# Course File

# Flexible AC Transmission Systems

IV B.Tech II Sem – A & B Sec – 2018-19

*Dr. Suresh Kumar Tummala*

Professor, EEE Department, GRIET

**GOKARAJU RANGARAJU**
**INSTITUTE OF ENGINEERING AND TECHNOLOGY**

## Department of Electrical & Electronics Engineering

**Course Tittle: Flexible AC Transmission Systems (IV B.Tech II Sem – A & B Sec – 2018-19)**

**Following documents are available in Course File.**

| S.No. | Points | Yes | No |
|---|---|---|---|
| 1 | Institute and Department Vision and Mission Statements | ✓ | |
| 2 | PEO & PO Mapping | ✓ | |
| 3 | Academic Calendar | ✓ | |
| 4 | Subject Allocation Sheet | ✓ | |
| 5 | Class Time Table, Individual Timetable (Single Sheet) | ✓ | |
| 6 | Syllabus Copy | ✓ | |
| 7 | Course Handout | ✓ | |
| 8 | CO-PO Mapping | ✓ | |
| 9 | CO-Cognitive Level Mapping | ✓ | |
| 10 | Lecture Notes | ✓ | |
| 11 | Tutorial Sheets with Solution | ✓ | |
| 12 | Soft Copy of Notes/Ppt/Slides | ✓ | |
| 13 | Sessional Question Paper and Scheme of Evaluation | ✓ | |
| 14 | Best, Average and Weak Answer Scripts for Each Sessional Exam. (Photocopies) | ✓ | |
| 15 | Assignment Questions and Solutions | ✓ | |
| 16 | Previous University Question Papers | ✓ | |
| 17 | Result Analysis | | ✓ |
| 18 | Feedback from Students | | ✓ |
| 19 | Course Exit Survey | | ✓ |
| 20 | CO Attainment for All Mids. | ✓ | |
| 21 | Remedial Action. | ✓ | |

**Dr. Suresh Kumar Tummala**

| | |
|---|---|
| **Course Instructor / Course Coordinator** | **Course Instructor / Course Coordinator** |
| **(Name)** | **(Signature)** |

*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 epicenter 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*

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

Programme Educational Objectives (B.Tech. – EEE)

Graduates will be able to

PEO 1: Have a successful technical or professional careers, including supportive and leadership roles on multidisciplinary teams.
PEO 2: Acquire, use and develop skills as required for effective professional practices.
PEO 3: Able to attain holistic education that is an essential prerequisite for being a responsible member of society.
PEO 4: Engage in life-long learning, to remain abreast in their profession and be leaders in our technologically vibrant society.

## Programme Outcomes (B.Tech. – EEE)

At the end of the Programme, a graduate will have the ability to

PO 1: Apply knowledge of mathematics, science, and engineering.
PO 2: Design and conduct experiments, as well as to analyze and interpret data.
PO 3: Design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.
PO 4: Function on multi-disciplinary teams.
PO 5: Identify, formulates, and solves engineering problems.
PO 6: Understanding of professional and ethical responsibility.
PO 7: Communicate effectively.
PO 8: Broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.
PO 9: Recognition of the need for, and an ability to engage in life-long learning.
PO 10: Knowledge of contemporary issues.
PO 11: Utilize experimental, statistical and computational methods and tools necessary for engineering practice.
PO 12: Demonstrate an ability to design electrical and electronic circuits, power electronics, power systems; electrical machines analyze and interpret data and also an ability to design digital and analog systems and programming them.

## PEOs & POs Mapping

| Programme Educational Objectives (PEOs) | Programme Outcomes (POs) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | M | M | - | - | H | - | - | H | H | - | H | H |
| 2 | - | - | M | M | H | H | H | - | - | - | - | H |
| 3 | - | - | - | - | H | H | M | M | M | M | H | H |
| 4 | - | - | - | M | M | H | M | H | H | - | M | H |

* H: Strongly Correlating (3); M: Moderately Correlating (2)& L: Weakly Correlating (1)

**GOKARAJU RANGARAJU**
**INSTITUTE OF ENGINEERING AND TECHNOLOGY**

**Department of Electrical & Electronics Engineering**

## ACADEMIC CALENDAR
## Academic Year 2018-19

### III & IV B.TECH – FIRST SEMESTER

| S. No. | EVENT | PERIOD | DURATION |
|---|---|---|---|
| 1 | 1st Spell of Instructions | 02-07-2018 to 01-09-2018 | 9 Weeks |
| 2 | 1st Mid-term Examinations | 03-09-2018 to 05-09-2018 | 3 Days |
| 3 | 2nd Spell of Instructions | 06-09-2018 to 24-10-2018 | 7 Weeks |
| 4 | 2nd Mid-term Examinations | 25-10-2018 to 27-10-2018 | 3 Days |
| 5 | Preparation | 29-10-2018 to 06-11-2018 | 1 Week 3 Days |
| 6 | End Semester Examinations (Theory/ Practical’s) Regular/Supplementary | 08-11-2018 to 08-12-2018 | 4 Weeks 3 Days |
| 7 | Commencement of Second Semester, A.Y 2018-19 | 10-12-2018 | |

### III & IV B.TECH – SECOND SEMESTER

| S. No. | EVENT | PERIOD | DURATION |
|---|---|---|---|
| 1 | 1st Spell of Instruction | 10-12-2018 to 02-02-2019 | 8 Weeks |
| 2 | 1st Mid-term Examinations | 04-02-2019 to 06-02-2019 | 3 Days |
| 3 | 2nd Spell of Instruction | 07-02-2019 to 06-04-2019 | 8 Weeks 3 Days |
| 4 | 2nd Mid-term Examinations | 08-04-2019 to 10-04-2019 | 3 Days |
| 5 | Preparation | 11-04-2019 to 17-04-2019 | 1 Week |
| 6 | End Semester Examinations (Theory/ Practical’s) Regular | 18-04-2019 to 08-05-2019 | 3 Weeks |
| 7 | Supplementary and Summer Vacation | 09-05-2019 to 22-06-2019 | 6 Weeks 3 Days |
| 8 | Commencement of First Semester, A.Y 2019-20 | 24-06-2019 | |

Dean of Academic Affairs

## Subject Allotment

| II YEAR(GR17) | Section-A | Section-B |
|---|---|---|
| Managerial Economics and Financial Analysis | | |
| Power Generation and Distrubution | SN | SN |
| AC Machines | VVSM | VVSM |
| Control Systems | Dr DGP | MS |
| Princeples of Digital Electronics | PRK | PRK |
| AC Machines Lab | PPK/DSR | PPK/DSR |
| Control Systems Lab | MS/PSVD | MS/PSVD |
| Analog and Digital Electronics Lab | RAK/DKK | RAK/DKK |
| Value Education and Ethics | | |
| Gender Sensitization Lab | MS/PSVD | MS/PSVD |
| III YEAR (GR15) | | |
| Computer Methods in Power systems | VVRR/MP | VVRR/MP |
| Switch Gear & Protection | PSVD | Dr JSD |
| Management Science | | |
| Utilization of Electrical Energy | MRE | MRE |
| Non Conventional Sources of Energy | | |
| Neural and Fuzzy Systems | | |
| Sensors & Transducers | UVL | UVL |
| Power Systems Lab | GSR/YSV | GSR/YSV |
| Industry Oriented Mini Project Lab | PPK/AVK/Dr JP | MP/Dr JP |
| IV YEAR (GR15) | | |
| Programmable Logic Controllers | PK | PK |
| Flexible AC Transmission Systems | Dr TSK | Dr TSK |
| EHV AC Transmission | | |
| Power System Automation | | |
| Modern Power Electronics | AVK | AVK |
| DSP Based Electromechanical Systems | | |
| Advaced Control Systems | | |
| Programmable Logic Controllers-Lab | VVSM | PK |
| Main Projects | RAK/Dr SVJK | PK/VVRR |
| M.Tech PE | | |
| Modeling and Analysis of Electrical Machines | Dr BPB | |
| Digital control of power Electronics and Drive Systems | Dr DGP | |
| FACTS and Custom power Devices | Dr TSK | |
| Smart Grids | VVRR | |

| | | |
|---|---|---|
| Audit Course -2 | YSV/UVL | |
| Power Quality Lab | Dr BPB | |
| Digital Signal Processing Lab | AVK | |
| MINI Projects | Dr JP/GSR | |
| M.Tech PS | | |
| Digital Protection of Power System | Dr JSD | |
| Power System Dynamics -II | Dr SVJK | |
| FACTS and Custom power Devices | Dr TSK | |
| Smart Grids | VVRR | |
| Audit Course -2 | YSV/UVL | |
| Power Quality Lab | Dr BPB | |
| Power System Protection Lab | VUR | |
| MINI Projects | Dr JP/GSR | |
| Other Dept. | | |
| BEE (I YEAR) CSE (6) | MNSR,MK,MVK, | |
| BEE Lab | MNSR,MK,MVK,YSV,VUR,PS,UVL,MRE,GBR | |
| EET (II YEAR) Mech (2) | KS | KS |
| EET LAB ( II TEAR) Mech (2) | KS,DKK,PPK, | |

# TIME TABLE

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING
GRIET/PRIN/06/G/01/18-19 wef: 10 Dec 2018
B.Tech - EEE - A IV Year - II Semester

| Day/Hour | 10:00-10:50 | 10:50-11:40 | 11:40-12:30 | 12:30-1:00 | 1:00-1:30 | 1:30-2:20 | 2:20-3:10 | 3:10-4:00 |
|---|---|---|---|---|---|---|---|---|
| MONDAY | PLC Lab | | | | BREAK | FACTS | | PLC |
| TUESDAY | FACTS | | MPE | | | FACTS | | PLC |
| WEDNESDAY | MPE | | PLC | | | PROJECTS | | |
| THURSDAY | PROJECTS | | | | | PROJECTS | | |
| FRIDAY | PLC | | MPE | | | PROJECTS | | |
| SATURDAY | PROJECTS | | | | | PROJECTS | | |

| Room No. | |
|---|---|
| Theory | 4502 |
| Lab | 4510 / 4513 |

| | |
|---|---|
| Class Incharge: | P Praveen Kumar |

| Subject Code | Subject Name | Faculty Code | Faculty name | Almanac | |
|---|---|---|---|---|---|
| GR15A4030 | Programmable Logic Controllers | PK | P Prashanth Kumar | 1st Spell of Instructions | 10-12-2018 to 06-02-2019 |
| GR15A4032 | Flexible AC Transmission Systems | Dr TSK | Dr T Suresh Kumar | UMAR | 07-02-2019 to 09-02-2019 |
| GR15A4036 | Modern Power Electronics | AVK | A Vinay Kumar | 2nd Spell of Instructions | 11-02-2019 to 03-04-2019 |
| GR15A4038 | Programmable Logic Controllers-Lab | VVSM | VVS Madhuri | 2nd Mid-term Examinations | 04-04-2019 to 06-04-2019 |
| GR15A4144 | Main Projects | RAK/Dr SVJK | R Anil Kumar/ Dr S V Jayaram Kumar | Preparation | 08-04-2019 to |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | 17-04-2019 |
| | | | | End Semester Examinations (Theory/ Practicals) Regular | 18-04-2019 to 08-05-2019 |
| | | | | Supplementary and Summer Vacation | 09-05-2019-to 22-06-2019 |
| | | | | | |
| | | | | Commencement of Second Semester , AY | 24-06-2019 |

HOD Co-ordinator DAA

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

GRIET/PRIN/06/G/01/18-19 wef: 10 Dec 2018

B.Tech - EEE - B IV Year - II Semester

| Day/Hour | 10:00-10:50 | 10:50-11:40 | 11:40-12:30 | 12:30-1:00 | 1:00-1:30 | 1:30-2:20 | 2:20-3:10 | 3:10-4:00 |
|---|---|---|---|---|---|---|---|---|
| MONDAY | PROJECTS | | | | BREAK | FACTS | | PLC |
| TUESDAY | FACTS | | MPE | | | FACTS | | PLC |
| WEDNESDAY | MPE | | PLC | | | PROJECTS | | |
| THURSDAY | PLC Lab | | | | | PROJECTS | | |
| FRIDAY | PLC | | MPE | | | PROJECTS | | |
| SATURDAY | PROJECTS | | | | | PROJECTS | | |

| Room No. | |
|---|---|
| Theory | 4502 |
| Lab | 4510 / 4513 |

| | |
|---|---|
| Class Incharge: | P Praveen Kumar |

| Subject Code | Subject Name | Faculty Code | Faculty name | Almanac | |
|---|---|---|---|---|---|
| GR15A4030 | Programmable Logic Controllers | PK | P Prashanth Kumar | 1st Spell of Instructions | 10-12-2018 to 06-02-2019 |
| GR15A4032 | Flexible AC Transmission Systems | Dr T S K | Dr T Suresh Kumar | 1st Mid-term Examinations | 07-02-2019 to 09-02-2019 |

| | | | | | |
|---|---|---|---|---|---|
| GR15A4036 | Modern Power Electronics | AVK | A Vinay Kumar | 2nd Spell of Instructions | 11-02-2019 to 03-04-2019 |
| GR15A4038 | Programmable Logic Controllers-Lab | PK | P Prashanth Kumar | 2nd Mid-term Examinations | 04-04-2019 to 06-04-2019 |
| GR15A4144 | Main Projects | PK/VVRR | P Prashanth Kumar/ V Vijaya Rama Raju | Preparation | 08-04-2019 to 17-04-2019 |
| | | | | End Semester Examinations (Theory/ Practicals) Regular | 18-04-2019 to 08-05-2019 |
| | | | | | |
| | | | | Supplementary and Summer Vacation | 09-05-2019-to 22-06-2019 |
| | | | | | |
| | | | | Commencement of Second Semester , AY | 24-06-2019 |

## Individual Time Table

| Day/Hour | 10:00-10:50 | 10:50-11:40 | 11:40-12:30 | 12:30-1:00 | 1:00-1:30 | 1:30-2:20 | 2:20-3:10 | 3:10-4:00 |
|---|---|---|---|---|---|---|---|---|
| MONDAY | | | | | BREAK | FACTS (A & B) | | |
| TUESDAY | FACTS (A & B) | | | | | FACTS (A & B) | | |
| WEDNESDAY | | | | | | | | |
| THURSDAY | | | | | | | | |
| FRIDAY | | | | | | | | |
| SATURDAY | | | | | | | | |

## Syllabus – Flexible AC Transmission Systems

Course Code: GR15A4032 L T P C 3 1 0 4

UNIT I

FACTS Concepts: Transmission line inter connections, Power flow in an AC system, loading capability limits, Dynamic stability considerations, importance of controllable parameters, basic types of FACTS controllers, benefits from FACTS controllers.

UNIT II

Voltage Source Converters: Single phase three phase full wave bridge converters, transformer connections for 12, 24 and 48 pulse operation. Three level voltage source converters, pulse width modulation converter, basic concept of current source Converters, comparison of current source converters with voltage Source converters.

UNIT III

Static Shunt Compensation: Objectives of shunt compensation, midpoint voltage regulation, voltage instability prevention, improvement of transient stability, Power oscillation damping, Methods of controllable var generation, variable impedance type static var generators, switching converter type var generators, hybrid var generators.

UNIT IV

SVC and STATCOM: The regulation and slope transfer function and dynamic performance, transient Stability enhancement and power oscillation damping, operating point control and summary of compensator control.

UNIT V

Static Series Compensation: Concept of series capacitive Compensation, improvement of transient stability, power oscillation damping, Functional requirements, GTO Thyristor controlled series capacitor (GSC), Thyristor switched series capacitor (TSSC) and Thyristor controlled series capacitor (TCSC), control schemes for GSC, TSSC and TCSC.

TEXT BOOKS:

1. “Understanding FACTS Devices” N.G. Hingorani and L.Guygi IEEE Press Publications 2000.

## COURSE OBJECTIVES

Academic Year : 2018-19
Semester : II
Name of the Program: B.Tech Year: IV Section: A/B

Course/Subject: Flexible AC Transmission Systems Course Code: GR15A4032

Name of the Faculty: Dr. T. Suresh Kumar
Designation: PROFESSOR.

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

1. Understand Load ability of the transmission line.
2. Emphasize the importance of the voltage and reactive power control in electrical systems
3. State different compensation techniques through FACTS devices
4. Analyse the real and reactive power flow and control in transmission lines

## COURSE OUTCOMES

Academic Year : 2018-19
Semester : II
Name of the Program: B.Tech Year: IV Section: A/B

Course/Subject: Flexible AC Transmission Systems Course Code: GR15A4032

Name of the Faculty: Dr. T. Suresh Kumar
Designation: PROFESSOR.

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

1. Express different types of FACTS controllers and their role in improving power system performance.
2. Understand the operating principles of various FACTS devices.
3. Relate the performance and applications of VSI & CSI.
4. Know the importance of compensation methods in power system network.
5. Extend the knowledge of active & reactive power and voltage control with FACTS devices.
6. Analyse role of SVC&STATCOM in improving the power system dynamics.
7. Analyse the use of control schemes of TCSC, TSSC, GSC in improving the power quality.

# GUIDELINES TO STUDY THE COURSE / SUBJECT

Academic Year : 2018-19
Semester : II
Name of the Program: B.Tech Year: IV Section: A/B

Course/Subject: Flexible AC Transmission Systems Course Code: GR15A4032

Name of the Faculty: Dr. T. Suresh Kumar
Designation: PROFESSOR.

Guidelines to study the Course/ Subject: Flexible AC Transmission Systems

Course Design and Delivery System (CDD):

- 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, adviser, counselor, facilitator, and motivator and not just as a teacher alone

# COURSE SCHEDULE

Academic Year : 2018-19
Semester : II
Name of the Program: B.Tech Year: IV Section: A/B

Course/Subject: Flexible AC Transmission Systems Course Code: GR15A4032

Name of the Faculty: Dr. T. Suresh Kumar
Designation: PROFESSOR.

The Schedule for the whole Course / Subject is:

| S. No. | Description | Total No. of periods |
|---|---|---|
| 1 | FACTS Concepts: Transmission line inter connections, Power flow in an AC system, loading capability limits, Dynamic stability considerations, importance of controllable parameters, basic types of FACTS controllers, benefits from FACTS controllers | 12 |
| 2 | Voltage Source Converters: Single phase three phase full wave bridge converters, transformer connections for 12, 24 and 48 pulse operation. Three level voltage source converters, pulse width modulation converter, basic concept of current source Converters, comparison of current source converters with voltage Source converters. | 12 |
| 3 | Static Shunt Compensation: Objectives of shunt compensation, midpoint voltage regulation, voltage instability prevention, improvement of transient stability, Power oscillation damping, Methods of controllable var generation, variable impedance type static var generators, switching converter type var generators, hybrid var generators. | 12 |
| 4 | SVC and STATCOM: The regulation and slope transfer function and dynamic performance, transient Stability enhancement and power oscillation damping, operating point control and summary of compensator control. | 12 |
| 5 | Static Series Compensation: Concept of series capacitive Compensation, improvement of transient stability, power oscillation damping, Functional requirements, GTO Thyristor controlled series capacitor (GSC), Thyristor switched series capacitor (TSSC) and Thyristor controlled series capacitor (TCSC), control schemes for GSC, TSSC and TCSC. | 12 |

Total No. of Instructional periods available for the course 60 Periods

## SCHEDULE OF INSTRUCTIONS COURSE PLAN

Academic Year : 2018-19
Semester : II
Name of the Program: B.Tech Year: IV Section: A/B

Course/Subject: Flexible AC Transmission Systems Course Code: GR15A4032

Name of the Faculty: Dr. T. Suresh Kumar
Designation: PROFESSOR.

The Schedule for the whole Course / Subject is:
*Text Book (T1):* Understanding FACTS Devices” N.G. Hingorani and L.Guygi IEEE Press Publications 2000

| S.No | Unit No. | Date | No. of Hours | Topics |
|---|---|---|---|---|
| 1 | I | 17.12.2018 | 2 | Introduction |
| 2 | I | 18.12.2018 | 2 | FACTS Concepts: Transmission line inter connections |
| 3 | I | 31.12.2018 | 2 | Power flow in an AC system, Loading capability limits |
| 4 | I | 07.01.2019 | 2 | Dynamic stability considerations |
| 5 | I | 08.01.2019 | 2 | Importance of controllable parameters |
| 6 | I | 21.01.2019 | 2 | Benefits from FACTS controllers |
| 7 | I | 22.01.2019 | 2 | Basic types of FACTS controllers |
| 8 | II | 28.01.2019 | 2 | Voltage Source Converters: Single phase three phase full wave bridge converters |
| 9 | II | 29.01.2019 | 2 | transformer connections for 12, 24 pulse operation |
| 10 | II | 04.02.2019 | 2 | transformer connections for 48 pulse operation |
| 11 | II | 05.02.2019 | 2 | Three level voltage source converters |
| 12 | II | 11.02.2019 | 2 | pulse width modulation converter |

| | | | | |
|---|---|---|---|---|
| 13 | II | 12.02.2019 | 2 | basic concept of current source Converters |
| 14 | II | 18.02.2019 | 2 | comparison of current source converters with voltage Source converters. |
| 15 | III | 19.02.2019 | 2 | Static Shunt Compensation: Objectives of shunt compensation, midpoint voltage regulation |
| 16 | III | 25.02.2019 | 2 | Voltage instability prevention |
| 17 | III | 26.02.2019 | 2 | Improvement of transient stability, |
| 18 | III | 26.02.2019 | 2 | Power oscillation damping |
| 19 | III | 05.03.2019 | 2 | Methods of controllable var generation |
| 20 | III | 05.03.2019 | 2 | Variable impedance type static var generators |
| 21 | III | 11.03.2019 | 2 | Switching converter type var generators |
| 22 | III | 12.03.2019 | 2 | Hybrid var generators |
| 23 | IV | 12.03.2019 | 2 | SVC and STATCOM: The regulation and slope transfer function and dynamic performance |
| 24 | IV | 18.03.2019 | 2 | transient Stability enhancement and power oscillation damping |
| 25 | IV | 19.03.2019 | 2 | operating point control and summary of compensator control |
| 26 | V | 19.03.2019 | 2 | Static Series Compensation: Concept of series capacitive Compensation |
| 27 | V | 25.03.2019 | 2 | Improvement of transient stability |
| 28 | V | 26.03.2019 | 2 | Power oscillation damping |
| 29 | V | 26.03.2019 | 2 | Functional requirements, GTO Thyristor controlled series capacitor (GSC) |
| 30 | V | 01.04.2019 | 2 | Thyristor switched series capacitor (TSSC) |
| 31 | V | 02.04.2019 | 2 | Thyristor controlled series capacitor (TCSC) |
| 32 | V | 02.04.2019 | 2 | Control schemes for GSC, TSSC and TCSC |

# CO – PO Mapping

| P-Outcomes<br>C-Outcomes | a | b | c | d | e | f | g | h | i | j | k | l |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | H |  |  |  | H | H | H | H | H |  | H | H |
| 2 | H | H | H | M | H |  | H | H | H |  | M | H |
| 3 | H | H |  | M | H |  | H | H | M | M | H | M |
| 4 |  | M | M |  |  |  | M |  |  | M |  | M |
| 5 |  |  | H |  | H |  | H |  | M |  |  |  |
| 6 |  | M |  |  | H |  |  |  |  |  | M | H |
| 7 | H |  |  |  | H |  | H |  | H |  | H |  |

# ILLUSTRATIVE VERBS FOR STATING INSTRUCTIONAL OBJECTIVES

**These verbs can also be used while framing questions for Continuous Assessment Examinations as well as for End – Semester (final)Examinations**

## ILLUSTRATIVE VERBS FOR STATING GENERAL OBJECTIVES/OUTCOMES

| | | | |
|---|---|---|---|
| **Know** | **Understand** | **Design** |  |

## ILLUSTRATIVE VERBS FOR STATING SPECIFIC OBJECTIVES/OUTCOMES:

### A. COGNITIVE DOMAIN (KNOWLEDGE)

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| **Knowledge** | **Comprehension Understanding** | **Application of knowledge & comprehension** | **Analysis Of whole w .r.t. its constituents** | **Synthesis** | **Evaluation<br>Judgment** |
| **Define<br>Identify** | **Convert<br>Describe (a Procedure)<br>Distinguish<br>Explain why/how** | **Demonstrate<br>Prepare<br>Relate<br>Show<br>Solve** | **Differentiate<br>Discriminate<br>Distinguish<br>Separate** | **Categorize<br>Combine<br>Design<br>Generate<br>Plan** | **Compare** |

| **B. AFFECTIVE DOMAIN (ATTITUDE)** | **C. PSYCHOMOTOR DOMAIN (SKILLS)** |
|---|---|
| **Assist<br>Change<br>Select<br>Develop** | **Bend<br>Calibrate<br>Compress<br>Conduct<br>Connect<br>Convert<br>Decrease<br>Dissect<br>Draw<br>Extend<br>Feed<br>File<br>Grow<br>Increase<br>Insert<br>Keep<br>Elongate<br>Limit<br>Manipulate<br>Move Precisely<br>Paint<br>Perform<br>Prepare<br>Remove<br>Replace<br>Report<br>Reset<br>Set<br>Straighten<br>Strengthen<br>Time<br>Transfer<br>Type<br>Weigh** |

Department of Electrical & Electronics Engineering

Academic Year: **2018-19**
Year: **IV**
Semester: **II**

**MID Exam – I (Descriptive)**
**Flexible AC Transmission Systems**
**Code: GR15A4032**

Date: **05/02/2019**
Duration: **90 min**
Max Marks: **15**

Note: Answer any three questions. All questions carry equal marks.

| Q.No. | | Question | Max. Marks | CO | BL |
|---|---|---|---|---|---|
| 1. | a | Discuss the Opportunities for FACTS | [5] | CO-1 | L2 |
| 2. | a | What limits the loading Capability? | [5] | CO-2 | L3 |
| 3. | a | What is the relative importance of Controllable Parameters | [5] | CO-2 | L3 |
| 4. | a | Discuss Brief description and definitions of FACTS Controllers | [5] | CO-3 | L2 |

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Academic Year: **2018-19**
Year: **IV**
Semester: **II**

**MID Exam – II (Descriptive)**
**Flexible AC Transmission Systems**
**Code: GR15A4032**

Date: **02/04/2019**
Duration: **90 min**
Max Marks: **15**

Note: Answer any three questions. All questions carry equal marks.

| Q.No. | | Question | Max. Marks | CO | BL |
|---|---|---|---|---|---|
| 1. | a | Discuss Midpoint Voltage Regulation for line segmentation | [5] | CO-4 | L2 |
| 2. | a | Explain Power Oscillation Damping | [5] | CO-5 | L3 |
| 3. | a | Discuss summary of compensator control | [5] | CO-6 | L3 |
| 4. | a | Discuss in brief about Thyristor Controlled Series Compensator | [5] | CO-7 | L2 |

# GOKARAJU RANGARAJU
## INSTITUTE OF ENGINEERING AND TECHNOLOGY

Department of Electrical & Electronics Engineering

Academic Year: **2018-19**
Year: **IV**
Semester: **I**

**MID Exam – I (Objective)**
**Flexible AC Transmission Systems**
**Code: GR15A4032**

Date: **05/02/2019**
Duration: **10 min**
Max Marks: **05**

**Roll No:** ☐☐☐☐☐☐☐☐☐☐

Note: Answer all the questions. All questions carry equal marks.

1. What are the sources of Real Power [ ]
   (a) AC Generators (b) DC Generators (c) All AC & DC Generators (d) None
2. What is the need of reactive power [ ]
   (a) operation of electric devices (b) operation of electromagnetic energy devices (c) operation of mechanical devices (d) None
3. STATCOM was first implemented in [ ]
   (a) 1955 (b) 1956 (c) 1957 (d)1958
4. UPFC was first implemented in [ ]
   (a) 1996 (b) 1997 (c) 1998 (d) 1999
5. What is the reactive power value ‘Q’ for electromagnetic devices [ ]
   (a) positive (b) negative (c) zero (d) none
6. UPFC full form ______________________________________.
7. Shunt compensators are connected parallel to the transmission lines with the help of ________________
8. Series compensators are connected in _____________ with the transmission lines
9. Electromagnetic devices store energy in their ________________ fields.
10. FACTS devices are made by advanced ___________________ control equipment’s

# GOKARAJU RANGARAJU
## INSTITUTE OF ENGINEERING AND TECHNOLOGY

### Department of Electrical & Electronics Engineering

Academic Year: **2018-19**
Year: **IV**
Semester: **I**

**MID Exam – II (Objective)**
**Flexible AC Transmission Systems**
**Code: GR15A4032**

Date: **02/04/2019**
Duration: **10 min**
Max Marks: **05**

**Roll No:**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |

Note: Answer all the questions. All questions carry equal marks.

