigation methods used for AC Drives for P-Q considerations. [10]

10 Explain the method of mitigation for improving equipment immunity. [10]

OR

11 Explain the principle of three phase voltage source converter with neat diagram. [10]

---ooOoo---

Code No: **RT42023C** **R13** **Set No. 1**

IV B.Tech II Semester Regular Examinations, April/May - 2017
FACTS: FLEXIBLE ALTERNATING CURRENT TRANSMISSION SYSTEMS
(Electrical and Electronics Engineering)

Time: 3 hours **Max. Marks: 70**

Question paper consists of Part-A and Part-B
Answer ALL sub questions from Part-A
Answer any THREE questions from Part-B
*****

PART–A ***(22 Marks)***

1. a) Distinguish between transient stability and steady state stability in power flow systems. [4]
   b) Mention the importance of self commutating converters? [3]
   c) Write the three important objectives of shunt compensation. [3]
   d) What is meant by switched transients in thyristor switched capacitor? [4]
   e) What are the characteristics differences between TSSC and TCSC? [4]
   f) Mention the practical applications of IPFC. [4]

PART–B ***(3x16 = 48 Marks)***

2. a) Discuss the various categories of FACTS controllers in brief. [8]
   b) Describe the parameter trade-off of high power devices. [8]

3. a) Explain the three phase full-wave bridge converter with necessary waveforms. [8]
   b) Enumerate the relative merits and demerits of current source converters over voltage source converters. [8]

4. a) Explain the concept of end of line voltage support to prevent voltage stability in shunt compensation. [8]
   b) Describe any of the variable impedance type static VAR generators. [8]

5. a) Discuss the implementation of the VAR reserve control. [8]
   b) Enumerate the operating features of STATCOM. [8]

6. a) Explain the power oscillation and sub synchronous oscillation damping in series capacitive compensation. [8]
   b) Describe the configuration and characteristics of basic thyristor-switched series capacitor. [8]

7. a) Explain the implementation of the UPFC by back-to-back voltage sourced converters. [8]
   b) Discuss the variation of real and reactive powers in IPFC schemes. [8]

Code No: **RT42023C** **R13** **Set No. 2**

IV B.Tech II Semester Regular Examinations, April/May - 2017

FACTS: FLEXIBLE ALTERNATING CURRENT TRANSMISSION SYSTEMS

(Electrical and Electronics Engineering)

Time: 3 hours **Max. Marks: 70**

Question paper consists of Part-A and Part-B
Answer ALL sub questions from Part-A
Answer any THREE questions from Part-B

*****

PART–A ***(22 Marks)***

1. a) Mention the voltage and current ratings of high power devices. [4]
   b) What are the effects of harmonics in a three phase bridge converter. [4]
   c) What is meant by power oscillations damping? [3]
   d) Draw the V-I characteristics of thyristor switched capacitor and explain. [4]
   e) Write any three functional requirements of series compensation. [3]
   f) What is a stand-alone series and shunt compensation? [4]

PART–B ***(3x16 = 48 Marks)***

2. a) Explain various loading capability limits in power flow systems. [8]
   b) Describe relative importance of different types of controllers. [8]

3. a) Enumerate single phase full-wave bridge converter operation. [8]
   b) Discuss three-phase current source converter operation in brief. [8]

4. a) Explain midpoint voltage regulation for line segmentation using shunt compensation. [8]
   b) Emphasize features of thyristor controlled reactor. [8]

5. a) Obtain transfer function of static VAR compensator and mention its compensation effect on stability. [8]
   b) Explain necessary modifications in static VAR generation characteristics due to regulation slope. [8]

6. a) Draw and explain the impedance versus delay angle characteristics of TCSC. [8]
   b) Discuss improvement of transient stability using series compensation on transmission systems. [8]

7. a) Describe dependence of real and reactive power flow control in UPFC. [8]
   b) Write a comparison between IPFC and UPFC. [8]

Code No: **RT42023C** **R13** **Set No. 3**

IV B.Tech II Semester Regular Examinations, April/May - 2017
FACTS: FLEXIBLE ALTERNATING CURRENT TRANSMISSION SYSTEMS
(Electrical and Electronics Engineering)

Time: 3 hours **Max. Marks: 70**

Question paper consists of Part-A and Part-B
Answer ALL sub questions from Part-A
Answer any THREE questions from Part-B

*****

PART–A ***(22 Marks)***

1. a) Write the importance of controllable parameters in AC power flow systems. [4]
   b) Mention the various types of current source converters. [4]
   c) What is meant by controllable VAR generation? [3]
   d) Why static compensator not used as perfect voltage regulator? [3]
   e) Write the objectives of series compensation. [4]
   f) List out the technical benefits of UPFC. [4]

PART–B ***(3x16 = 48 Marks)***

2. a) Explain the dynamic stability considerations of an interconnected transmission system. [8]
   b) Discuss the losses and speed of switching of high power devices. [8]

3. a) Describe the voltage-sourced converter concept with necessary schematics. [8]
   b) Explain the square wave voltage harmonics for a single phase bridge converter. [8]

4. a) Discuss the improvement of voltage stability using shunt compensation. [8]
   b) Write a comparison between thyristor controlled reactor and thyristor switched reactor. [8]

5. a) Write a comparison between STATCOM and SVC in the following
   (i) V-I characteristics (ii) transient stability. [8]
   b) What is meant by power oscillation damping? Explain its functional control implementation. [8]

6. a) Explain the operation of basic GTO-controlled series capacitor. [8]
   b) Discuss the configuration and operation of TCSC. [8]

7. a) Describe the basic operating principles and concepts of UPFC. [8]
   b) Explain the control structure of IPFC. [8]

|''|'''||''||'''||||

Code No: **RT42023C** **R13** **Set No. 4**

IV B.Tech II Semester Regular Examinations, April/May - 2017

FACTS: FLEXIBLE ALTERNATING CURRENT TRANSMISSION SYSTEMS

(Electrical and Electronics Engineering)

Time: 3 hours **Max. Marks: 70**

Question paper consists of Part-A and Part-B

Answer ALL sub questions from Part-A

Answer any THREE questions from Part-B

*****

PART–A ***(22 Marks)***

1. a) What are the requirements of high speed power devices? [4]
   b) What is the principle of voltage source converter? [4]
   c) List out the requirements of shunt compensation. [3]
   d) Mention the various control approaches in static VAR generation. [4]
   e) Write the basic principle difference between series and shunt compensation. [4]
   f) Explain the any three applications of UPFC. [3]

PART–B ***(3x16 = 48 Marks)***

2. a) Discuss the technical benefits of FACTS technology. [8]
   b) Explain the power flow considerations of a transmission interconnected systems. [8]

3. a) Describe the operation of three-phase full-wave bridge converter. [8]
   b) Distinguish between voltage source and current source converters. [8]

4. a) Describe the basic thyristor switched capacitor and its operation. [8]
   b) Explain the power oscillation damping in shunt compensation. [8]

5. a) Discuss the operation of STATCOM with a neat diagram and characteristics. [8]
   b) Write a short note on transient stability enhancement using STATCOM and SVC. [8]

6. a) Enumerate the basic operating control schemes of TSSC and TCSC. [8]
   b) Discuss the effect of series capacitive compensation in transmission lines. [8]

7. a) Describe the various transmission control capabilities of UPFC. [8]
   b) Explain the basic two-converter Interline Power Flow Controller scheme. [8]

Code No: **RT42023C** **R13** **Set No. 1**

IV B.Tech II Semester Regular/Supplementary Examinations, April - 2018

FLEXIBLE ALTERNATING CURRENT TRANSMISSION SYSTEMS

(Electrical and Electronics Engineering)

Time: 3 hours **Max. Marks: 70**

Question paper consists of Part-A and Part-B
Answer ALL sub questions from Part-A
Answer any THREE questions from Part-B

*****

PART–A *(22 Marks)*

1. a) List and explain briefly important controllable parameters that are considered for power flow control. [4]
   b) Explain basic principle of voltage source converter. [4]
   c) Explain necessity of VAR compensation in transmission system. [3]
   d) Explain different losses that are encountered with FC – TCR arrangement. [4]
   e) List merits of Hybrid compensator. [3]
   f) Explain main objectives and usefulness of UPFC in power industry. [4]

PART–B *(3x16 = 48 Marks)*

2. a) Name and explain different types of stability issues that limit transmission capability. [8]
   b) What are FACT controllers and explain different categories of FACT controllers [8]

3. Explain the operation of three phase full wave bridge type voltage source converter with a neat circuit along with the necessary waveforms [16]

4. a) Explain prevention of voltage stability with the help of end of line voltage support. [8]
   b) Explain basic operation of Thyristor Switched Capacitor with necessary waveforms. [8]

5. a) Explain with a neat block diagram general control scheme of Static Var Compensator (SVC). [8]
   b) What is transient stability? How attainable enhancement of transient stability can be done by SVC and STATCOM? [8]

6. a) Explain with a neat functional diagram, implementation of Var Reserve (operating point) control for damping of Power oscillations in the system. [8]
   b) Explain about basic GTO-controlled series capacitor with principle of operation and necessary waveforms. [8]

7. a) Give a comparison between UPFC to IPFC. [8]
   b) Explain principle of operation of IPFC with neat diagram. [8]

Code No: **RT42023C** **R13** **Set No. 2**

IV B.Tech II Semester Regular/Supplementary Examinations, April - 2018

FLEXIBLE ALTERNATING CURRENT TRANSMISSION SYSTEMS

(Electrical and Electronics Engineering)

Time: 3 hours **Max. Marks: 70**

Question paper consists of Part-A and Part-B
Answer ALL sub questions from Part-A
Answer any THREE questions from Part-B

*****

PART–A *(22 Marks)*

1. a) Explain need of transmission interconnection. [3]
   b) Distinguish between current source and voltage source converters. [4]
   c) Explain need of dynamic voltage control in a transmission system. [4]
   d) List different methods of controllable VAR generation [3]
   e) Explain important features of GTO thyrister controlled series capacitor. [4]
   f) Explain the importance of Interline power flow controller(IPFC) [4]

PART–B *(3x16 = 48 Marks)*

2. a) Explain different dynamic stability considerations that were taken for a transmission interconnection. [8]
   b) Explain relative importance of different types of FACTS controllers. [8]

3. a) Explain reasons for possessing harmonics in a single phase bridge circuit and how it can be nullified. [8]
   b) Explain operation of three phase full wave diode converter (neglecting commutation angle) with a neat circuit and necessary waveforms. [8]

4. a) Explain the operation of two-machine Power system with an ideal midpoint reactive compensator with an equivalent circuit and necessary phasor diagram. [8]
   b) Explain in detail about power oscillation damping and why it is considered as dynamic event. [8]

5. a) Explain TSC – TCR type static var generator with a neat functional control Scheme. [8]
   b) Explain with reasons, why static compensator is not used as a perfect terminal voltage regulator but allowed to vary in proportion with compensating current. [8]

6. a) Explain main elements of the overall static compensator control system. [8]
   b) Explain concept of voltage stability and improvement of transient stability. [8]

7. a) Discuss the features of UPFC. [6]
   b) Explain the basic operating principles and characteristics of Interline Power Flow Controller (IPFC). [10]

Code No: **RT42023C** **R13** **Set No. 3**

IV B.Tech II Semester Regular/Supplementary Examinations, April - 2018

FLEXIBLE ALTERNATING CURRENT TRANSMISSION SYSTEMS

(Electrical and Electronics Engineering)

Time: 3 hours **Max. Marks: 70**

Question paper consists of Part-A and Part-B
Answer ALL sub questions from Part-A
Answer any THREE questions from Part-B

*****

PART–A *(22 Marks)*

1. a) Explain concept of power flow in ac system and explain difference when one of the parallel path is replaced with HVDC transmission. [4]
   b) Explain reasons for absence of neutral connection in a full wave circuit. [4]
   c) List functional requirements of reactive shunt compensators. [3]
   d) List major functions pf TSC –TCR type Var generator. [4]
   e) Explain basic idea behind series capacitive compensation. [3]
   f) Explain basic UPFC control scheme. [4]

PART–B *(3x16 = 48 Marks)*

2. a) List various FACTS controllers with their control attributes. [8]
   b) Explain loss and speed of switching in high power FACTs devices. [8]

3. Explain operation of single phase full wave voltage source converter with a neat circuit and necessary waveforms. [16]

4. a) List advantages and disadvantages of current source versus voltage source converters. [8]
   b) Explain how equal area criterion helps to evaluate effectiveness of shunt compensation and other flow control techniques on transient stability improvement. [8]

5. a) Explain implementation of functional control scheme for damping power oscillations in power system. [8]
   b) Explain basic circuit arrangement of Thyristor – Switched Series Capacitor (TSSC) with its principle of operation. [8]

6. a) Explain in detail about basic thyristor – controlled series capacitor scheme. [8]
   b) Illustrate effect of capacitor voltage reversal by TCR. [8]

7. a) Explain capability of UPFC to control real and reactive power flow in transmission line. [8]
   b) Explain functional control of shunt and series converter. [8]

Code No: **RT42023C** **R13** **Set No. 4**

IV B.Tech II Semester Regular/Supplementary Examinations, April - 2018

FLEXIBLE ALTERNATING CURRENT TRANSMISSION SYSTEMS

(Electrical and Electronics Engineering)

Time: 3 hours **Max. Marks: 70**

Question paper consists of Part-A and Part-B
Answer ALL sub questions from Part-A
Answer any THREE questions from Part-B
*****

PART–A *(22 Marks)*

1. a) What are the benefits with FACTs controller? [3]
   b) Distinguish between self-commutating converters with line-commutating converters. [4]
   c) Explain different methods of controllable VAR generation. [4]
   d) Explain basic operating principle of reactive power generation by a rotating synchronous compensator (condenser). [4]
   e) List general objectives of series compensation. [4]
   f) What do you mean by dynamic performance of UPFC? [3]

PART–B *(3x16 = 48 Marks)*

2. a) What do you mean by loading capability and explain different kinds of limitations? [8]
   b) Distinguish between shunt connected controllers with series connected controllers. [8]

3. a) Explain techniques that are realized for harmonic elimination and voltage control. [8]
   b) Explain basic concept of current-source converter. Explain operation of 3-Φ CSC. [8]

4. a) Distinguish in terms of merits and demerits for a two machine transmission power system w.r.t midpoint voltage support and End of line voltage support. [8]
   b) Explain operation of basic thyristor-controlled reactor with waveforms. [8]

5. a) Explain basic Fixed Capacitor–Thyristor-Controlled reactor type Static Var Generator with a neat circuit and its output characteristics. [8]
   b) Explain in detail about steady – state relationship or V-I characteristic of static VAR compensator. [8]

6. a) Compare between STATCOM and SVC in terms of operational and performance characteristics along with application benefits. [8]
   b) With a neat diagram, explain operation of thyrister switched series capacitor. [8]

7. a) Explain the basic operating principles of UPFC with a conceptual representation. [8]
   b) Compare between UPFC with IPFC. [8]

Code No: **RT42023C** **R13** **Set No. 1**

IV B.Tech II Semester Regular/Supplementary Examinations, April/May - 2019

FLEXIBLE ALTERNATING CURRENT TRANSMISSION SYSTEMS

(Electrical and Electronics Engineering)

Time: 3 hours **Max. Marks: 70**

Question paper consists of Part-A and Part-B
Answer ALL sub questions from Part-A
Answer any THREE questions from Part-B

*****

PART–A *(22 Marks)*

1. a) Why electrical transmission systems are interconnected? Explain. [4]
   b) What are voltage sourced converters? Why voltage sourced converters are preferred for FACTS application. [4]
   c) What is reactive power? What is its significance? Discuss the sources of reactive power. [4]
   d) What are the advantages of thyristor switched capacitors compared to fixed capacitors? [4]
   e) What are the objectives of series compensation? [3]
   f) What is meant by unified controller? [3]

PART–B *(3x16 = 48 Marks)*

2. a) A power of 1600 MW is flowing through two parallel paths having line impedances of 10Ω and 6Ω respectively. The full load capacity of each of the low impedance line is 900 MW. (i) Find the power flow through each of the line, and (ii) How much reactance is to be added in the low impedance line to remove the overloading on the line? [8]
   b) What are the benefits of FACTS controllers? List different types of FACTS controllers? [8]

3. a) With a neat circuit diagram and necessary waveforms, discuss the working of a single-phase bridge converter. [10]
   b) What are harmonics? What are their sources? How to measure the harmonics? [6]

4. a) What are the objectives of reactive shunt compensation? [4]
   b) Explain how midpoint voltage regulation of a transmission line increases the power transfer capacity of the lines. Also explain how it provides power oscillation damping. [12]

5. a) What is a STATCOM? Discuss its construction and working. [8]
   b) Compare between fixed capacitor thyristor controlled reactor (FC-TCR) with thyristor switched capacitor thyristor controlled reactor (TSC-TCR). [8]

6. Explain the working of thyristor controlled series capacitor (TCSC). Draw and discuss their V-I operating characteristics in voltage control mode and reactance control mode. Also discuss the applications of TCSC. [16]

7. a) What are the advantages of combined shunt and series controller than the individual controllers? [6]
   b) With a neat diagram, explain the operation and applications of UPFC. [10]

Code No: **RT42023C** **R13** **Set No. 2**

IV B.Tech II Semester Regular/Supplementary Examinations, April/May - 2019

FLEXIBLE ALTERNATING CURRENT TRANSMISSION SYSTEMS

(Electrical and Electronics Engineering)

Time: 3 hours **Max. Marks: 70**

Question paper consists of Part-A and Part-B
Answer ALL sub questions from Part-A
Answer any THREE questions from Part-B
*****

PART–A *(22 Marks)*

1. a) Why GTOs are preferred over SCRs and IGBTs for FACTS application? Discuss. [4]
   b) What are the sources of harmonics in the power systems? What are the effects of harmonics? [4]
   c) Define reactive power. How the synchronous machines were used for reactive power compensation? [4]
   d) What is the use of thyristor switched capacitor? What are the precautions to be taken while operating thyristor switched capacitor? [4]
   e) Why series compensation is more effective than shunt compensation? [3]
   f) What is the use of interline power flow controller? [3]

PART–B *(3x16 = 48 Marks)*

2. a) What are FACTS controllers? How power flow can be controlled in transmission lines using FACTS? List different types of FACTS controllers. [8]
   b) Consider that a two line parallel transmission is transmitting power from surplus generation area to the deficit area. If the line reactances are 8Ω and 12Ω respectively, how much is the power flowing through each of the lines if the total power transmitted is 1000MW. If each line rated only for 500MW, how much reactance is to be added to the overloaded line to avoid the overloading. [8]

3. a) Differentiate between voltage sourced and current sourced converters. Also mention the applications of voltage sourced converters. [8]
   b) With a neat circuit diagram, explain the operation of a three-phase current sourced converter. [8]

4. a) Discuss how end of line voltage support improves voltage stability in radial lines. [8]
   b) What are the methods of controllable VAR generation? With a neat schematic and waveforms, discuss the working of thyristor switched reactor. [8]

5. Discuss in detail the working of a Thyristor Switched Capacitor – Thyristor Switched Reactor (TSC–TCR). Also draw and discuss their V-I operating characteristics. [16]

6. a) Explain how series compensation improves power transfer capacity of transmission line. [8]
   b) Discuss the working of Thyristor Switched Series Capacitor (TSSC). [8]

7. What is unified power flow controller (UPFC)? Explain its principle, operation and applications. [16]

Code No: **RT42023C** **R13** **Set No. 3**

IV B.Tech II Semester Regular/Supplementary Examinations, April/May - 2019

FLEXIBLE ALTERNATING CURRENT TRANSMISSION SYSTEMS

(Electrical and Electronics Engineering)

Time: 3 hours **Max. Marks: 70**

Question paper consists of Part-A and Part-B
Answer ALL sub questions from Part-A
Answer any THREE questions from Part-B

*****

PART–A *(22 Marks)*

1. a) What limits the loading capacity of a transmission line? Explain briefly. [4]
   b) Why GTOs are used in voltage sourced converters rather than SCRs? Discuss. [4]
   c) Draw and explain the power-angle characteristics of a transmission line with ideal midpoint compensation. [4]
   d) What are static VAR compensators? What are their advantages? [4]
   e) List different series compensators. [3]
   f) What are the parameters of the transmission line can be controlled by UPFC? [3]

PART–B *(3x16 = 48 Marks)*

2. Consider a mesh network in which generators at two different sites (A and B) are sending power to a load center (C) through a network consisting of three lines. The lines AB, BC and AC have continuous ratings of 1000 MW, 1250 MW and 2000 MW respectively. One of the generators (at A) is generating 2000 MW and the other is generating 1000 MW, a total of 3000 MW is delivered to load center. If the impedances of the line AB, BC and AC are 10, 5, and 10 respectively, (a) Find the power flowing through each of the line. (b) If a capacitor whose reactance is -5 ohms at the synchronous frequency is inserted in line AC, find the power flowing through each of the line. (c) If an inductor whose reactance is 7 ohm is inserted in series with line AB, find the power flowing through each of the line. [16]

3. a) What are harmonics? Define total harmonic distortion. [4]
   b) With a neat circuit diagram and necessary waveforms, discuss the working of a three-phase full-wave bridge converter. Comment on the harmonics produced by this converter. [12]

4. a) What is the need for reactive power compensation in transmission systems? [4]
   b) With a neat circuit diagram and necessary waveforms, discuss the operation of a Thyristor Controlled Reactor (TCR). Also represent their V-I operating area. [12]

5. With a neat diagram, explain the functional control scheme for Thyristor Switched Capacitor – Thyristor Switched Reactor (TSC–TCR). Also draw the loss versus output characteristics of TSC-TCR and discuss its advantages compared to FC-TCR. [16]

6. a) Discuss how series capacitive compensation improves the transient stability of a line. [8]
   b) Discuss the working of a GTO thyristor controlled Series Capacitor (GSC). [8]

7. a) Differentiate between unified control and coordinated control schemes. [4]
   b) What is interline power flow controller? With a schematic diagram, explain its working. Also list its applications. [12]

Code No: **RT42023C** **R13** **Set No. 4**

IV B.Tech II Semester Regular/Supplementary Examinations, April/May - 2019

FLEXIBLE ALTERNATING CURRENT TRANSMISSION SYSTEMS

(Electrical and Electronics Engineering)

Time: 3 hours **Max. Marks: 70**

Question paper consists of Part-A and Part-B
Answer ALL sub questions from Part-A
Answer any THREE questions from Part-B
*****

PART–A *(22 Marks)*

1. a) What is GTO? Draw its structure and explain its working. [4]
   b) Discuss the principle of operation of a current sourced converter. [4]
   c) Differentiate between thyristor switched reactor (TSR) and thyristor controlled reactor (TCR). [4]
   d) Compare between SVC and STATCOM. [4]
   e) Why some range of the firing angle delay is inhibited in the operation of TCSC? [3]
   f) What happens if a voltage perpendicular to the line current is injected at sending end of the line? [3]

PART–B *(3x16 = 48 Marks)*

2. a) By considering a simple two machine transmission system, explain power flow through ac lines. Also derive the expression for active and reactive powers at both sending- and receiving ends. [8]
   b) List and discuss different types of FACTS controllers. Give examples for each type and mention their applications. [8]

3. a) Draw the shape of output voltage generated by a single-phase bridge converter and derive the expressions for rms values of fundamental and harmonic components. [8]
   b) Explain the principle of a voltage sourced converter. Why voltage sourced converters are preferred than current sourced converters for FACTS application? [8]

4. a) Explain the principle of midpoint voltage regulation of a transmission line. [8]
   b) Explain how midpoint voltage regulation for a transmission line increases the transient stability margin. [8]

5. a) What is a STATCOM? Discuss its advantages and applications. [8]
   b) What is the advantage of regulation slope control? Draw and explain the control scheme for STATCOM with regulation slope control. [8]

6. a) Explain the principle of operation of series capacitive compensation. [8]
   b) Explain how it improves voltage stability and provides power oscillation damping. [8]

7. a) Discuss the roles of shunt and series converters in unified power flow controller. [6]
   b) With the help of phasor diagrams, explain how UPFC provides voltage regulation, line impedance compensation and phase shifting. [10]

Code No: **RT42023C** **R13** **Set No. 1**

IV B.Tech II Semester Supplementary Examinations, July/August - 2017

FLEXIBLE ALTERNATING CURRENT TRANSMISSION SYSTEMS

(Electrical and Electronics Engineering)

Time: 3 hours **Max. Marks: 70**

Question paper consists of Part-A and Part-B
Answer ALL sub questions from Part-A
Answer any THREE questions from Part-B

*****

PART–A *(22 Marks)*

1. a) What are the factors which limit loading capability? [4]
   b) What is the principle of current source converter? [3]
   c) What is mid-point voltage regulation with respect to shunt compensation? [3]
   d) Draw the *V-I* characteristic of the SVC and the STATCOM. [4]
   e) Draw basic Thyristor-Switched Series Capacitor scheme and represent its parameters. [4]
   f) What is the basic operating principle of unified power flow controller? [4]

PART–B *(3x16 = 48 Marks)*

2. a) Discuss the benefits of FACTS controllers. [8]
   b) Briefly discuss the requirement and characteristics of high power devices. [8]

3. a) With a neat schematic diagram, explain the operation of single-phase full bridge converter. [8]
   b) Discuss the basic concept of voltage sourced converter with circuit diagram. [8]

4. a) Discuss how to prevent voltage instability at the end of line by using shunt compensation. [8]
   b) Explain the working and characteristic of Thyristor Controlled Reactor. [8]

5. a) Briefly describe the way by which the transient stability is enhanced with static VAR compensator. [8]
   b) Explain the operation of STATCOM with an aid of block diagram. [8]

6. Explain the voltage stability enhancement and power oscillation damping with series capacitive compensation. [16]

7. Briefly discuss the IPFC with necessary diagrams and its characteristics. [16]

Code No: **RT42023C** **R13** **Set No. 1**

IV B.Tech II Semester Supplementary Examinations, September - 2020

FLEXIBLE ALTERNATING CURRENT TRANSMISSION SYSTEMS

(Electrical and Electronics Engineering)

Time: 3 hours **Max. Marks: 70**

Question paper consists of Part-A and Part-B
Answer ALL sub questions from Part-A
Answer any THREE questions from Part-B
*****

PART–A *(22 Marks)*

1. a) What are the objectives of FACTS controllers? [4]
   b) Why in general voltage sourced converters is preferred over current sourced converters in FACTS controllers. [3]
   c) Why shunt compensation is always attempted at midpoint of a transmission line. [4]
   d) What are the advantages of slope in SVC dynamic characteristics? [4]
   e) State the objective of series compensation. [4]
   f) Explain the basic operating principle of an UPFC. [3]

PART–B *(3x16 = 48 Marks)*

2. a) Discuss various limitations on the loading of a transmission line. [8]
   b) Explain different high power devices used in FACTS devices with their voltage and current ratings. [8]

3. a) Explain in brief about current sourced converters. [8]
   b) Derive expression for square–wave voltage harmonics for a single–phase bridge converter. [8]

4. a) Discuss how to prevent voltage instability using shunt compensation connecting at the end of line. [8]
   b) Explain the power oscillation damping with shunt compensation. [8]

5. Describe the transfer function and dynamic performance of SVC and STATCOM with necessary diagrams. [16]

6. a) What is meant by variable impedance type series compensator? Explain the operation of Thyristor Controlled Series Capacitor (GCSC). [8]
   b) Explain the basic control schemes of TCSC and TSSC. [8]

7. a) What is Interline Power Flow Controller? How is it different from Unified Power Flow Controller? Discuss its applications. [8]
   b) Explain the implementation of UPFC by two back-to-back voltage sourced converters. [8]

Gokaraju Rangaraju Institute of Engineering & Technology							
Dept: EEE IV Year II Sem MID-I Academic Year: 2022-23							
Subject Name: Constitution of India (GR20A2003)-A Section							
Date: 14.02.2023							
Course Attainment Analysis							
S.No	Name	Q1.a [3M] CO1	Q1.b [2M] CO1	Q2. [5M] CO2	Q3. [5M] CO3	Q4.a [3M] CO2	Q4.b [2M] CO3
1	Abhijit Padhy	3	2			3	2
2	Adepu Shiva Kumar	3	2	4		2	2
3	Afsha Sultana	3	2	5		3	2
4	Aggarapu Siri	3	2	5		3	2
5	Akkanapally Niranjan	3	2		4	2	2
6	B.Mounika	3	2	5	4		
7	Boju Ashwin Kumar	AB	AB	AB	AB	AB	AB
8	Budamagunta Sricharan	2	2		3	1	1
9	Cherukupally Devaraju	3	2			1	0
10	Chidugu Sindhu	3	2	5		3	2
11	Sai Surya Vidul Chintamaneni	3			4	2	2
12	Chinthapanti Manikanta	3	2	3			
13	D Kavya Kirthi	3	2	5		3	2
14	Dharmapuri Vedavyas Manjunath	3	2	3		3	2
15	Gajula Lakshmi Priya	2	2		3	2	2
16	Ganta Chandra Sekhar	2	2	3			
17	Gardas Srinivas	3	2	3		2	2
18	Gorupati Akhila	3	2	4		3	1
19	Gunda Arjun	2	2	3		2	1
20	Jadhav Dattahari	3	2			3	2
21	Jalla Tharuni	3	2	5		2	2
22	Jangam Sai Deep	2	2			1	2
23	Jula Vamshi Krishna Sagar	2	2	3		3	1
24	K Ravi Abhiram Varma	3	2				
25	Kakunuri Venkata Akash Reddy	3	2				
26	Kalmi Manasa	1	2	3		3	2
27	Katkuri Laxman	3	2	3		3	2
28	Kolikapogu Ramkumar	3	2				1
29	Kunchala Venkata Sai	3	2			3	2
30	Mallavarapu Lohith Kumar	2	2			3	1
31	Manupati Harika	3		3		3	
32	Meesala Dinesh	2	2			1	2
33	Mohammad Abdul Sami	3	2		4	2	2
34	Mohammed Yaseen Malik Qureshi	2	2	2		2	2
35	Naragani Pravardh	3	2	5		3	2
36	Nimmanagoti Sowmya	2	2	5		3	2
37	Nithish Edla	3	2				
38	Odiveti Nitish Kumar	3	2			3	
39	Pakanati Krishnabhaskar	AB	AB	AB	AB	AB	AB
40	Pallam Sai Keerthana	3	2	4		3	2
41	Pandilla Madhav	3	2	3		2	2

42	Peravally Veda Pranavrai	3	2			3	
43	Polisetty Samanvita	AB	AB	AB	AB	AB	AB
44	Puli Shireesha	3	2	5		3	2
45	Rayabarapu Vishnu	3	2			3	
46	Revathi.G	3	2	4		3	2
47	Sanam Rama Gangadhar	3	2	3		3	1
48	Saraswathi Srikari	3	2	5		3	2
49	Simhadri Rajshri	3	2	4		3	2
50	Suchismita Das	3	2	5		3	2
51	Ruperao Vaishnavi	3	2		5	3	2
52	Talakayala Lahari	3	2	3		3	1
53	Talluri Sasidhar	3	2	3		3	2
54	Thatipamula Vihal	3	2			3	1
55	Vaishnavi Gorantla	3	2	5		3	2
56	Vakkalanka Satya Shreyas	3	2	5		3	2
57	Vishal.K	AB	AB	AB	AB	AB	AB
58	Boddu Deepika	2	2			3	
59	Sai Prasad	3	2	4		3	2
60	Deekshitha	3	2	4		2	2
61	Saritha	3	2	4		2	2
62	Ashwanth	AB	AB	AB	AB	AB	AB
63	Srikanth	3	2	5		3	2
	Grand Total	**161**	**112**	**143**	**27**	**133**	**83**
	NSA	**58.0**	**56.0**	**36.0**	**7.0**	**51.0**	**47.0**
	Attempt %=(NSA/Total no of students)*100	**87.9**	**84.8**	**54.5**	**10.6**	**77.3**	**71.2**
	Average (attainment)= Total/NSA	**2.8**	**2.0**	**4.0**	**3.9**	**2.6**	**1.8**
	Attainment%= (Avg/max. Marks for question)*100	**92.53**	**100.00**	**198.61**	**128.57**	**130.39**	**58.87**
		CO1	CO1	CO2	CO3	CO2	CO3
		CO1	**130.38**				
		CO2	**105.94**				
		CO3					

Gokaraju Rangaraju Institute of Engineering & Technology

Dept: EEE IV Year II Sem MID-II Academic Year:2022-23

Subject Name: Power Quality and FACTS (GR18A4071)-B Section

Date: 14.02.2023

MID-I Marks

	Roll Numbers	Name	Subjective (15M)	Objective (5M)	Total (20M)
1	19241A0261	Ailaboina Prathyusha	14	2	16
2	19241A0262	Allem Ramakrishna Reddy	10	3	13
3	19241A0263	Angadala Roshan Yadav	11	4	15
4	19241A0264	Asam Srinidhi	10	2	12
5	19241A0265	B Umesh	9	1	10
6	19241A0266	Bhuma Mahesh	AB	AB	AB
7	19241A0267	Bonala Anusha	13	1	14
8	19241A0268	C V S Nikhila Varma	8	4	12
9	19241A0269	C Venkateshwari	15	1	16
10	19241A0270	Chekkirala Rohith	AB	AB	AB
11	19241A0271	Chella Sai Krishna	13	2	15
12	19241A0272	Chennu Venkata Lakshmi Priyanka	7	3	10
13	19241A0273	Choul Lavith	7	3	10
14	19241A0274	Doddi Bhavya	13	4	17
15	19241A0275	Gonae Harsha Vardhan	AB	AB	AB
16	19241A0276	Gone Naga Jyothi	13	4	17
17	19241A0277	Gujjula Prathap	9	2	11
18	19241A0278	Jonnalagadda Jhansi	14	3	17
19	19241A0279	Karri Sushith	7	2	9
20	19241A0280	Kothakota Rohanth Reddy	12	3	15
21	19241A0281	M Shashank	9	3	12
22	19241A0282	Manjula Rambabu	11	3	14
23	19241A0283	Manupuri Mrudhula	11	2	13
24	19241A0284	Marakala Divya	14	3	17
25	19241A0285	Megavath Uma	15	3	18
26	19241A0286	Murra Harshavardhana Reddy	14	3	17
27	19241A0287	Nagilla Anjali	14	3	17
28	19241A0288	Nagireddy Shiva Smaran Reddy	13	2	15
29	19241A0289	Padhiyar Sarthak Yogesh	5	1	6
30	19241A0290	Pendur Sai Teja	13	2	15
31	19241A0291	Potnuru Sai Srinivas	10	1	11
32	19241A0292	Pratheek V	13	2	15
33	19241A0293	Rudroju Sushanth	10	2	12
34	19241A0294	T Sridhar Yadav	8	1	9
35	19241A0295	Saranga Prem Sai	14	2	16
36	19241A0296	Shaik Ashraf	10	1	11
37	19241A0297	Shaik Babu Saheb	7	2	9
38	19241A0298	Sravani Bannuru	14	2	16
39	19241A0299	Sumit Kumar Nishad	7	2	9
40	19241A02A1	V Karthik	8	1	9
41	19241A02A2	Varahabhatla Suguna Manasa	9	2	11
42	19241A02A3	Varala Sai Ganesh	6	1	7
43	19241A02A4	Vattem Rohith Shekar	14	2	16
44	19241A02A5	Veeramaneni Suchitha	15	1	16

45	19241A02A6	Veerla Prasanthi	15	2	17
46	19241A02A7	Velpula Sai Rishyendranadh	11	2	13
47	20245A0206	Pravallika	AB	AB	AB
48	20245A0207	Sujan Goud	13	3	16
49	20245A0208	Ravikanth	13	3	16
50	20245A0209	Mahindra	11	3	14
51	20245A0210	Navinash	AB	AB	AB
52	20245A0211	Venkatesh	15	3	18
53	20245A0212	Mamatha	13	1	14
54	20245A0213	Musharraf	14	2	16
55	20245A0214	Pranay Jonathan	5	3	8
56	20245A0215	Sree Samanvitha	12	2	14
57	20245A0216	Sathish	15	**3**	18
58	20245A0217	Nutan Kumar	12	4	16
59	20245A0218	Harshitha	13	3	16
60	20245A0219	Shruthi	10	2	12
61	20245A0220	Alekya	13	2	15
62	20245A0221	Santosh Goud	11	3	14
63	20245A0222	Vijay Kumar	AB	AB	AB
64	20245A0223	Sathvik Yadav	7	3	10
65	20245A0224	Anurag	6	3	9

Gokaraju Rangaraju Institute of Engineering & Technology

Dept: EEE IV Year II Sem MID-II Academic Year: 2022-23

Subject Name: Power Quality and FACTS (GR18A4071)-A Section

Date: 27.04.2023

Course Attainment Analysis

S.No	Roll Numbers	Name	Q1. [5M] CO3	Q2. [5M] CO4	Q3.a [3M] CO4	Q3.b [2M] CO4	Q4.a [3M] CO5	Q4.b [2M] CO5
1	19241A0201	Abhijit Padhy	3	3	2	2		
2	19241A0202	Adepu Shiva Kumar	4	3	2	2		
3	19241A0203	Afsha Sultana	3	4	3	2		
4	19241A0204	Aggarapu Siri	4	4	3	2		
5	19241A0205	Akkanapally Niranjan		4	3	2	2	2
6	19241A0206	B.Mounika	5	4	3	2		
7	19241A0207	Boju Ashwin Kumar	4		3	2		
8	19241A0208	Budamagunta Sricharan	2	3	2	2		
9	19241A0209	Cherukupally Devaraju	2	3	2	2		
10	19241A0210	Chidugu Sindhu	5	5	2	2		
11	19241A0211	Sai Surya Vidul Chintamaneni	3	3	2	2		
12	19241A0212	Chinthapanti Manikanta	5					
13	19241A0213	D Kavya Kirthi	5	5	2	2		
14	19241A0214	Dharmapuri Vedavyas Manjunath	4	3	2	2		
15	19241A0215	Gajula Lakshmi Priya		4	2	2	2	2
16	19241A0216	Ganta Chandra Sekhar	1	3	3	2		
17	19241A0217	Gardas Srinivas	2	3	2	2		
18	19241A0218	Gorupati Akhila	3	4	3	2		
19	19241A0219	Gunda Arjun	4	3	2	2		
20	19241A0220	Jadhav Dattahari	3	4	3	0		
21	19241A0221	Jalla Tharuni	5	5	3	2		
22	19241A0222	Jangam Sai Deep		4	1	2		
23	19241A0223	Jula Vamshi Krishna Sagar	3	3	2	2		
24	19241A0224	K Ravi Abhiram Varma		3	3	2		
25	19241A0225	Kakunuri Venkata Akash Reddy	4	3				
26	19241A0226	Kalmi Manasa	4	4	2			
27	19241A0227	Katkuri Laxman		3	2	2	2	2
28	19241A0228	Kolikapogu Ramkumar	2	2	3	1		
29	19241A0229	Kunchala Venkata Sai		2	3	2		
30	19241A0230	Mallavarapu Lohith Kumar	3	2				
31	19241A0231	Manupati Harika		3	3		3	
32	19241A0232	Meesala Dinesh		5	2	2		
33	19241A0233	Mohammad Abdul Sami		4	3	2	2	2
34	19241A0234	Mohammed Yaseen Malik Qureshi	3	3	2	2		
35	19241A0235	Naragani Pravardh	3		3	2	2	2
36	19241A0236	Nimmanagoti Sowmya	4	4			2	2
37	19241A0237	Nithish Edla	3				2	
38	19241A0238	Odiveti Nitish Kumar	3	4	2	1		
39	19241A0239	Pakanati Krishnabhaskar	AB	AB	AB	AB	AB	AB
40	19241A0240	Pallam Sai Keerthana	4	3	3	2		
41	19241A0241	Pandilla Madhav	2	3	2	2		
42	19241A0242	Peravally Veda Pranavrai	4	2	2	2		
43	19241A0243	Polisetty Samanvita		2	2	2	2	
44	19241A0244	Puli Shireesha	4	3	3	2		
45	19241A0246	Rayabarapu Vishnu		4	2	2		
46	19241A0247	Revathi.G	4	5	3	2		

47	19241A0249	Sanam Rama Gangadhar	4	4	2	2		
48	19241A0250	Saraswathi Srikari	4	4	3	2		
49	19241A0251	Simhadri Rajshri	4	4	3	2		
50	19241A0252	Suchismita Das	3	5	3	2		
51	19241A0253	Ruperao Vaishnavi		4	3	2	3	2
52	19241A0254	Talakayala Lahari		0	2	2	2	2
53	19241A0255	Talluri Sasidhar	4	3	2	2		
54	19241A0256	Thatipamula Vihal	4	3	2	2		
55	19241A0257	Vaishnavi Gorantla	4	5	3	2		
56	19241A0258	Vakkalanka Satya Shreyas	4	4	2	2		
57	19241A0259	Vishal.K	2	1	2			
58	19241A0260	Boddu Deepika	1	2		2		
59	20245A0201	Sai Prasad		3	3	2	3	2
60	20245A0202	Deekshitha	4	4	3	2		
61	20245A0203	Saritha	4	4	2	2		
62	20245A0204	Ashwanth		4	3	2	2	2
63	20245A0205	Srikanth		4	3	2	3	2
		Grand Total	**159**	**199**	**138**	**104**	**32**	**22**
		NSA	**46.0**	**58.0**	**56.0**	**54.0**	**14.0**	**11.0**
		Attempt %=(NSA/Total no of students)*100	**69.7**	**87.9**	**84.8**	**81.8**	**21.2**	**16.7**
		Average (attainment)= Total/NSA	**3.5**	**3.4**	**2.5**	**1.9**	**2.3**	**2.0**
		Attainment%= (Avg/max. Marks for question)*100	**69.13**	**68.62**	**82.14**	**96.30**	**76.19**	**100.00**
			CO3	CO4	CO4	CO4	CO5	CO5
			CO3	**69.13**				
			CO4	**82.35**				
			CO5	**88.10**				

Gokaraju Rangaraju Institute of Engineering & Technology

Dept: EEE IV Year II Sem MID-II Academic Year: 2022-23

Subject Name: Power Quality and FACTS (GR18A4071)-B Section

Date: 27.04.2023

Course Attainment Analysis

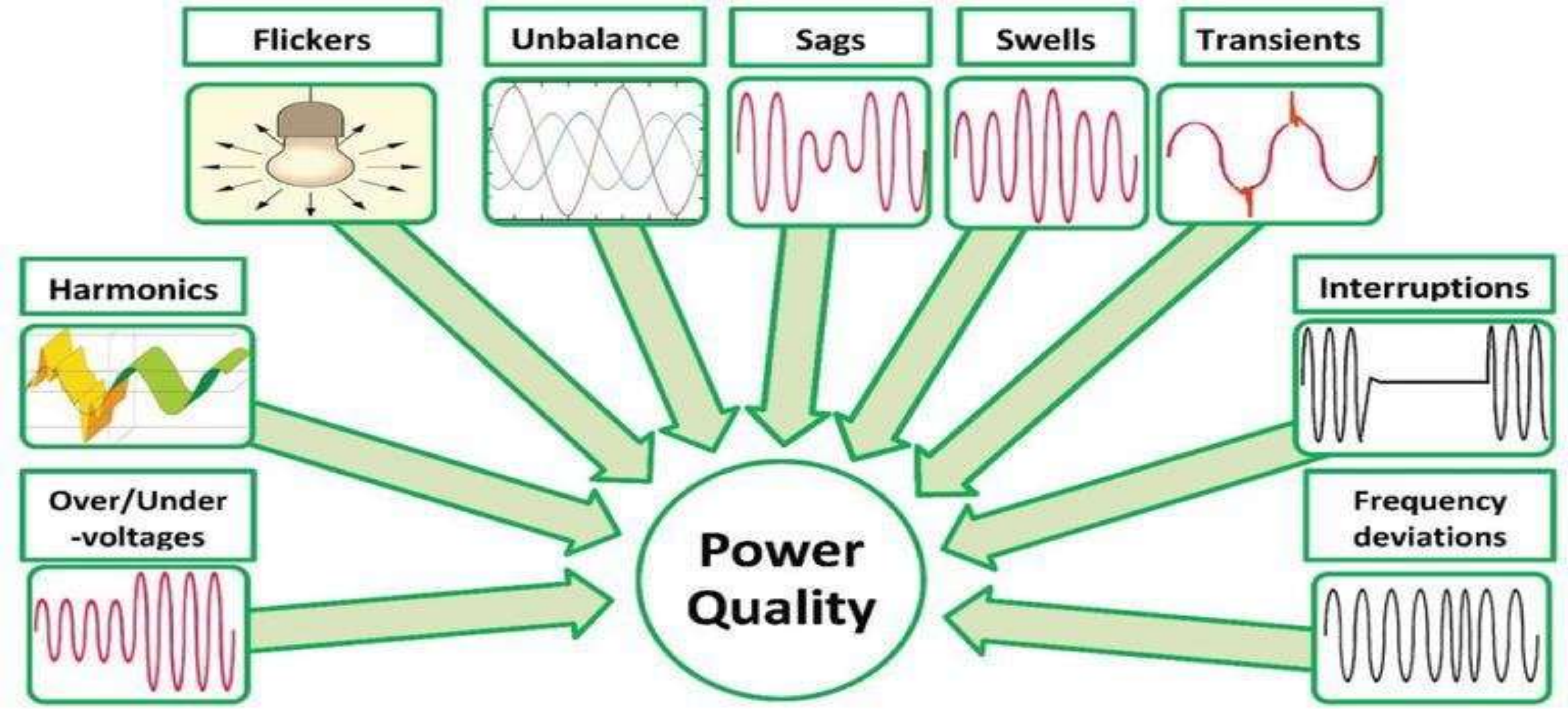
S.No	Roll Numbers	Name	Q1. [5M] CO3	Q2. [5M] CO4	Q3.a [3M] CO4	Q3.b [2M] CO4	Q4.a [3M] CO5	Q4.b [2M] CO5
1	19241A0261	Ailaboina Prathyusha	3	3	2	2		
2	19241A0262	Allem Ramakrishna Reddy	5	4	3	2		
3	19241A0263	Angadala Roshan Yadav	4	4	3	2		
4	19241A0264	Asam Srinidhi	2	3	2	2		
5	19241A0265	B Umesh	2	4	2	2		
6	19241A0266	Bhuma Mahesh	3	2				
7	19241A0267	Bonala Anusha	4	5	3	2		
8	19241A0268	C V S Nikhila Varma	3	2	3	2		
9	19241A0269	C Venkateshwari	5	4	3	2		
10	19241A0270	Chekkirala Rohith		4	3	2		
11	19241A0271	Chella Sai Krishna	2	4	3	2		
12	19241A0272	Chennu Venkata Lakshmi Priyanka	3	2	2			
13	19241A0273	Choul Lavith	3	3	2			
14	19241A0274	Doddi Bhavya	3	5	3	2		
15	19241A0275	Gonae Harsha Vardhan	4	2	3			
16	19241A0276	Gone Naga Jyothi	5	4	3	1		
17	19241A0277	Gujjula Prathap	4	4	2	2		
18	19241A0278	Jonnalagadda Jhansi	4	4	2	2		
19	19241A0279	Karri Sushith	4	3	3	2		
20	19241A0280	Kothakota Rohanth Reddy	5	5	3	2		
21	19241A0281	M Shashank	4	5	3	2		
22	19241A0282	Manjula Rambabu	4	4	2	2		
23	19241A0283	Manupuri Mrudhula	4	3	3	2		
24	19241A0284	Marakala Divya	4	4	3	2		
25	19241A0285	Megavath Uma	4	5	3	2		
26	19241A0286	Murra Harshavardhana Reddy	4	4	3			
27	19241A0287	Nagilla Anjali	5	4	3	2		
28	19241A0288	Nagireddy Shiva Smaran Reddy	4	3	3	2		
29	19241A0289	Padhiyar Sarthak Yogesh		4	2	0		
30	19241A0290	Pendur Sai Teja	4	4	2	2		
31	19241A0291	Potnuru Sai Srinivas	2	4	3	2		
32	19241A0292	Pratheek V	4	4	2	2		
33	19241A0293	Rudroju Sushanth	3	3	2	2		
34	19241A0294	T Sridhar Yadav	4	3	2	2		
35	19241A0295	Saranga Prem Sai	4	4	3	2		
36	19241A0296	Shaik Ashraf	5	4	3	2		
37	19241A0297	Shaik Babu Saheb	4	4	3	2		
38	19241A0298	Sravani Bannuru	4	4	3	2		
39	19241A0299	Sumit Kumar Nishad	2					
40	19241A02A1	V Karthik	4	3	3	2		
41	19241A02A2	Varahabhatla Suguna Manasa	4	3	2			
42	19241A02A3	Varala Sai Ganesh		3	2			
43	19241A02A4	Vattem Rohith Shekar	4	3	3	2		
44	19241A02A5	Veeramaneni Suchitha	4	4	3	2		