1. A SVC has no inertia compared to synchronous condensers and can be extremely fast in response with _______ cycles. [ ]
a. 2-3 b. 4-5 c. 1-2 d. none

2. 1. Fixed Capacitor-Thyristor Controlled Reactor (FC-TCR)
2. Thyristor Switched Capacitor - Thyristor Controlled Reactor (TSCTCR).
The second type is more flexible than the first one and requires smaller rating of the reactor and consequently generates ____________ harmonics [ ]
a. Adequate b. Less c. More d. None

3. By connecting the TCR in delta, the triplen harmonics are eliminated on the line side. The harmonics present in the line current are of the order ____________ [ ]
a. n = 6k±1 b. n = 5k±1 c. n = 6k±2 d. n = 5k±2

4. The transfer function between change in the SVC susceptance ($\Delta B_{SVC}$) and the change in the SVC voltage ($\Delta V_{SVC}$) is independent of frequency if only ______________ component of $V_{SVC}$ is considered. [ ]
a. 3rd Order b. 5th Order c. fundamental d. None

5. Increase in the power flow in a line requires _________________ capacitor [ ]
a. Shunt b. Series c. Series - Shunt d. None

6. Series Capacitors have been used in long distance EHV transmission lines for _________________ power transfer [ ]
a. Decreasing b. Increasing c. Balancing d. None

7. The first demonstration project of TCSC was commissioned in __________ [ ]
a. 1991 b. 1992 c. 1993 d. 1994

8. The TCSC reactance corresponding to the fundamental frequency, is obtained by taking the ratio of the peak value of the fundamental frequency component to the peak value of the ____________ line current [ ]

a. sinusoidal b. trapezoidal c. sawtooth d. ramp

9. The line overcurrent protection detects fault currents in the line and rapidly implements thyristor bypass to _____________ duty on MOV (metal oxide varistors) and capacitors [ ]
a. Increase b. Reduce c. Maintain d. None

10. In the presence of FACTS controllers, three phase models considering switching action of the thyristor or other power semiconductor devices are most _____________ [ ]
a. Accurate b. Inaccurate c. stable d. None

## Evaluation Strategy

Academic Year : 2018-19
Semester : II
Name of the Program : B.Tech Year: IV Section : A
Course : Flexible AC Transmission Systems
Name of the Faculty : Dr. T. Suresh Kumar Dept. : EEE
Designation : Professor
Target
a. Percentage of Pass : 95%

Method of Evaluation
a. Daily Attendance
b. Assignments
c. Mini Projects
d. Internal Examinations
e. Semester / End Examination

List out any new topic(s) or any innovation you would like to introduce in teaching the subjects in this semester

Case Study of any one existing application

Signature of Faculty
Dt.:

**GOKARAJU RANGARAJU**
**INSTITUTE OF ENGINEERING AND TECHNOLOGY**

Department of Electrical & Electronics Engineering

# IV B.Tech II Sem – EEE – A & B
# Flexible AC Transmission System
# (2018-2019)

## Assignment

1. Discuss the Opportunities for FACTS
2. Discuss Midpoint Voltage Regulation for line segmentation
3. Explain improvement of Transient Stability
4. Explain Power Oscillation Damping
5. Discuss the Opportunities for FACTS
6. Discuss in brief about Thyristor Controlled Series Compensator (TCSC)
7. Discuss in brief about GTO Thyristor controlled series capacitor (GSC)
8. Discuss summary of compensator control in SVC & STATCOM

# Flexible AC Transmission Systems

## (Unit-I)

Dr. T. Suresh Kumar
*Professor, EEE Department, GRIET*

# What is FACTS?

FACTS technology is a collection of controllers, which can be applied individually or in coordination with others to control one or more of the interrelated system parameters, such as series impedance, shunt impedance, current, voltage, and damping of oscillations.

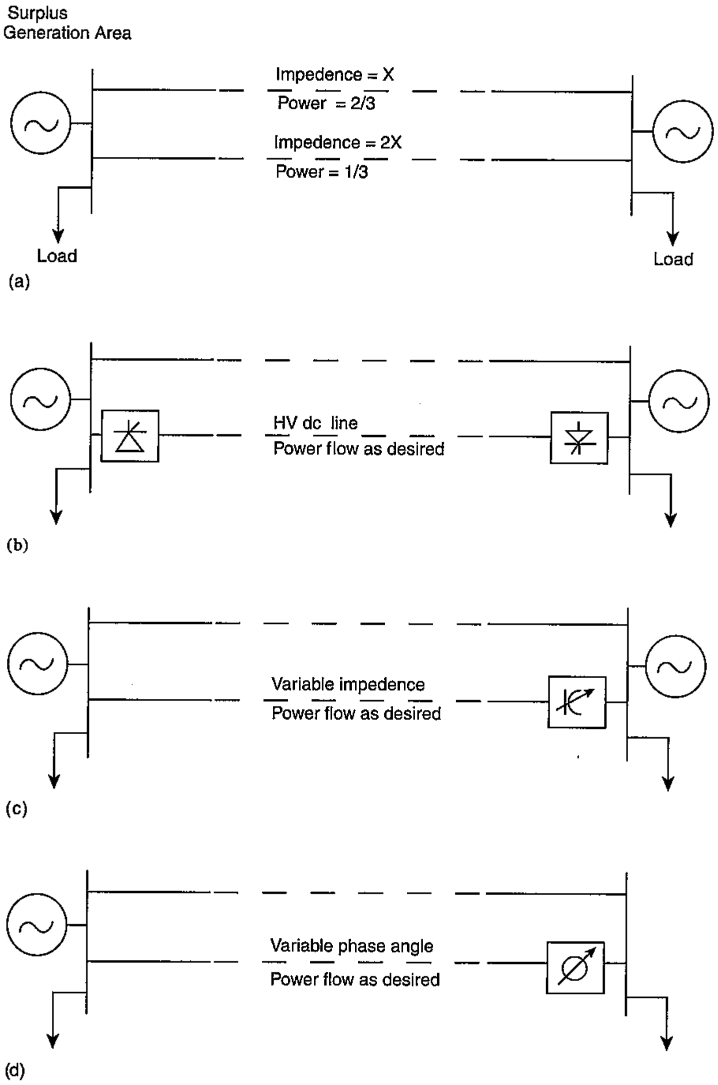


**Figure 1.1** Power flow in parallel paths: (a) ac power flow with parallel paths; (b) power flow control with HVDC; (c) power flow control with variable impedance; (d) power flow control with variable phase angle.

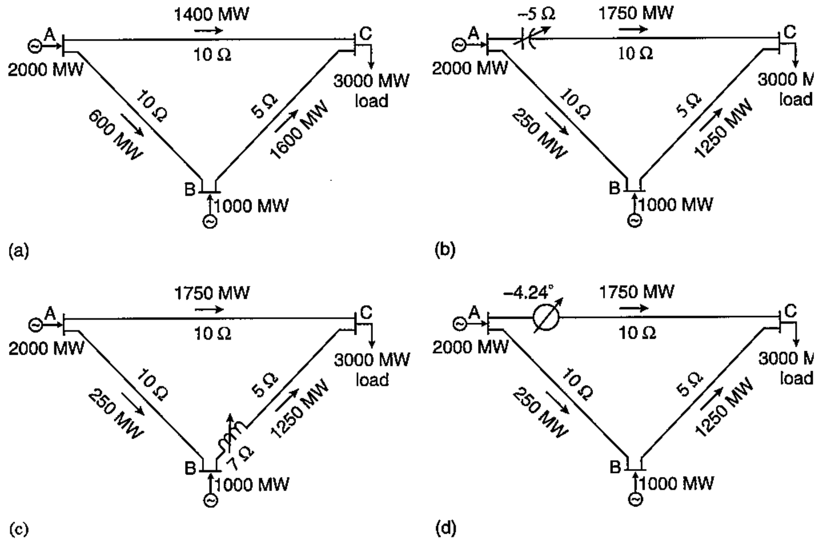


**Figure 1.2** Power flow in a mesh network: (a) system diagram; (b) system diagram with Thyristor-Controlled Series Capacitor in line AC; (c) system diagram with Thyristor-Controlled Series Reactor in line BC; (d) system diagram with Thyristor-Controlled Phase Angle Regulator in line AC.

# What limits the Loading Capability?

- Thermal

  For overhead line, thermal capability is a function of ambient temperature, wind conditions, conditions of conductor, and ground clearance. The FACTS technology can help in making an effective used of newfound line capability.

- Dielectric

  Being designed very conservatively, most lines can increase operation voltage by 10% or even higher. FACTS technology could be used to ensure acceptable over-voltage and power flow conditions

- Stability

  The stability issues that limit the transmission capability include:

  transient stability, dynamic stability, steady-state stability, frequency collapse. Voltage collapse, and sub-synchronous resonance.

  The FACTS technology can certainly be used to overcome any of the stability limits.

# A Simple Example of FACTS

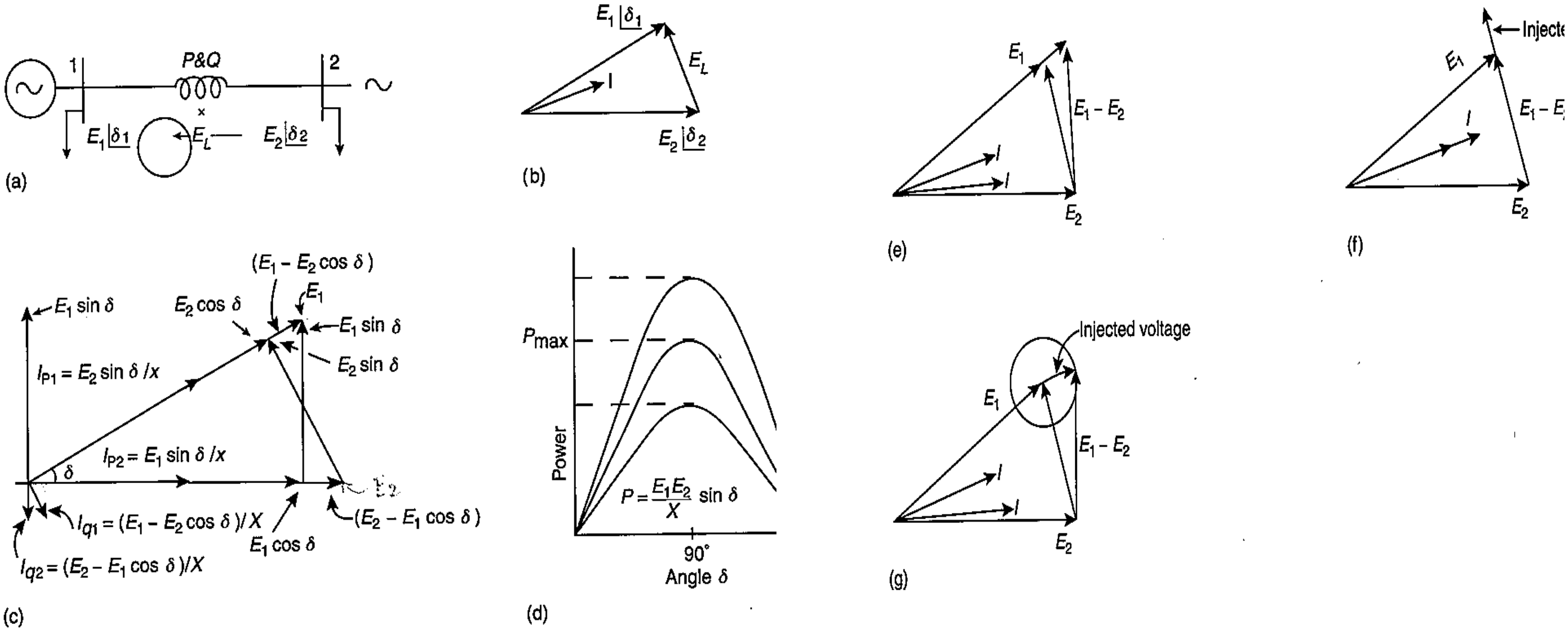


**Figure 1.3** Ac power flow control of a transmission line: (a) simple two-machine system; (b) current flow perpendicular to the driving voltage; (c) active and reactive power flow phasor diagram; (d) power angle curves for different values of $X$; (e) regulating voltage magnitude mostly changes reactive power; (f) injecting voltage perpendicular to the line current mostly changes active power; (f) injecting voltage phasor in series with the line. (Note that for clarity the phasors are identified by their magnitudes in this figure.)

# Basic types of FACTS Controllers

- Series controllers:
  The series controller could be a variable impedance or a variable source both are power electronics based. In principle, all series controllers inject voltage in series with the line.

- Shunt controllers:
  The shunt controllers may be variable impedance connected to the line voltage causes a variable current flow hence represents injection of current into the line.

- Combined series-series controllers:
  The combination could be separate series controllers or unified series-series controller--- Interline Power Flow Controller.

- Combined series-shunt controllers:
  The combination could be separated series and shunt controllers or a unified power flow controller

# Relative Importance of Different Types of Controllers

- For a given MVA size, the series controller is several times more powerful than the shunt controller in application of controlling the power/current flow.
- Drawing from or injecting current into the line, the shunt controller is a good way to control voltage at and around the point of connection.
- The shunt controller serves the bus node independently of the individual lines connected to the bus.
- Series connected controllers have to be designed to ride through contingency and dynamic overloads, and ride through or bypass short circuit currents.
- A combination of series and shunt controllers can provide the best of effective power/current flow and line voltage.
- FACTS controllers may be based on thyristor devices with no gate turn-off or with power devices with gate turn-off capability.
- The principle controllers are based on the dc to ac converters with bidirectional power flow capability.

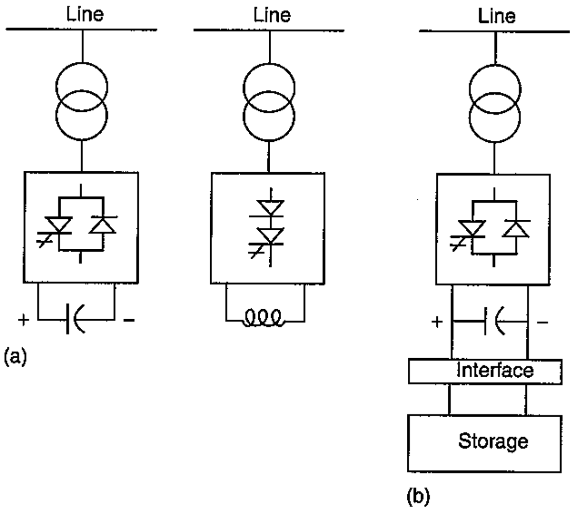
# Relative Importance of Different Types of Controllers(cont.)

- Energy storage systems are needed when active power is involved in the power flow.
- Battery, capacitor, superconducting magnet, or any other source of energy can be added in parallel through an electronic interface to replenish the converter’s dc storage.
- A controller with storage is more effective for controlling the system dynamics.
- A converter-based controller can be designed with high pulse order or pulse width modulation to reduce the low order harmonic generation to a very low level.
- A converter can be designed to generate the correct waveform in order to act as an active filter.
- A converter can also be controlled and operated in a way that it balances the unbalanced voltages, involving transfer of energy between phases.
- A converter can do all of these beneficial things simultaneously I the converter is so designed.

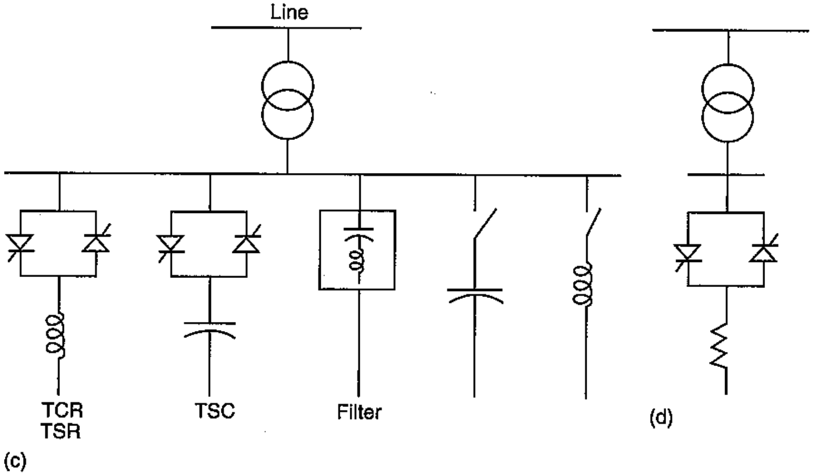
# Brief Description and Definitions of FACTS controllers

- *Shunt connected controllers*
- *Series connected controllers*
- *Combined shunt and series connected controllers*

# Shunt connected controllers



Shunt-connected Controllers: (a) Static Synchronous Compensator (STATCOM) based on voltage-sourced and current-sourced converters; (b) STATCOM with storage, i.e., Battery Energy Storage System (BESS) Superconducting Magnet Energy Storage and large dc capacitor; (c) Static VAR Compensator(SVC), Static VAR Generator (SVG), Static VAR System (SVS), Thyristor-Controlled Reactor (TCR), Thyristor-Switched Capacitor (TSC), and Thyristor-Switched Reactor (TSR); (d) Thyristor-Controlled Braking Resistor.



# Series connected controllers

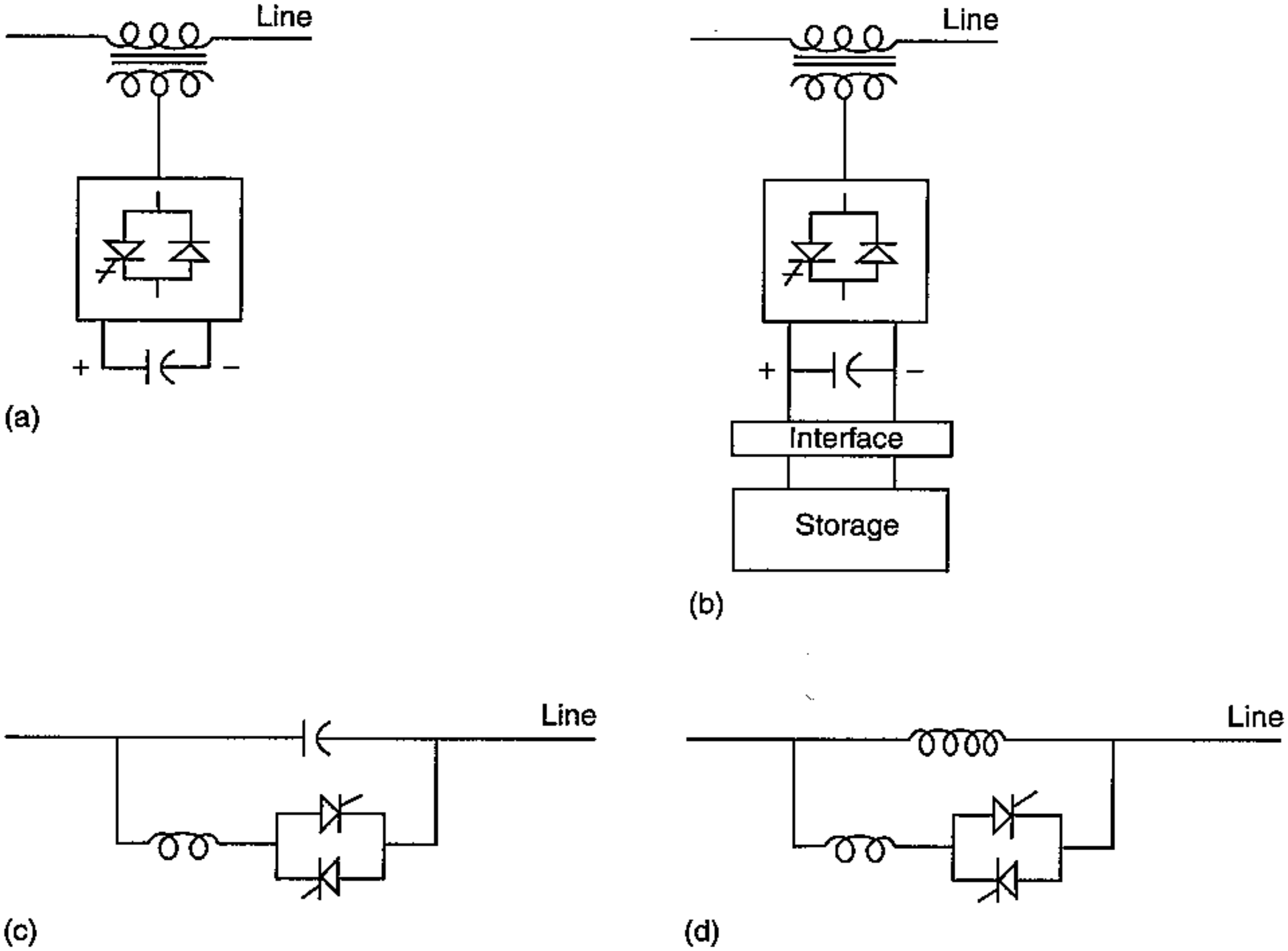


**Figure 1.6** (a) Static Synchronous Series Compensator (SSSC); (b) SSSC with storage; (c) Thyristor-Controlled Series Capacitor (TCSC) and Thyristor-Switched Series Capacitor (TSSC); (d) Thyristor-Controlled Series Reactor (TCSR) and Thyristor-Switched Series Reactor (TSSR).

# Combined shunt and series connected controllers

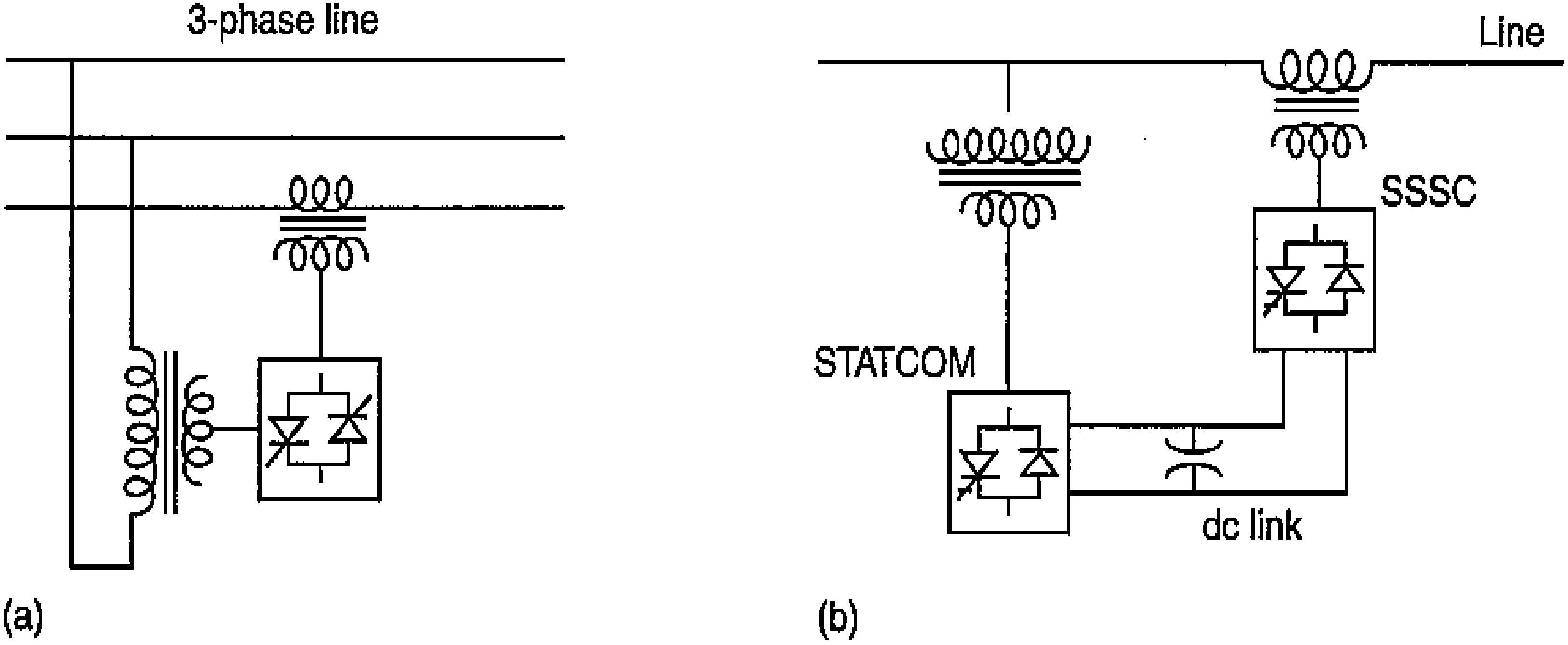


**Figure 1.7** (a) Thyristor-Controlled Phase-Shifting Transformer (TCPST) or Thyristor-Controlled Phase Angle Regulator (TCPR); (b) Unified Power Flow Controller UPFC).

# Other controllers

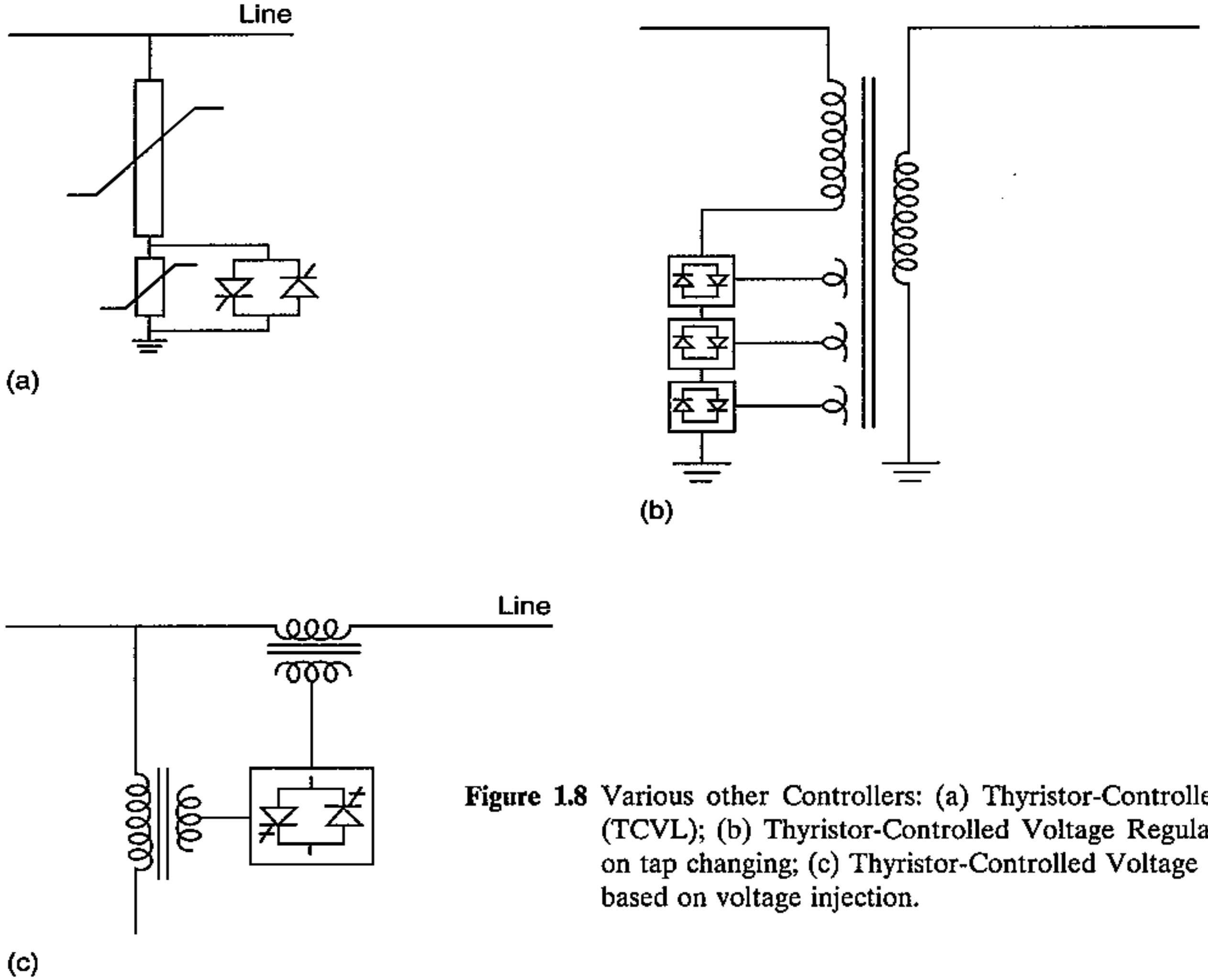
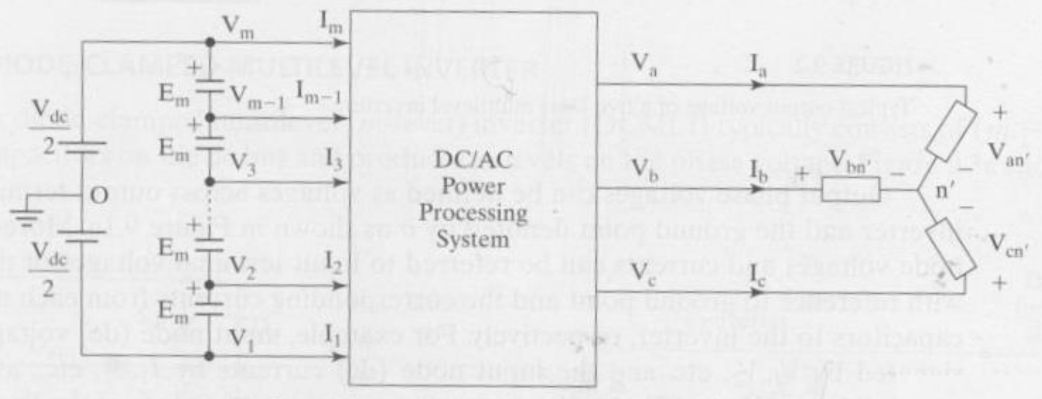
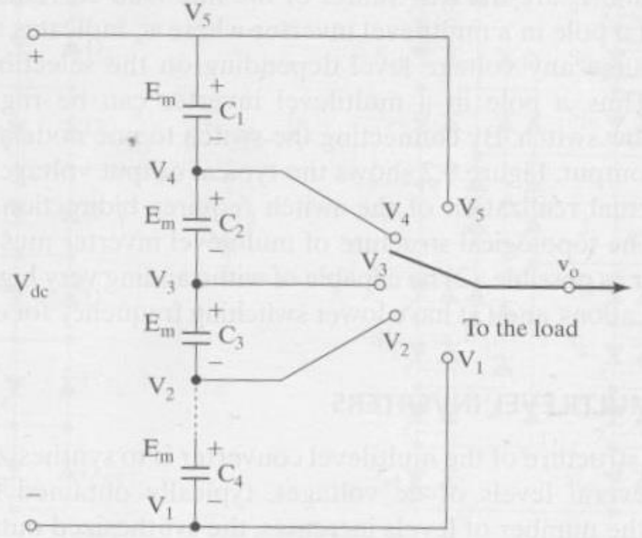


**Figure 1.8** Various other Controllers: (a) Thyristor-Controlled Voltage Limiter (TCVL); (b) Thyristor-Controlled Voltage Regulator (TCVR) based on tap changing; (c) Thyristor-Controlled Voltage Regulator (TCVR) based on voltage injection.