45	19241A02A6	Veerla Prasanthi	4	4			3	2
46	19241A02A7	Velpula Sai Rishyendranadh	4	4	2	2		
47	20245A0206	Pravallika	AB	AB	AB	AB	AB	AB
48	20245A0207	Sujan Goud	4	3	2	2		
49	20245A0208	Ravikanth	4	3	2	2		
50	20245A0209	Mahindra	4	3	3	2		
51	20245A0210	Navinash		3	2	2		
52	20245A0211	Venkatesh	4	4	3	2		
53	20245A0212	Mamatha	4	3	3	2		
54	20245A0213	Musharraf		4	2	2	3	2
55	20245A0214	Pranay Jonathan		3	2	2		
56	20245A0215	Sree Samanvitha	4	4	3	2		
57	20245A0216	Sathish		4	3	2	2	2
58	20245A0217	Nutan Kumar		2	2	2	2	2
59	20245A0218	Harshitha	4	4	2	2		
60	20245A0219	Shruthi	3	3	3	2		
61	20245A0220	Alekya	4	4	3	2		
62	20245A0221	Santosh Goud		2	2	2		
63	20245A0222	Vijay Kumar		2	4	2		
64	20245A0223	Sathvik Yadav	4	3	3	2		
65	20245A0224	Anurag	3	3	3	2		
66	20245A0225	Tarun	2	2	3	2		
		Grand Total	**205**	**224**	**163**	**109**	**10**	**8**
		NSA	**55.0**	**64.0**	**62.0**	**56.0**	**4.0**	**4.0**
		Attempt %=(NSA/Total no of students)*100	**83.3**	**97.0**	**93.9**	**84.8**	**6.1**	**6.1**
		Average (attainment)= Total/NSA	**3.7**	**3.5**	**2.6**	**1.9**	**2.5**	**2.0**
		Attainment%= (Avg/max. Marks for question)*100	**74.55**	**70.00**	**87.63**	**97.32**	**83.33**	**100.00**
			CO3	CO4	CO4	CO4	CO5	CO5
			CO3	**74.55**				
			CO4	**84.99**				
			CO5	**91.67**				

Unit-1
FACTS Concepts

Transmission Interconnections, Power Flow and Dynamic Stability Considerations of a Transmission Interconnection, Relative Importance of Controllable Parameters, Basic Types of FACTS Controllers -Shunt Connected Controllers, Series Connected Controllers, Combined Shunt and Series Connected controllers.

Power Quality Issues



Transmission Interconnections

System Parameters

- Series impedance and shunt impedance
- Voltage
- Current
- Phase angle
- Active power and reactive power

- P=(V1V2/X) * SinS

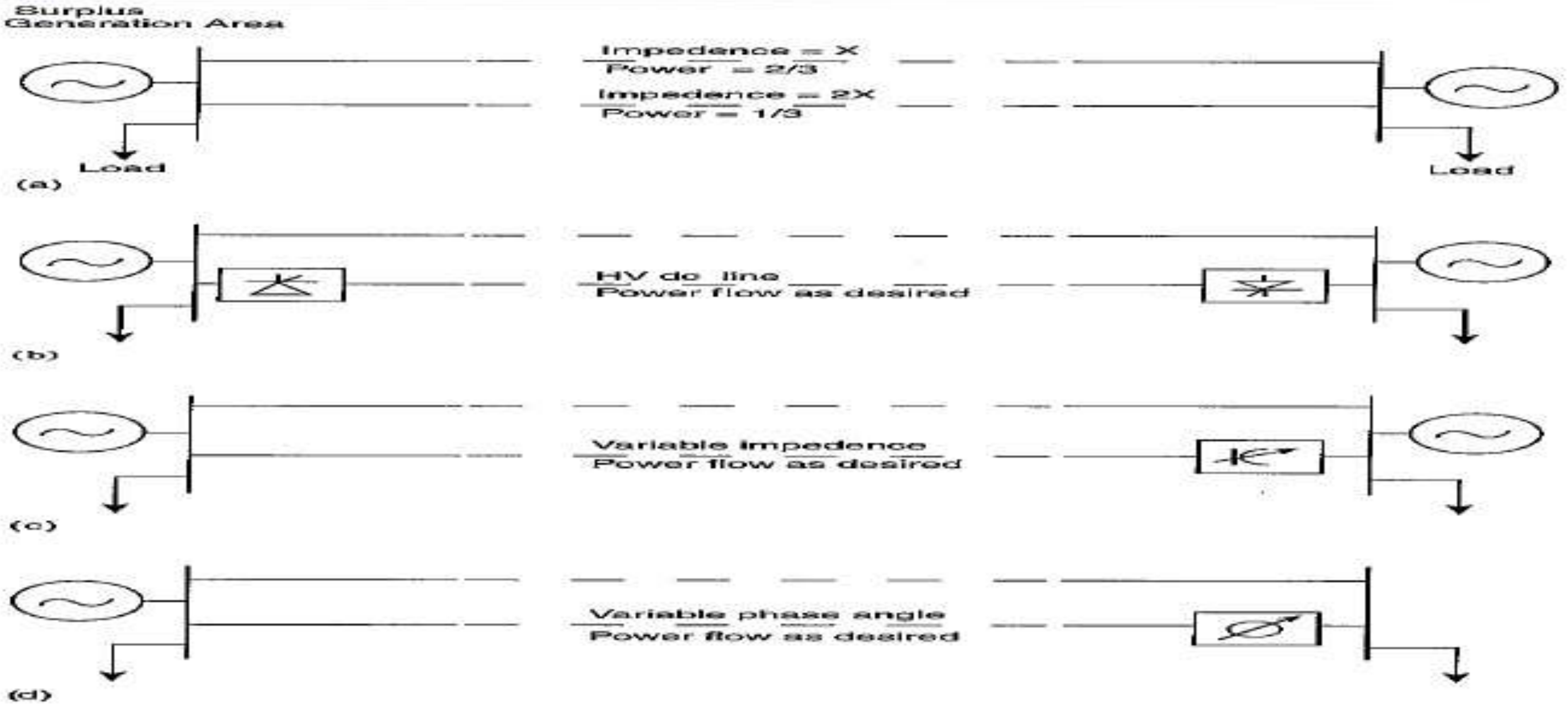
Power Flow in AC system

Power Flow in an AC System

- In ac system, the electrical generation and load must balance at all times.
- The electrical system is self-regulating.
- If generation is less than load, voltage and frequency drop.
- Active power flows from surplus generation areas to deficit areas.

Power Flow in Parallel Paths

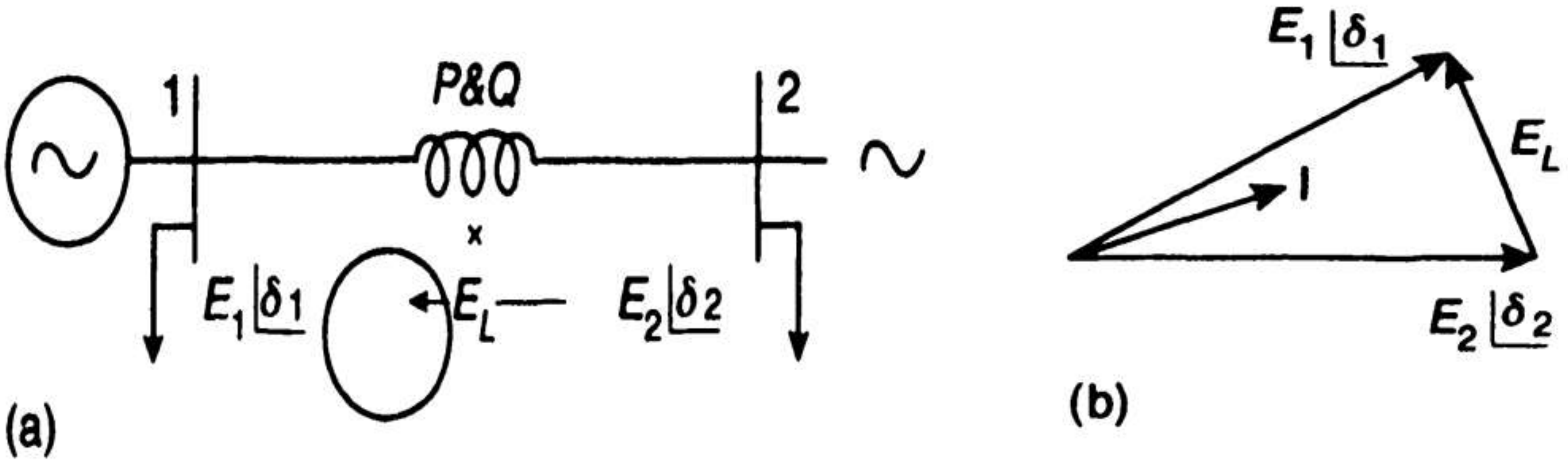
Power Flow in Parallel Paths



Loading Capability limits

- Thermal Limits
- Dielectric
- Steady state, Transient, dynamic stability, Frequency collapse, voltage collapse, Resonance

Dynamic Stability Considerations



Cont..

Active component of the current flow at E_1 is:

$$I_{p1} = (E_2 \sin \delta)/X$$

Reactive component of the current flow at E_1 is:

$$I_{q1} = (E_1 - E_2 \cos \delta)/X$$

Thus, active power at the E_1 end:

$$P_1 = E_1 (E_2 \sin \delta)/X$$

Reactive power at the E_1 end:

$$Q_1 = E_1 (E_1 - E_2 \cos \delta)/X \qquad (1.1)$$

Cont..

Similarly, active component of the current flow at E_2 is:

$$I_{p2} = (E_1 \sin \delta)/X$$

Reactive component of the current flow at E_2 is:

$$I_{q2} = (E_2 - E_1 \cos \delta)/X$$

Thus, active power at the E_2 end:

$$P_2 = E_2 (E_1 \sin \delta)/X$$

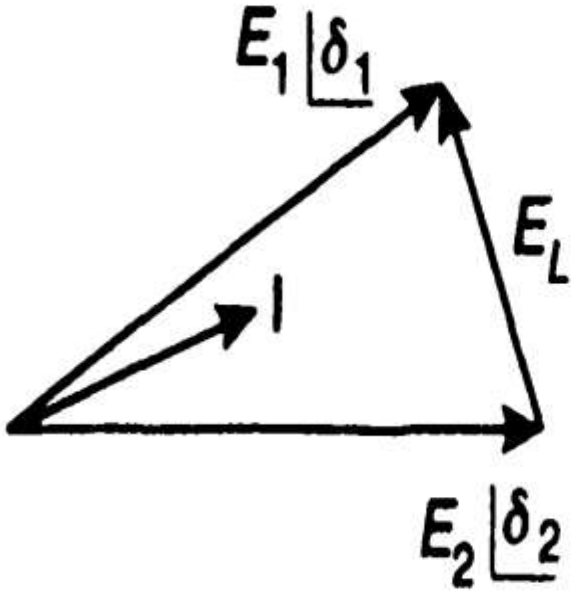
Reactive power at the E_2 end:

$$Q_2 = E_2 (E_2 - E_1 \cos \delta)/X \qquad (1.2)$$

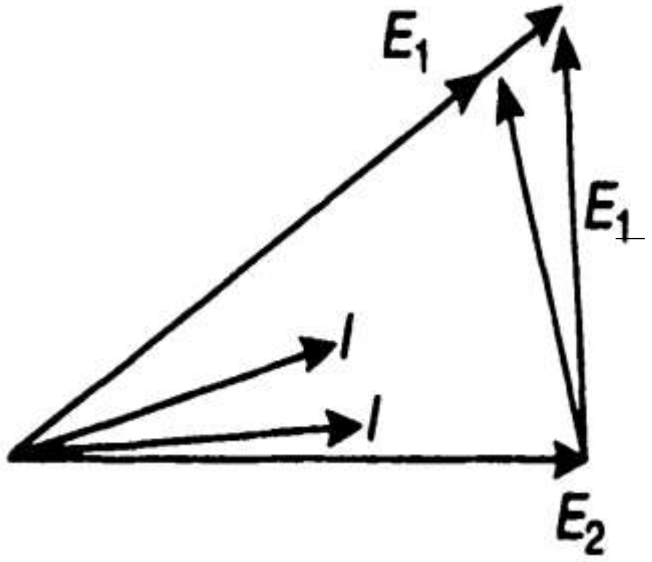
Naturally P_1 and P_2 are the same:

$$P = E_1 (E_2 \sin \delta)/X \qquad (1.3)$$

Changing of any bus voltage : Reactive power will be controlled

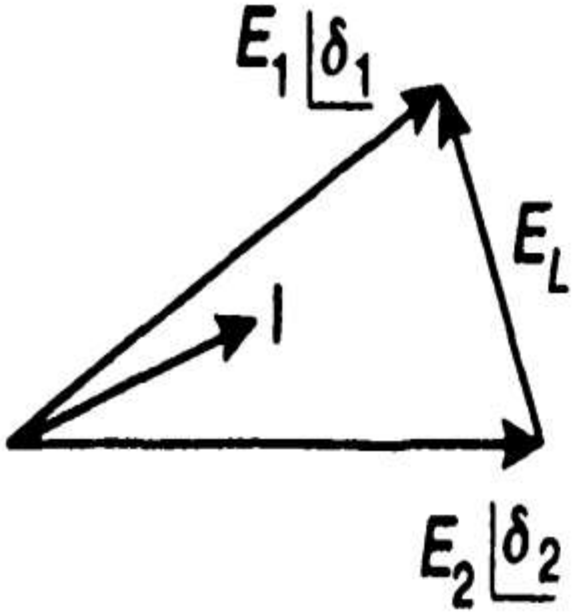


Before

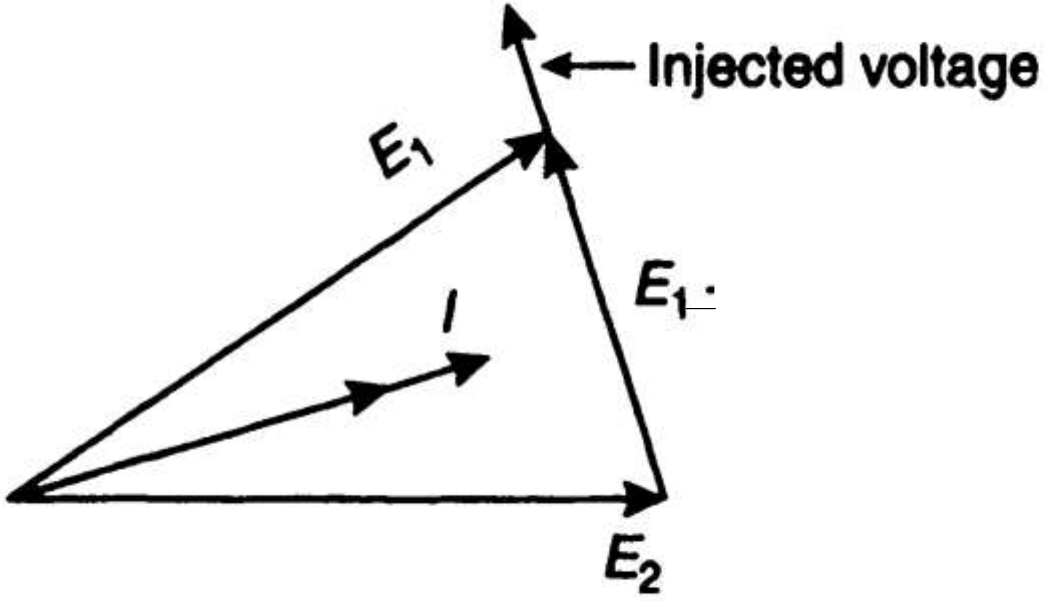


After

Injecting voltage into the line: Active Power will be controlled

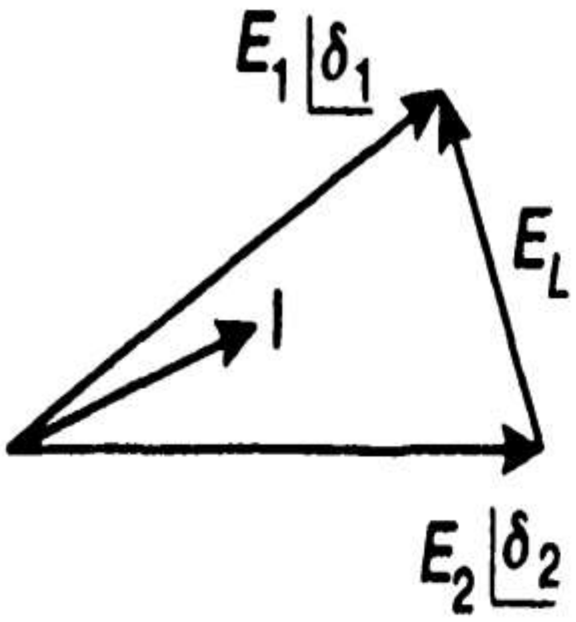


Before

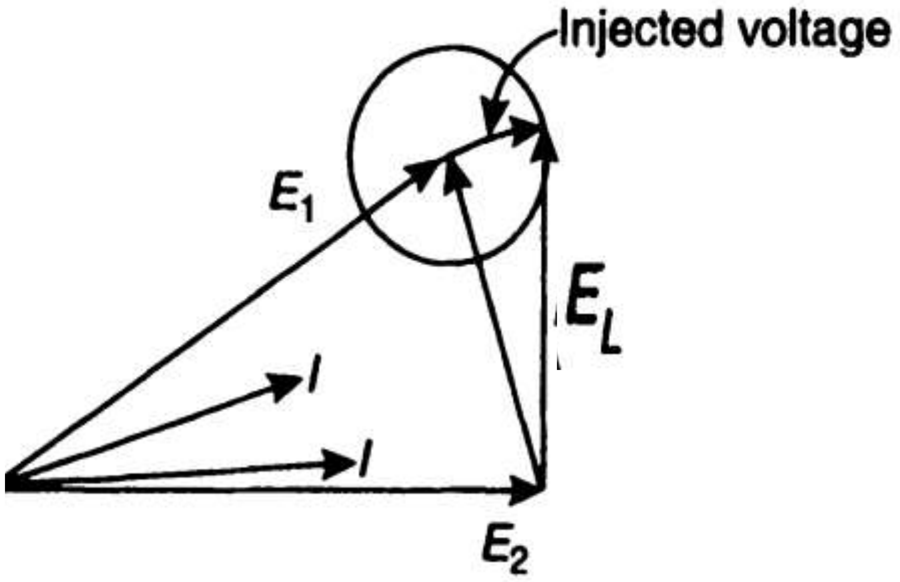


After

Injecting voltage to the bus with phase : Both Active and Reactive Powers can be controlled

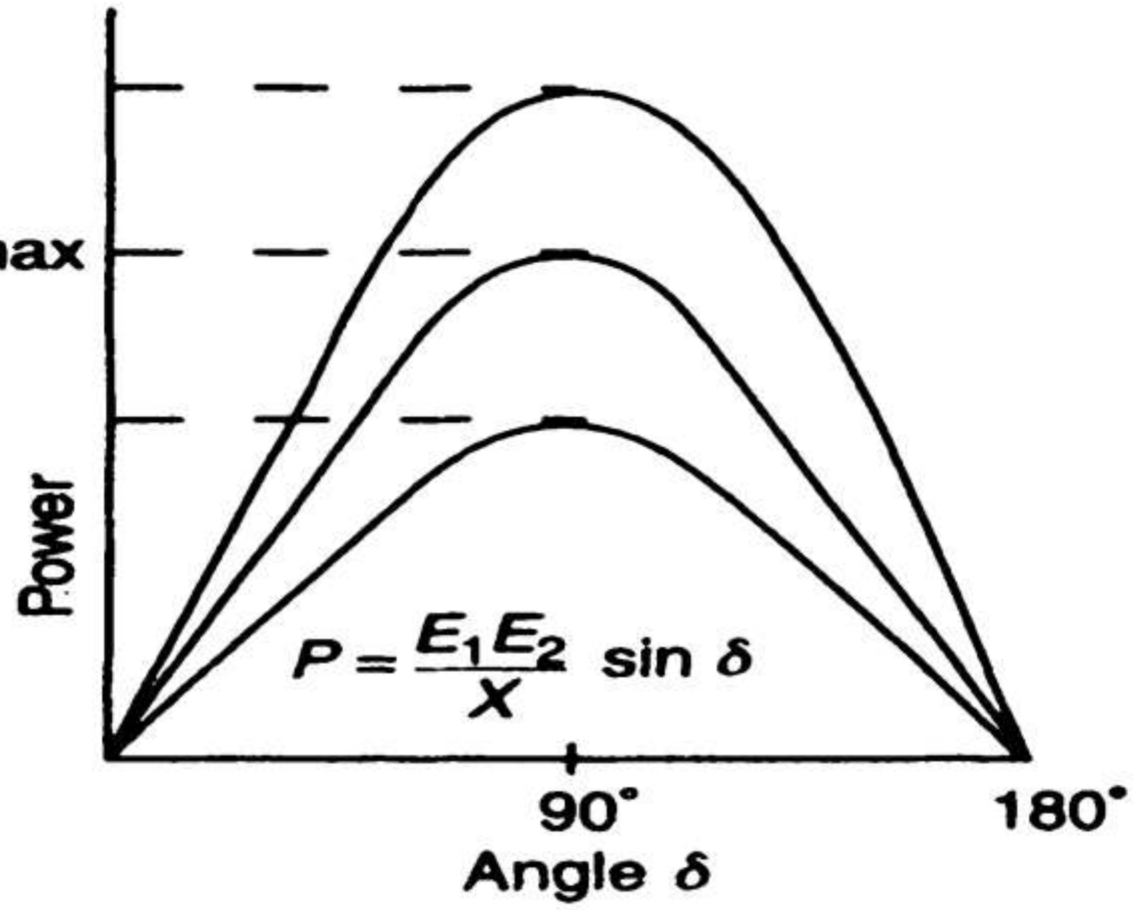


Before



After

Power Angle curve



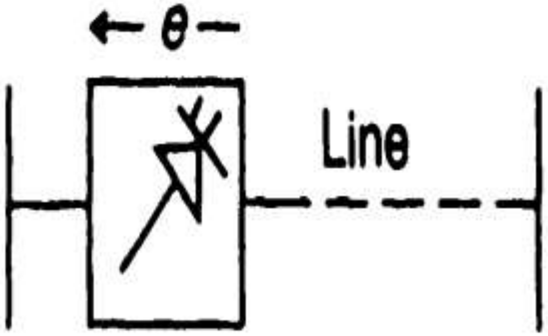
Basic Types of FACTS Controllers

- Series controllers
- Shunt Controllers
- Combined Series –series Controllers
- Combined Series- shunt Controllers

Cont..