# Multilevel Inverter(High Pulse Order)



(a) Three-phase multilevel power processing system



(b) Schematic of single pole of multilevel inverter by a switch

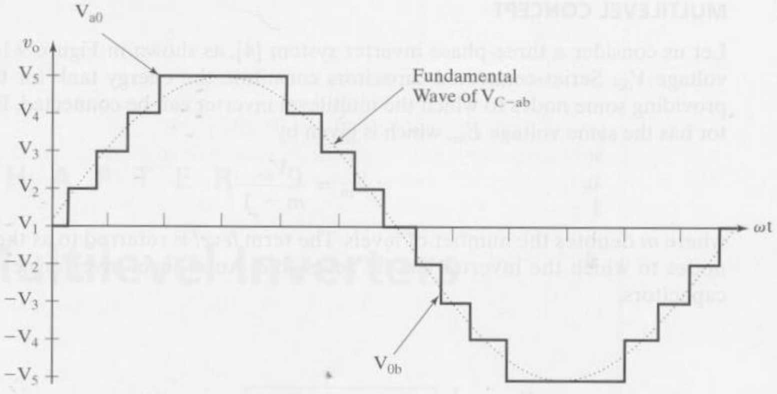
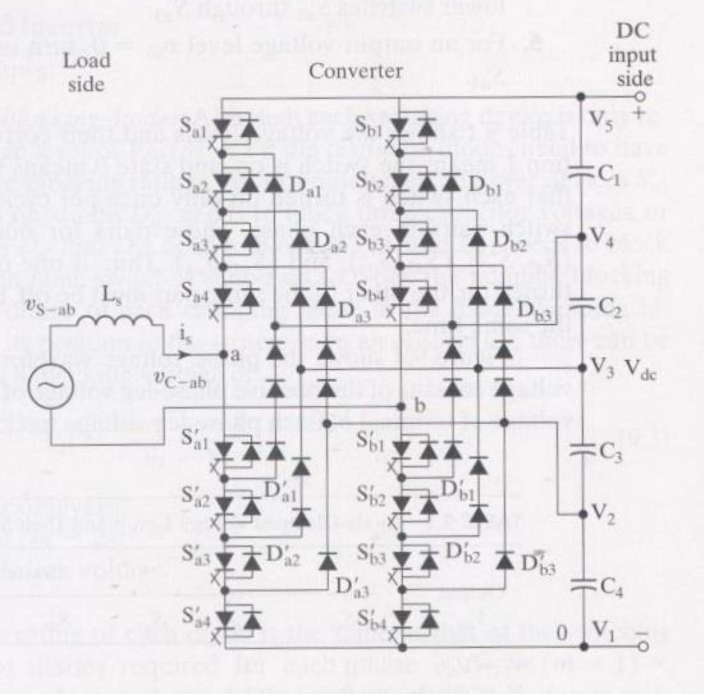


FIGURE 9.2

Typical output voltage of a five-level multilevel inverter.

# Single-phase diode-clamped five-level bridge multilevel inverter and switching states



(b) Single-phase bridge

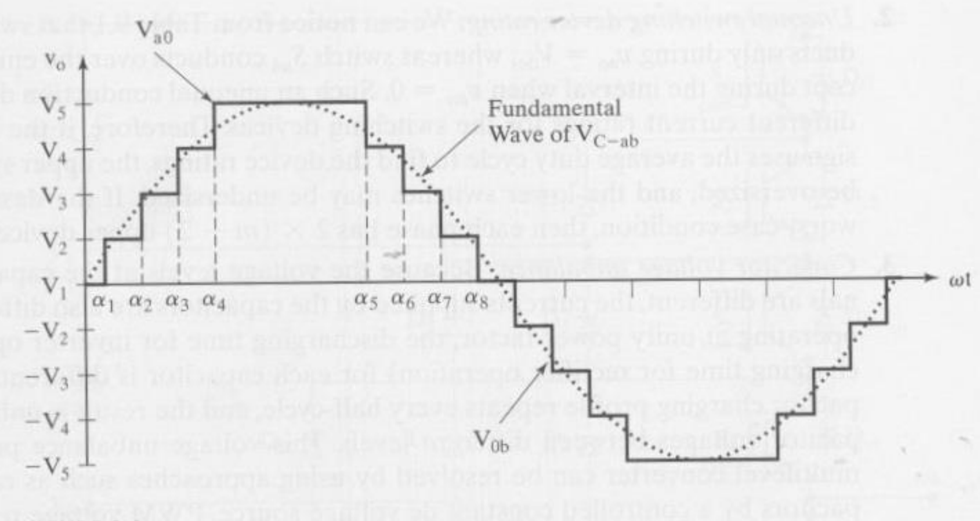


FIGURE 9.4

Phase and fundamental voltage waveforms of a five-level inverter.

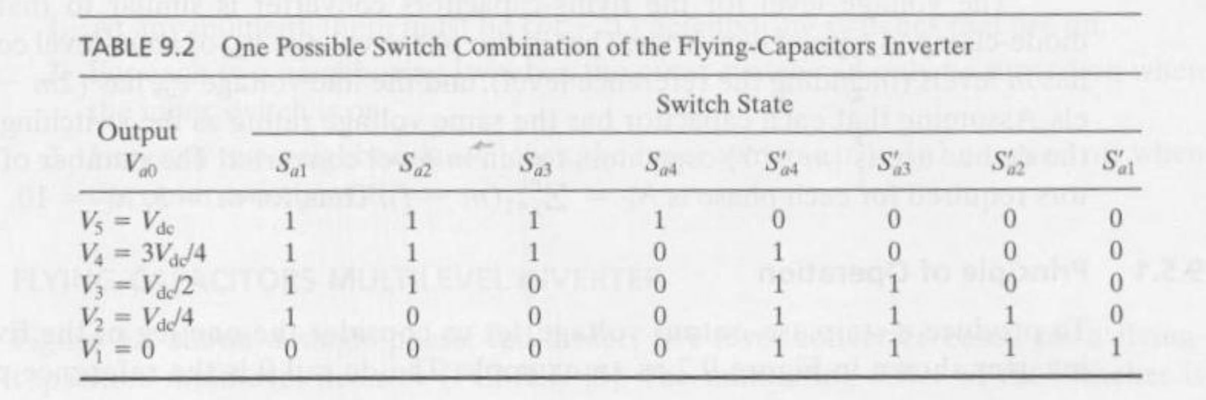
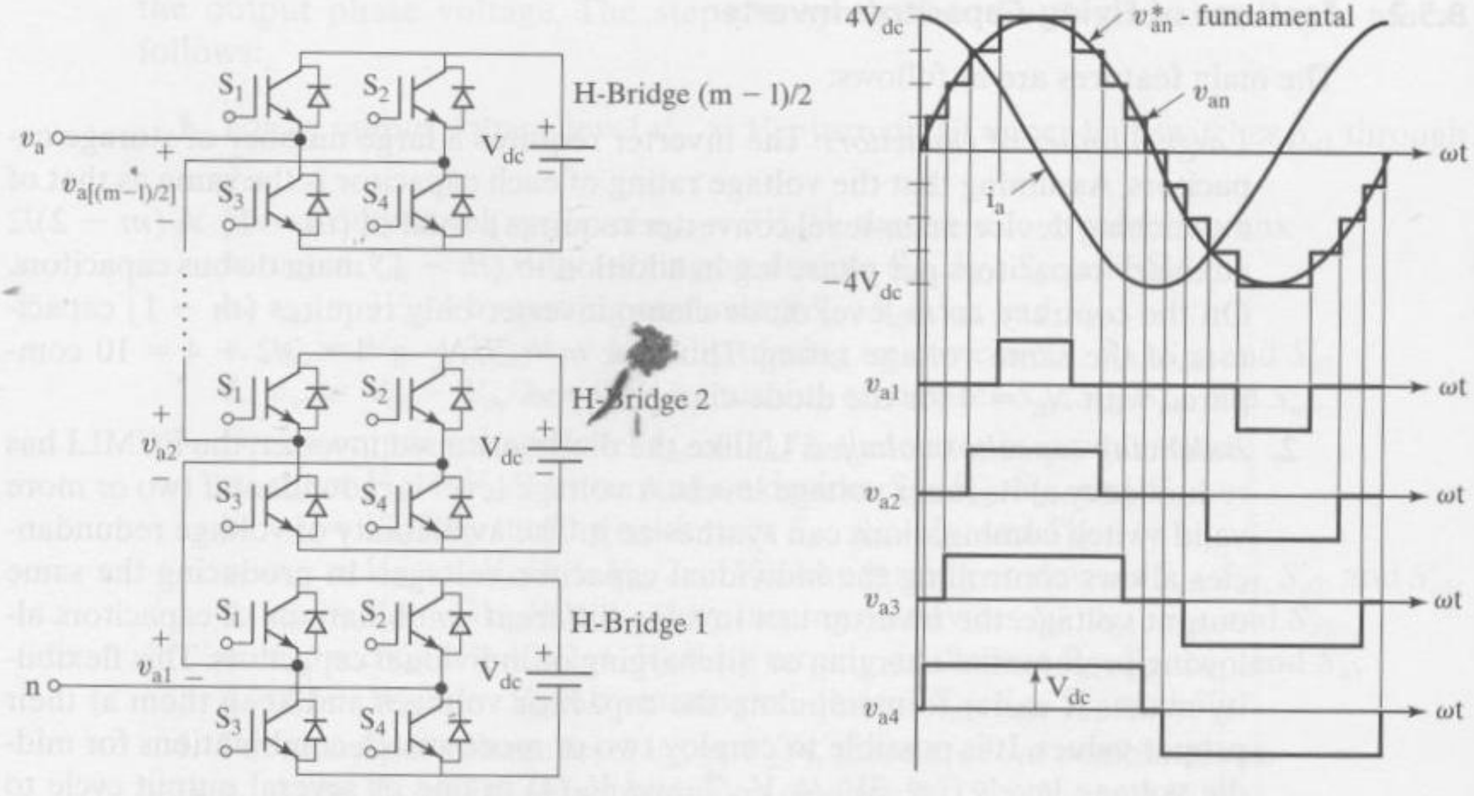


TABLE 9.2 One Possible Switch Combination of the Flying-Capacitors Inverter

| Output | Switch State | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $V_{a0}$ | $S_{a1}$ | $S_{a2}$ | $S_{a3}$ | $S_{a4}$ | $S'_{a4}$ | $S'_{a3}$ | $S'_{a2}$ | $S'_{a1}$ |
| $V_5 = V_{dc}$ | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| $V_4 = 3V_{dc}/4$ | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 |
| $V_3 = V_{dc}/2$ | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 |
| $V_2 = V_{dc}/4$ | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 |
| $V_1 = 0$ | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |

# Cascaded multilevel inverter



(a) Circuit diagram

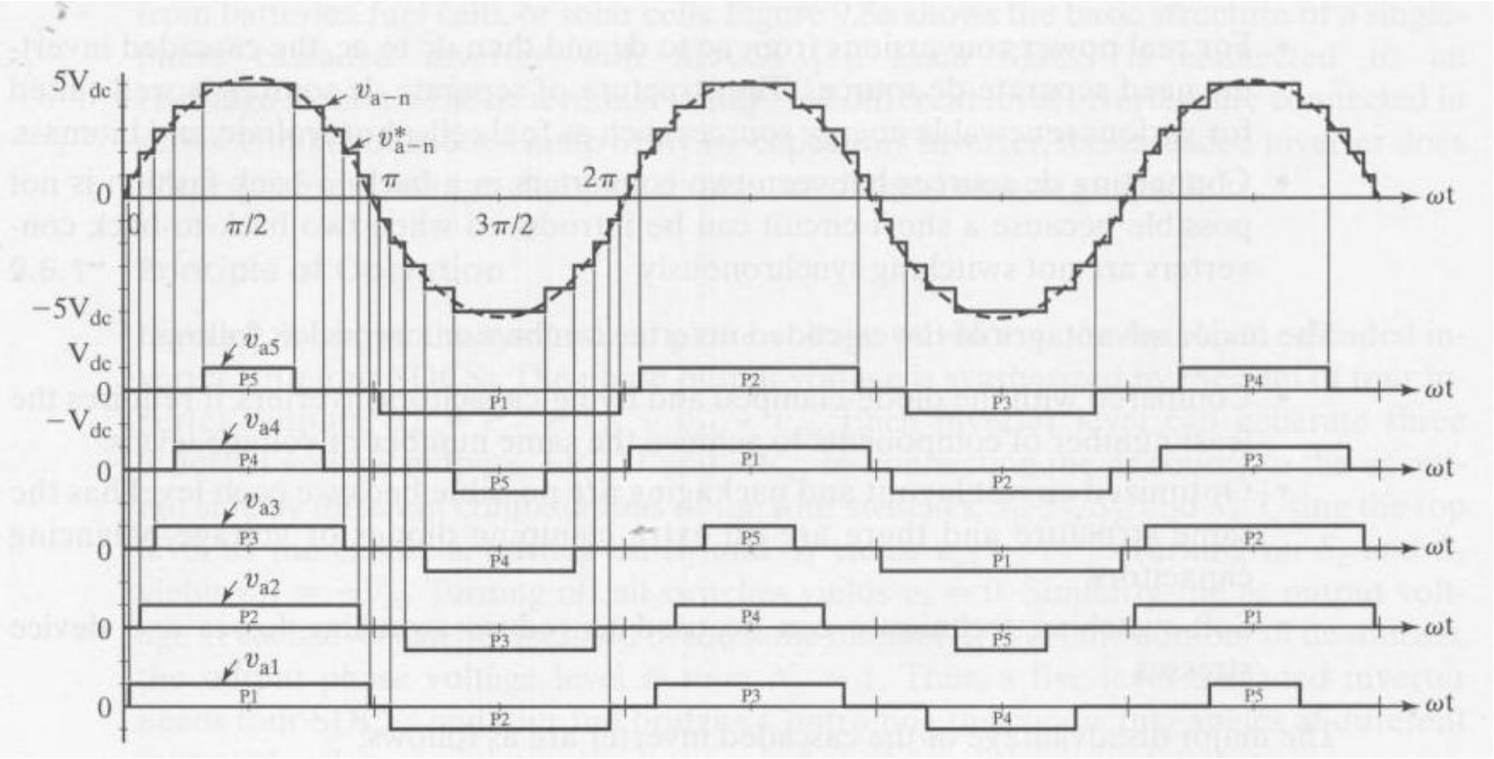
(b) Output waveform of 9-level phase voltage

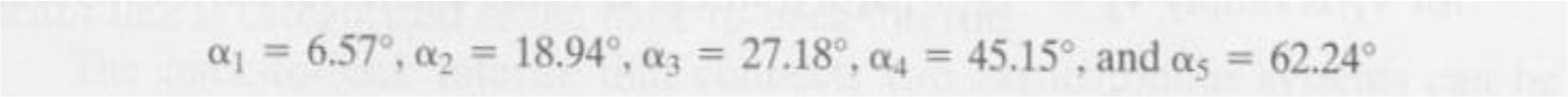
FIGURE 9.8

Single-phase multilevel cascaded H-bridge inverter. [Ref. 7]

# Multilevel inverter combine with selective harmonic elimination

Find switching angles that 5th, 7th, 11th, and 13th harmonics can be eliminated from the output waveform.





$\alpha_1 = 6.57°$, $\alpha_2 = 18.94°$, $\alpha_3 = 27.18°$, $\alpha_4 = 45.15°$, and $\alpha_5 = 62.24°$

# Reactive power compensation using multilevel converter

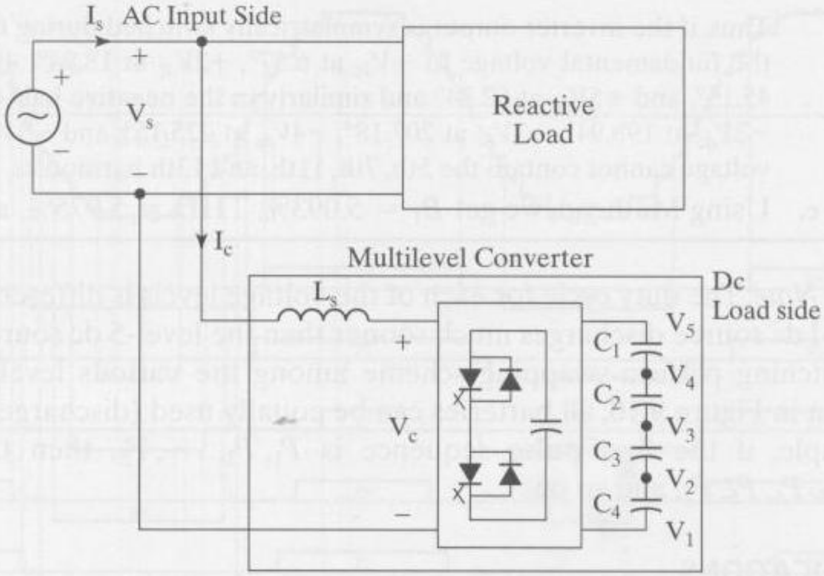
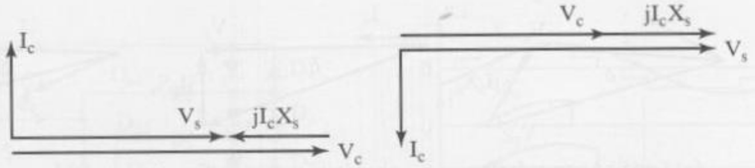


FIGURE 9.11

A multilevel converter connected to a power system for reactive power compensation. [Ref. 5]



(a) Leading current

(b) Lagging current

FIGURE 9.12

Phasor diagrams of the source and the converter voltages for reactive power compensation.

# Back-to-back inverter using two diode-clamped multilevel converters

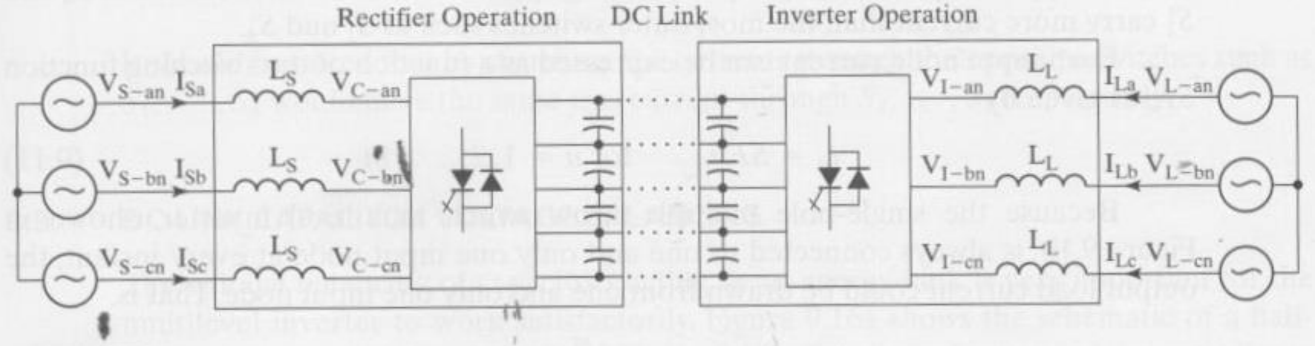
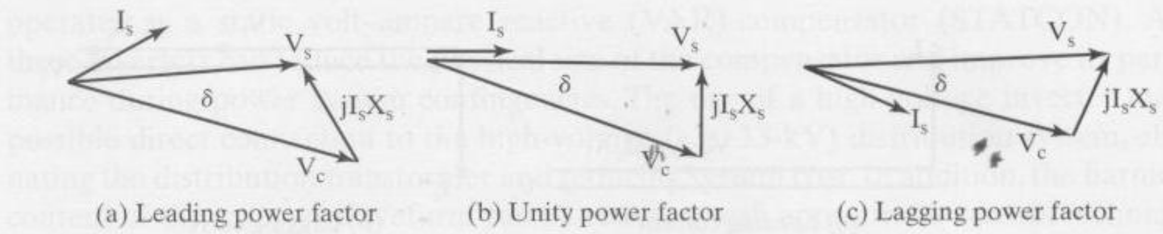


FIGURE 9.13

Back-to-back intertie system using two diode-clamped multilevel converters. [Ref. 5]

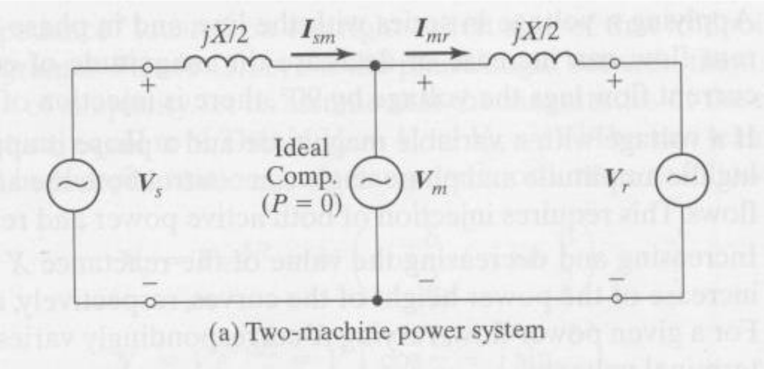


(a) Leading power factor (b) Unity power factor (c) Lagging power factor

FIGURE 9.14

Phasor diagram of the source voltage, converter voltage, and current showing real power conversions.

# TCR, thyristor control reactor (shunt connected controller)



(a) Two-machine power system

$$i_L(t) = \frac{1}{L}\int_{\alpha}^{\omega t} v(t)dt = \frac{V_m}{\omega L}(\sin \omega t - \sin \alpha)$$

Note: Due to the phase control, harmonic currents of low order also appear. Passive filters may be necessary to eliminate these harmonics. Transformers with Y-delta connections are normally used to at the sending end to avoid harmonic injection to the ac supply line.

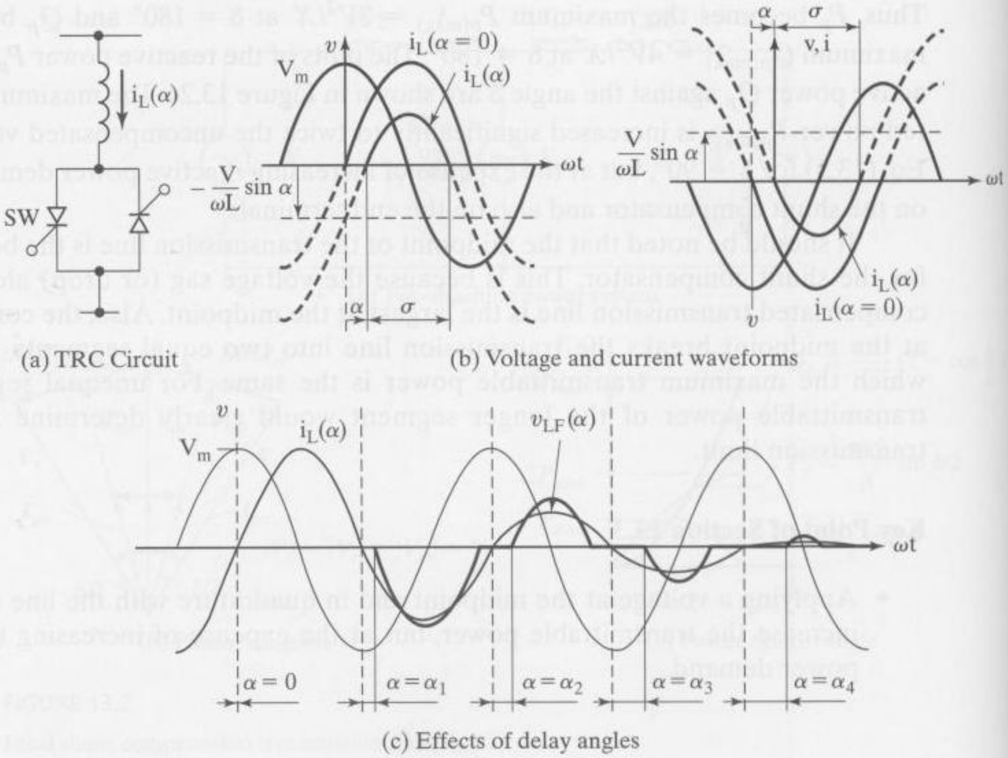
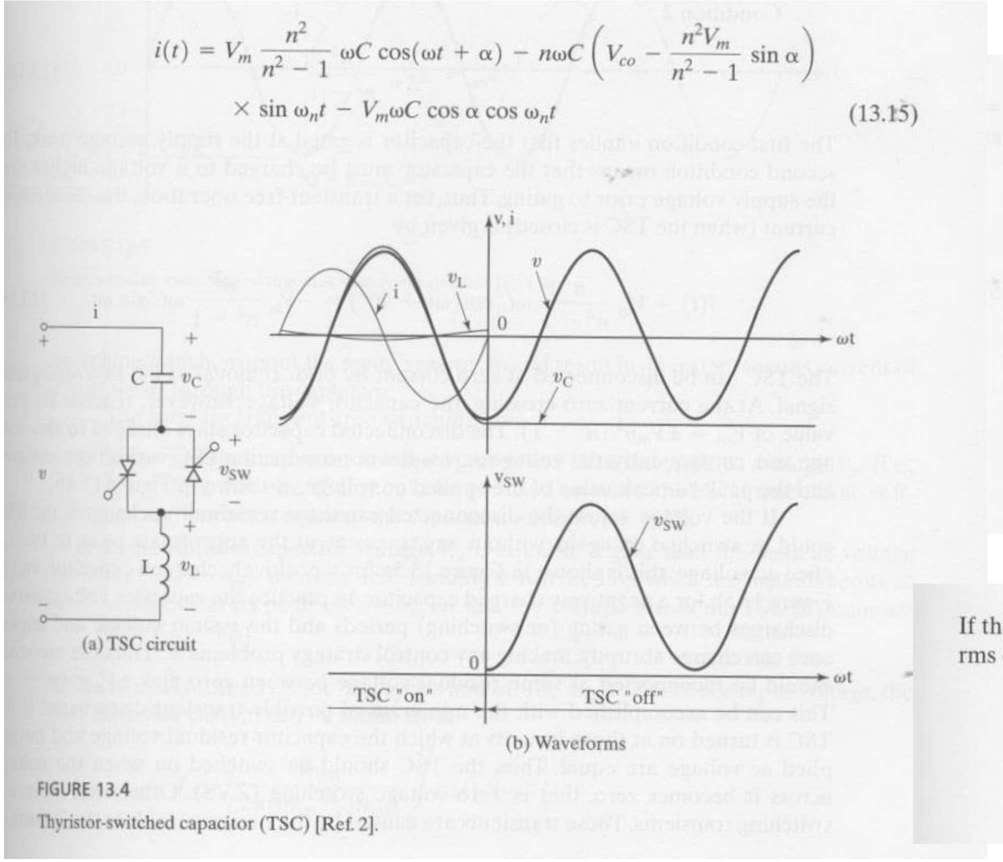


FIGURE 13.3

Thyristor-controlled reactor (TCR) Ref [2].

# TSC, thyristor-switched capacitor (shunt connected controller)



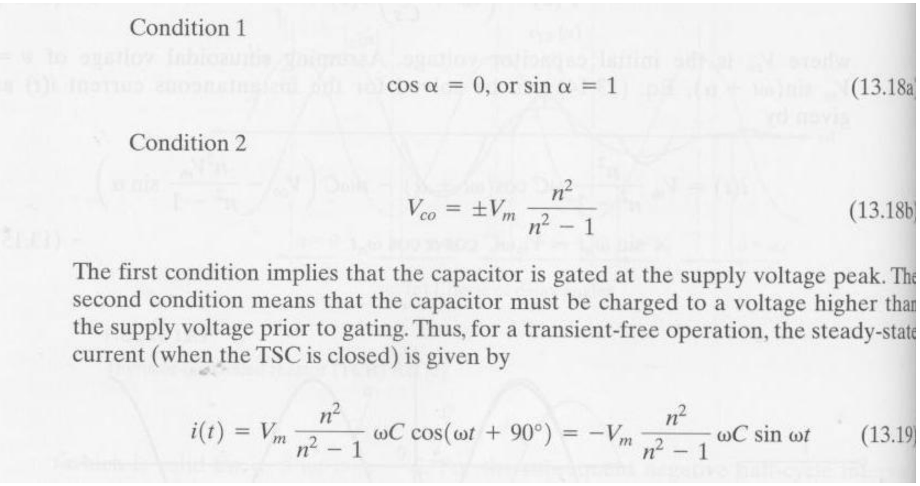
$$i(t) = V_m \frac{n^2}{n^2-1}\,\omega C \cos(\omega t + \alpha) - n\omega C\left(V_{co} - \frac{n^2 V_m}{n^2-1}\sin\alpha\right) \times \sin\omega_n t - V_m \omega C \cos\alpha \cos\omega_n t \qquad (13.15)$$

(a) TSC circuit

(b) Waveforms

FIGURE 13.4

Thyristor-switched capacitor (TSC) [Ref. 2].



Condition 1

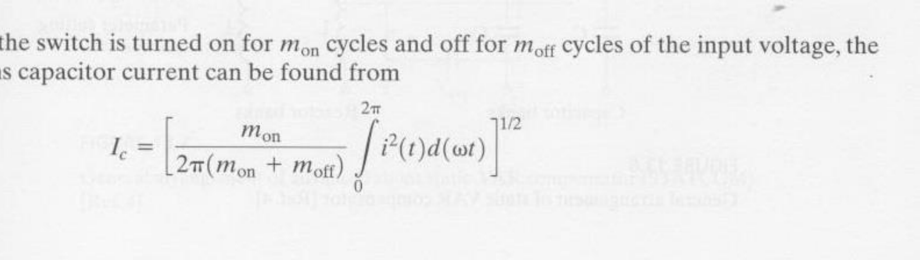
$$\cos\alpha = 0, \text{ or } \sin\alpha = 1 \qquad (13.18a)$$

Condition 2

$$V_{co} = \pm V_m \frac{n^2}{n^2-1} \qquad (13.18b)$$

The first condition implies that the capacitor is gated at the supply voltage peak. The second condition means that the capacitor must be charged to a voltage higher than the supply voltage prior to gating. Thus, for a transient-free operation, the steady-state current (when the TSC is closed) is given by

$$i(t) = V_m \frac{n^2}{n^2-1}\,\omega C \cos(\omega t + 90°) = -V_m \frac{n^2}{n^2-1}\,\omega C \sin\omega t \qquad (13.19)$$



If the switch is turned on for $m_{\text{on}}$ cycles and off for $m_{\text{off}}$ cycles of the input voltage, the rms capacitor current can be found from

$$I_c = \left[\frac{m_{\text{on}}}{2\pi(m_{\text{on}} + m_{\text{off}})}\int_0^{2\pi} i^2(t)\,d(\omega t)\right]^{1/2}$$

Note: The thyristors can be always turned on for supplying constant Qc or controlled with duty cycle for more flexible feature.

# SVC, Static VAR Compensator (shunt connected controller)

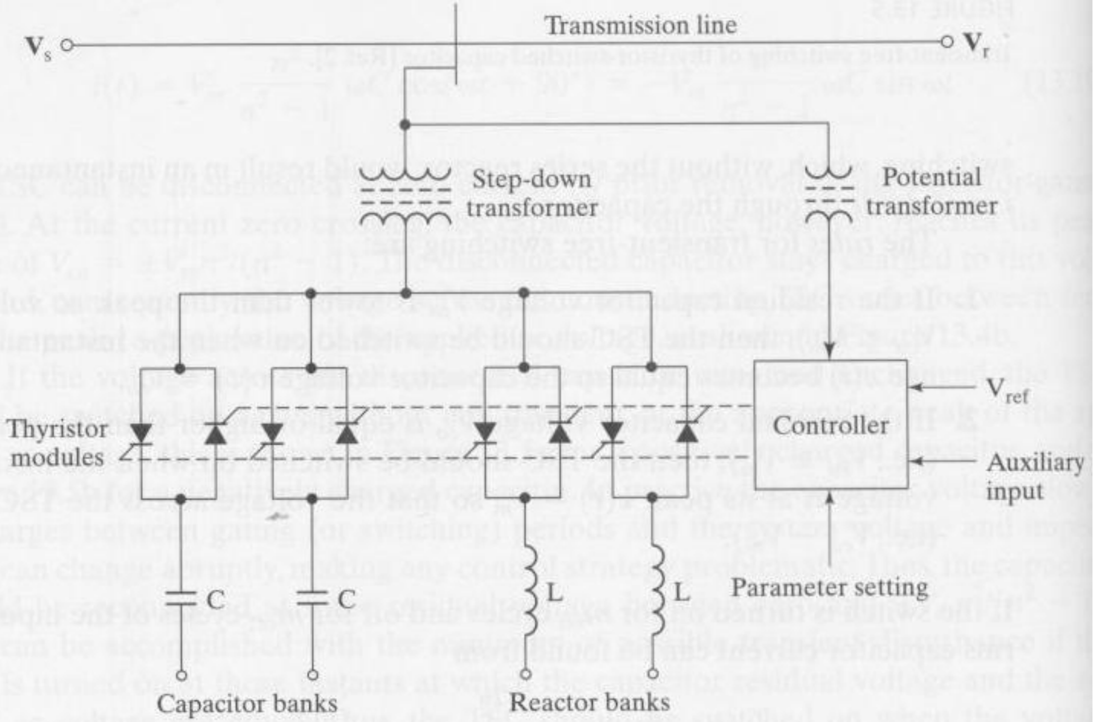


FIGURE 13.6
General arrangement of static VAR compensator [Ref. 4].

Note: The control strategy usually aims to maintain the transmission line voltage at a fixed level.

# STATCOM, Static Compensator---Advanced Static VAR Compensator (shunt connected controller)

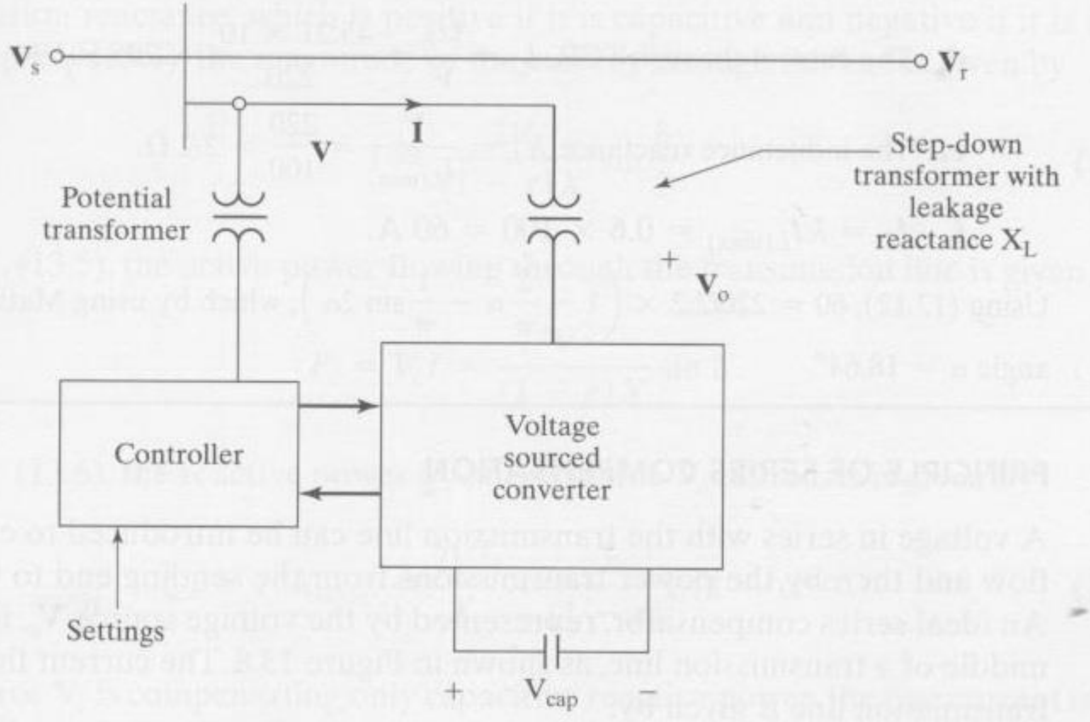


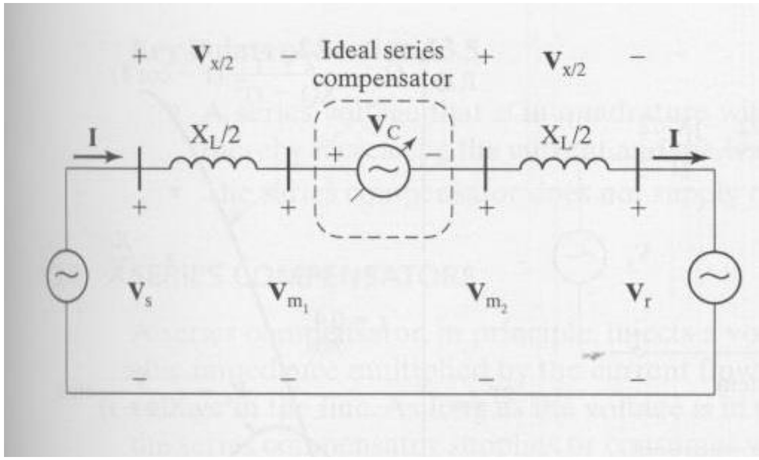
FIGURE 13.7

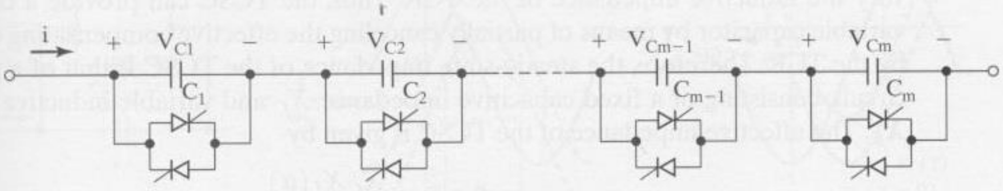
General arrangement of advanced shunt static-VAR compensator (STATCOM) [Ref. 4].

The main features:

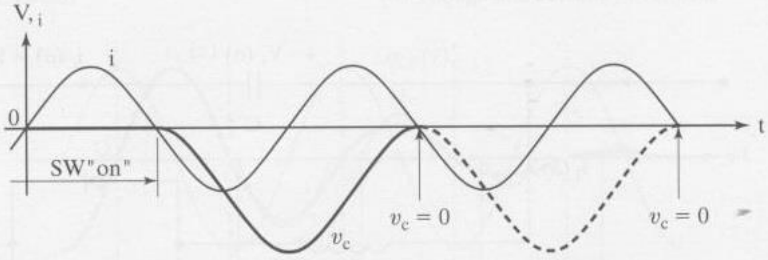
1. Wide operating range
2. Lower rating than SVC
3. Increased transient rating and superior capability to handle dynamic system disturbances

# TSSC, thyristor-switched series capacitor (series-connected controller)





(a) Series-connected capacitors



SW is allowed to turn on at $v_c = 0$

(b) Switching at zero current and capacitor offset voltage

FIGURE 13.10

Thyristor-switched series capacitor [Ref. 2].

Note:

1. A capacitor is inserted by turning off, and bypassed by turning on the corresponding thyristor switch.
2. The equivalent capacitance is between 0 and C/m.

# TCSC, thyristor-controlled series capacitor (series-connected controller)

$$X_L(\alpha) = X_L \frac{\pi}{\pi - 2\alpha - \sin 2\alpha} \qquad \text{for } X_L \le X_L(\alpha) \le \infty \qquad (13.27b)$$

$$X_T(\alpha) = \frac{X_C X_L(\alpha)}{X_L(\alpha) - X_C} \qquad (13.27a$$

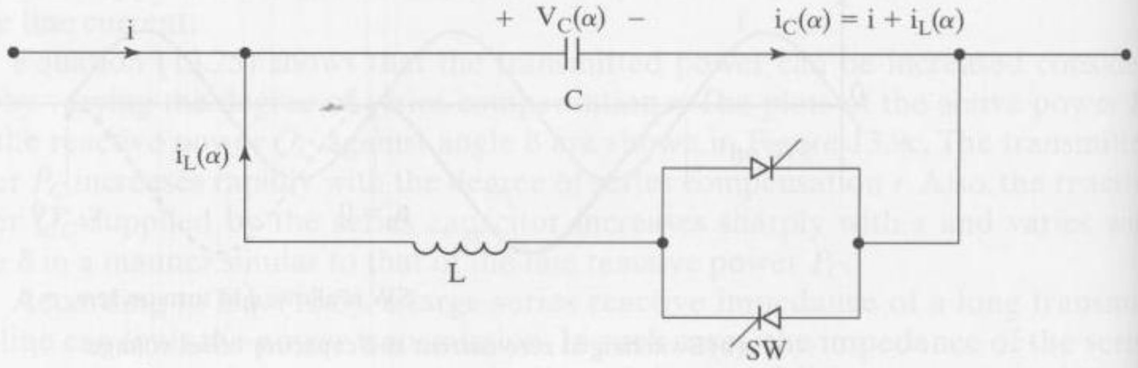


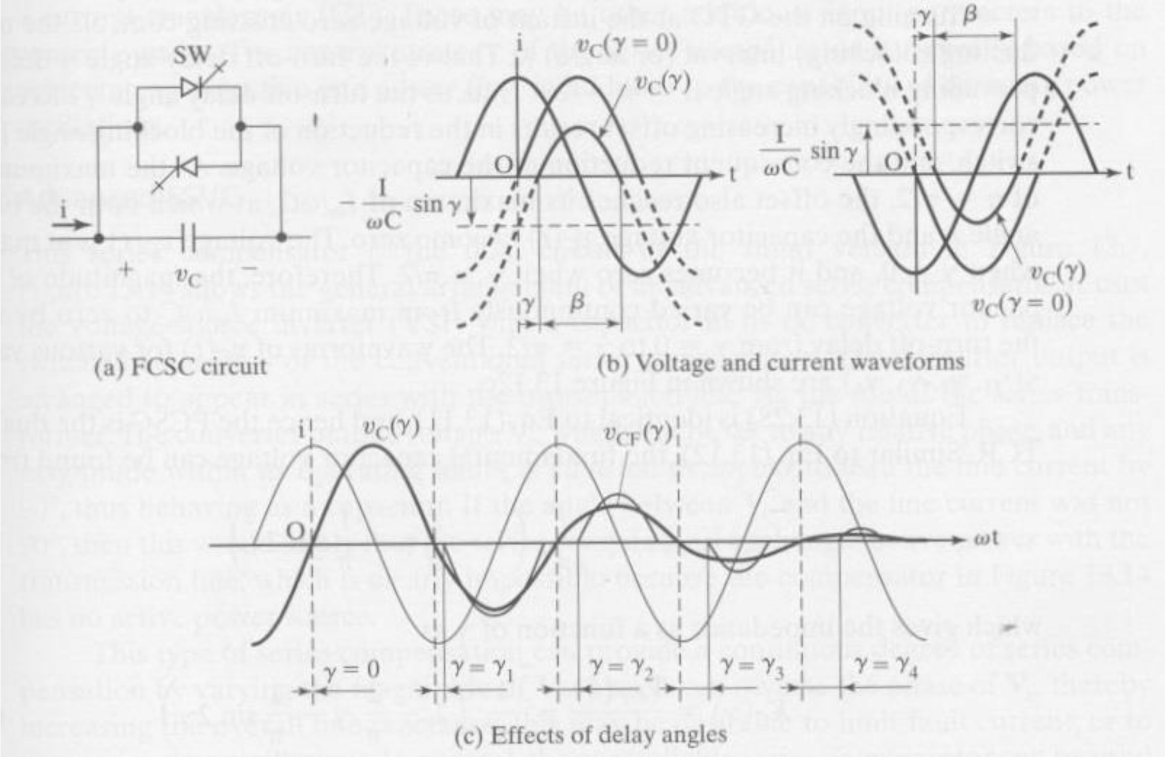
**FIGURE 13.11**

Thyristor-controlled series capacitor (TCSC).

Note: The TCSC behaves as a tunable parallel LC-circuit to the line current. As the impedance of XL is varied from its maximum (infinity) toward its minimum wL, the TCSC increases its capacitive impedance.

# FCSC, forced-commutation-controlled series capacitor
# (series-connected controller)

$$v_C(t) = \frac{1}{C}\int_{\gamma}^{\omega t} i(t)dt = \frac{I_m}{\omega C}(\sin \omega t - \sin \gamma) \qquad (13.28)$$



(a) FCSC circuit

(b) Voltage and current waveforms

(c) Effects of delay angles

**FIGURE 13.12**

Forced-commutation-controlled series capacitor (FCSC) Ref [2].

Note: The operation of FCSC is similar to the TSC, except the switches is replaced by forced commutated devices.

# SSVC. Series static VAR compensator (series-connected controller)

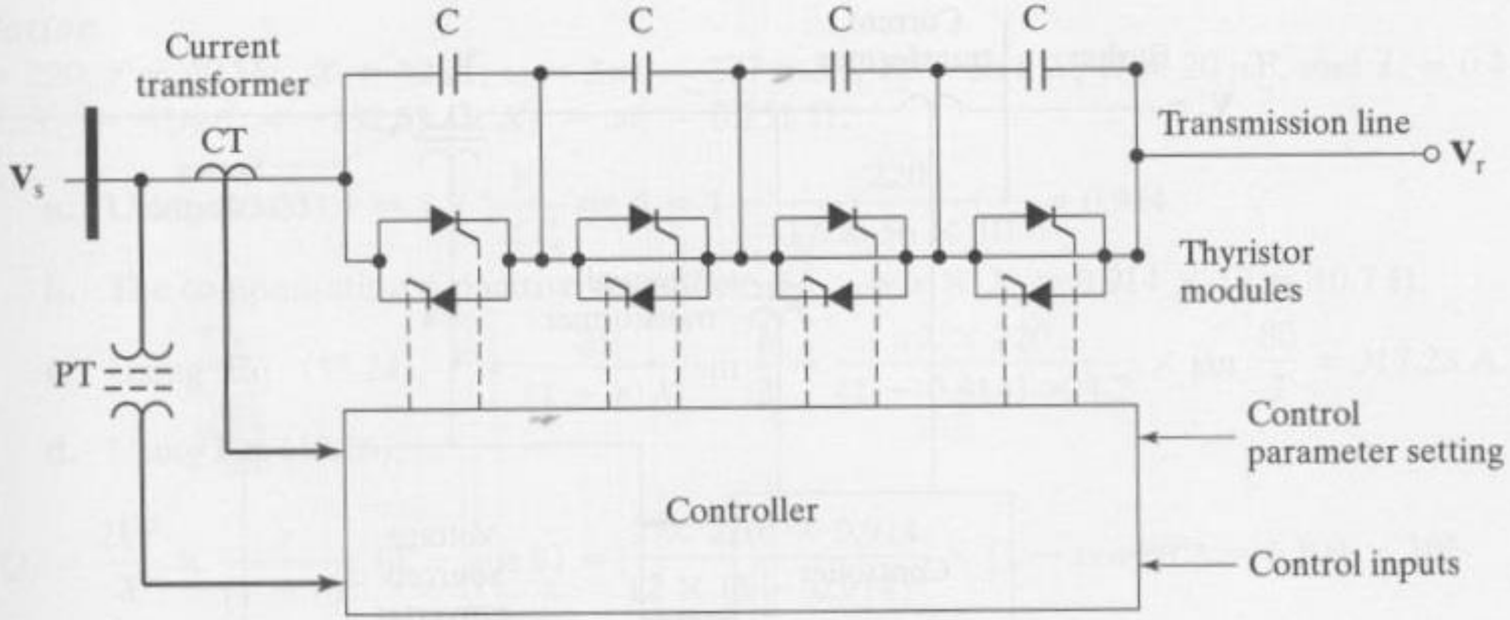


FIGURE 13.13

General arrangement of series static VAR compensator [Ref. 4].

Note: The control strategy of the SSVC is typically based on achieving an objective line power flow in addition to the capability of damping power oscillations.

# Advanced SSVC, series-connected STATCOM

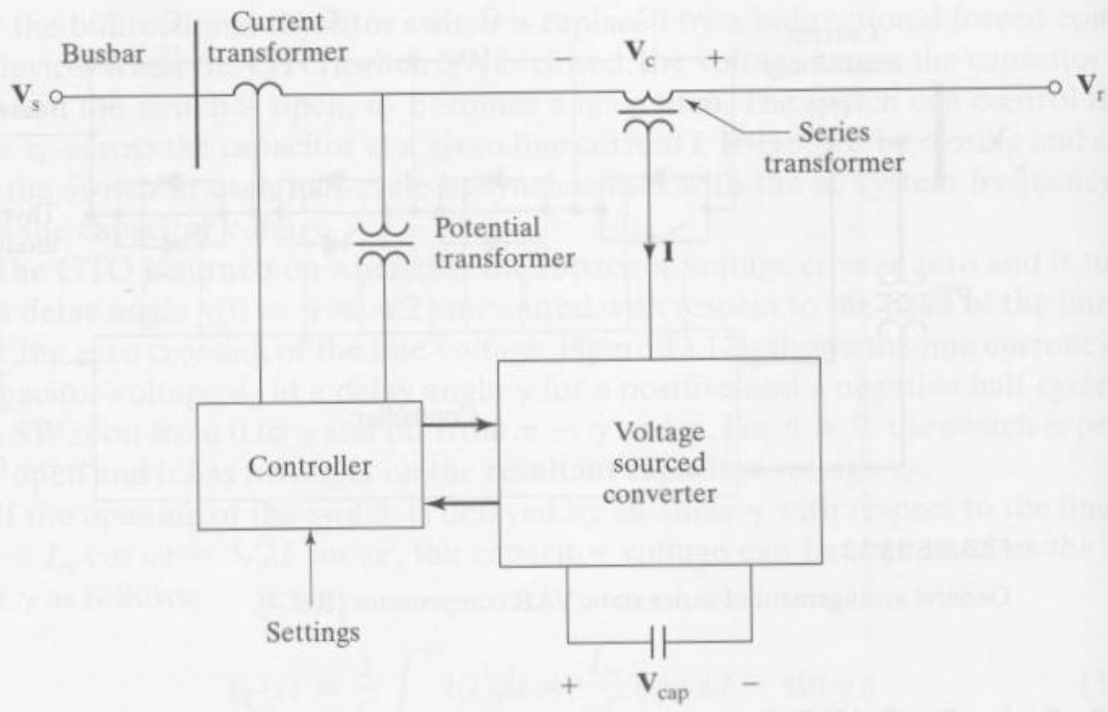
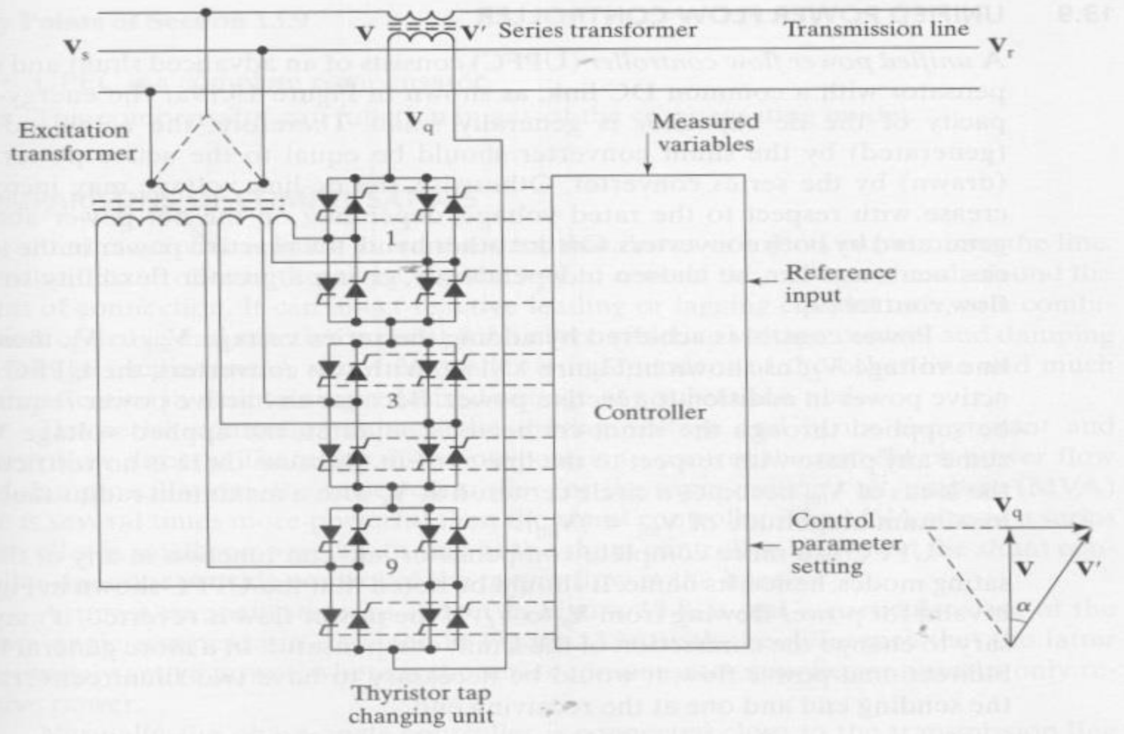


**FIGURE 13.14**

General arrangement of advanced series static VAR compensator [Ref. 4].

1. This series-connected STATCOM is the dual circuit of shunt-connected STATCOM (Fig.13.7).
2. This type of series compensation can provide a continuous degree of series compensation by varying the magnitude of Vc. Also, it can reverse the phase of Vc, thereby increasing the overall line reactance; this can be desirable to limit fault current, or to dampen power oscillations.

# PAC, phase-angle compensator (series-connected controller)



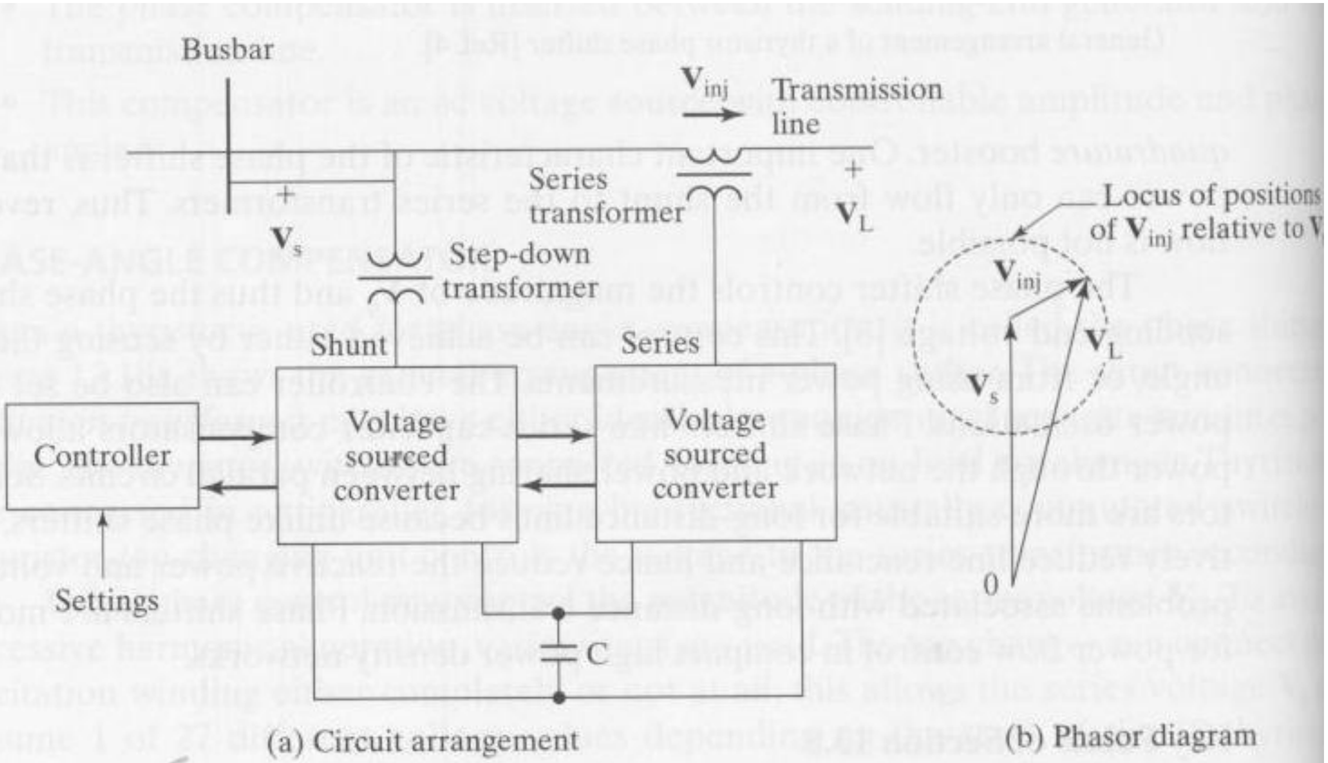
(a) Circuit arrangement (b) Phasor diagram

FIGURE 13.18

General arrangement of a thyristor phase shifter [Ref. 4].

1. The transforming arrangement between the excitation and series transformers ensures that Vq is always at 90 degrees to V (called quadrature booster)
2. The phase shifter controls the magnitude of Vq and thus the phase shift alpha to the sending-end voltage.

# UPFC, unified power flow controller (combined shunt and series connected controllers)



(a) Circuit arrangement (b) Phasor diagram

FIGURE 13.19

Unified power flow controller [Ref. 4].

1. The UPFC consists of an a series STATCOM and a shunt SATACOM with a common DC link.
2. Power control is achieved by adding series voltage Vinj to Vs, thus giving the line voltage VL.
3. With two converters, the UPFC can supply active power in addition to reactive power.

# FACTS
# (Flexible AC Transmission Systems)

## Unit - 3

## Static Shunt Compensation

**Contents:**

Objectives of shunt compensation, midpoint voltage regulation voltage instability prevention, improvement of transient stability, Power oscillation damping.

# Objectives – Shunt Compensators

- It has been recognized that the steady state transmittable power can be increased and the voltage profile along the line can be controlled by appropriate reactive shunt compensation.