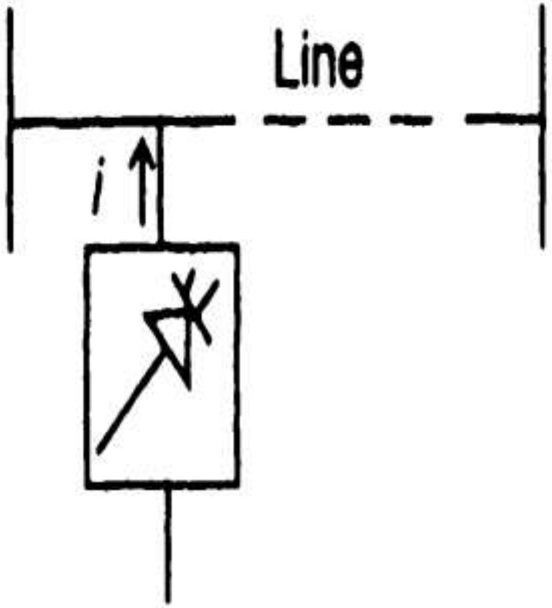
(a)

General Symbol of FACTS controller



(b)

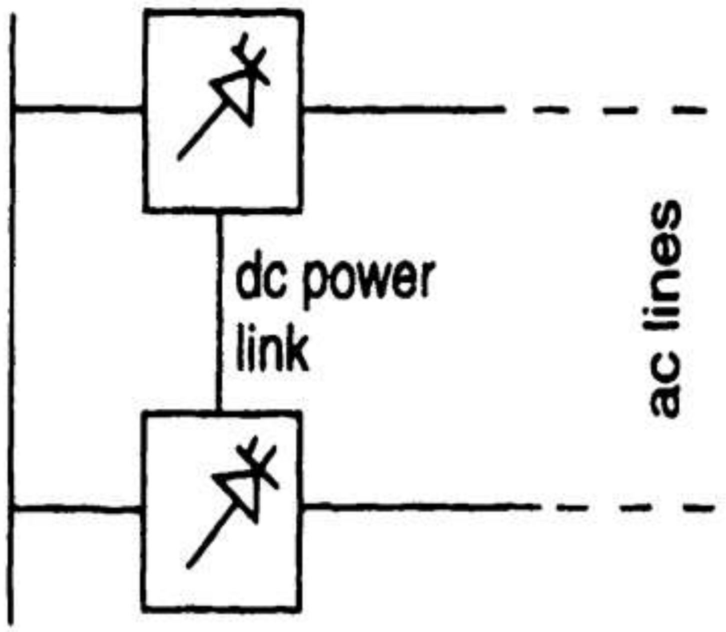
Series controller



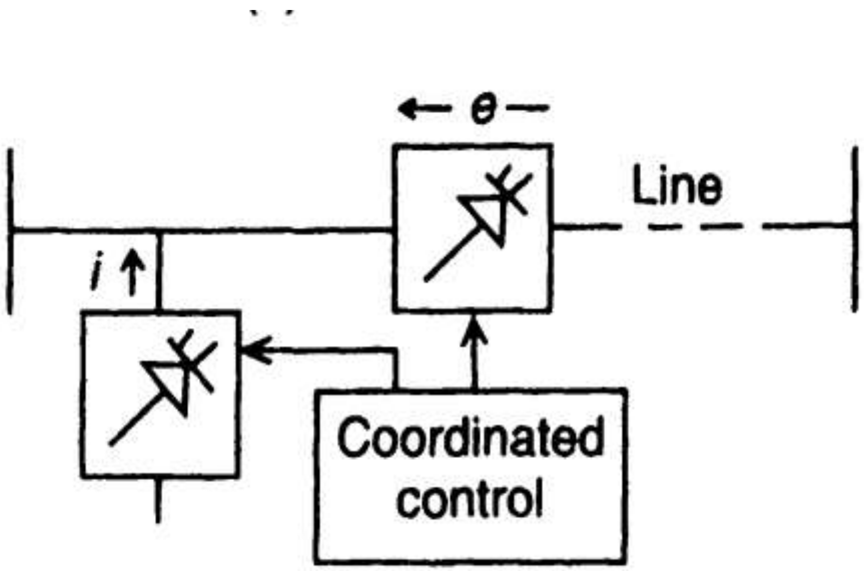
Shunt Controller

(c)

Cont..

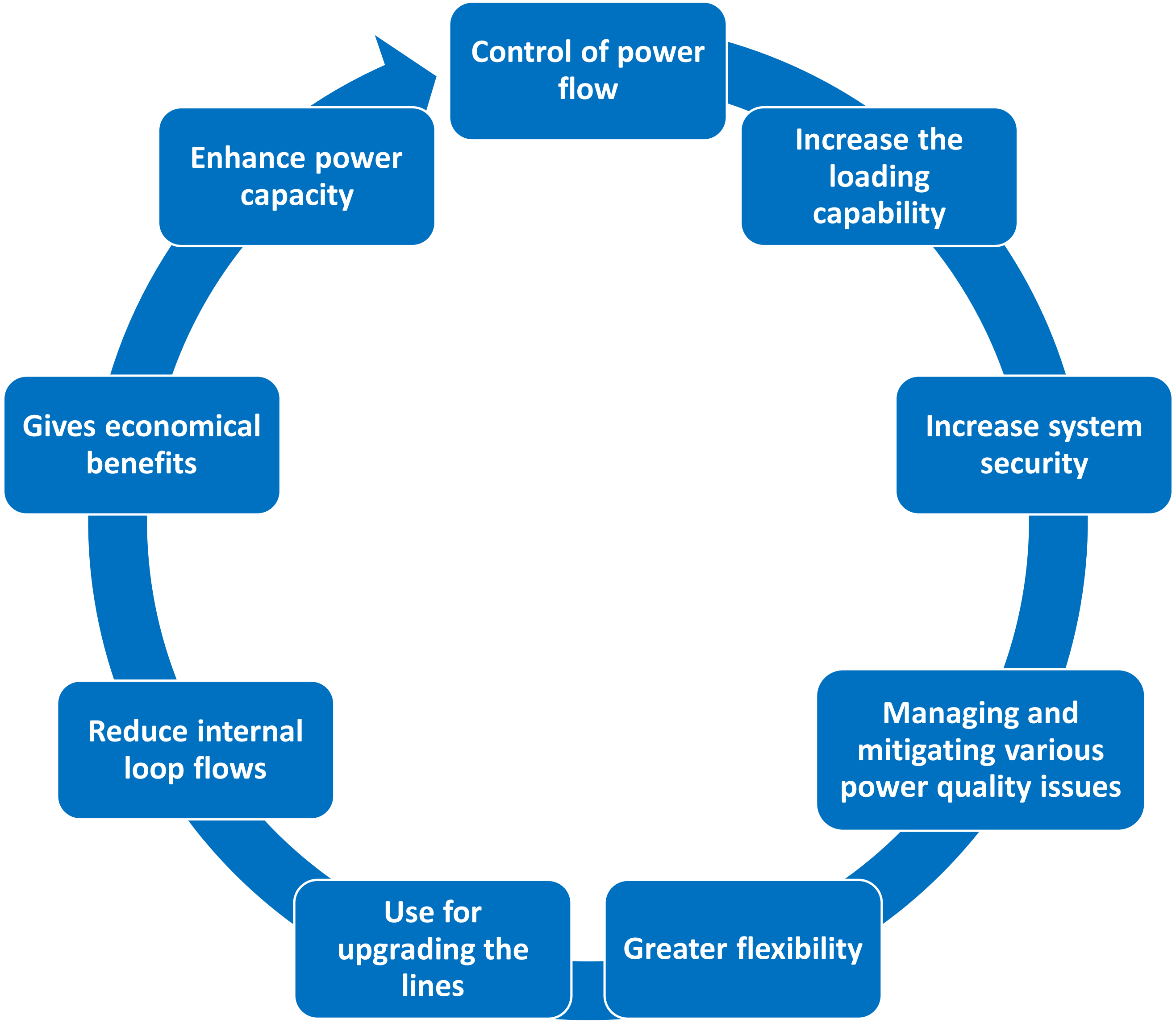


Combined series-series controller



Combined Series – shunt controller

Benefits From FACTS Technology



Unit -2

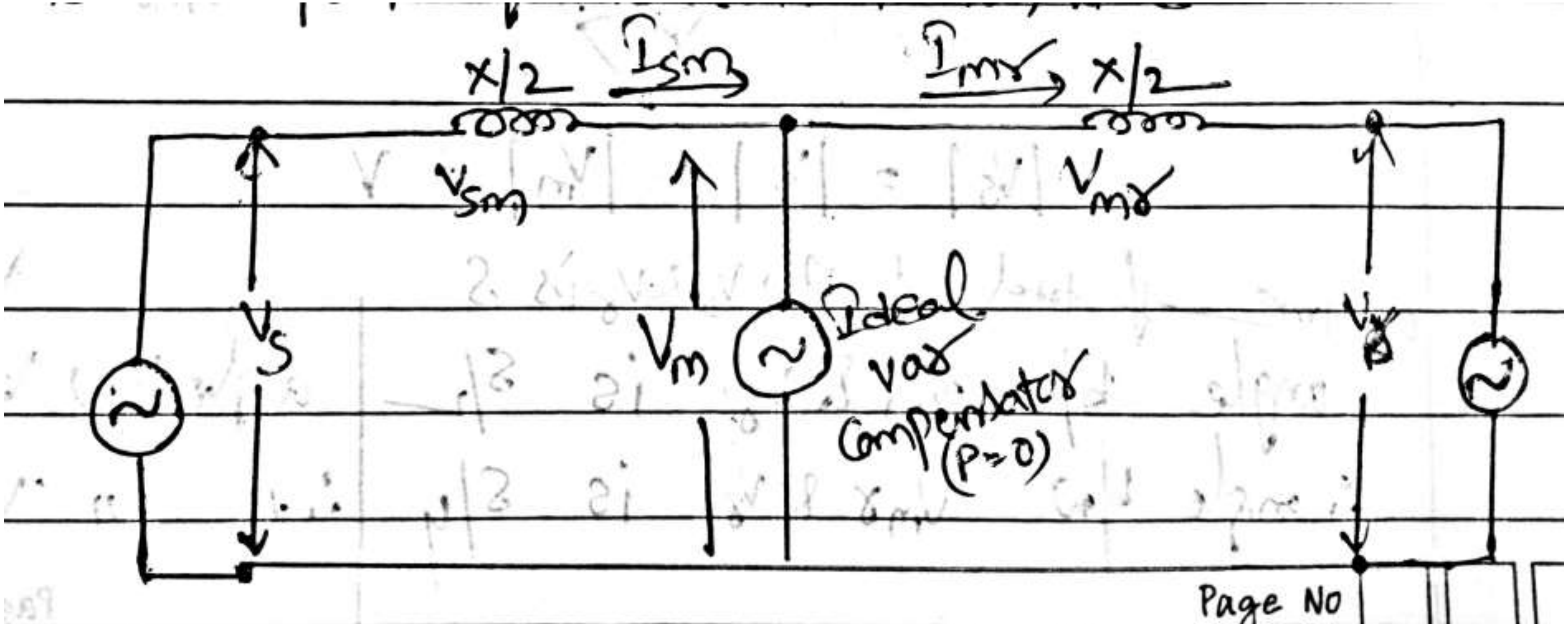
Shunt Compensators

Objectives of shunt compensation, Mid point voltage regulation, Improvement of Transient stability, power oscillation damping, Principle of operation of FC-TCR(SVC) compensator, characteristic of FC-TCR and control diagram, Basic concept of voltage source converter, principle of operation of STATCOM, characteristic of STATCOM, control diagram

Objectives of shunt compensation *(can be done with reactors or capacitors)*

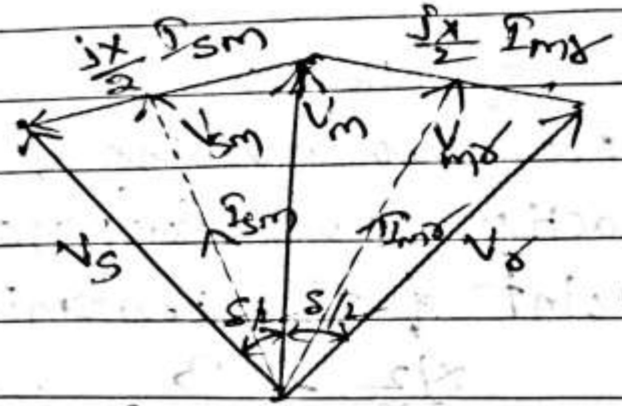
- **Steady state transmittable power**
- **Controlled voltage**
- **Withstanding of load demand**
- **Used to minimize over voltages (by shunt reactors)**
- **Used to improve poor voltages (shunt capacitors)**

Mid point Voltage Regulation



Two Bus Transmission System

Phasor diagram



I_{sm} is in phase with V_{sm}

I_{mr} is in phase with V_{mr}

$|V_s| = |V_r| = |V_m| = V$

assume total angle b/w V_s & V_r is δ

angle b/w V_m & V_r is $\delta/2$

∴ angle b/w V_{mr} & V_r is $\delta/4$

angle b/w V_s & V_m is $\delta/2$

∴ " V_{sm} & V_s is $\delta/4$

Page No

Expressions for P & Q

$\therefore \quad V_{sm} = V_s \cos \delta/4$

$\Rightarrow \quad \boxed{V_{sm} = V \cos \delta/4} \quad \because |V_s| = |V_r| = |V|$

& $\quad V_{mr} = V_r \cos \delta/4$

$\Rightarrow \quad \boxed{V_{mr} = V \cos \delta/4} \quad \because |V_s| = |V_r| = V$

$\therefore \quad \boxed{V_{sm} = V_{mr} = V \cos \delta/4}$

$L = \frac{X}{2} + \frac{X}{2} = X$

Similarly $\quad \boxed{I_{sm} = I_{mr} = I} = \frac{1}{L} \int V_{sm}\, dt$

$I = \frac{1}{X} \int V \cos \delta/4 \; d\delta$

$\boxed{I = \frac{4V}{X} \frac{\sin \delta/4}{1/4} = \frac{4V}{X} \sin \delta/4}$

Transmitted power is

$P = V_{sm} \cdot I_{sm} = V_{mr} \cdot I_{mr}$

$= V \cos \delta/4 \cdot I$

$\Rightarrow \quad \boxed{P = VI \cos \delta/4} \quad \therefore \quad \boxed{Q = VI \sin \delta/4}$

$P = V \cdot \frac{4V}{X} \sin \delta/4 \cdot \cos \delta/4$

$P = \frac{2V^2}{X} \, 2 \sin \delta/4 \cdot \cos \delta/4 \qquad (2 \sin A \cos A = \sin 2A)$

$P = \frac{2V^2}{X} \sin 2\frac{\delta}{4}$

Page No

Cont..

classmate

$$\boxed{P = \frac{2V^2}{X} \sin \delta/2} \quad \text{—— (1)}$$

$\sin 2A = 2 \sin A \cos A$

$\cos 2A = \cos^2 A - \sin^2 A$

$= 2\cos^2 A - 1$

$= 1 - 2\sin^2 A$

$\sin^2 A = \frac{1}{2}(1 - \cos 2A)$

$\cos^2 A = \frac{1}{2}(1 + \cos 2A)$

Similarly we have

$$Q = VI \sin \delta/4$$

$$Q = V \frac{4V}{X} \sin \delta/4 \cdot \sin \delta/4$$

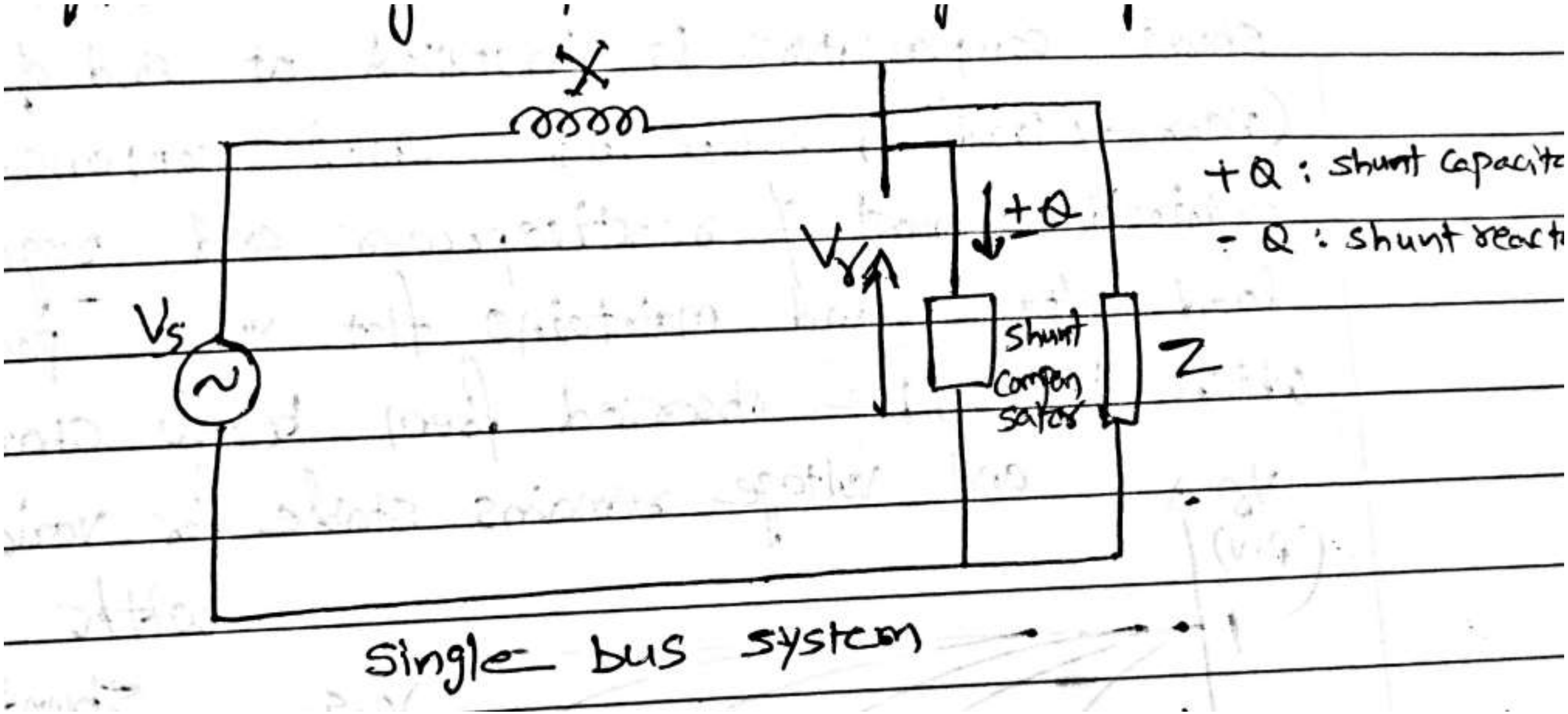
$$Q = \frac{4V^2}{X} \sin^2 \delta/4$$

since formula $\sin^2 A = \frac{1}{2}(1 - \cos$

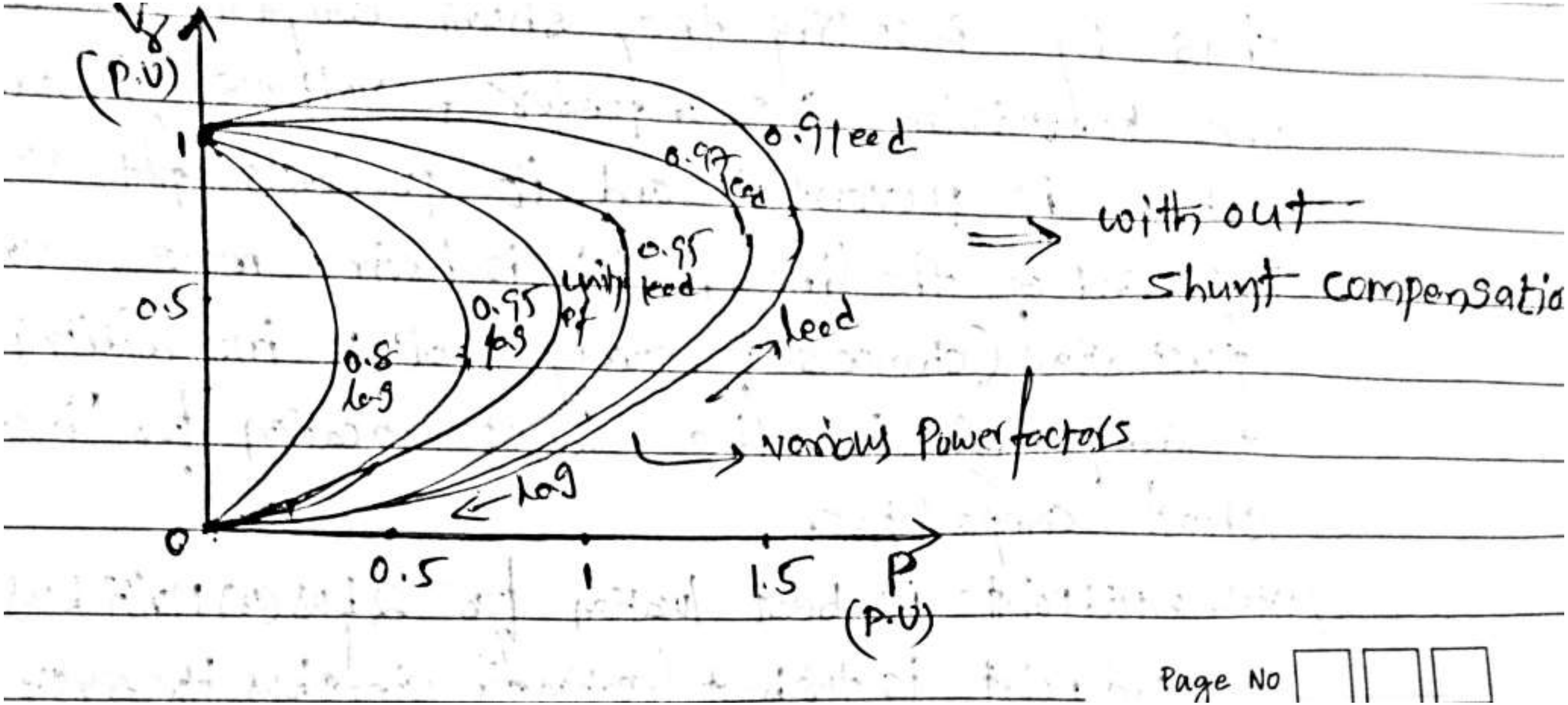
$$Q = \frac{4V^2}{X} \frac{1}{2}\left(1 - \cos 2\delta/4\right)$$

$$\boxed{Q = \frac{2V^2}{X}\left(1 - \cos \frac{\delta}{2}\right)} \quad \text{—— (2)}$$

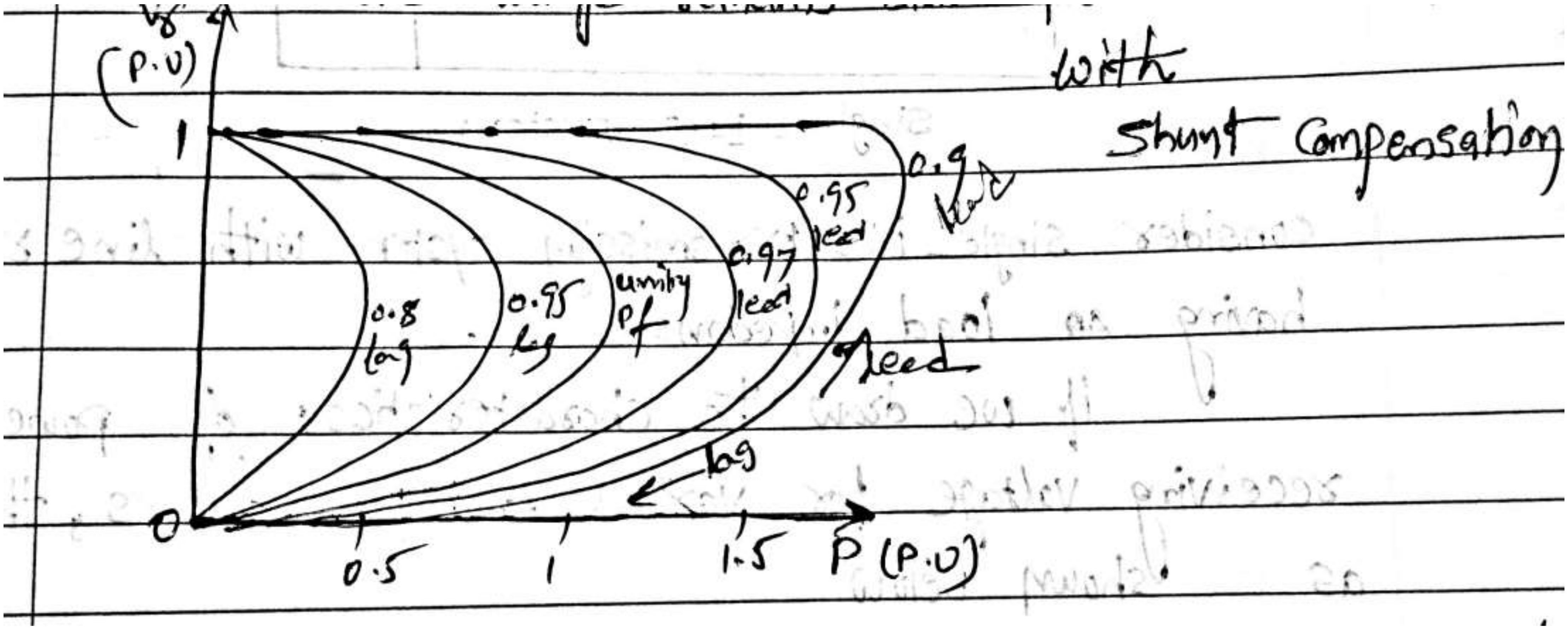
Voltage Instability Prevention



Voltage profile without shunt compensation

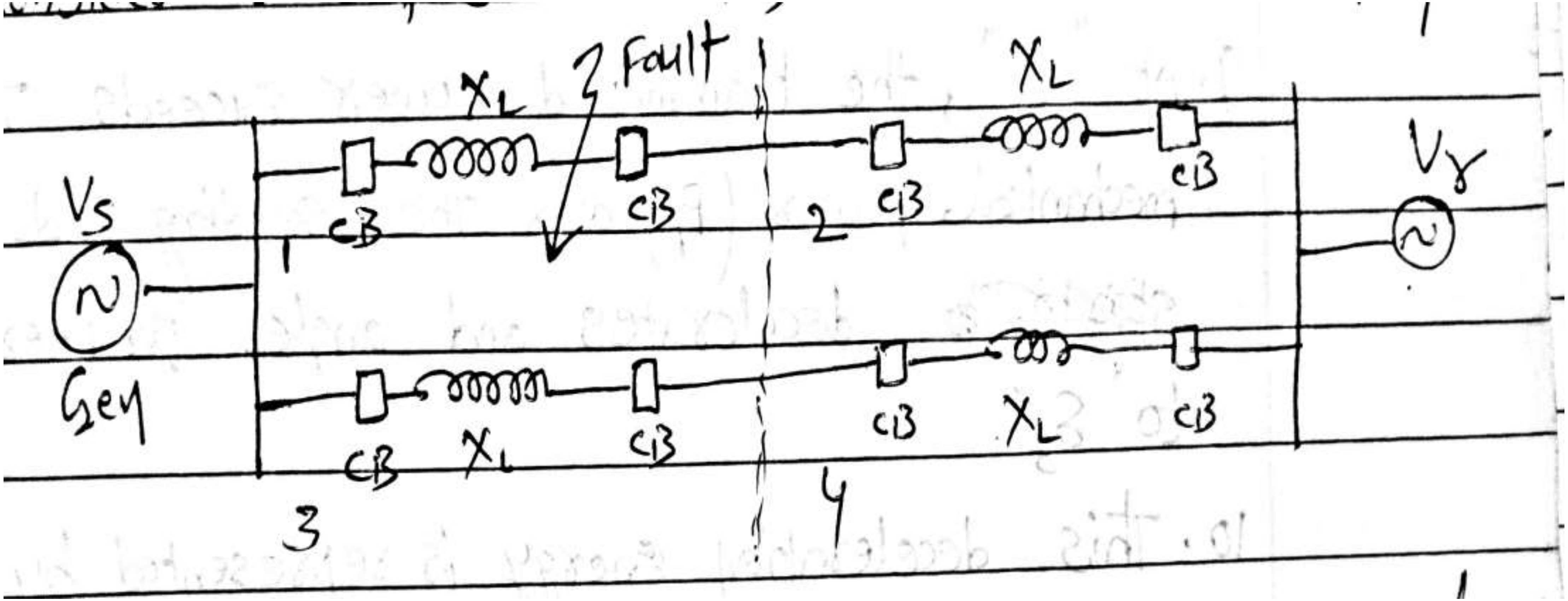


Voltage profile with shunt compensation

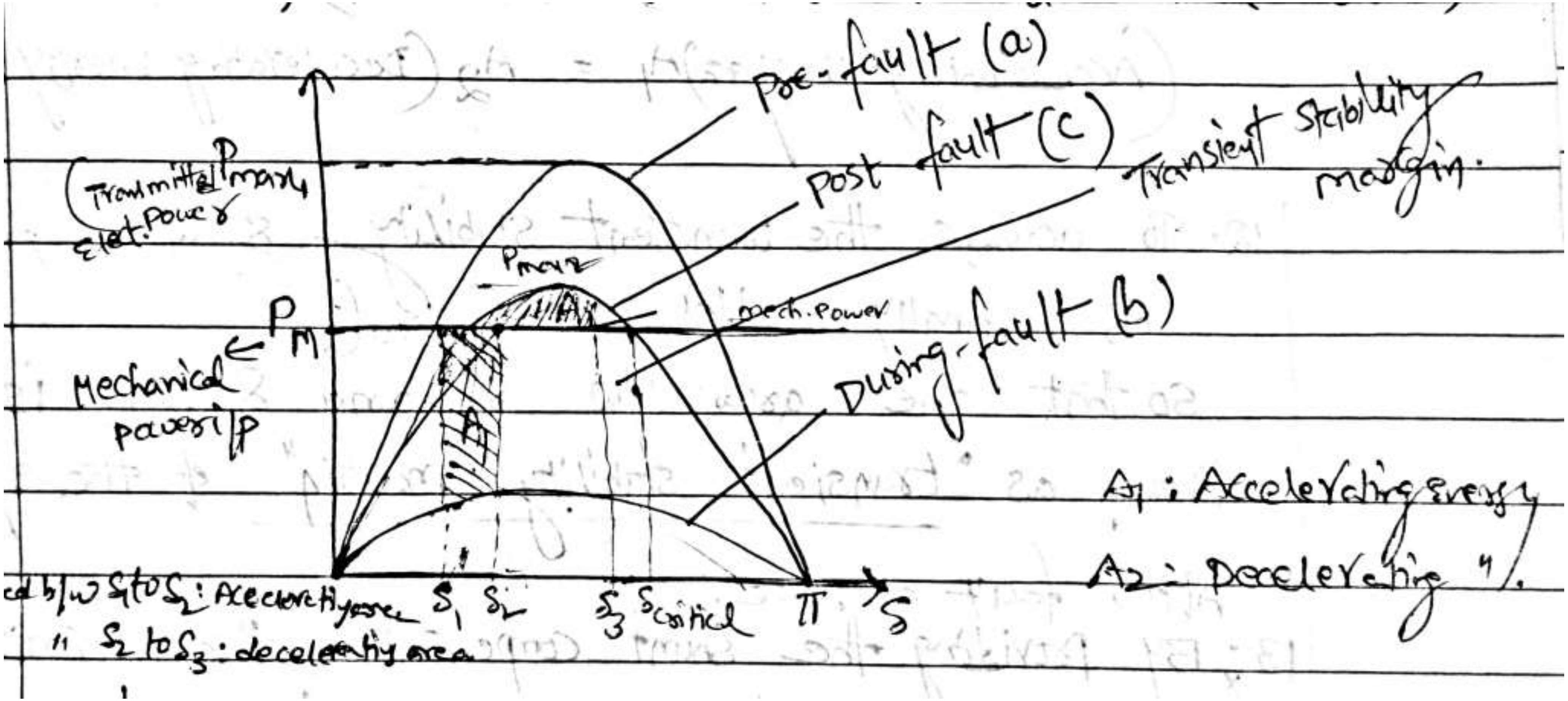


Define
Transient stability ?

Improvement of Transient Stability

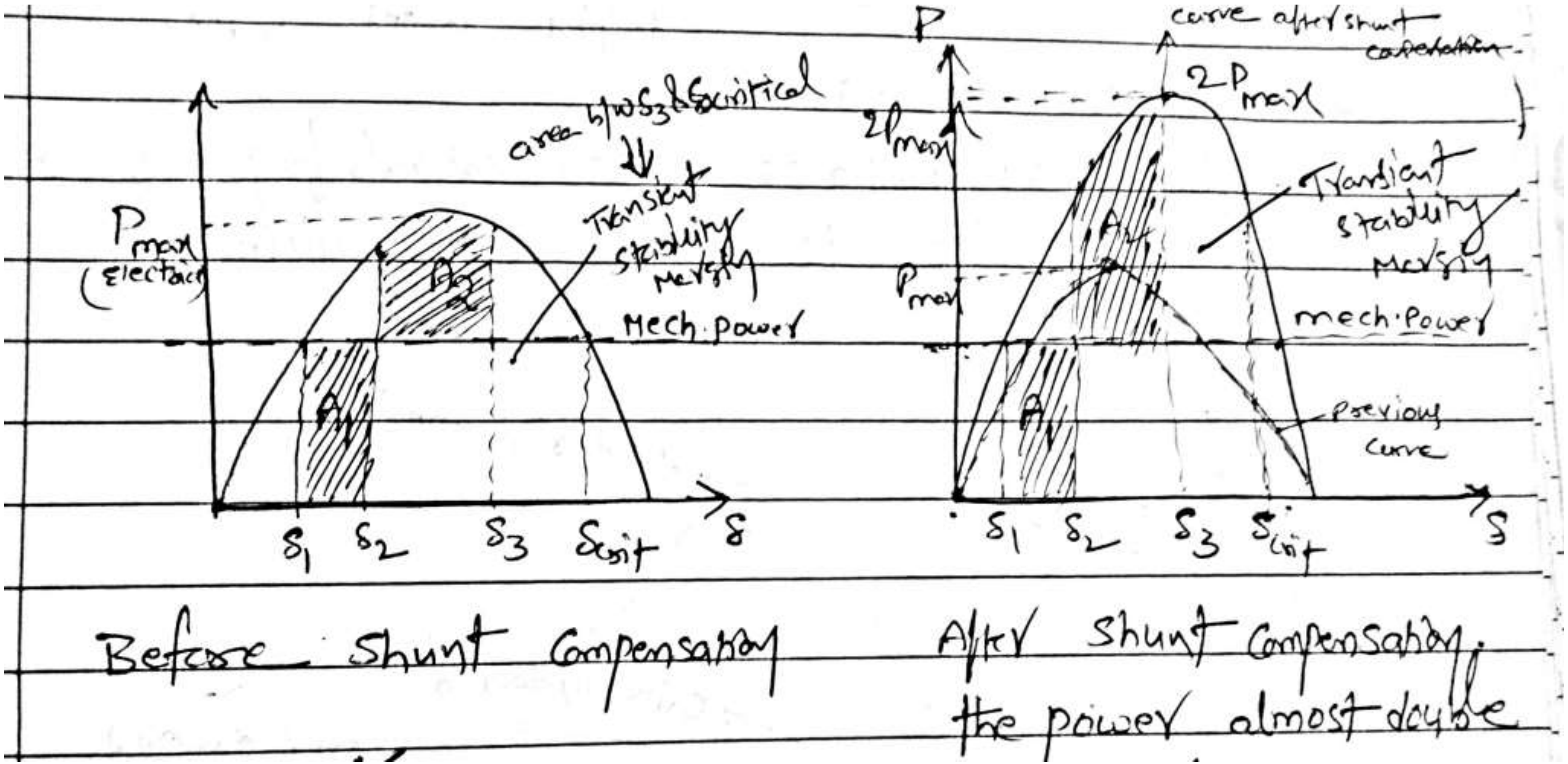


Power angle curve for pre ,post and during fault conditions

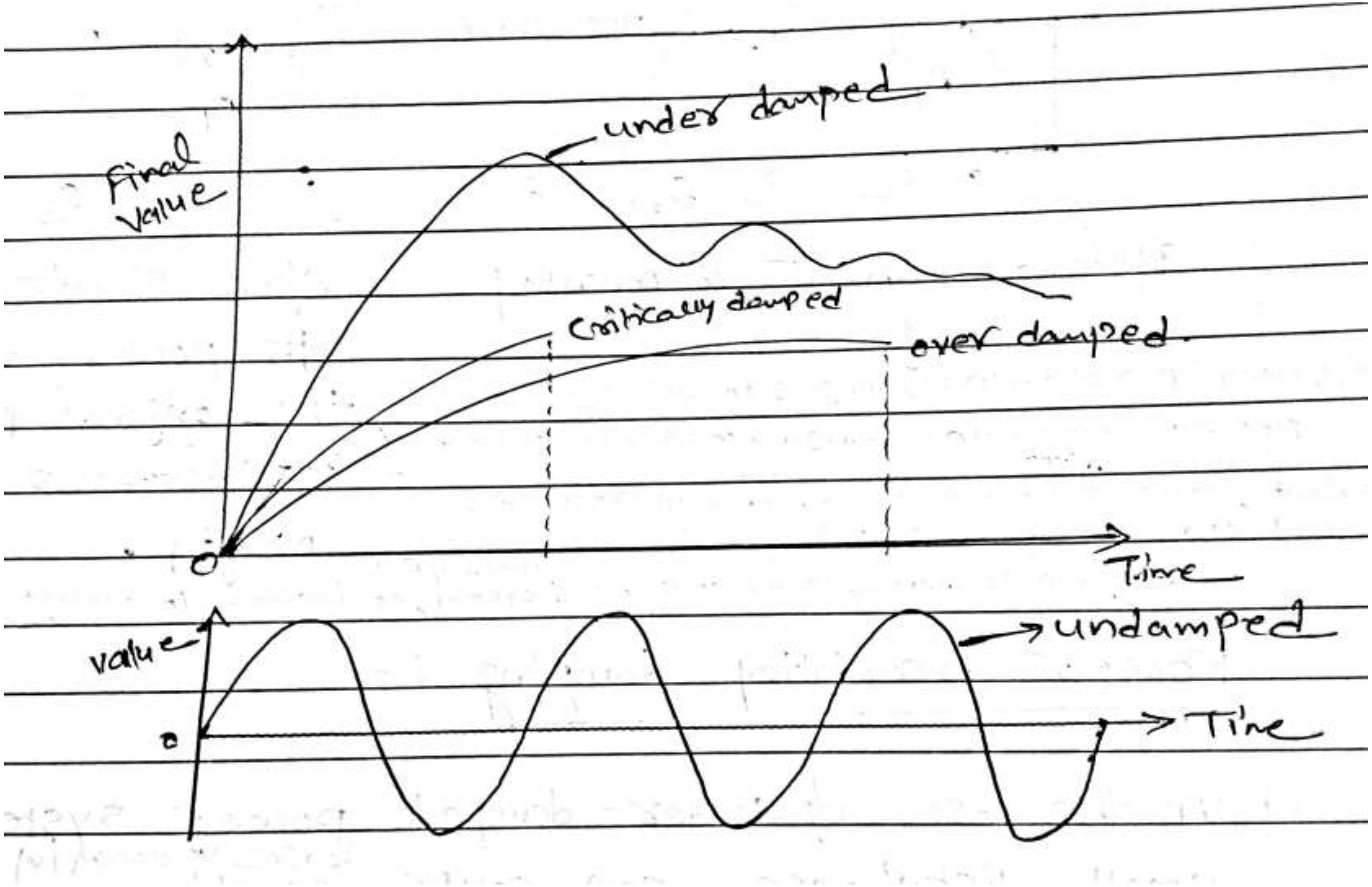


Note: Mech.I/p > Elect.O/p (Generator goes to Acceleration mode) ,
Elect.O/P > Mech I/P (Generator goes to Deceleration mode)

Before and after shunt compensation



Power Oscillation damping



Methods of controllable Var Generation

In addition to capacitors and inductors

- Mechanical switches
- Synchronous machines
- Appropriate switching control
- Line commutated thyristors (early 1970's)
- Gate turn off thyristors (recent days)
- By using SVG's

SVG –
(Static Var Generator)

- Semi conductor power circuits with different internal control strategies.
- Basic Classification of SVG

I. **Variable Impedance type**

II. **switching converter type**

III. **Hybrid Var generators**

Variable Impedance type

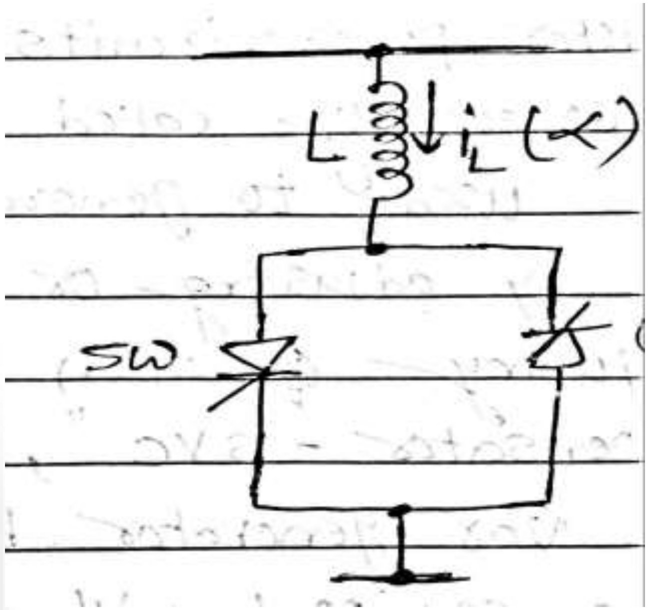
In this, Two types

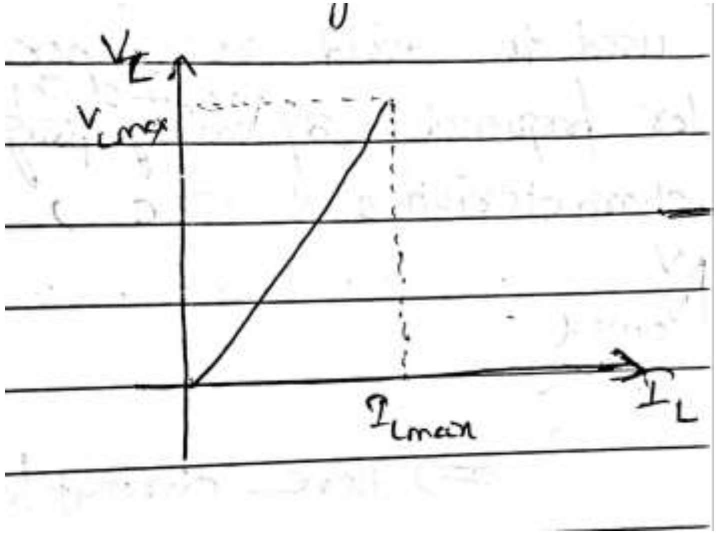
1.TSR (Thyristor Switched Reactor)