- Purpose:

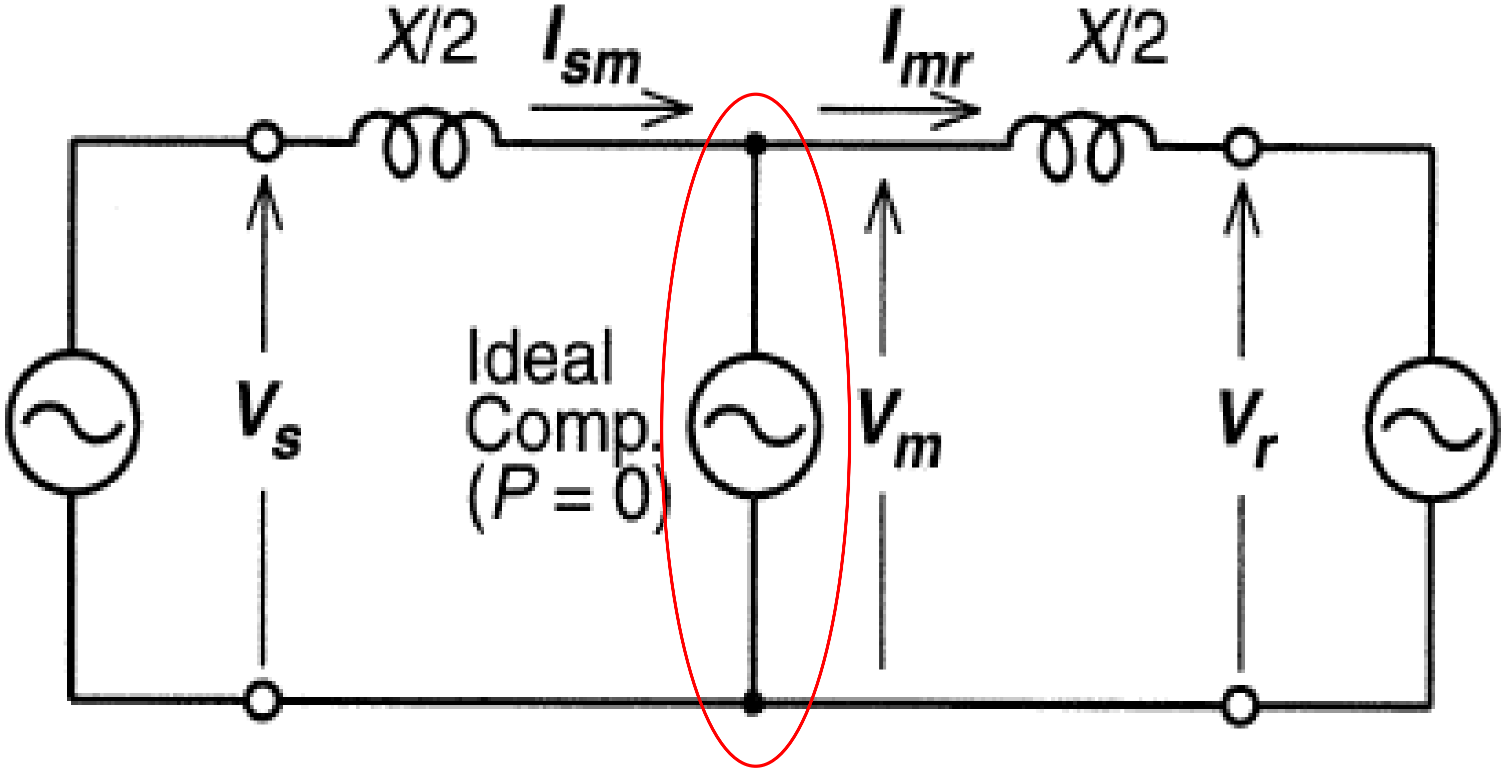
  To change the natural electrical characteristics of the transmission line to make it more compatible with the fundamental load demand.

# Objectives – Shunt Compensators

- Shunt connected, fixed or mechanically switched reactors are applied to minimize line overvoltage under light load conditions.
- Shunt connected, fixed or mechanically switched capacitors are applied to maintain voltage levels under heavy load conditions.
- Ultimate Objective of applying Shunt Compensation in a transmission system is to increase the transmittable power. This is required to improve the steady state transmission characteristics as well as the stability of the system.

# Midpoint Voltage Reg. for Line Segmentation

Consider simple two-machine (two-bus) transmission model in which an ideal var compensator is shunt connected at the midpoint of the transmission line.

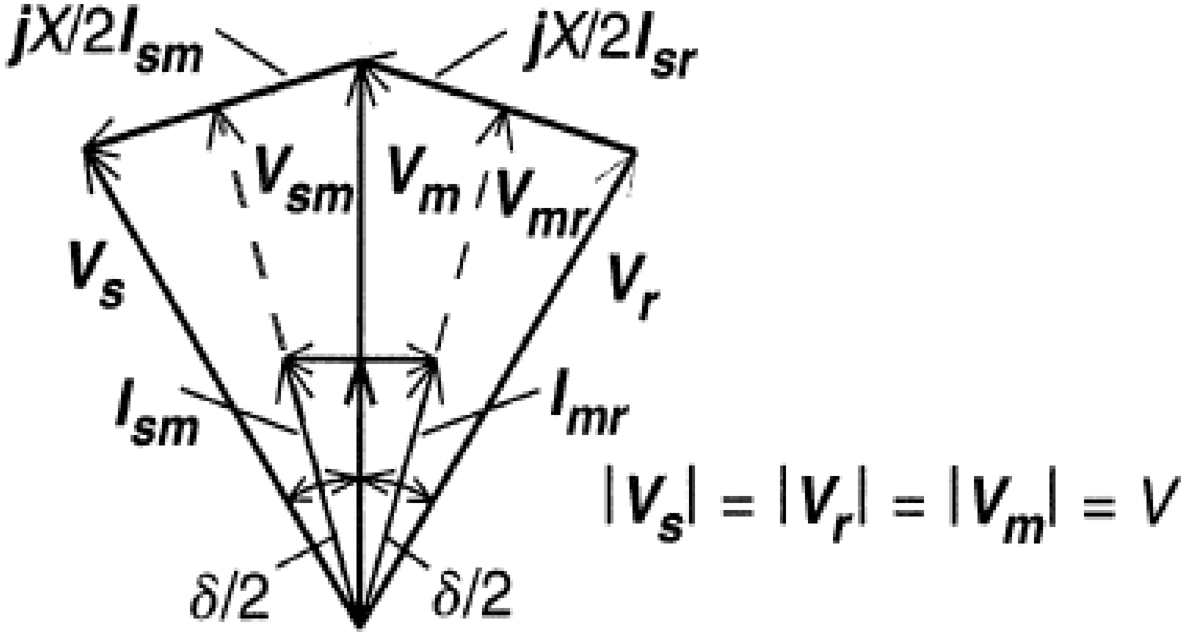


# Midpoint Voltage Reg. for Line Segmentation

- For simplicity, line is represented by the series line inductance.
- Compensator is represented by a sinusoidal AC voltage source, in-phase with the mid-point voltage $V_m$
- $V_m = V_s = V_r = V$ (amplitude identical)
- Total line is divide into two segments; first segment, with an impedance of X/2, carries power from the sending end to the midpoint, and the second segment, also with an impedance of X/2 carries power from the midpoint to the receiving end..

# Midpoint Voltage Reg. for Line Segmentation

- Relationship between voltages and line segment currents is shown in phasor diagram.



# Midpoint Voltage Reg. for Line Segmentation

- Midpoint var compensator exchanges only reactive power with the transmission line in this process.
- For the lossless system assumed, the real power is the same at each terminal of the line, and it can be derived readily from the phasor

$$V_{sm} = V_{mr} = V \cos\frac{\delta}{4}$$

$$I_{sm} = I_{mr} = I = \frac{4V}{X} \sin\frac{\delta}{4}$$

# Midpoint Voltage Reg. for Line Segmentation

- Transmitted power is

$$P = V_{sm} I_{sm} = V_{mr} I_{mr} = VI\cos\frac{\delta}{4}$$

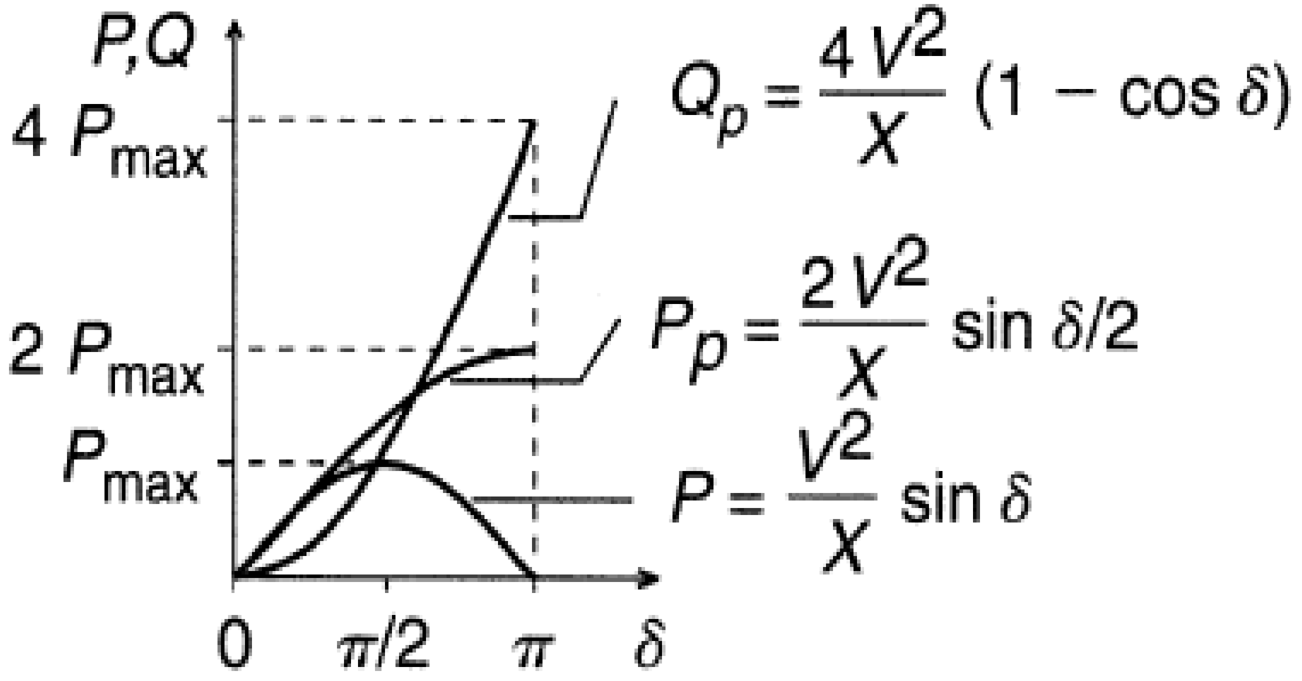
$$P = 2\frac{V^2}{X}\sin\frac{\delta}{2}$$

- Similarly

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

# Midpoint Voltage Reg. for Line Segmentation

- Relationship between real power P, reactive power Q and angle δ for the case of ideal shunt compensation is shown.



# Midpoint Voltage Reg. for Line Segmentation

- It can be observed that the midpoint shunt compensation can significantly increase the transmittable power (doubling its maximum value) at the expense of a rapidly increasing reactive power demand on the midpoint compensator.

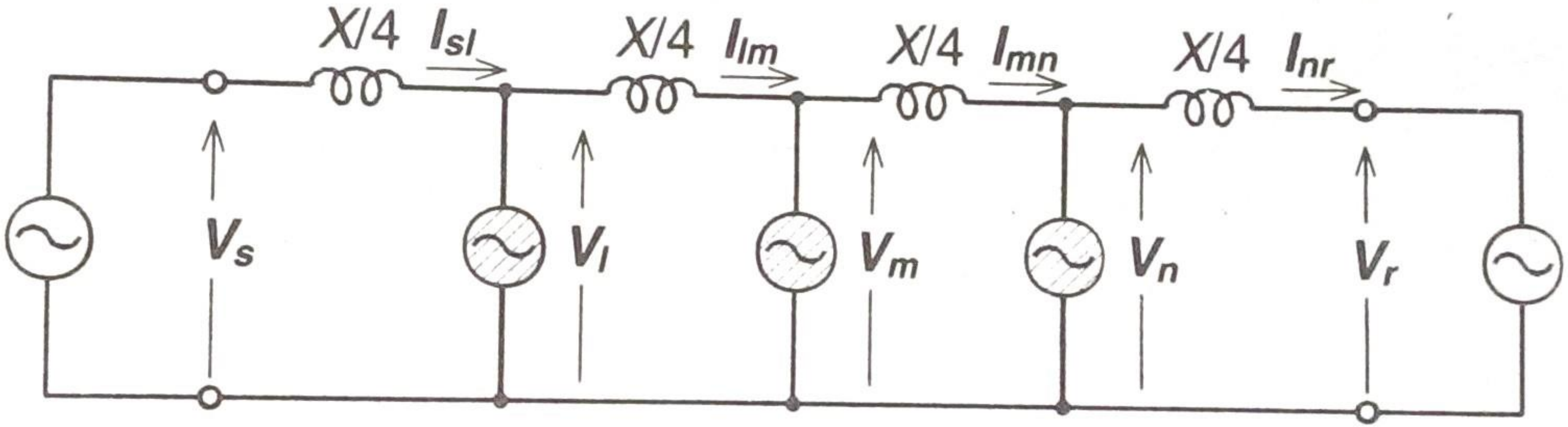
# Midpoint Voltage Reg. for Line Segmentation

- It is also evident that for the single line system of two machine model, the midpoint of the transmission line is the best location for the compensator.

- This is because the voltage sag along the uncompensated transmission line is the largest at the mid point. Also, the compensation at the midpoint breaks the transmission line into two equal segments for each of which the maximum transmittable power is the same.

# Midpoint Voltage Reg. for Line Segmentation

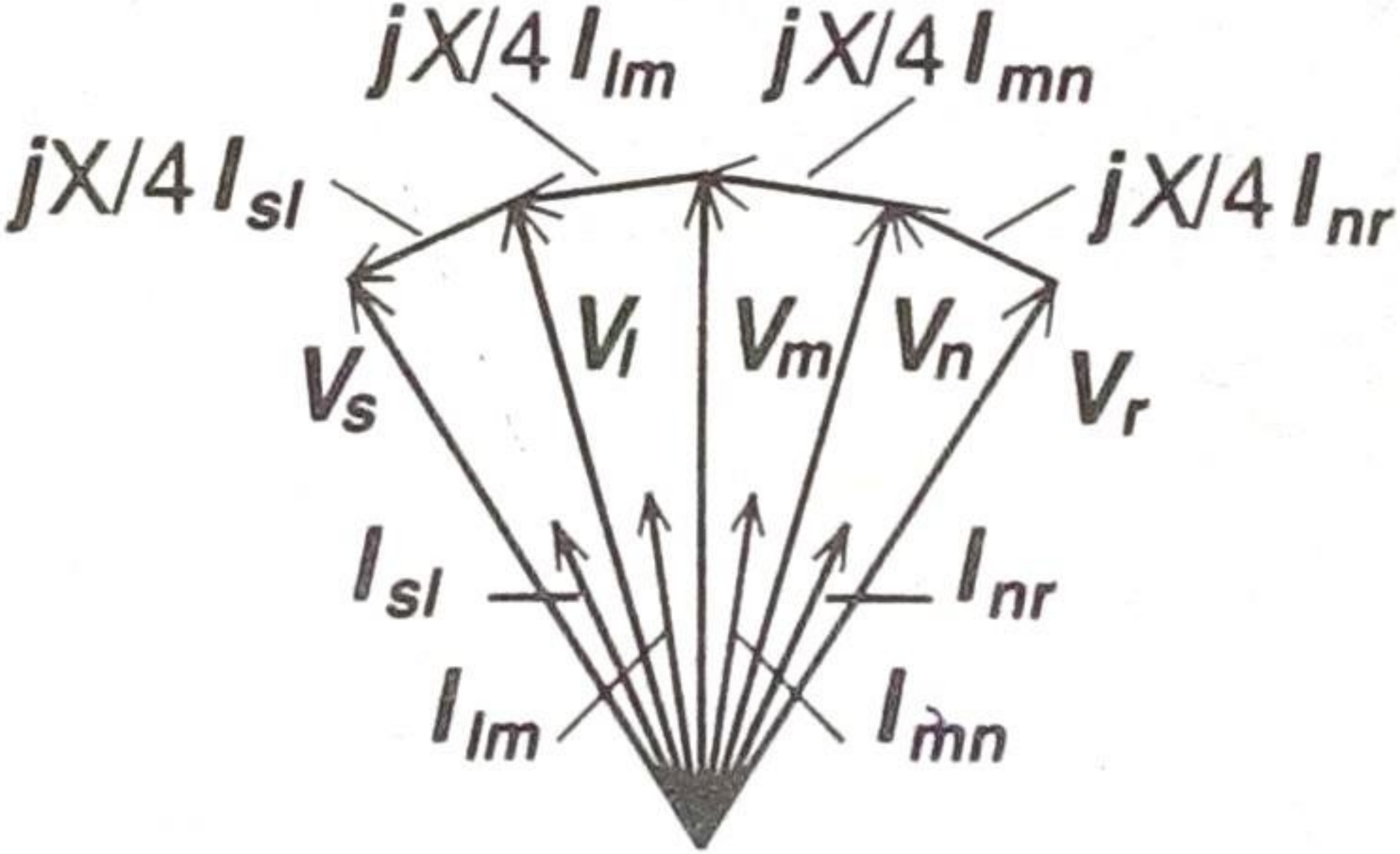
- The concept of transmission line segmentation can be expanded to the use of multiple compensators, located at equal segments of the transmission line, as shown in fig. for 4 line segment.



# Midpoint Voltage Reg. for Line Segmentation

- Theoretically, the transmittable power would double with each doubling of the segments for the same overall line length. Further more, with the increase of the number of segments, the voltage variation along the line would rapidly decrease, approaching the ideal case of constant voltage profile.

# Midpoint Voltage Reg. for Line Segmentation

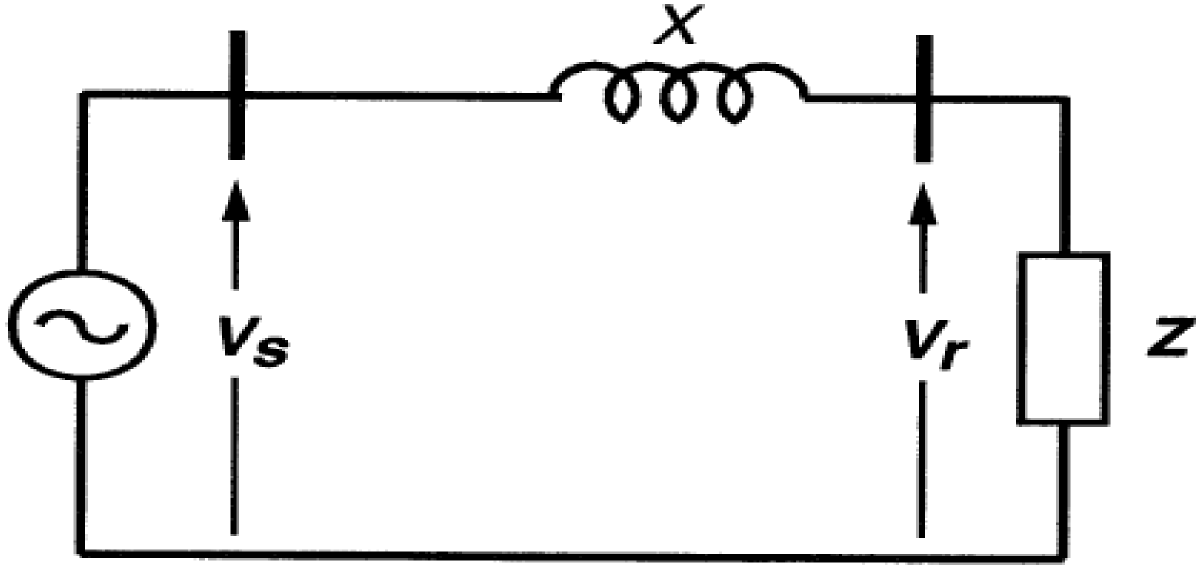


# End of Line Vg. Support to Prevent Vg. Instability

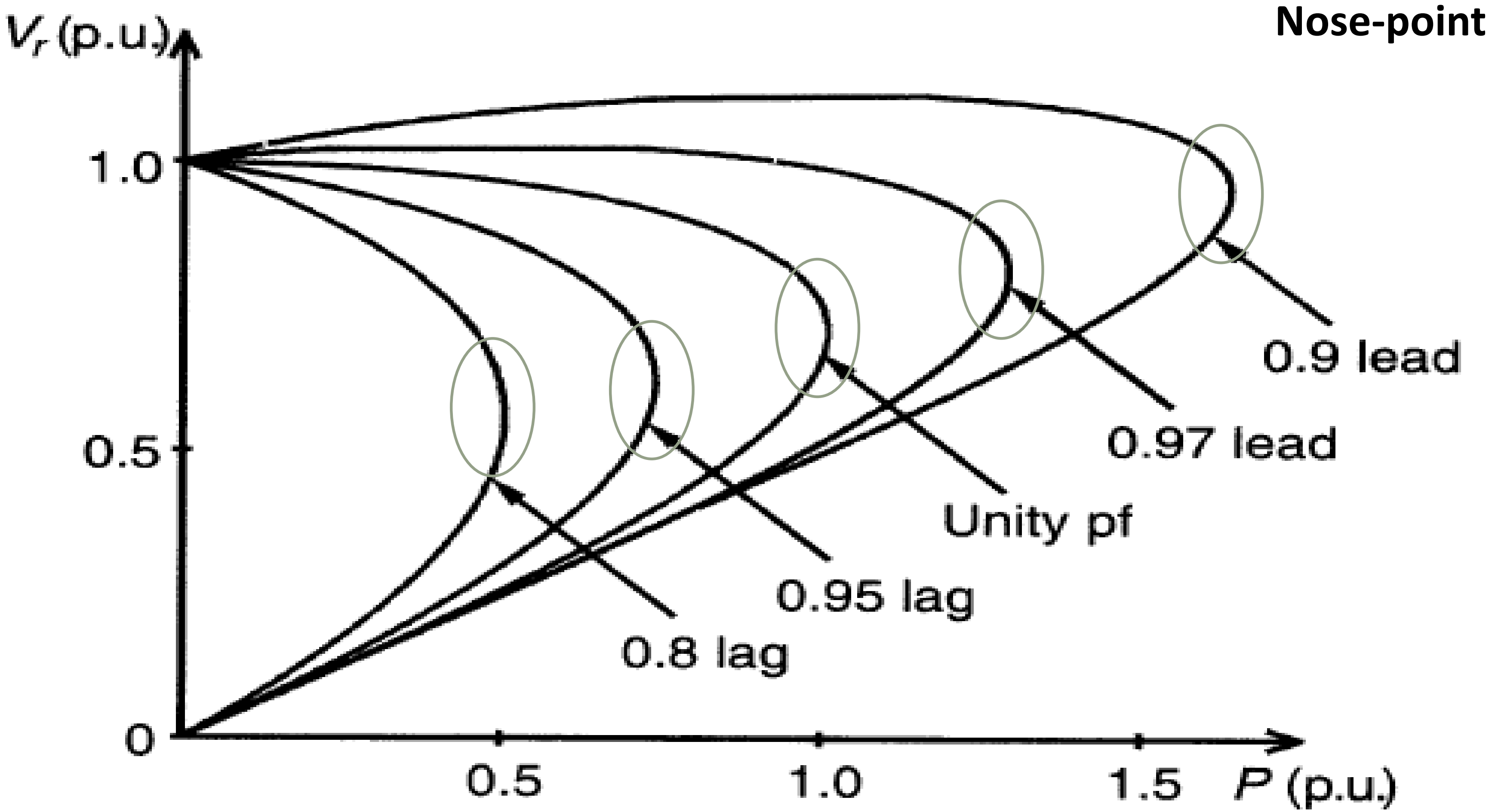
- If a passive load, consuming power ‘P’ at voltage ‘V’, is connected to the midpoint in place of the receiving-end part of the system, the sending end generator with the X/2 impedance and load would represent a simple radial system.
- Clearly, without compensation the voltage at the midpoint would vary with the load (and load power factor).

# End of Line Vg. Support to Prevent Vg. Instability

- A simple radial system with feeder line reactance of X and load impedance Z, is shown together with the normalized terminal voltage $V_r$ vs power 'P' plot at various power factors, ranging from 0.8 lag and 0.9 lead.



# End of Line Vg. Support to Prevent Vg. Instability

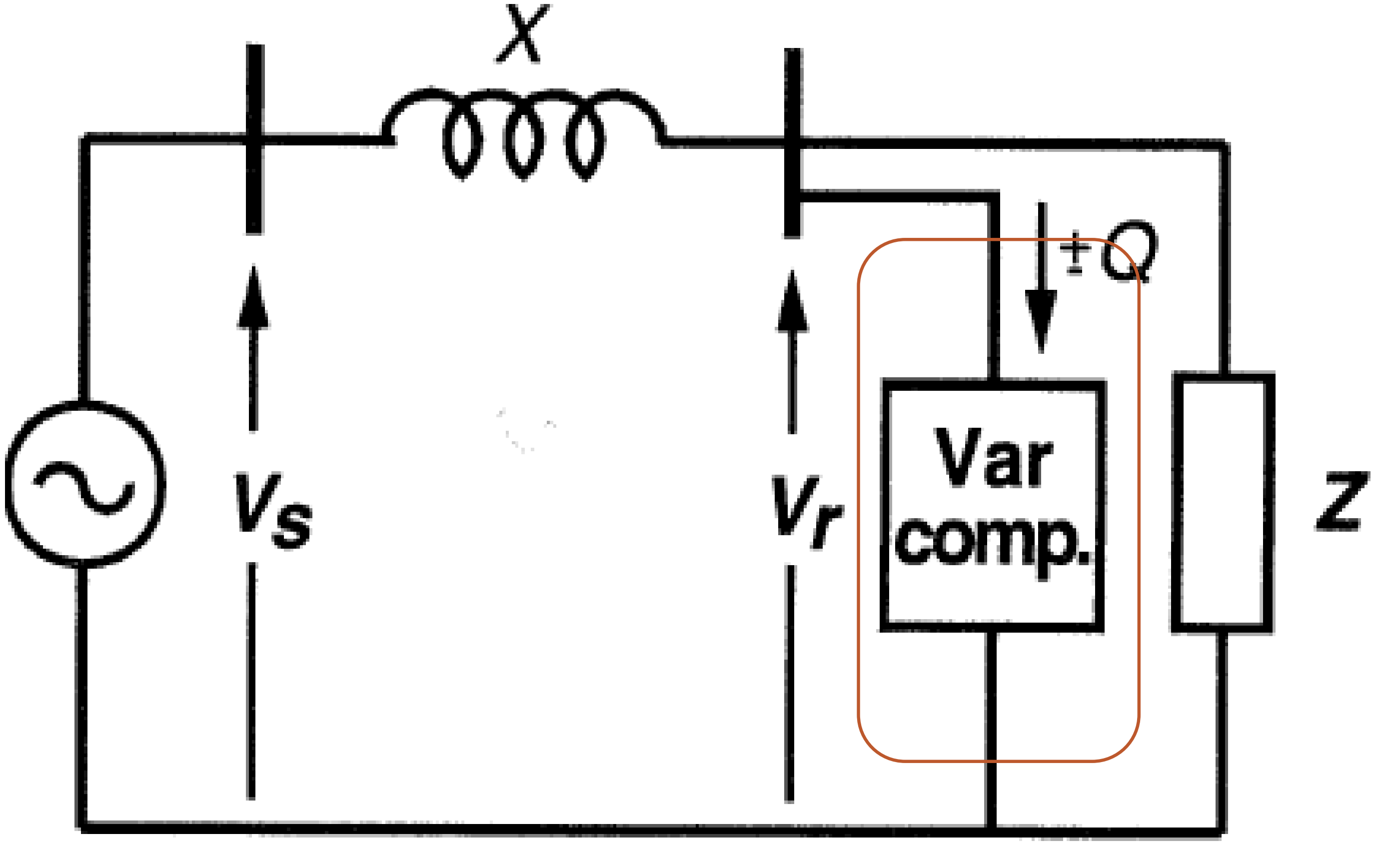


# End of Line Vg. Support to Prevent Vg. Instability

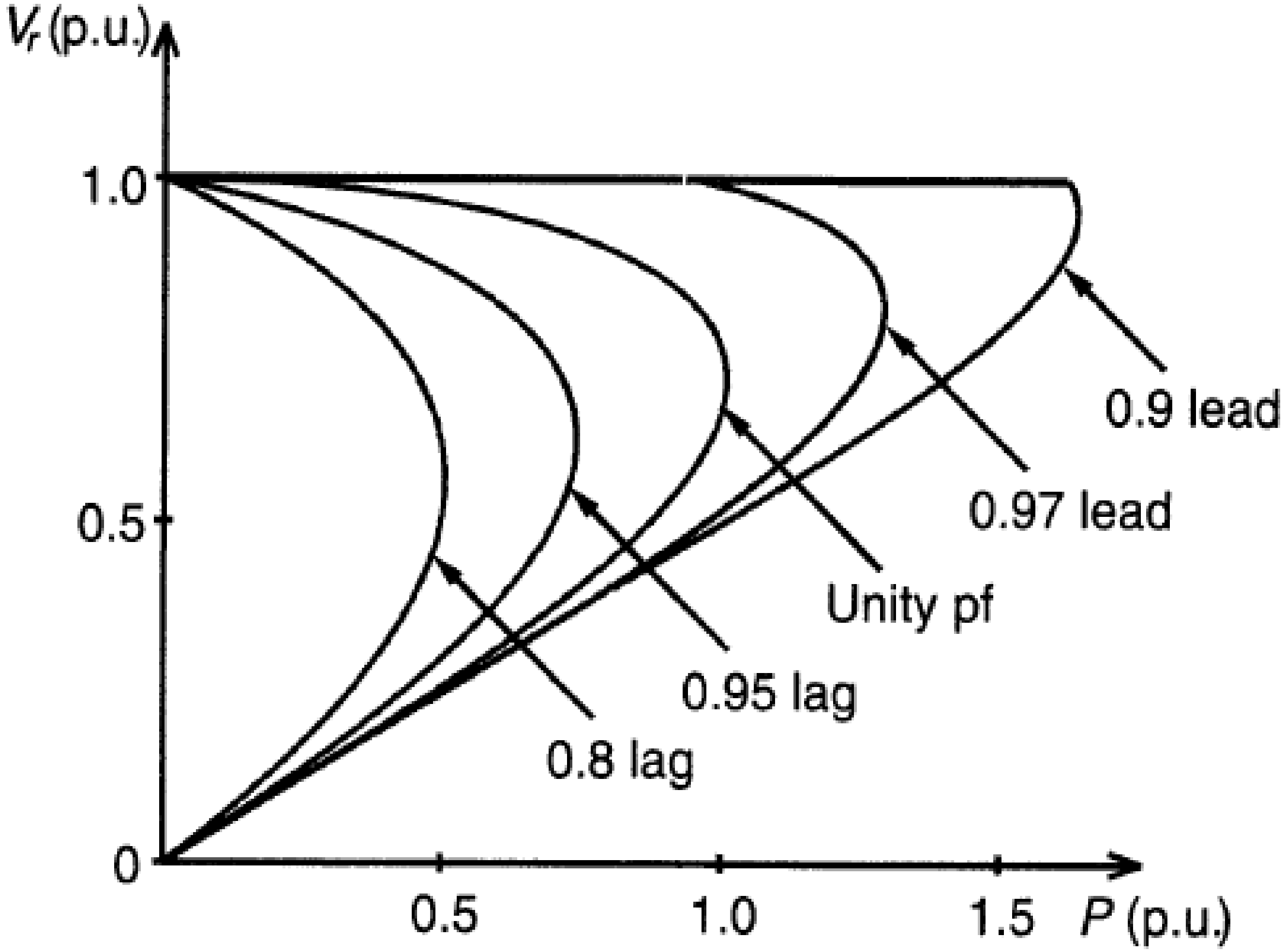
- The ‘nose-point’ at each plot given for a specific power factor represents the voltage instability corresponding to that system condition.

- It should be noted that the voltage stability limit decreases with inductive loads and increases with capacitive loads.

# End of Line Vg. Support to Prevent Vg. Instability



# End of Line Vg. Support to Prevent Vg. Instability



# End of Line Vg. Support to Prevent Vg. Instability

- From the graph, it clearly indicates that shunt reactive compensation can effectively increase the voltage stability limit by supplying the reactive load and regulating the terminal voltage ($V-V_r=0$).

- It is evident that for a radial line, the end of the line, where the largest voltage variation is experienced, is the best location for the compensator.

# End of Line Vg. Support to Prevent Vg. Instability

- Reactive shunt compensation is often used in practical applications to regulate the voltage at a given bus against load variations, or to provide voltage support for the load when, due to generation or line outages, the capacity of the sending end system becomes impaired.

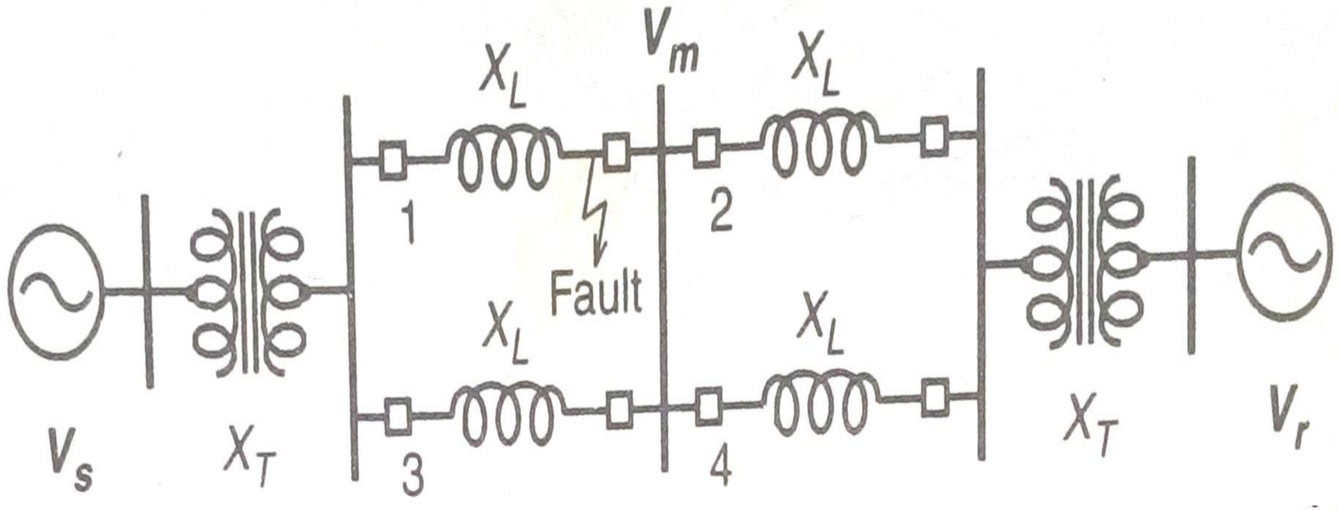
- The loss of one of the power sources could suddenly increase the load demand on the remaining part of the system, causing severe voltage depression that could result in an ultimate voltage collapse.

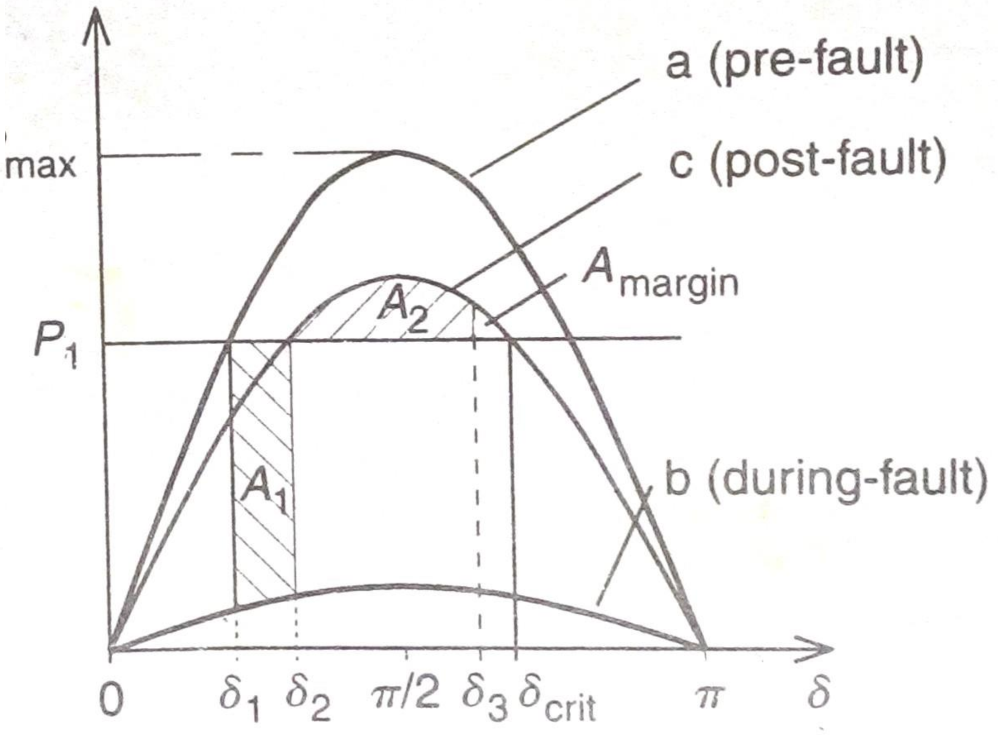
# Improvement of Transient Stability

- It is reasonable to expect that, with suitable and fast controls, shunt compensation will be able to change the power flow in the system during and following dynamic disturbance so as to increase the transient stability limit and provide effective power oscillation damping.

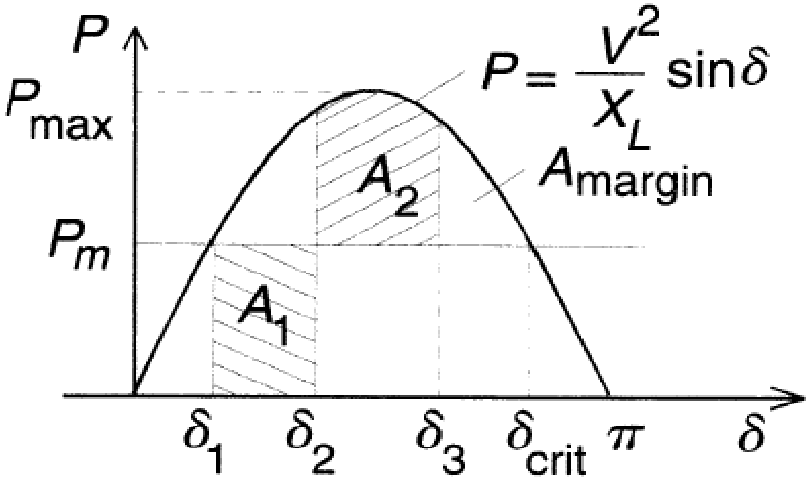
- The potential effectiveness of shunt on transient stability improvement can be conveniently evaluated by the equal area criterion.

# Improvement of Transient Stability

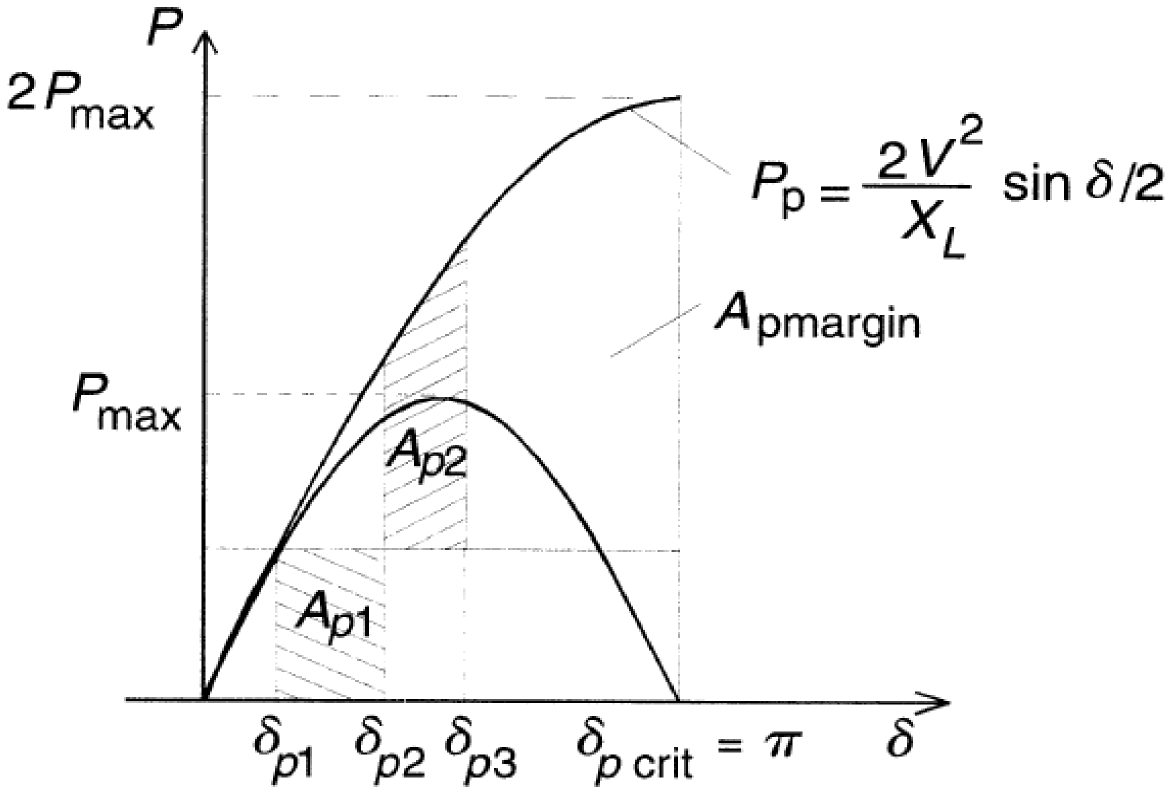




# Improvement of Transient Stability



(a)



(b)

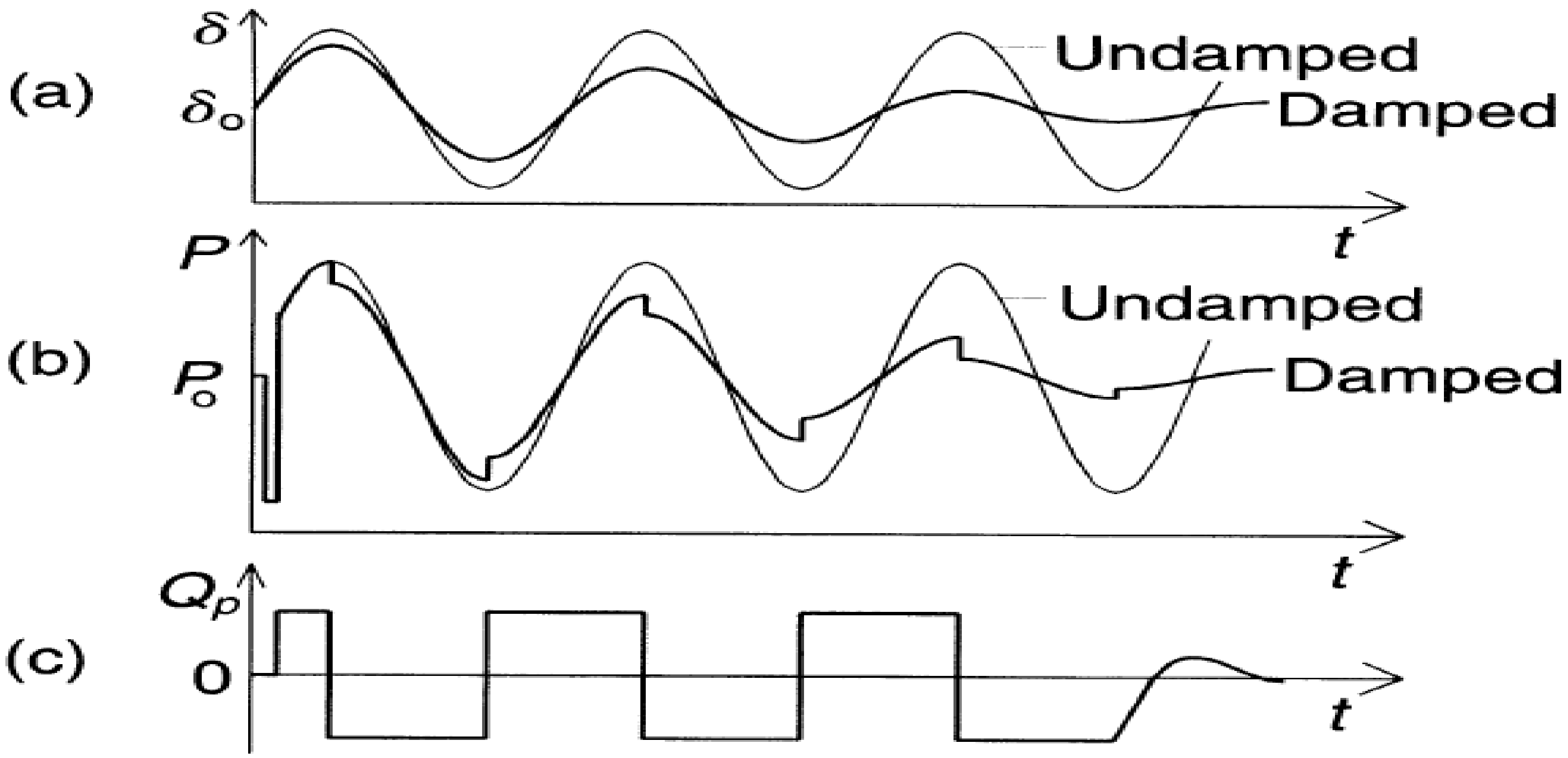
# Power Oscillation Damping

Lack of sufficient damping can be a major problem in a power system as it causes oscillations around the steady state value at the natural frequency.

Establishing the shunt compensation can counteract the acceleration and deceleration swings of the disturbed machines.

When machine accelerates, the electric power transmitted is increased to balance the excess mechanical power and conversely when machine decelerates, power transmitted is decreased to balance the insufficient mechanical power.

# Power Oscillation Damping



Waveforms illustrating power oscillation damping by reactive shunt compensation.

Figure (a), Generator angle
Figure(b), transmitted power
Figure (c), VAr output of the shunt compensator.

The damped and undamped oscillations of $\delta$ and $P$ are oscillated around their steady state values $\delta 0$ and $P0$.

The positive output of compensator (figure c) increases the midpoint voltage when machine accelerates and decrease the midpoint voltage when machine decelerates.

This illustration shows, the VAr output is controlled in a “bang-bang” manner.

# Compensator Requirements

The compensator must stay in synchronous operation with the ac system at the compensated bus under all operating conditions including major disturbances.

If the bus voltage be lost temporarily due to nearby faults, the compensator must be able to recapture synchronism immediately at fault clearing.

The compensator must be able to regulate the bus voltage for voltage support and improved transient stability, or control it for power oscillation damping and transient stability enhancement, on a priority basis as system conditions may require.

For a transmission line connecting two systems, the best location for var compensation is in the middle, whereas for a radial feed to a load the best location is at the load end.

# *Thank you!*

# FACTS

## (Flexible AC Transmission Systems)

## Unit - 3

## Var Generation

## Contents:

Variable impedance type static Var generators: Thyristor Controlled and Thyristor Switched Reactor(TCR and TSR), Thyristor Switched Capacitor(TSC)

Fixed Capacitor Thyristor Controlled Reactor Var Generator: Thyristor Switched Capacitor-Thyristor Controlled Reactor

Switching converter type var generators, Hybrid Var generators

# VARIABLE IMPEDANCE TYPE STATIC VAR GENERATORS

- The performance and operating characteristics of the impedance type var generators are determined by their major thyristor-controlled constituents:
- The thyristor controlled reactor and the Thyristor-Switched Capacitor.

# TCR and TSR

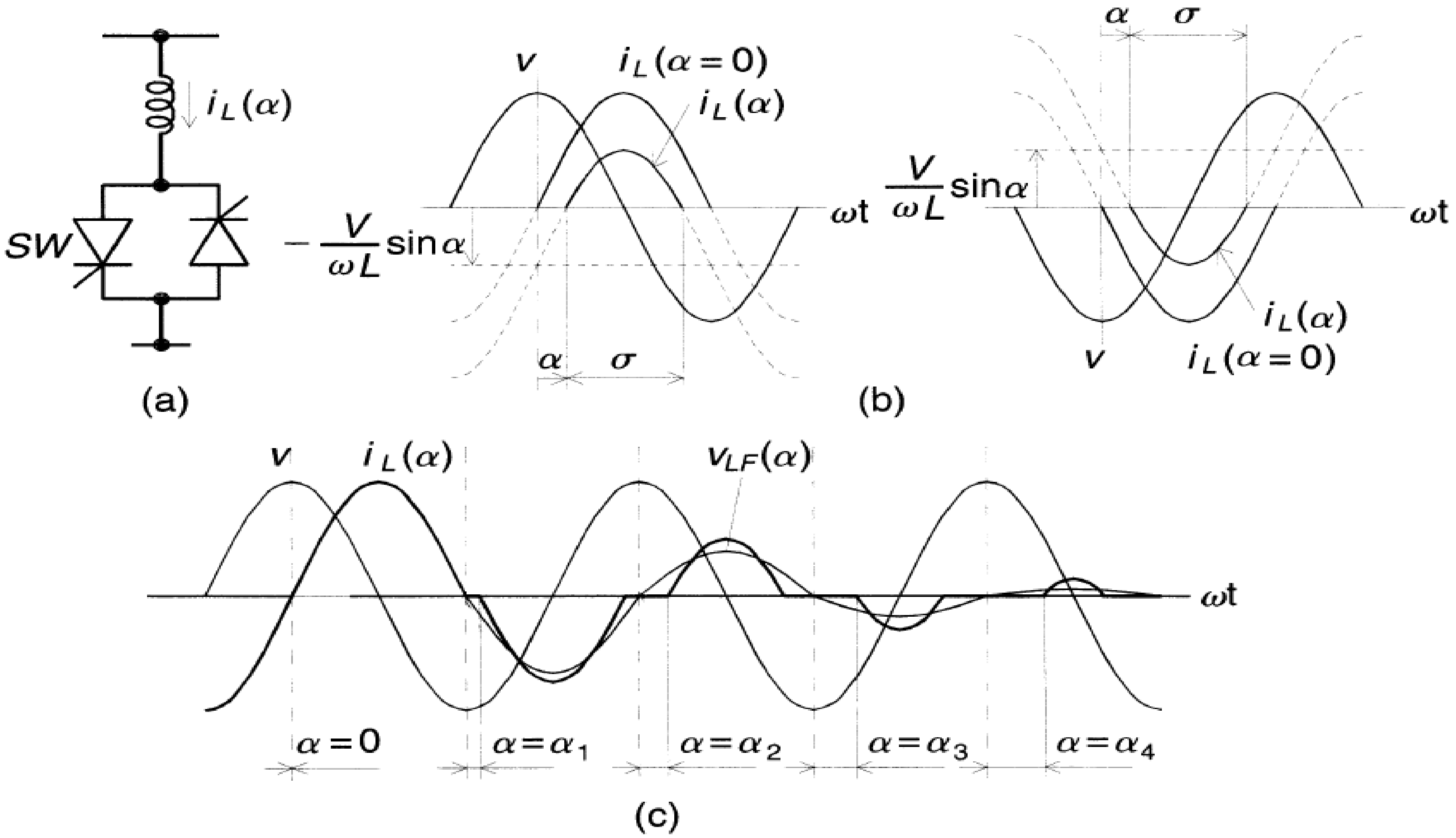
Thyristor-Controlled Reactor Consists of a reactor of Inductance L and a bidirectional thyristor valve (or switch) sw.

A thyristor valve can be brought into conduction by application of a gate pulse to thyristor. The valve will automatically block immediately after the ac current crosses zero, unless the gate signal is reapplied.

The current in the reactor can be controlled from maximum to zero by the method of firing delay angle control. When the gating of the valve is delayed by an angle α (0<=α<=90) with respect to the crest of the voltage, the current in the reactor can be expressed with V(t)=V cosωt as follows:

$$i_L(t) = \frac{1}{L}\int_{\alpha}^{\omega t} v(t)\, dt = \frac{V}{\omega L}(\sin \omega t - \sin \alpha)$$

The thyristor valve opens as the current reaches zero, is valid for the interval ($\alpha <= \omega t <= \pi-\alpha$). Fig a shows basic thyristor controlled reactor, b shows firing delay angle control and c shows the operating waveforms.



(a) (b)

(c)

Since the valve automatically turns off at the instant of current zero crossing this process actually controls the conduction interval (or angle) of the thyristor.

the delay angle σ defines the prevailing conduction angle σ. Thus, as the delay angle α increases, the correspondingly it results in the reduction of the conduction angle the valve σ.

here, $\sigma = \pi - 2\alpha$

At the maximum delay of $\alpha = \pi/2$, the offset also reaches its maximum of $V/\omega L$, at which both the conduction angle and the reactor current become zero.

the magnitude of the current in the reactor can be varied continuously by this method of delay angle control from maximum ($\alpha = 0$) to zero ($\alpha = \pi/2$).

Adjustment of current in the reactor can takes place for every half cycle only.

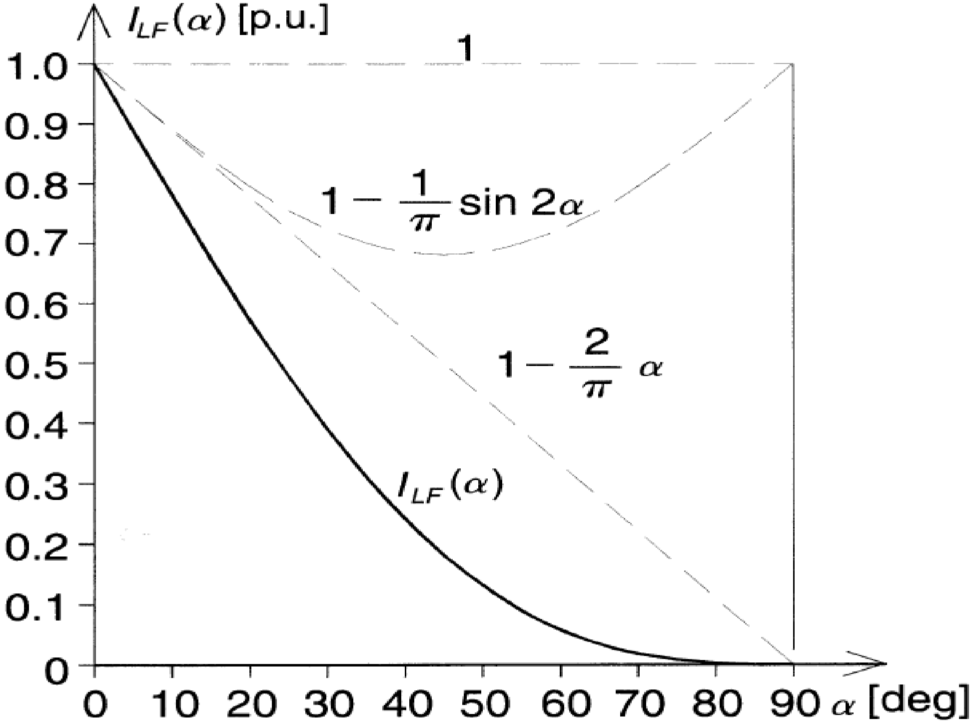
The amplitude of the fundamental reactor current $I_{lf}(\alpha)$ can be expressed as a function of angle α

$$I_{LF}(\alpha) = \frac{V}{\omega L}\left(1 - \frac{2}{\pi}\alpha - \frac{1}{\pi}\sin 2\alpha\right)$$

TCR can control the fundamental current continuously from to maximum as if it was a variable reactive admittance. Thus, an effective reactive admittance, $B_L(\alpha)$, for the TCR can be defined as

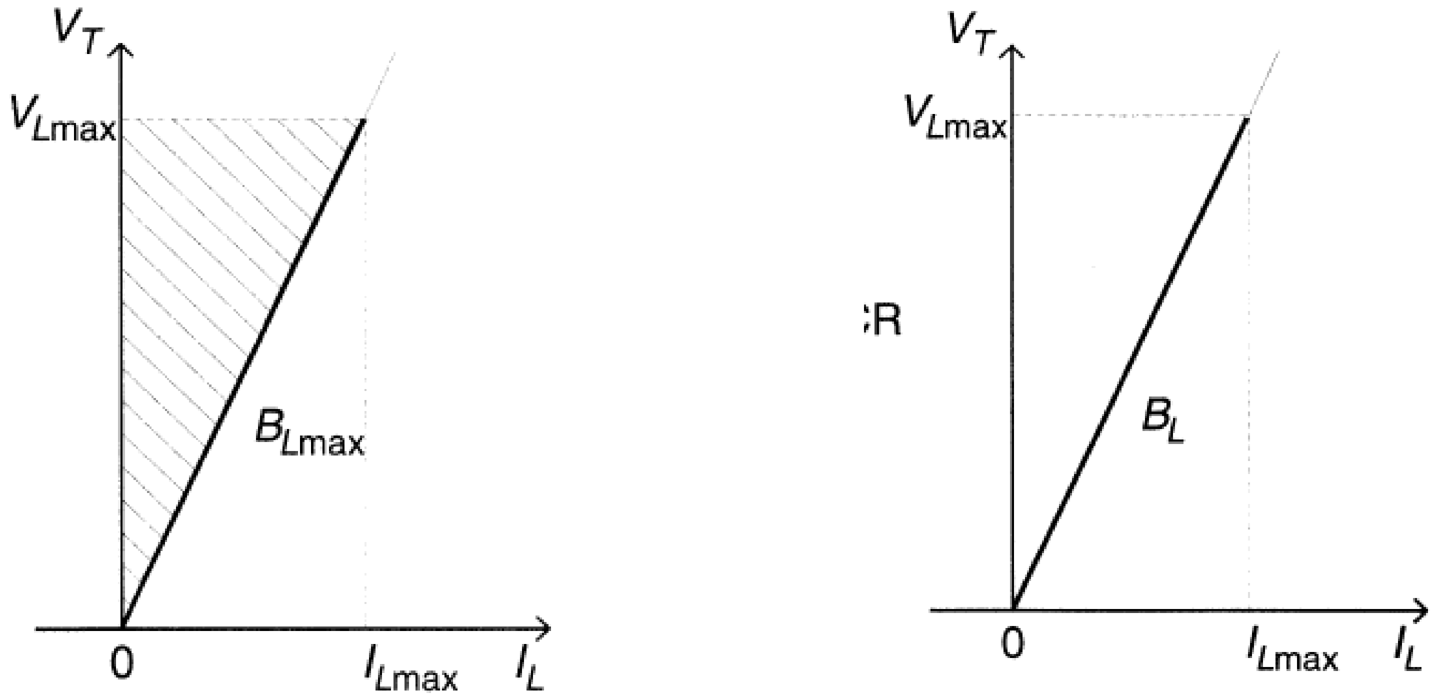
$$B_L(\alpha) = \frac{1}{\omega L}\left(1 - \frac{2}{\pi}\alpha - \frac{1}{\pi}\sin 2\alpha\right)$$

Amplitude variation of fundamental current component with delay angle is shown in figure below.



If the TCR switching is restricted to a fixed delay angle, usually $\alpha = 0$, then it becomes a thyristor-switched reactor (TSR).

TCR can be operated anywhere in a defined V-I area, the boundaries of which are determined by its maximum attainable admittance, voltage, and current ratings.



Operating V-I area of TCR and TSR

# THYRISTOR-SWITCHED CAPACITOR

It consists of a capacitor, a bidirectional thyristor valve, and a relatively small surge current limiting reactor.