2.TSC (Thyristor Switched Capacitor)

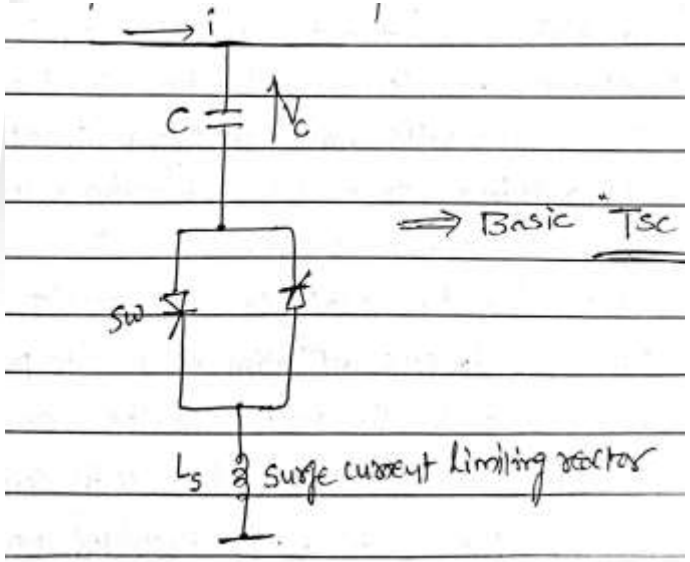
Structures of TSR & TSC and VI chars

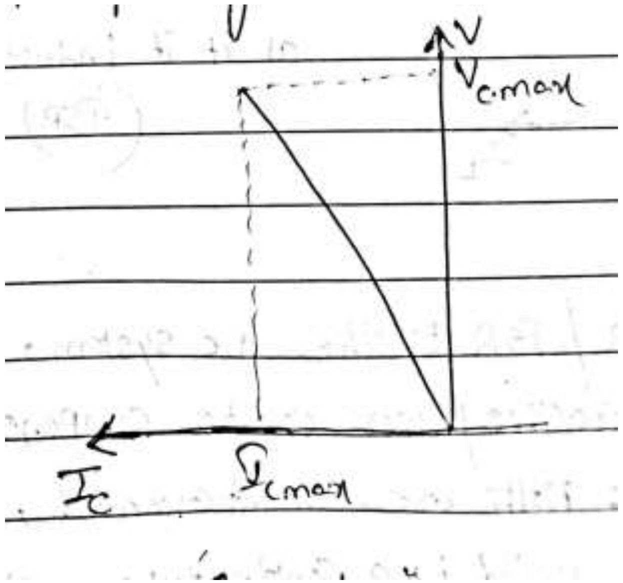
TSR



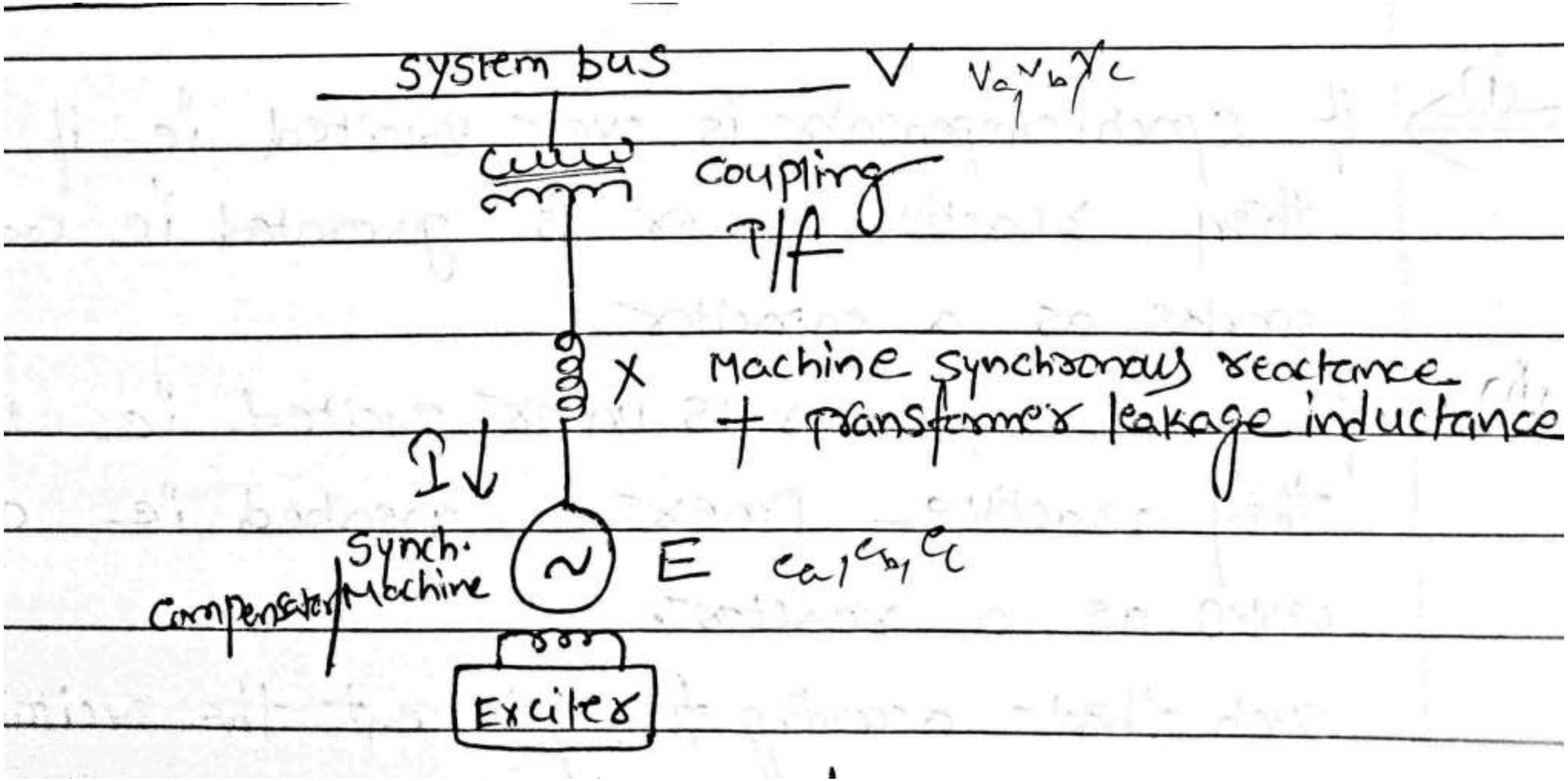


TSC





Switching converter type var generator



Cont..

Therefore reactive current $\boxed{I = \dfrac{V-E}{X}}$

The amount of reactive power

$$Q = I \cdot V$$ already it

$$\boxed{Q = \dfrac{V-E}{X} \cdot V} =$$

Note:

Case (1) :If synchronous compensator is over excited i’e *if E > V ,reactive power is generated.*

Case (2):If synchronous compensator is under excited i’e *If E < V ,reactive power is absorbed.*

Hybrid Var generators ??

Hybrid var generators

The combination of

Variable impedance type

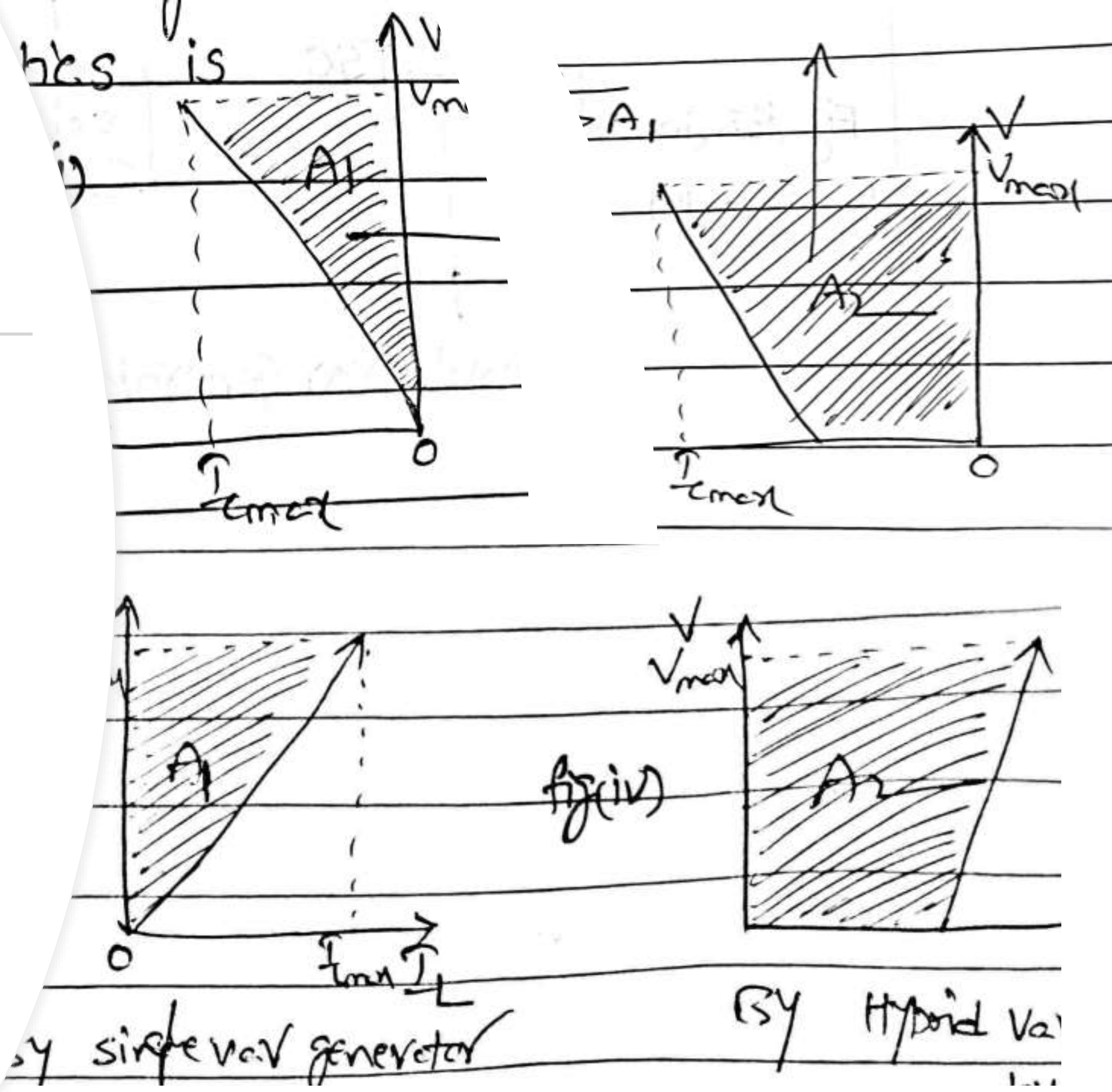
and

switching converter type

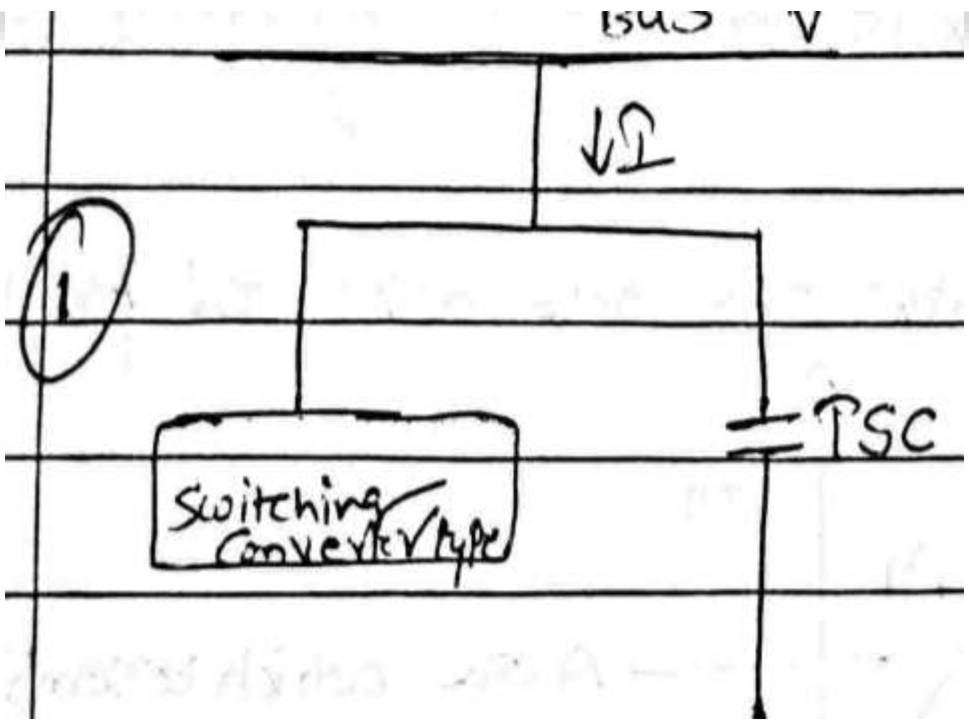
Adv: **More reactive power can be compensated**

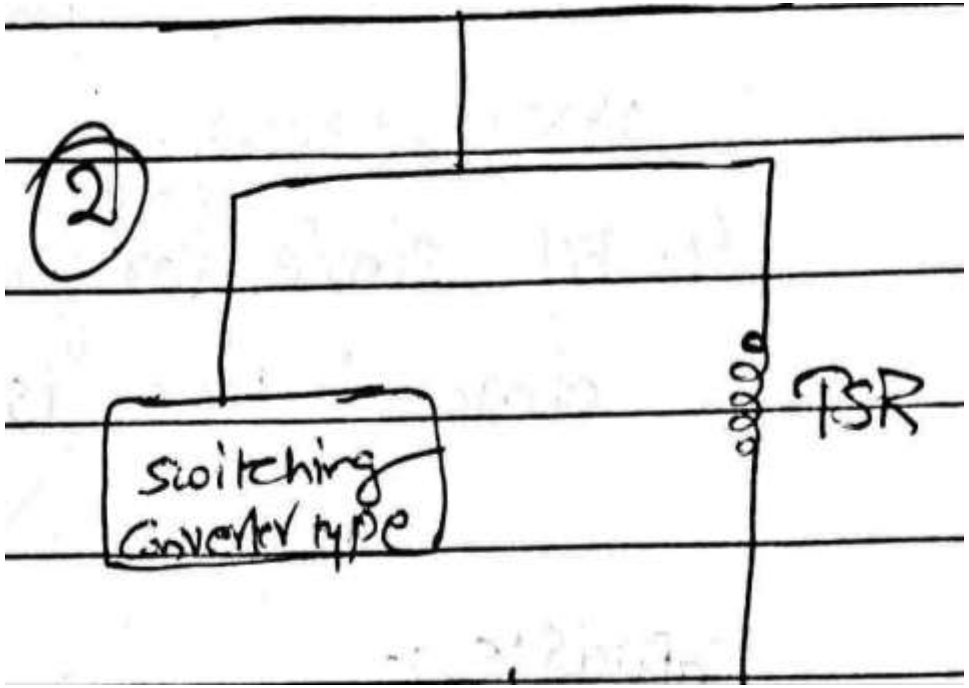
Comparison of VI chars for single Var generator and Hybrid Var generator

- **Capacitive**
- **Inductive**



Structure of Hybrid var generator





SVC and STATCOM

SVC - Static Var Compensator (General form of TSR,TSC)

STATCOM- Static Synchronous Compensator

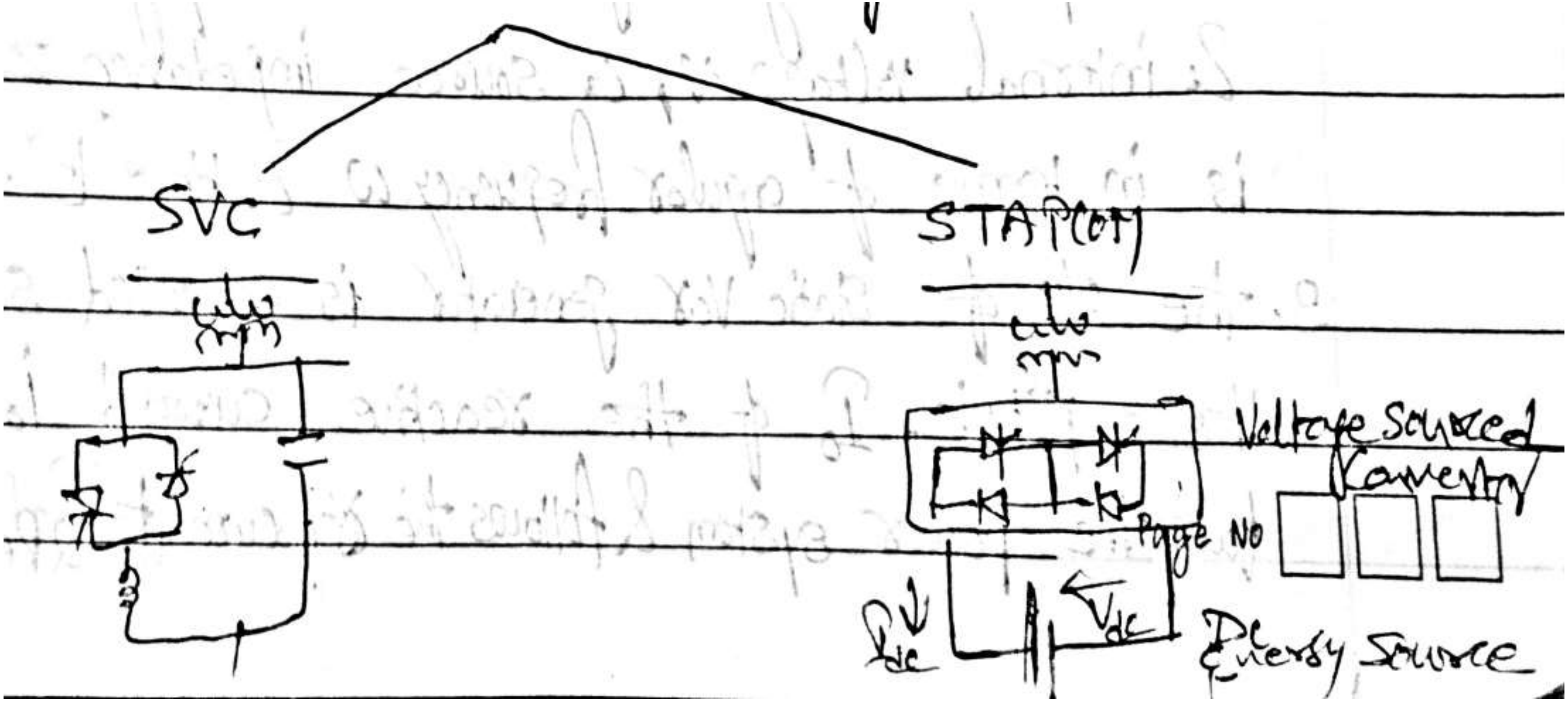
Comparison of SVC & STATCOM

SVC	STATCOM
1.First generation FACTS device. General form of TSR ,TSC	1.High end application device
2.Based on variable impedance type	2.Based on voltage sourced
3.Low cost & simple construction	3.High cost
4.Mainly controls the reactive power and bus voltage	4.Controls both real and reactive power

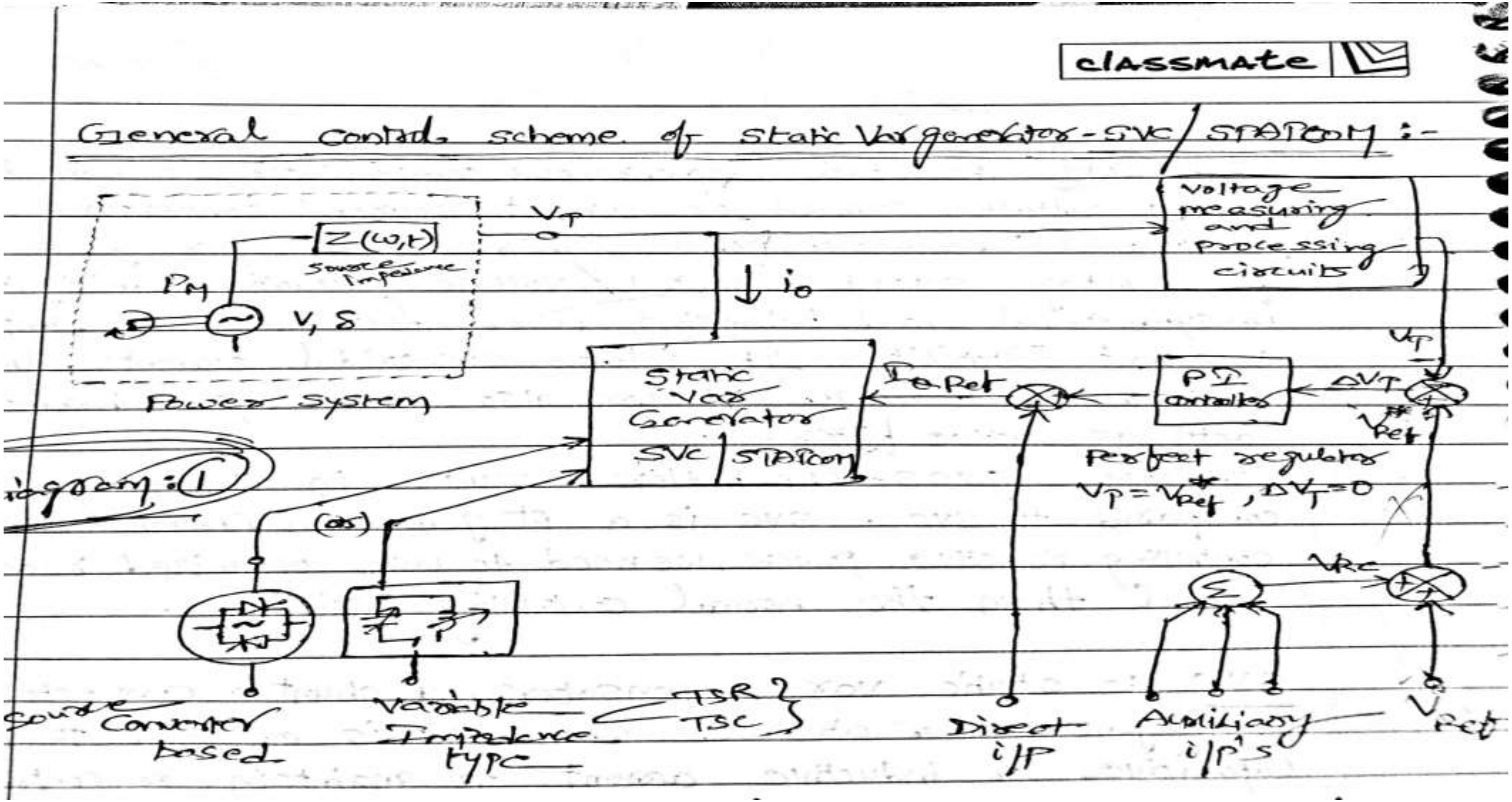
STATCOM superiority over SVC

- Voltage support & control
- Reduce voltage fluctuation & mitigation of voltage
- Unsymmetrical load balancing
- Power factor correction
- Improves transient stability
- Acts as an active filter i.e. absorbs system harmonics.