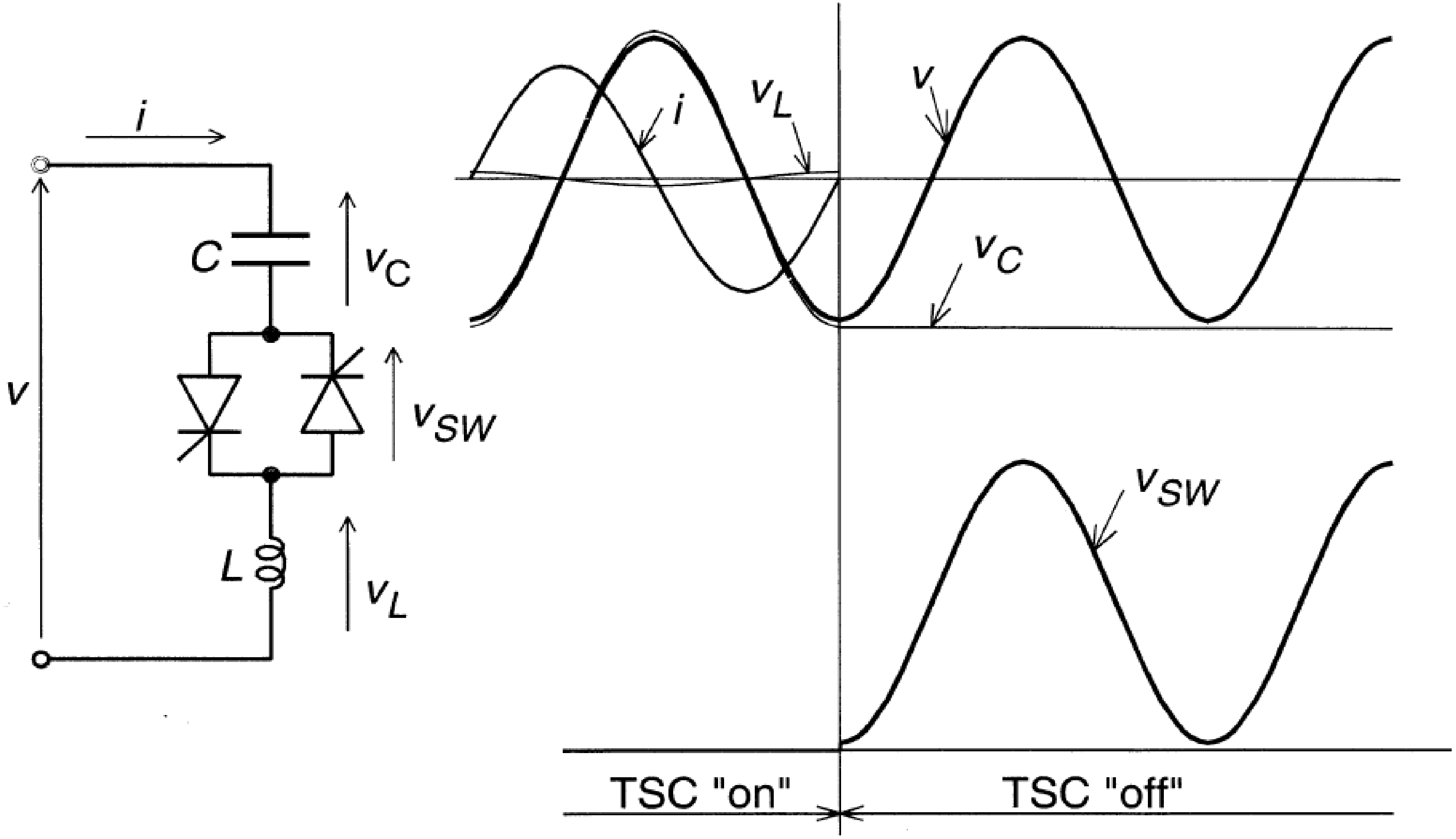
Under steady-state conditions, when the thyristor valve is closed and the TSC

branch is connected to a sinusoidal ac voltage source, the current in the branch is given by

$$i(\omega t) = V \frac{n^2}{n^2 - 1} \omega C \cos \omega t$$

where,

$$n = \frac{1}{\sqrt{\omega^2 LC}} = \sqrt{\frac{X_C}{X_L}}$$



Circuit diagram of TSC and corresponding waveforms

The TSC branch can be disconnected at any current zero by prior removal of the gate drive to the thyristor valve. At the current zero crossing, the capacitor voltage is shown in equation below.

$$V_c = \frac{n^2}{n^2 - 1} V$$

The disconnected capacitor stays charged to this voltage and consequently, the voltage across the non conducting thyristor valve varies between zero and the peak-to-peak value of the applied ac voltage as shown in the waveform.

If voltage across the disconnected capacitor remains unchanged, the TSC bank could be switched in again, without any transient, at the appropriate peak of the applied ac voltage, as illustrated for a positively and negatively charged capacitor in figure (a)and (b) below.

Normally, the capacitor bank is discharged after disconnection. Thus, the reconnection of the capacitor may have to be executed at some residual capacitor voltage.

The transient disturbance can be minimized by switching in TSC when capacitor residual voltage and ac voltage are equal.

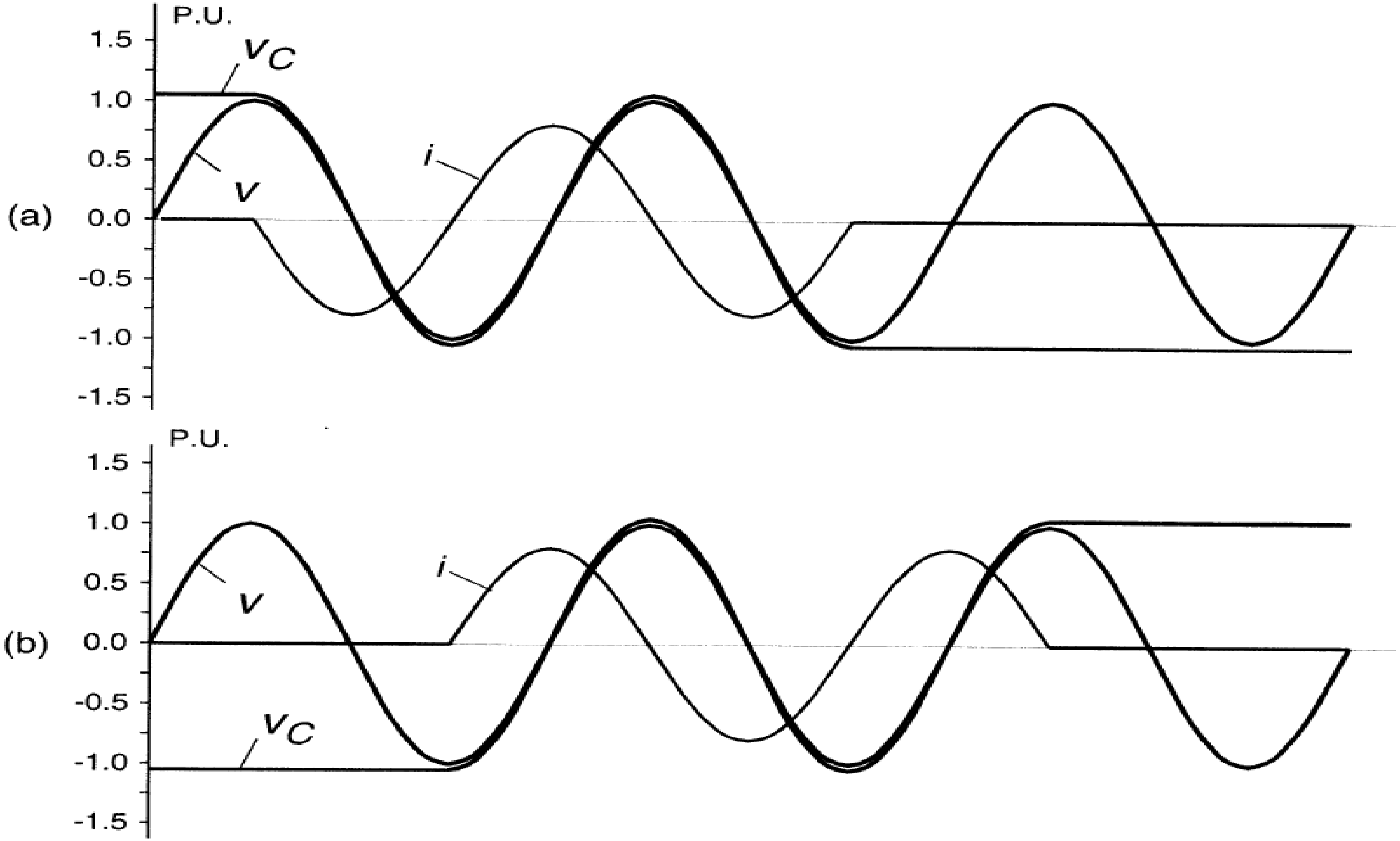
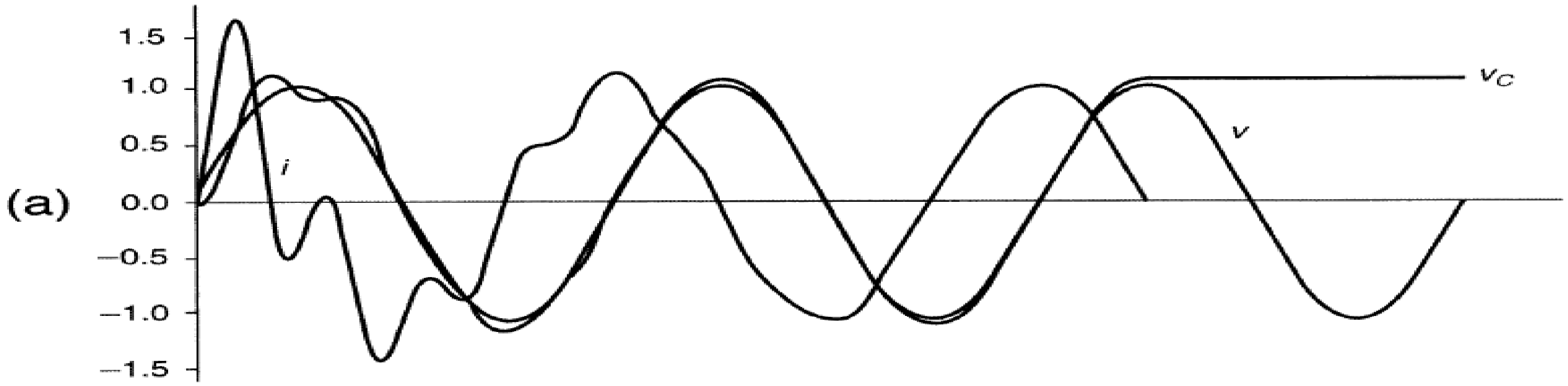
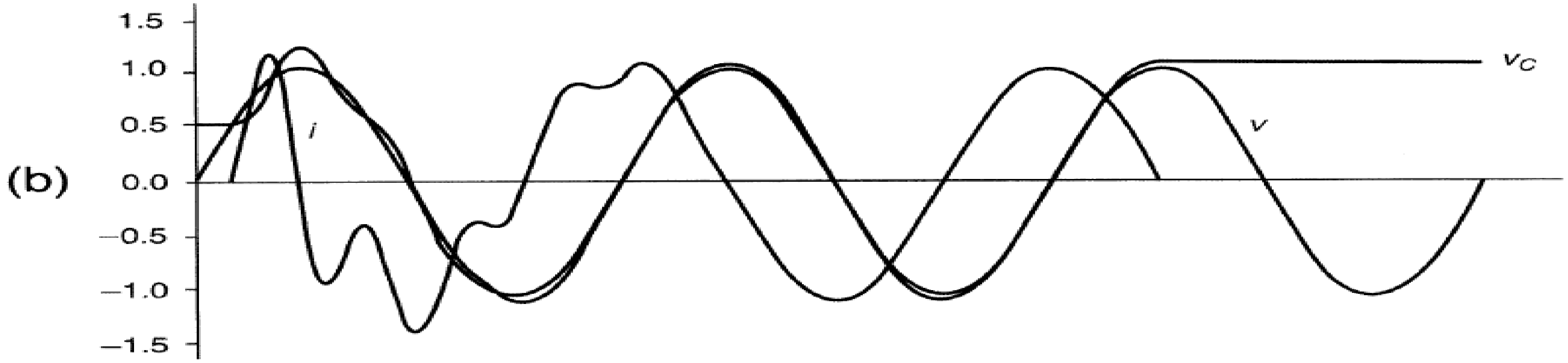


Figure below shows switching transients obtained with fully and partially discharged Capacitor.

P.U. (a) Capacitor fully discharged



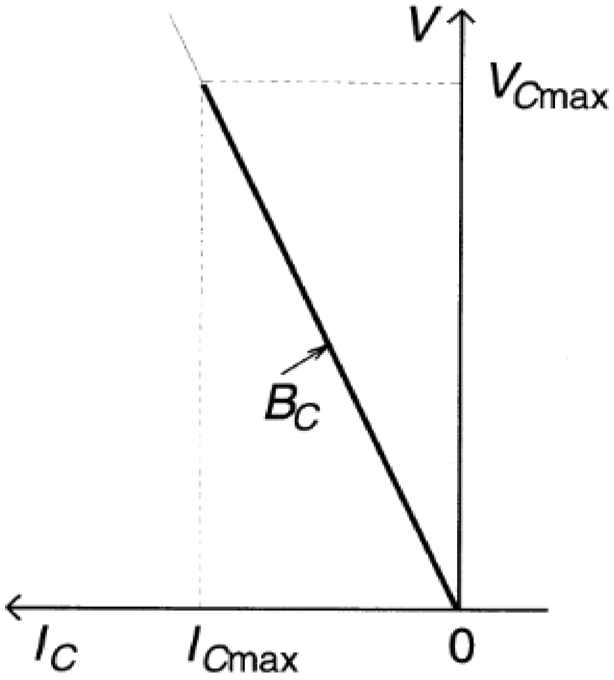
P.U. (b) Initial capacitor charge of 0.5 p.u.



firing delay angle control is not applicable to capacitors; the capacitor switching must take place at that specific instant in each cycle at which the conditions for minimum transients are satisfied.

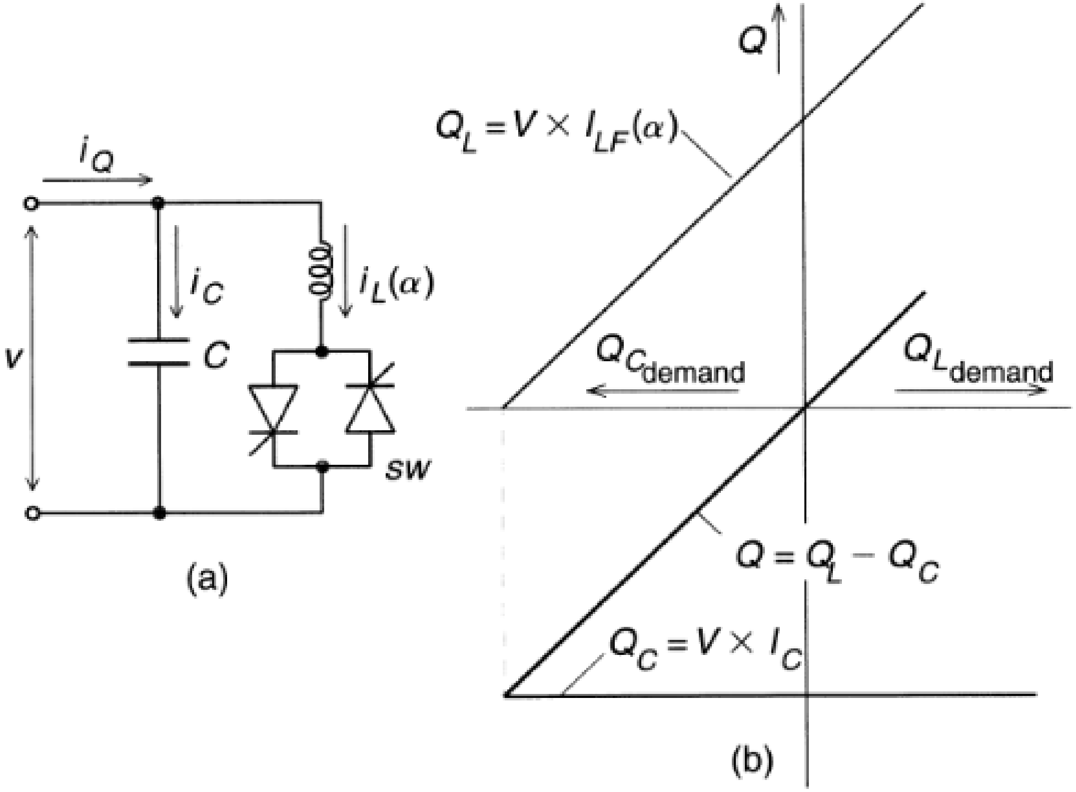
TSC branch can provide only a stepJike change in the reactive current it draws (maximum or zero).

The operating V-I area of single TSC is shown below.



# FIXED CAPACITOR-THYRISTOR CONTROLLED REACTOR

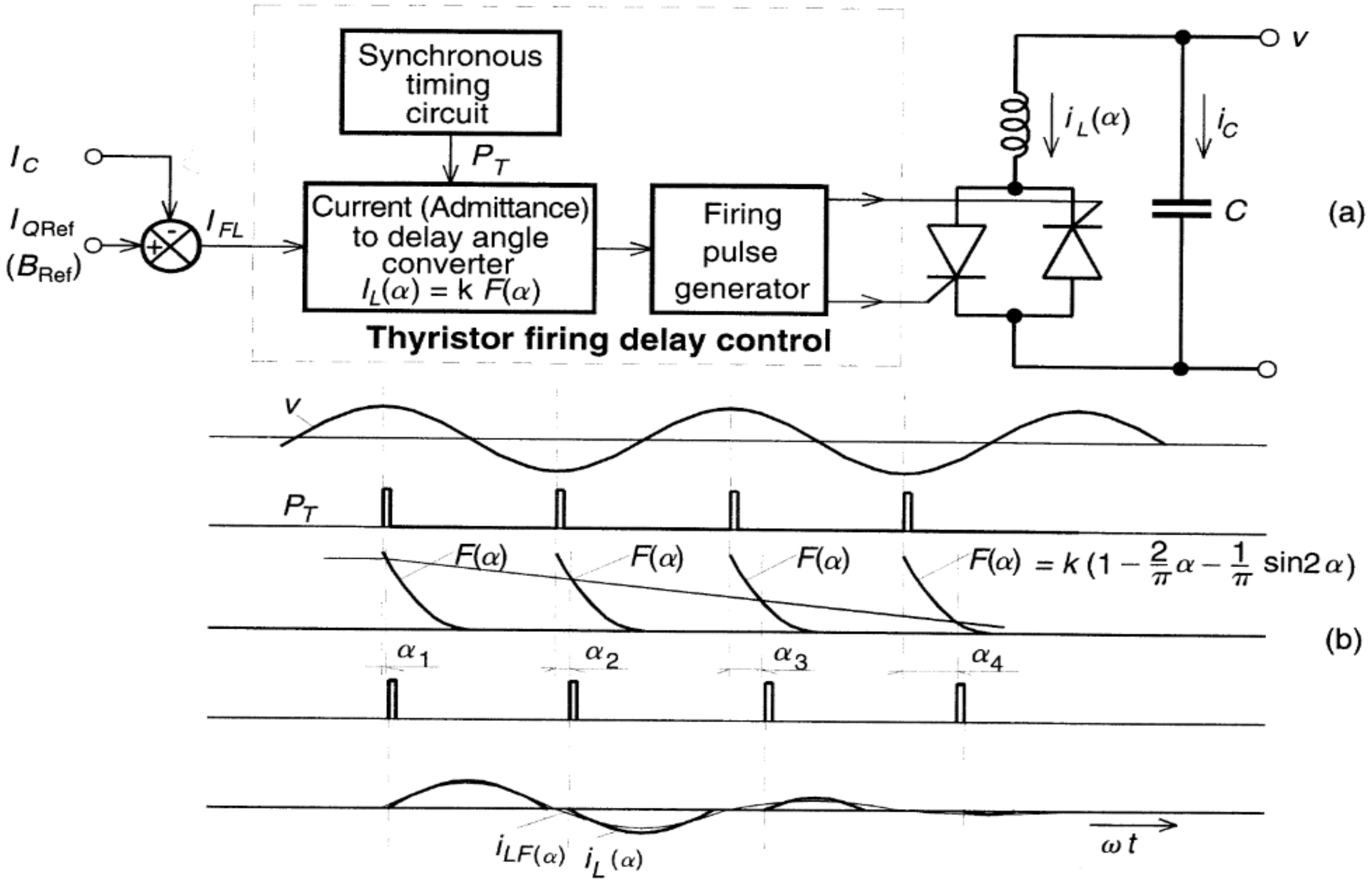
FC-TCR type var generator may be considered to consist of a variable reactor (controlled by delay angle α) and a fixed capacitor, with an overall var demand versus var output characteristic as shown in Figure below. (a) is basic FC-TCR and (b) is var demand vs var output characteristics.



(a)

(b)

The control of the thyristor-controlled reactor in the FC-TCR type var generator needs to provide four basic functions, as shown in figure below



Functional control scheme of FC-TCR and its corresponding waveforms

One function is **synchronous timing**. This function is usually provided by a phase locked loop circuit that runs in synchronism with the ac system voltage and generates appropriate timing pulses with respect to the peak of that voltage.

The second function is the **reactive current (or admittance) to firing angle conversion**. This can be provided by a real time circuit implementation of the mathematical relationship between the amplitude of the fundamental TCR current $I_{LF}(\alpha)$ and the delay angle $\alpha$.

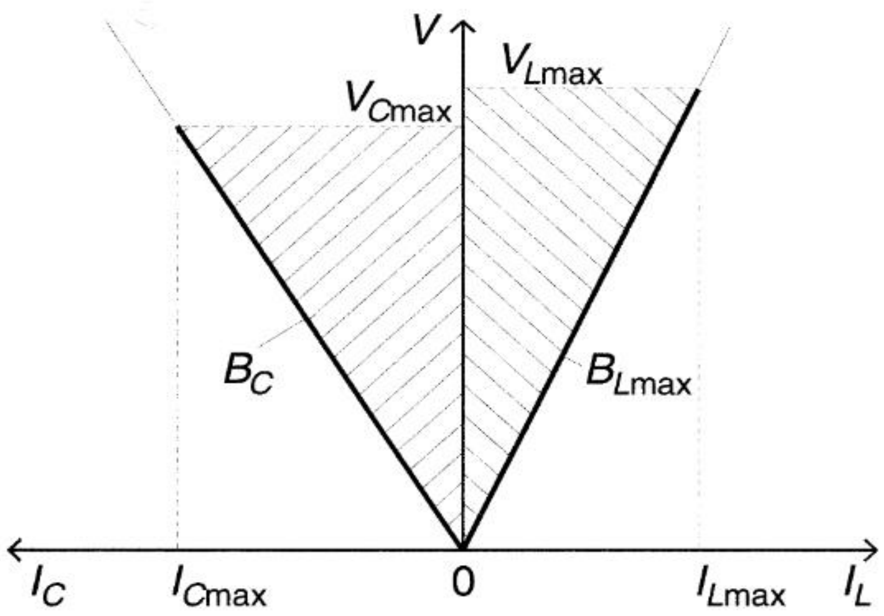
The third function is the **computation of the required fundamental reactor current $I_{FL}$**, from the requested total output current $I_Q$ (sum of the fixed capacitor and the TCR currents) defined by the amplitude reference input $I_{Qref}$ to the var generator control.

The fourth function is the **thyristor firing pulse generation**. This is accomplished by the firing pulse generator (or gate drive) circuit which produces the necessary gate current pulse for the thyristors to turn on in response to the output signal provided by the reactive current to flring angle converter.

The dynamic performance (e.g., the frequency band) of the var generator is limited by the firing angle delay control, which results in a time lag or transport lag with respect to the input reference signal. The actual transfer function of the FC-TCR type var generator can be expressed with the transport lag is

$$G(s) = ke^{-T_d S}$$

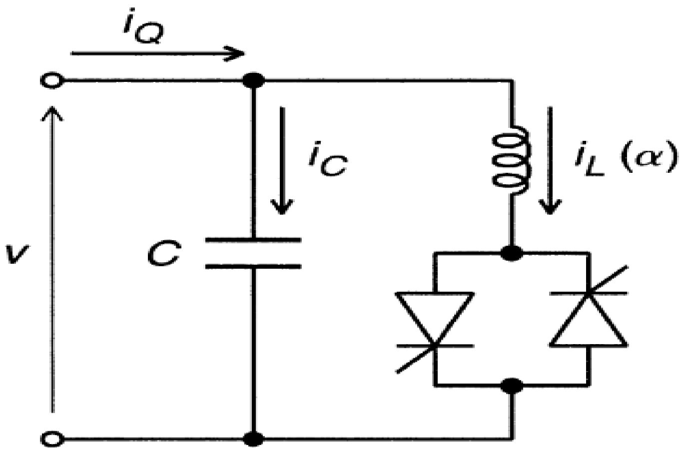
Operating V-I area of FC-TCR is shown below.

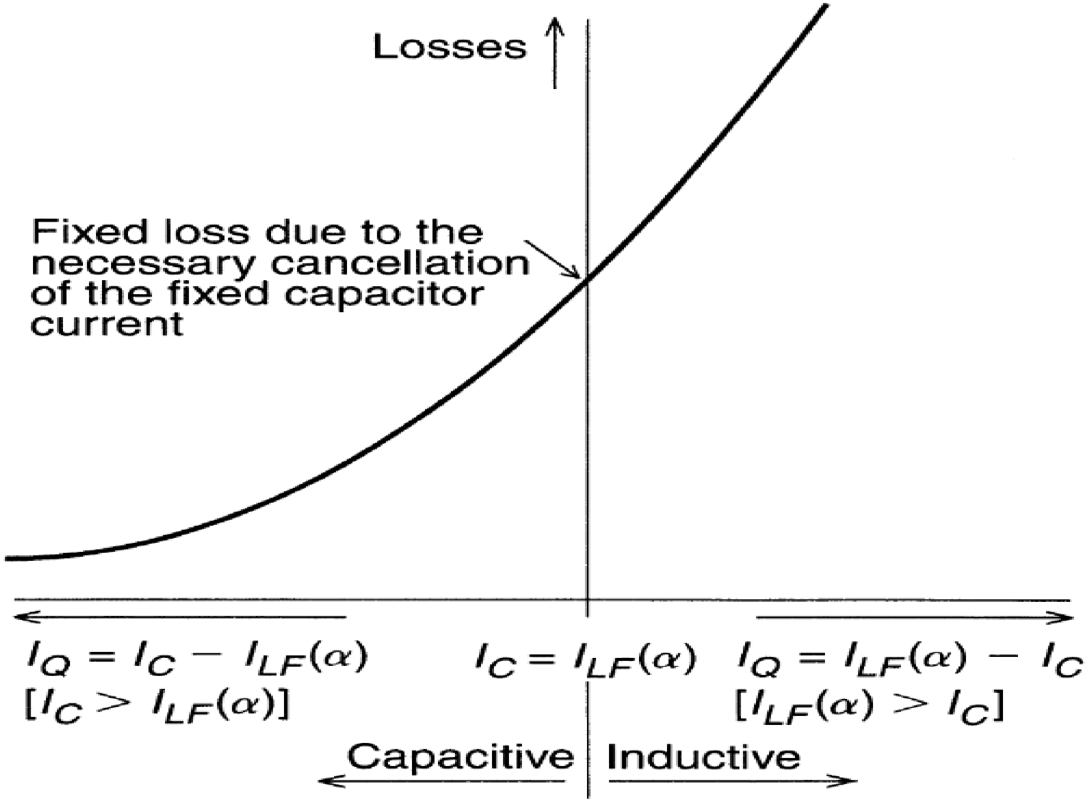


# THYRISTOR SWITCHED CAPACITOR-THYRISTOR CONTROLLED REACTOR

It is developed for dynamic compensation of transmission lines.

A basic single phase TSC-TSR is shown below along with loss vs var output characteristics.



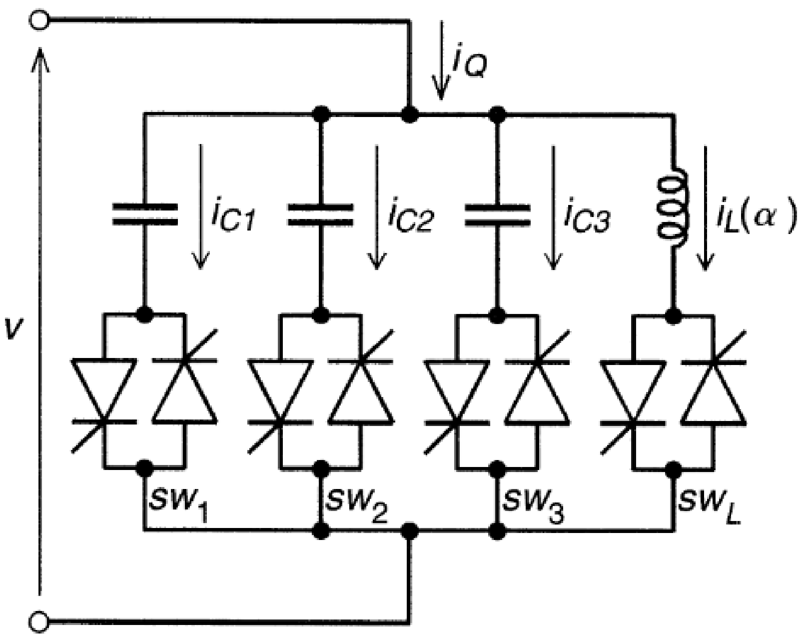


The number of branches, n, is determined by practical considerations that include the operating voltage level, maximum var output, current rating of the thyristor valves, bus work and installation cost etc.