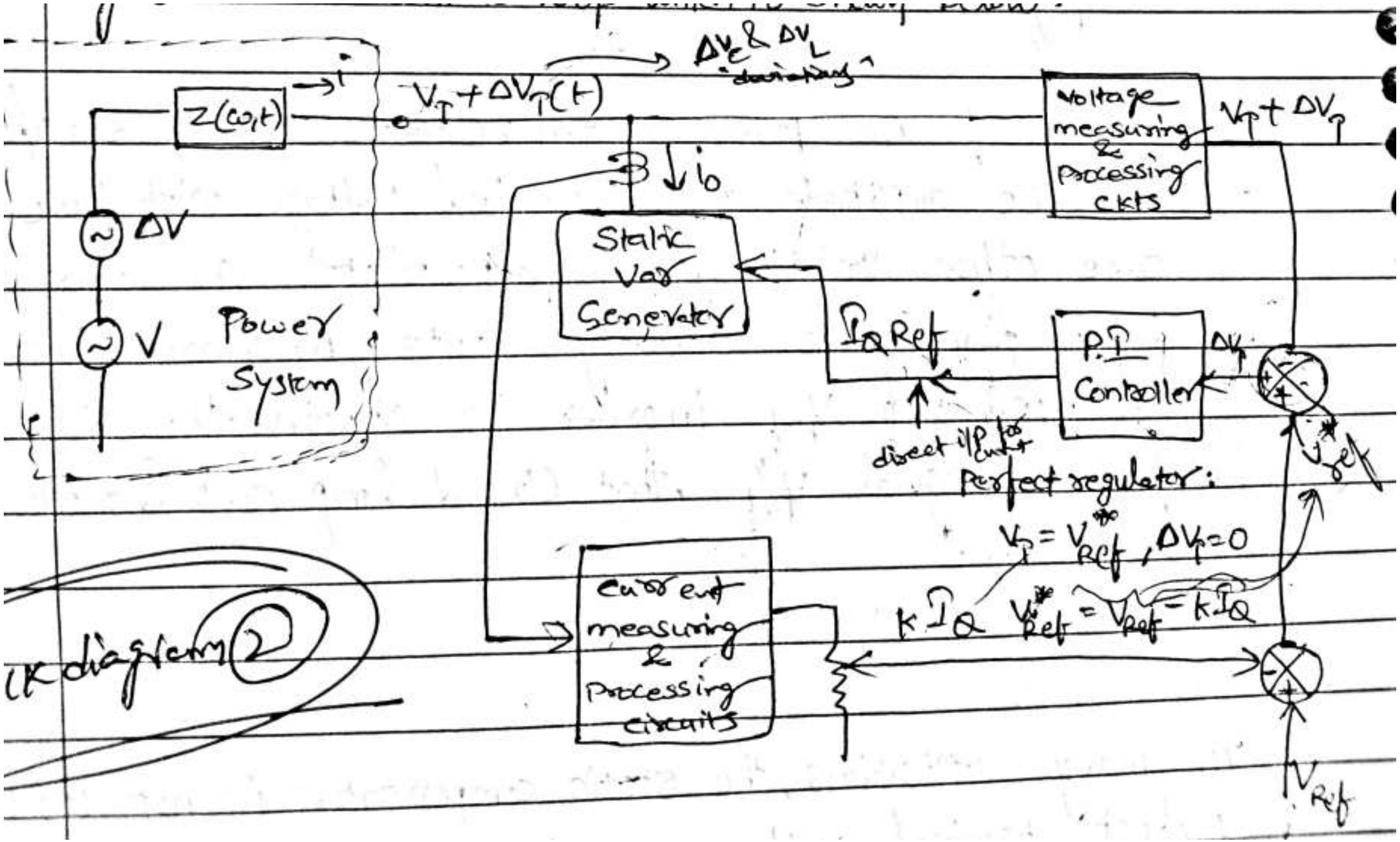
Structure of SVC & STATCOM



General Control scheme of SVC / STATCOM



Regulation & slope



Cont..

$$\boxed{V_{Ref}^{*} = V_{Ref} + K I_Q} \quad \text{——— (1)}$$

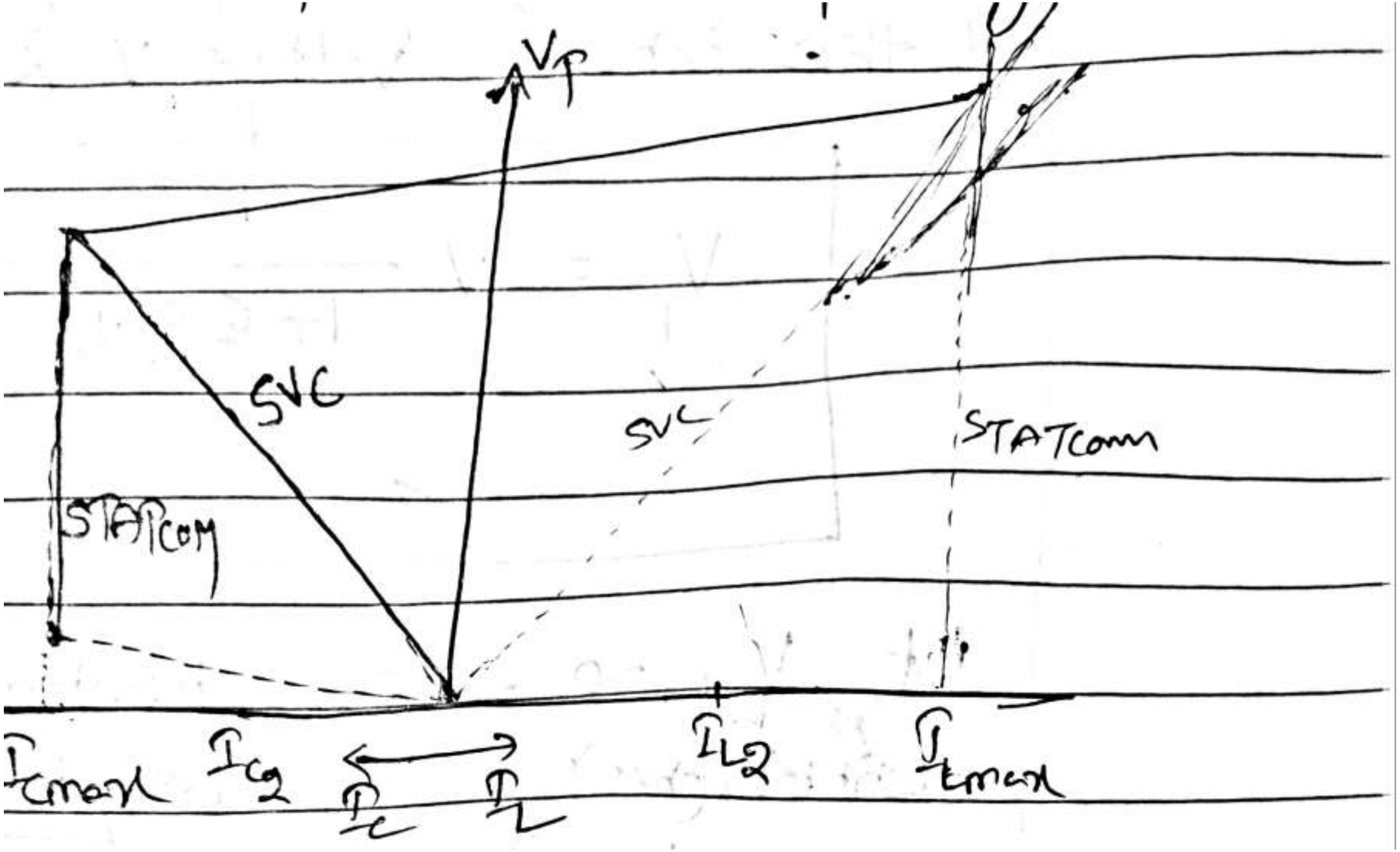
$\left\{ K I_Q : +ve \text{ for inductive current} \right.$
$\quad\quad : -ve \text{ for capacitive current}$

where K = The regulatory slope

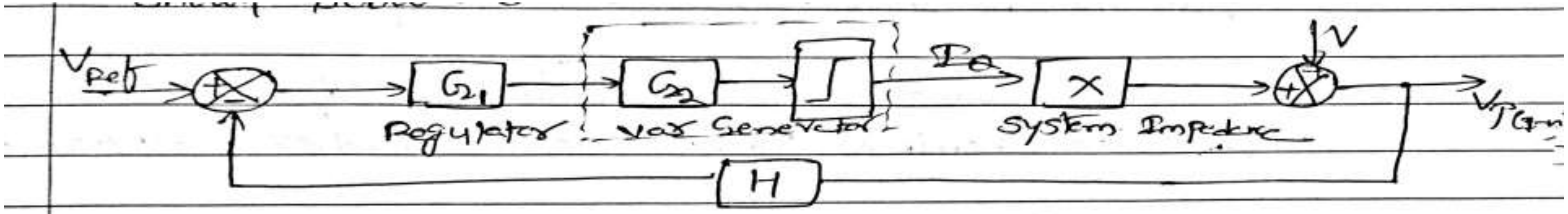
is defined as

$$\boxed{K = \frac{\Delta V_{Cmax}}{I_{Cmax}} = \frac{\Delta V_{Lmax}}{I_{Lmax}}}$$

VI chars of SVC & STATCOM



Transfer function



The terminal voltage V_T can be expressed ~~the~~ in terms of the internal voltage V & ref. voltage V_{ref}.

$$\boxed{V_T = V\frac{1}{1+G_1G_2HX} + V_{ref}\frac{G_1G_2X}{1+G_1G_2HX}} \quad \text{--- (1)}$$

let $V_{ref}=0$, then terminal voltage variation ΔV_T & Power system internal voltage variation ΔV can be expressed as

substitute in (above)

$$\boxed{\frac{\Delta V_T}{\Delta V} = \frac{1}{1+G_1G_2HX} = \frac{1}{1+GHX}} \quad \text{(2)}$$

Page No

Cont..

classmate

where $G_1 = \dfrac{1/K}{1+T_1 s}$

$G_2 = e^{-T_d s}$

$$\boxed{G = G_1 G_2 = \frac{1/K}{1+T_1 s} e^{-T_d s}}$$

$$\boxed{H = \frac{1}{1+T_2 s}}$$

T_1 = main time constant of PI controller

T_2 = time constant of amplitude measuring ckt

T_d = Transport lag of Var generator

dynamic performance

- ➡ **It is the function of power system impedance.`**

when $(s \longrightarrow 0)$,

Eq (2) becomes

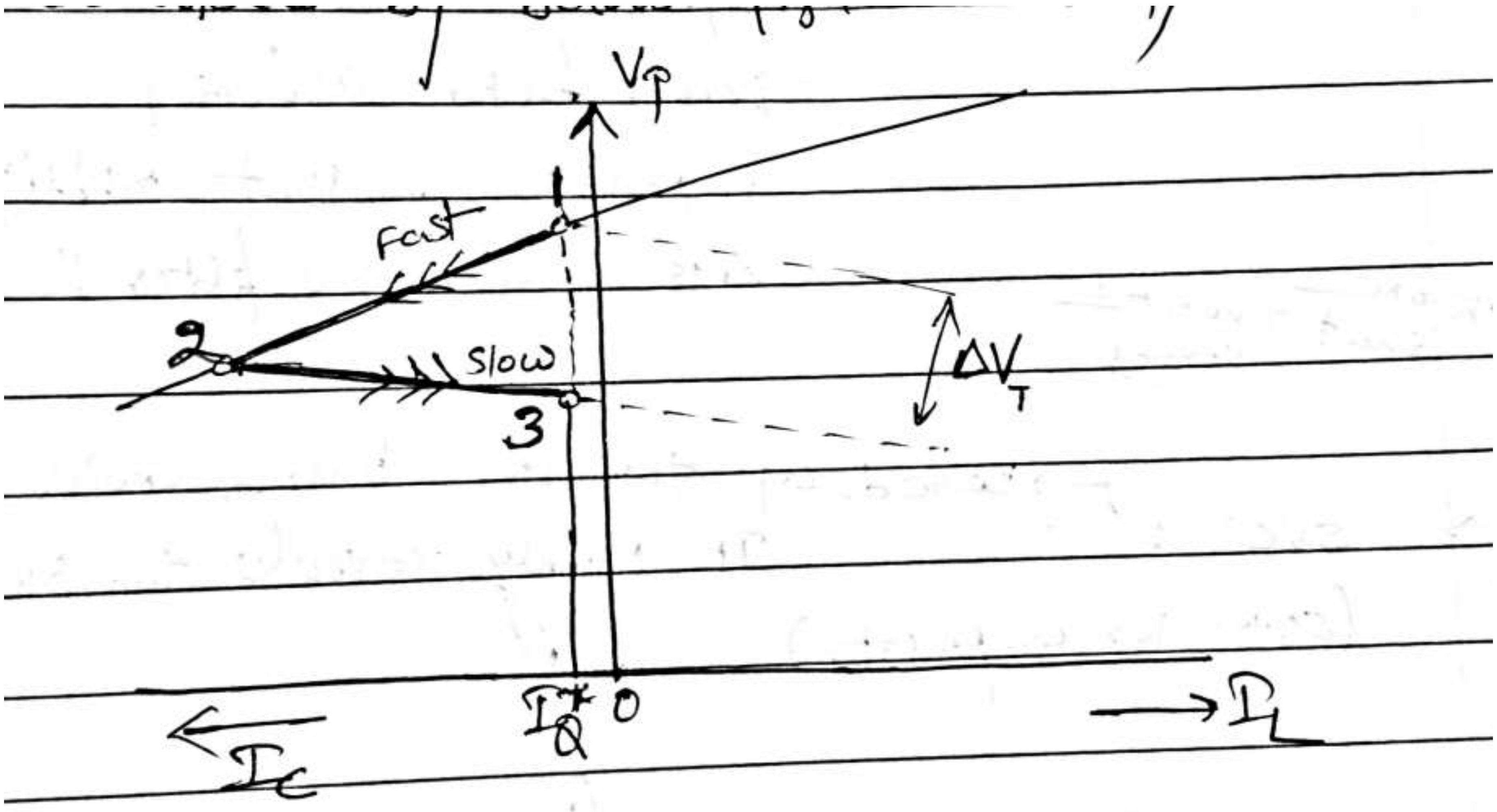
$$\frac{\Delta V_P}{\Delta V} = \frac{1}{1+GHX}$$

$$= \frac{1}{1+\left(\frac{1/K}{1+T_1(0)}\, e^{-t_d(0)}\right)\left(\frac{1}{1+T_2(0)}\right)X}$$

$$= \frac{1}{1+\left(\frac{1}{K}\right)X}$$

Page Nb

Var reverse control (operating point control)



Unit -3

Static Series Compensators

Objectives of series compensation, Improvement of Transient stability, power oscillation damping, Principle of operation of Thyristor controlled series compensator(TCSC), operating characteristics, TCSC control diagram, Principle of operation voltage source converter type series compensator(SSSC). Basic principle of operation of UPFC, transmission control capabilities of UPFC.

Key Difference between Shunt and series compensation

Basic power Equation

$$P = \frac{V1V2}{X} \sin \delta$$

Shunt compensation concentrates on voltage

Series compensation shows effect on impedance

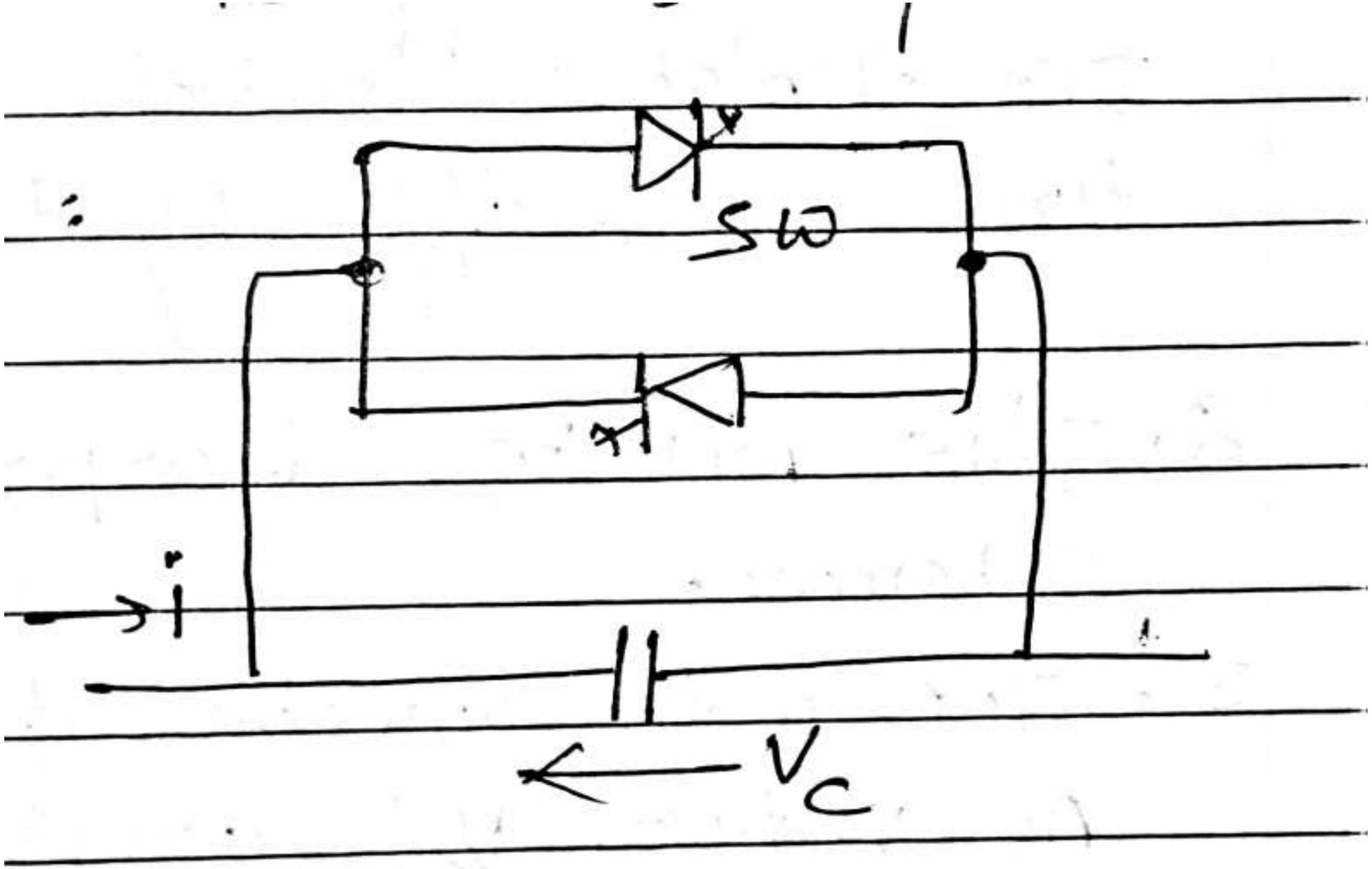
Series compensated Devices

1. GCSC (GTO Thyristor Controlled series capacitor)

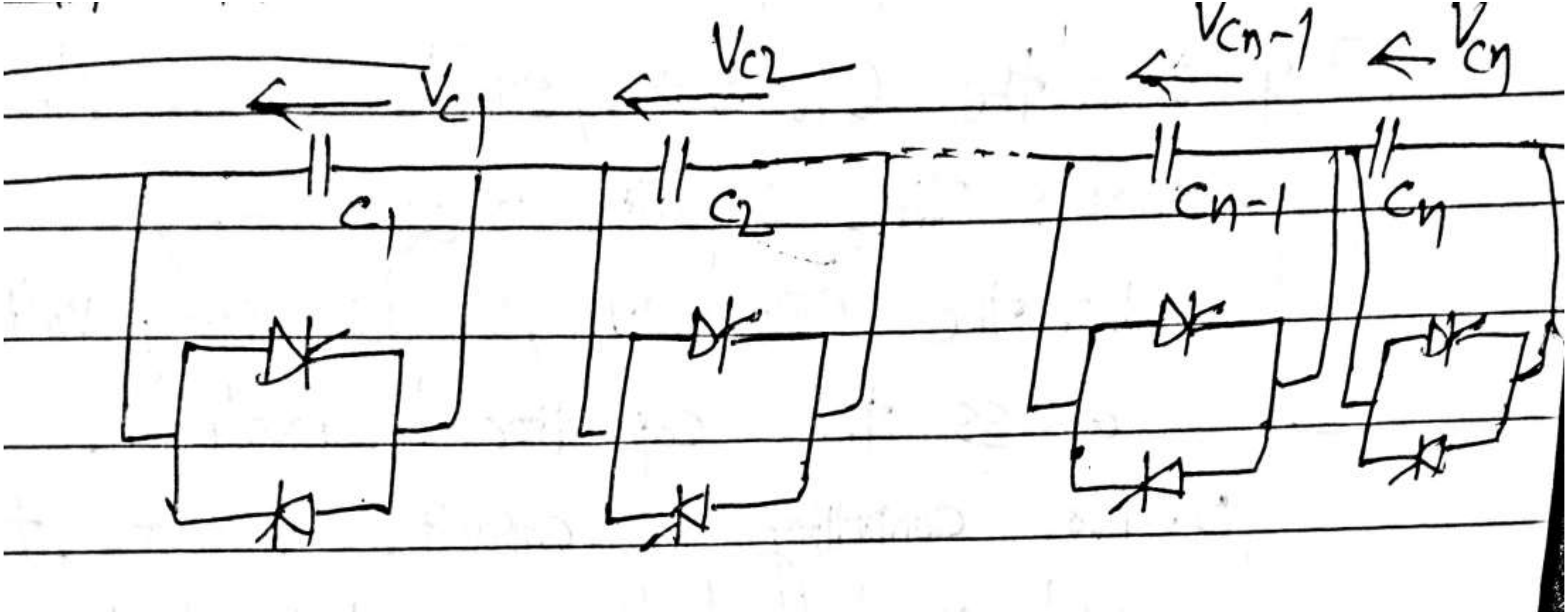
2. TSSC (Thyristor Switched series capacitor)

3. TCSC (Thyristor Controlled series capacitor)

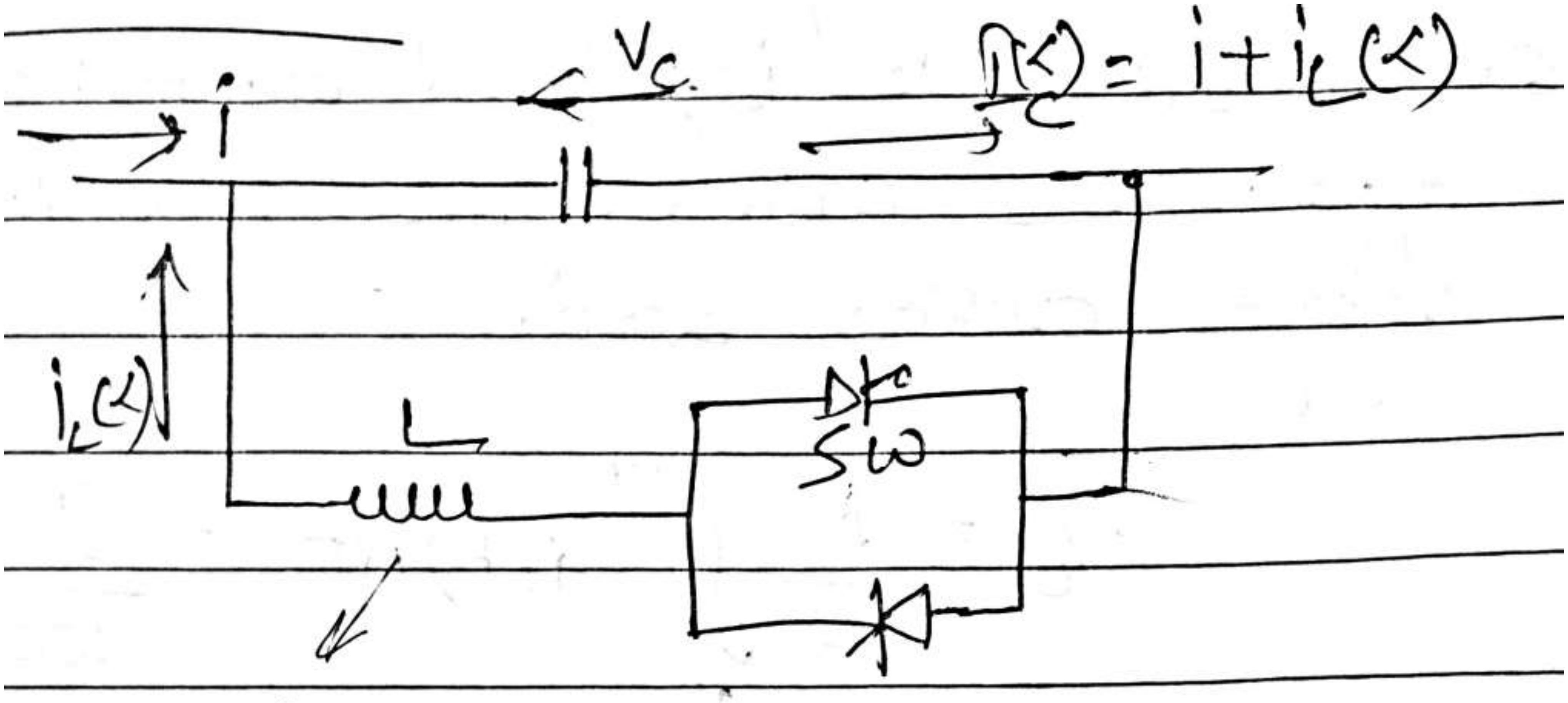
Structure of GCSC



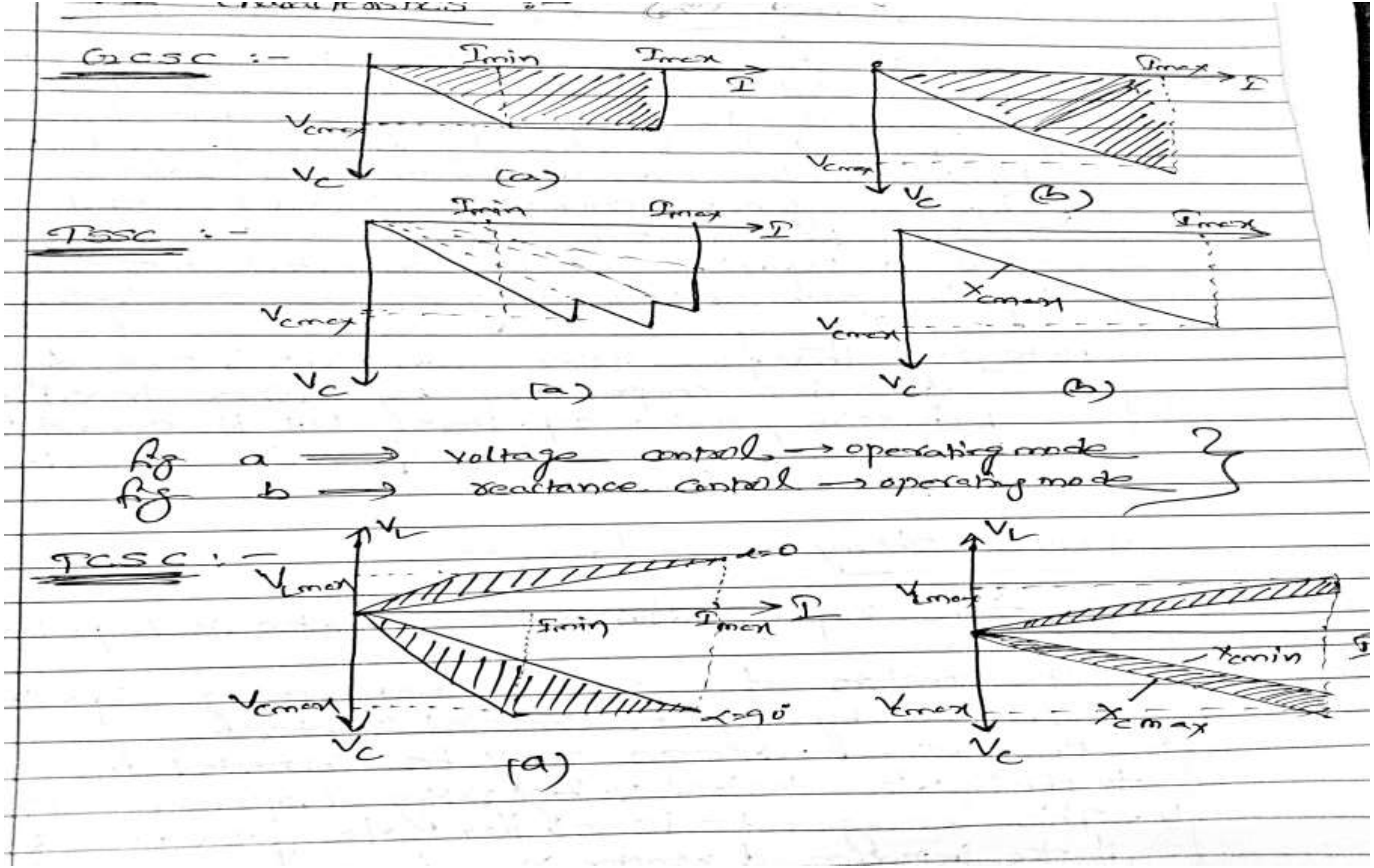
Structure of TSSC



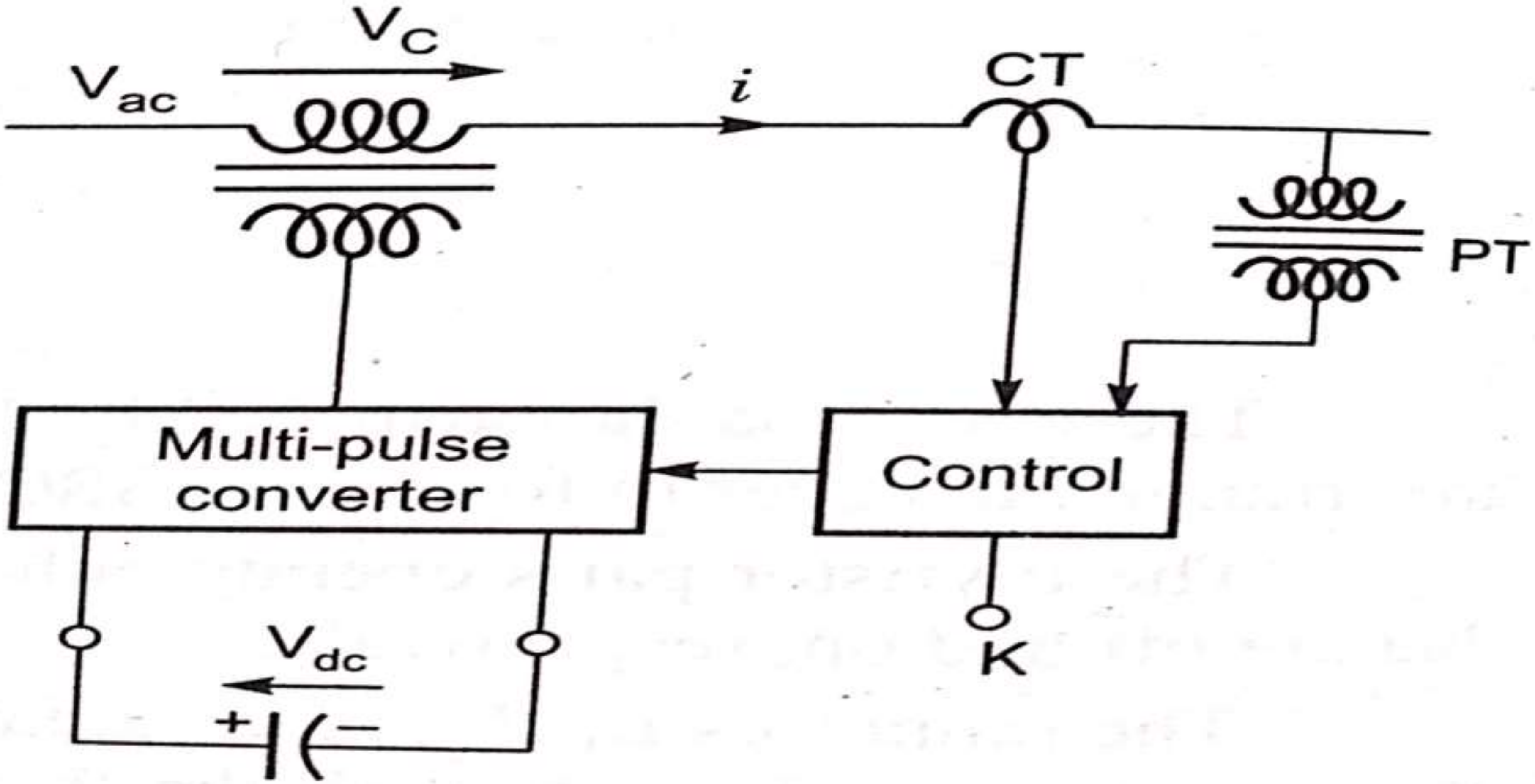
Structure of TCSC



V-I Chars of GCSC,TSSC,TCSC



Static Series Synchronous Compensator(SSSC)



Unified Power Flow Controller (UPFC)

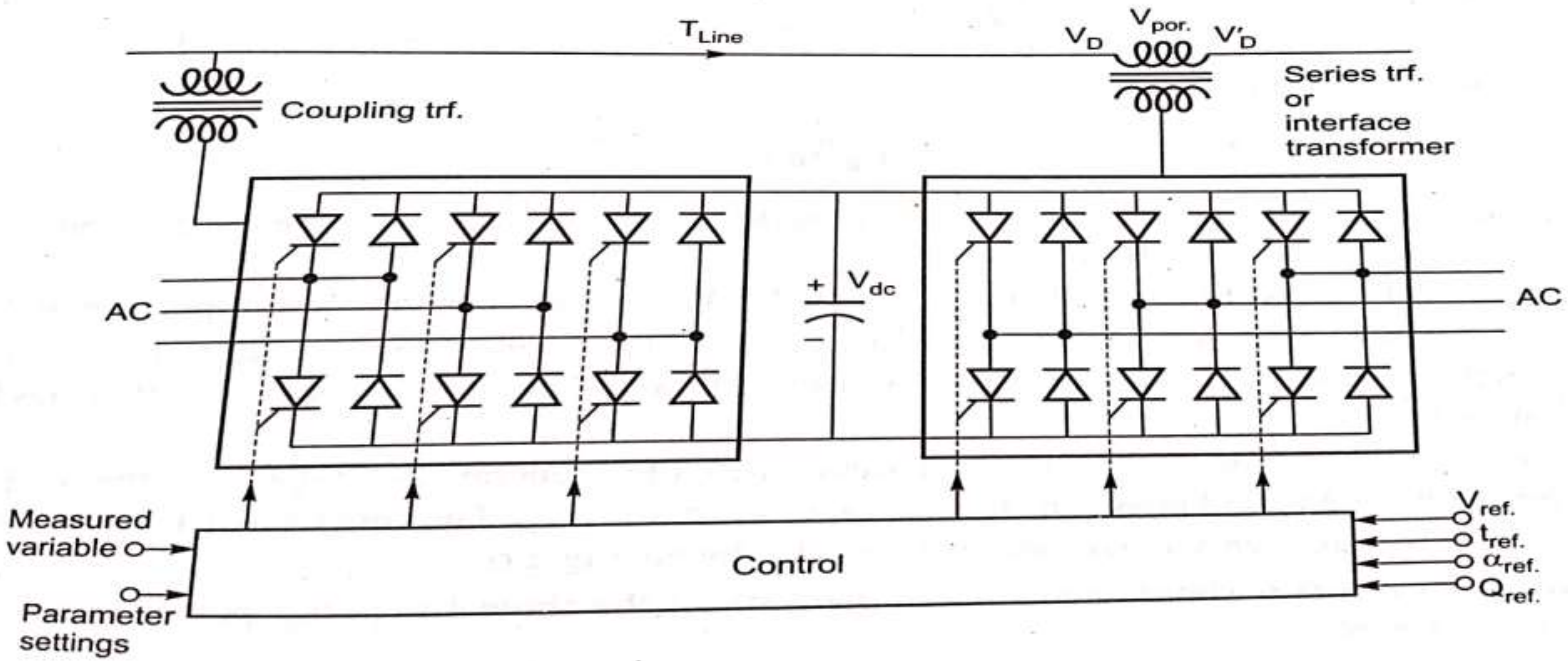
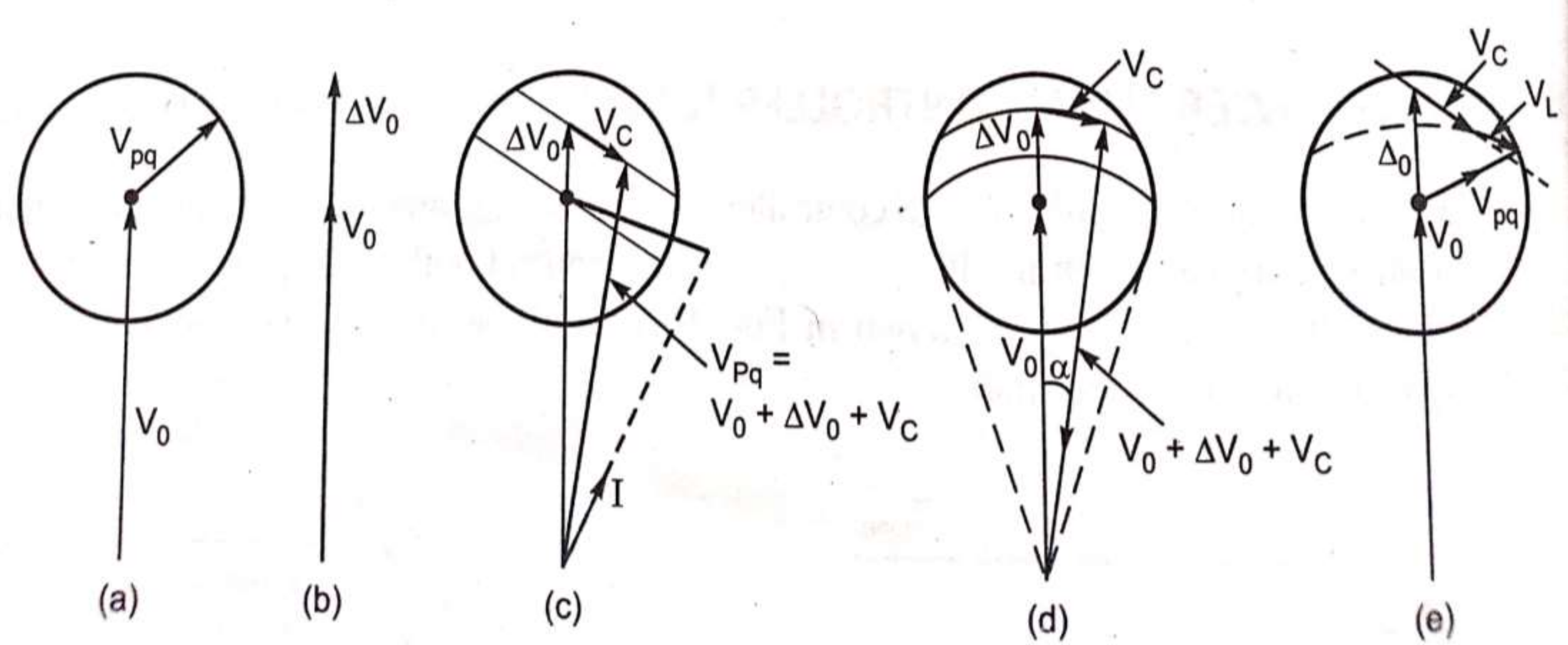


Fig. 10.12

Concepts of various transmission control capabilities of UPFC



GOKARAJU RANGARAJU INSTITUTE OF ENGNEERING AND TECHNOLOGGY
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Nizampet Road, Bachupally, Kukatpally, Hyderabad - 500090, Telangana, India
Tel: 7207344440, Email:info@griet.ac.in, www.griet.ac.in

STUDENT FEEDBACK

Faculty	: **DAVALA KARUNA KUMAR**
Subject	: Power Quality And FACTS (B.Tech, IV/IV B.Tech II Semester, EEE Sec-A)
Academic Year	: 2022 - 2023
Phase	: Phase-1

Sl.No	Question	Excellent	Good	Average	Poor	Q.Wise Total	Q.Wise %
1	Preparation and delivery of the lessons by the teacher	24	15	3	1	148	86.00
2	Subject Knowledge	21	19	2	1	146	85.00
3	Clarity in Communication	22	18	2	1	147	85.00
4	Using Modern Teaching Aids of ICT	22	18	2	1	147	85.00
5	Creating interest on the course in the class	23	16	3	1	147	85.00
6	Maintaining discipline in the class	23	17	2	1	148	86.00
7	Encouraging and clearing doubts in the class	23	17	2	1	148	86.00
8	Punctuality	23	16	2	2	146	85.00
9	Accessibility of the teacher	22	17	2	2	145	84.00
10	Overall grading of the teacher	22	18	2	1	147	85.00
	Total	225	171	22	12		
	Total Points	**900**	**513**	**44**	**12**	**1469**	**85.00**

No.Of Students Posted	**43**
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)

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STUDENT FEEDBACK

Faculty : **DAVALA KARUNA KUMAR**
Subject : Power Quality And FACTS (B.Tech, IV/IV B.Tech II Semester, EEE Sec-A)
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	16	14	0	0	106	88.00
2	Subject Knowledge	17	13	0	0	107	89.00
3	Clarity in Communication	17	13	0	0	107	89.00
4	Using Modern Teaching Aids of ICT	18	12	0	0	108	90.00
5	Creating interest on the course in the class	16	14	0	0	106	88.00
6	Maintaining discipline in the class	17	13	0	0	107	89.00
7	Encouraging and clearing doubts in the class	18	12	0	0	108	90.00
8	Punctuality	15	15	0	0	105	88.00
9	Accessibility of the teacher	16	14	0	0	106	88.00
10	Overall grading of the teacher	16	14	0	0	106	88.00
	Total	166	134	0	0		
	Total Points	**664**	**402**	**0**	**0**	**1066**	**89.00**

No.Of Students Posted	**30**
Total Percentage Awarded to The Faculty	**89.00**
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)

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STUDENT FEEDBACK

Faculty : **DAVALA KARUNA KUMAR**
Subject : Power Quality And FACTS (B.Tech, IV/IV B.Tech II 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	23	12	1	1	131	89.00
2	Subject Knowledge	22	13	1	1	130	88.00
3	Clarity in Communication	24	11	1	1	132	89.00
4	Using Modern Teaching Aids of ICT	23	12	1	1	131	89.00
5	Creating interest on the course in the class	24	11	1	1	132	89.00
6	Maintaining discipline in the class	24	11	1	1	132	89.00
7	Encouraging and clearing doubts in the class	24	10	2	1	131	89.00
8	Punctuality	24	11	1	1	132	89.00
9	Accessibility of the teacher	25	10	1	1	133	90.00
10	Overall grading of the teacher	25	10	1	1	133	90.00
	Total	238	111	11	10		
	Total Points	**952**	**333**	**22**	**10**	**1317**	**89.00**

No.Of Students Posted	**37**
Total Percentage Awarded to The Faculty	**89.00**
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)

IV B.Tech II Sem (EEE) Result Analysis

Academic Year: 2022-23 Total No. of Students Registered: 129

Course	Total No. of Students appeared	Total No. of Stude nts Passed	No. of Students Failed	Count of Students with Grade Point					
				GP (10)	GP (9)	GP (8)	GP (7)	GP (6)	GP (5)
PLC	129	128	01	26	43	32	19	05	03
PQ&FACTS	129	126	03	00	12	40	40	27	07
ESG	129	126	03	00	17	26	51	17	15
Proj. W. P-II	129	128	01	13	46	53	11	05	00

Arrears Position – IV year / II Semester

No. of students	All Pass	One Arrear	Two Arrears	Three Arrears	More than three arrears	Overall % of pass
129	124	02	02	01	00	96%

Performance overall Class Three Toppers

ROLL NO.	NAME	SGPA
19241A0252	Suchismita Das	9.60
19241A0210, 19241A0213 19241A0235, 19241A0261	Chidugu Sindhu, D Kavya Kirthi Naragani Pravardh, Ailaboina Prathyusha	9.40
19241A0204, 19241A0206 19241A0251, 19241A0257 19241A0258, 19241A0269 19241A02A5, 19241A02A6	Aggarapu Siri, B.Mounika Simhadri Rajshri, Vaishnavi Gorantla Vakkalanka Satya Shreyas, C Venkateshwari Veeramaneni Suchitha, Veerla Prasanthi	9.20

Class coordinator **HOD,EEE**

IV B.Tech - II Sem (EEE)

SECTION	Courses	PLC	PQ&FACTS	ESG	Proj. Work phase-II
	Course codes	GR18A4070	GR18A4071	GR18A4108	GR18A4108
A	TOTAL	63	63	63	63
	PASS	62	61	61	62
	PASS(%)	98.41%	96.82%	96.82%	98.41%
	FACULTY NAME	Dr Pakkiraiah B	D Karuna Kumar	Dr. J. Sridevi	Dr A Vinay Kumar/M N Sandhya Rani
	FACULTY ID	1593	760	516	881/882
B	TOTAL	66	66	66	66
	PASS	66	65	65	66
	PASS (%)	100%	98.48	98.48	100%
	FACULTY NAME	Dr Pakkiraiah B	D Karuna Kumar	Dr. J. Sridevi	Dr A Vinay Kumar/ G Sandhya Rani
	FACULTY ID	1593	760	516	881/888

Class coordinator **HOD,EEE**