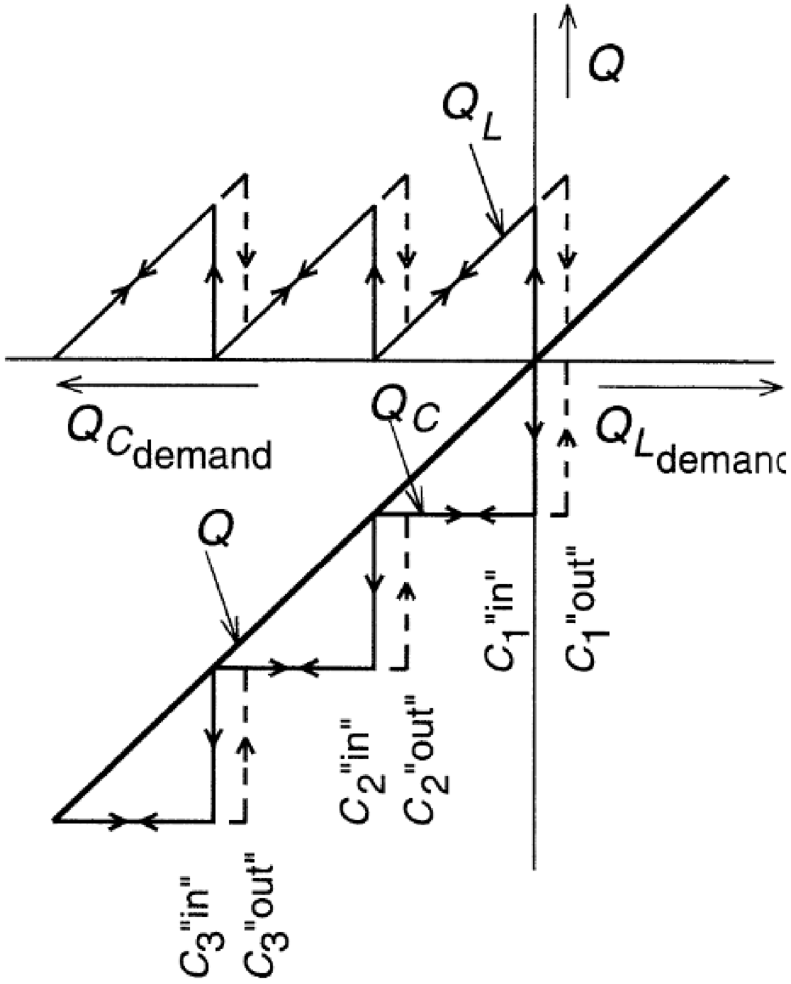
The total capacitive output range is divided into n intervals. In the first, the output of the var generator is controllable in the zero to $Q_{cmax}/n$, at same time, current in the TCR is set by the firing angle control so that sum of the var output of the TSC (negative) and that of the TCR (positive) equals the output required.

In the second, third, . . ., and nth intervals, the output is controllable in the by switching the second, third, . .., and nth capacitor bank and using the TCR to meet require var.

# Figure below shows the working of n branched TSC-TCR

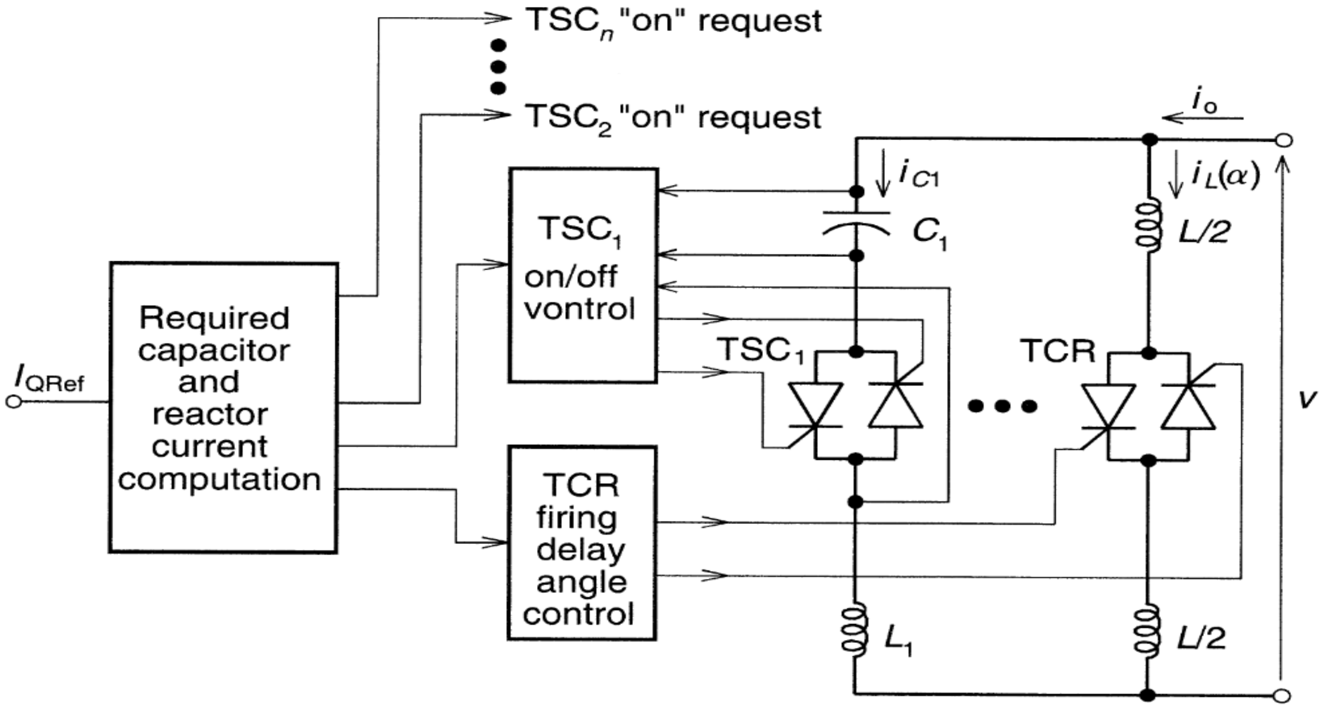


$$Q = V \times [I_{LF}(\alpha) - \Sigma I_{Cn}]$$

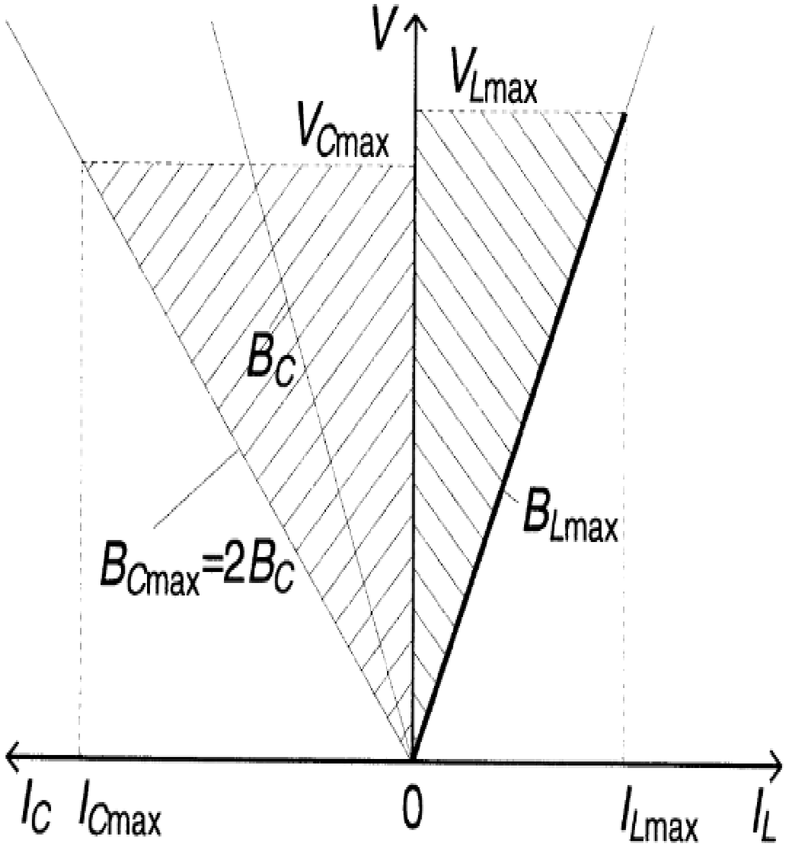


Functional control scheme of TSC-TCR determines

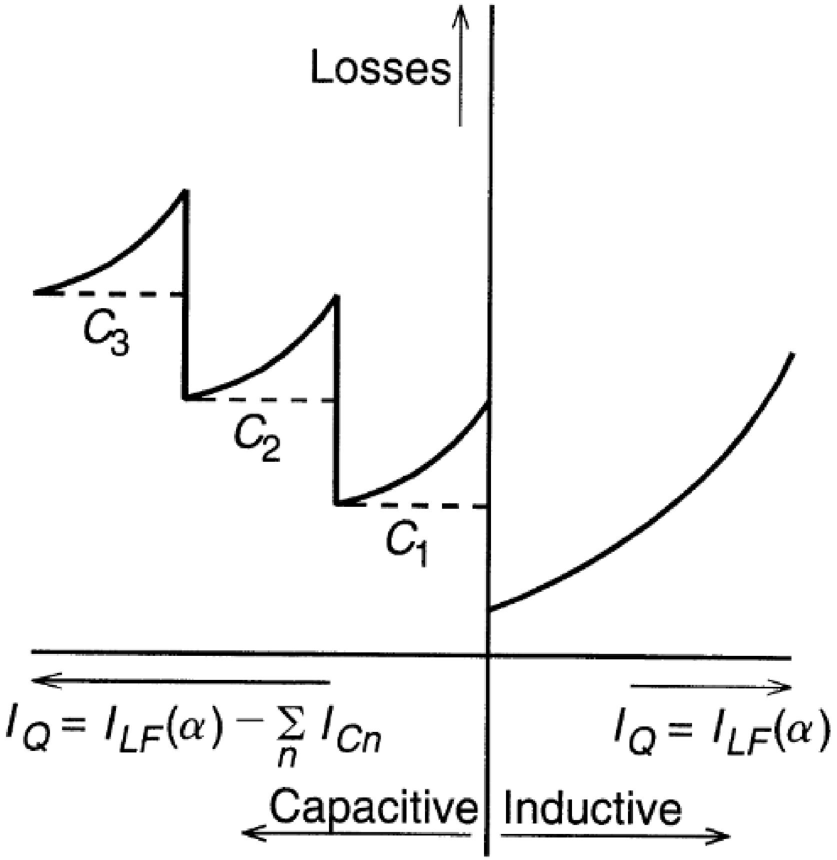
- The number of TSC branches needed to be switched in to approximate the required capacitive output current and computes the amplitude of the inductive current needed to cancel the surplus capacitive current.
- Controls the switching of the TSC branches in a "transient-free" manner.
- Varies the current in the TCR by firing delay angle control.



Fig



$V$
$V_{Lmax}$
$V_{Cmax}$
$B_C$
$B_{Lmax}$
$B_{Cmax}=2B_C$
$I_C$
$I_{Cmax}$
0
$I_{Lmax}$
$I_L$



Losses
$C_3$
$C_2$
$C_1$
$I_Q = I_{LF}(\alpha) - \sum_n I_{Cn}$
$I_Q = I_{LF}(\alpha)$
Capacitive
Inductive

# SWITCHING CONVERTER TYPE VAR GENERATORS

This can produce a variable shunt reactive impedance that can be adjusted to meet the shunt compensation requirements.

These employ DC to AC and AC to AC converters which are operated as voltage source and current source converters.

Because of these similarities with a rotating synchronous generator, they are termed Static Synchronous Generators.

A power converter of either type consists of an array of solid state switches which connect the input terminals to the output terminals.

Consequently, a switching power converter has no internal energy storage and therefore the instantaneous input power must be equal to the instantaneous output power. Also, the termination of the input and output must be complementary.

# Voltage source converters are preferred because

Current sourced converters require power semiconductors with bi-directional voltage blocking capability. The available high power semiconductors with gate turn-off capability (GTOs, IGBTs) either cannot block reverse voltage at all or can only do it with detrimental effect on other important parameters.

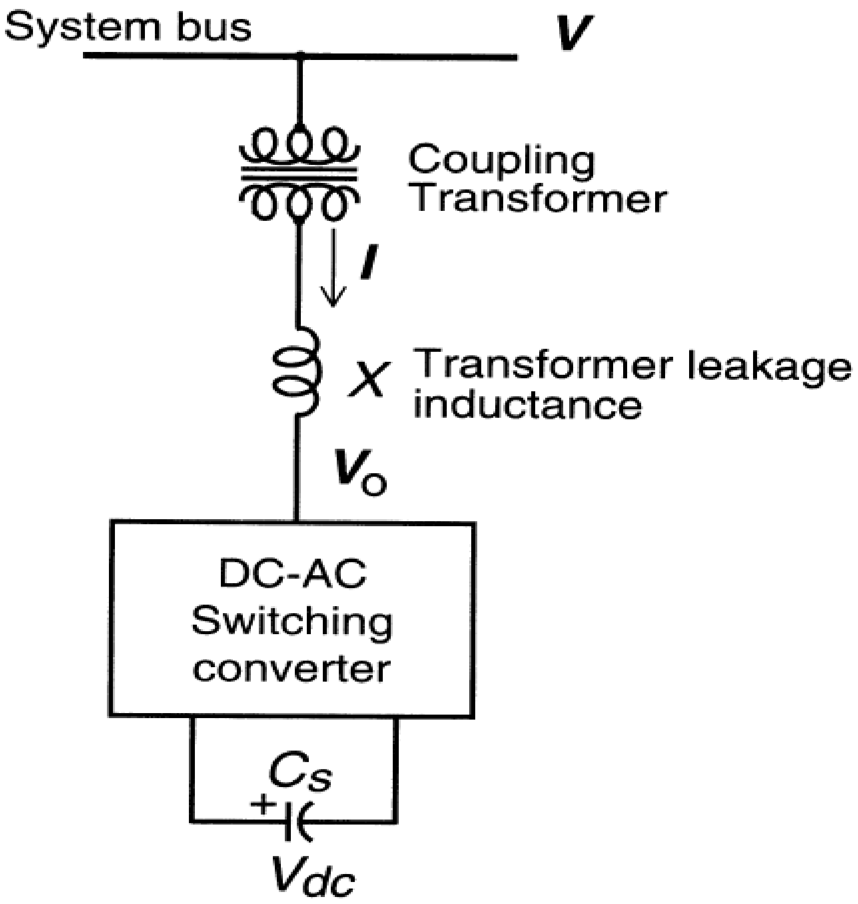
Practical current source termination of the converter dc terminals by a current charged reactor is much lossier than complementary voltage source termination by a voltage-charged capacitor.

The current-sourced converter requires a voltage source termination at ac terminals, usually in the form of a capacitive filter. The voltage sourced converter requires a current source termination at the ac terminals that is naturally provided by the leakage inductance of the coupling transformer.

The voltage source termination (i.e., a large dc capacitor) tends to provide an automatic protection of the power semiconductors against transmission line voltage transients. Current-sourced converters may require additional overvoltage protection or higher voltage rating for the semiconductors.

# BASIC OPERATING PRINCIPLE

The operating principle of var generator with voltage source converter is same as conventional synchronous machine. Schematic is shown below.



Let *V0* be the internal voltage of converter and *V* be the voltage of the AC system. Equations are shown below.

$$I = \frac{V - V_0}{X}$$

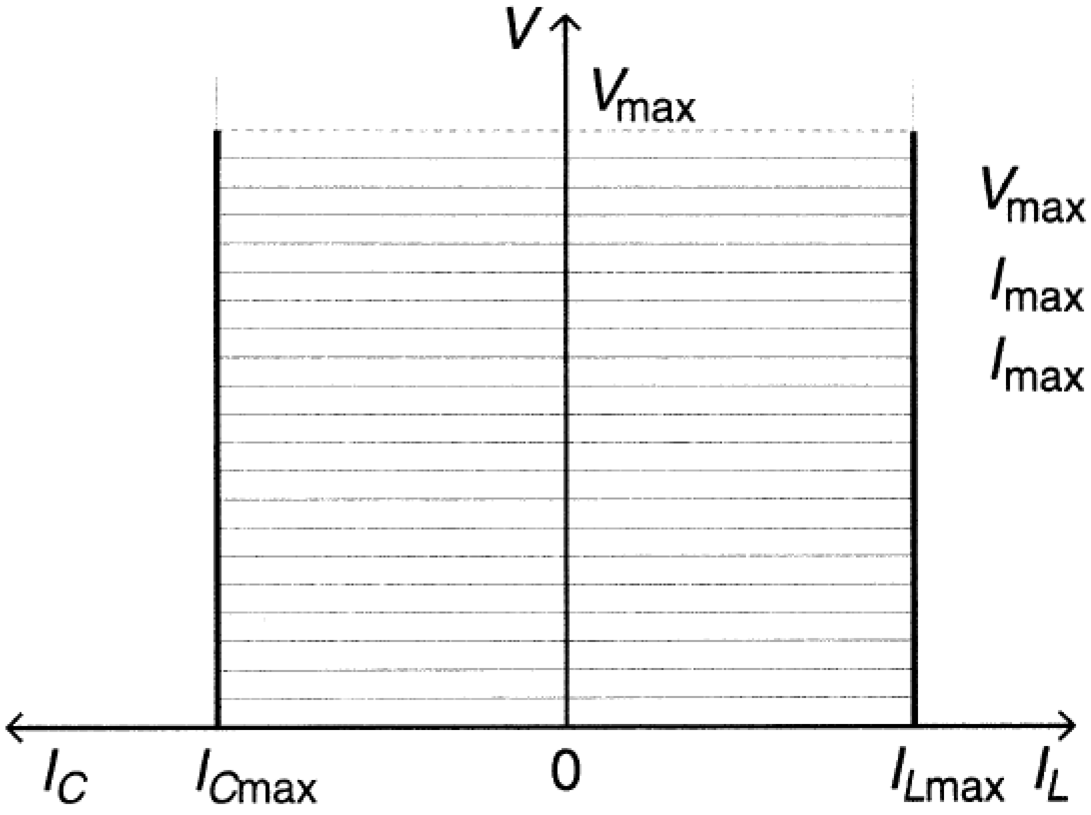
$$Q = \frac{1 - \dfrac{V_0}{V}}{X} V^2$$

When *V0* is greater than *V* the converter is seen as over excited by the AC system which results in leading current.

When *V0* is lesser than *V* the converter is seen as under excited by the AC system which results in lagging current.

The amount of reactive power exchanged depends on *V0/V* ratio.

# Operating VI area of voltage source converter type var generator



$V_{max}$ = voltage limit

$I_{max}$ = current limit

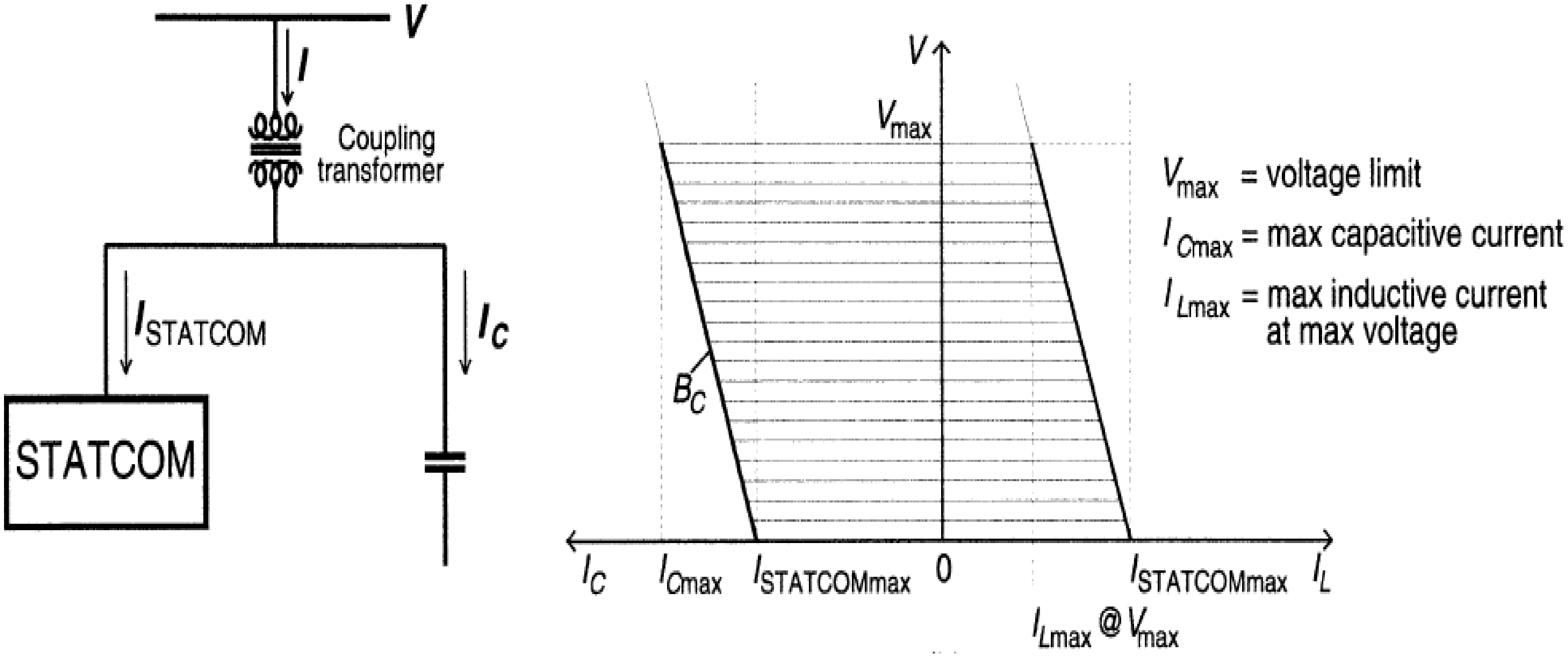
$I_{max} = I_{Lmax} = I_{Cmax}$

# HYBRID VAR GENERATORS

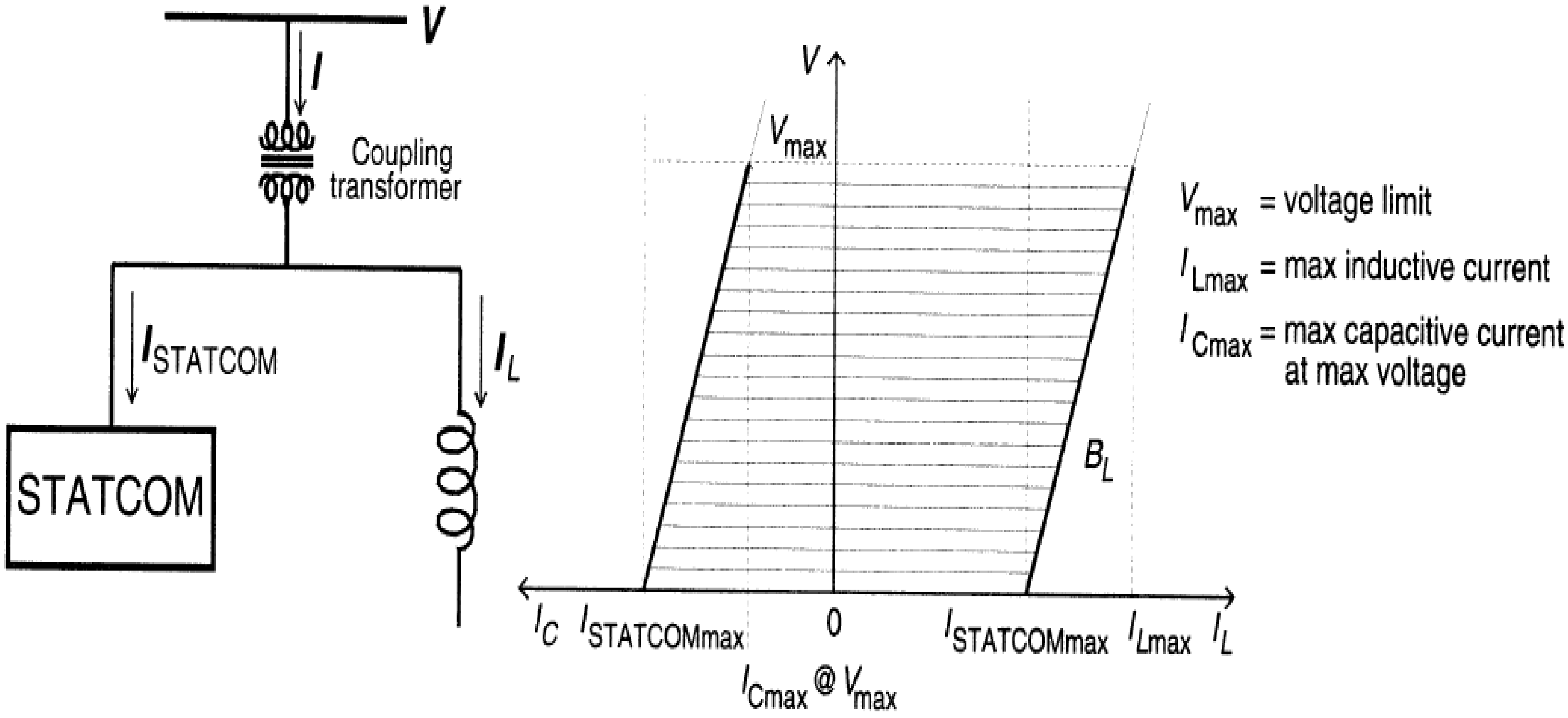
The combination of a converter-based var generator with a fixed capacitor or fixed reactor which can generate excess var than converter.

This will allow to move the operating characteristics of converter towards capacitive or inductive region.

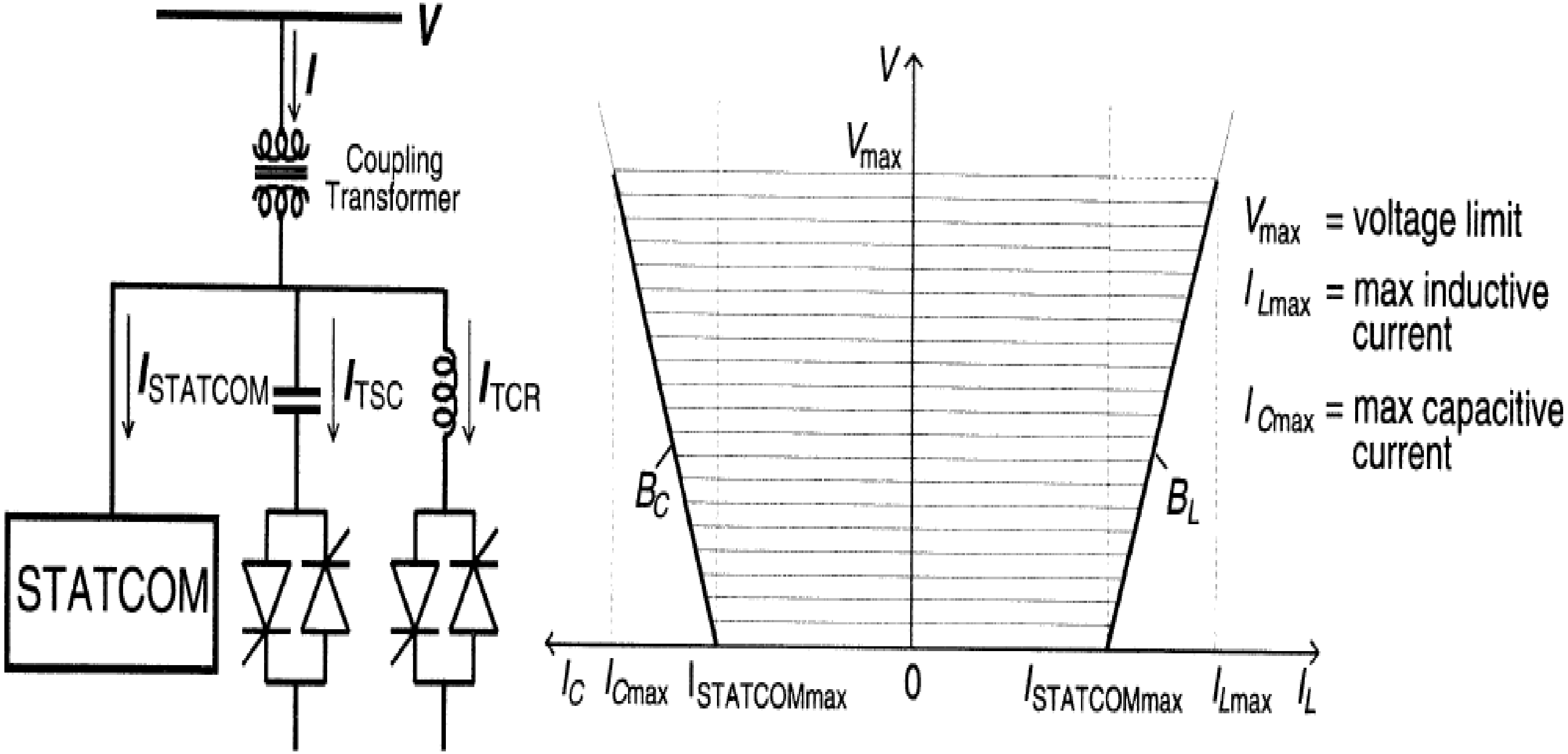
Some of the hybrid var generators are shown in the schematics below along with their operating VI area.



Combined converter-based fixed capacitor type var generator and its VI area.



Combined fixed converter based fixed reactor type var generator and its VI area.



Combined converter based and TSC-TCR type var generator and its VI area.

# *Thank you!*

# FACTS

## (Flexible AC Transmission Systems)

## Unit - 4

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## SVC & STATCOM

# CONTENTS

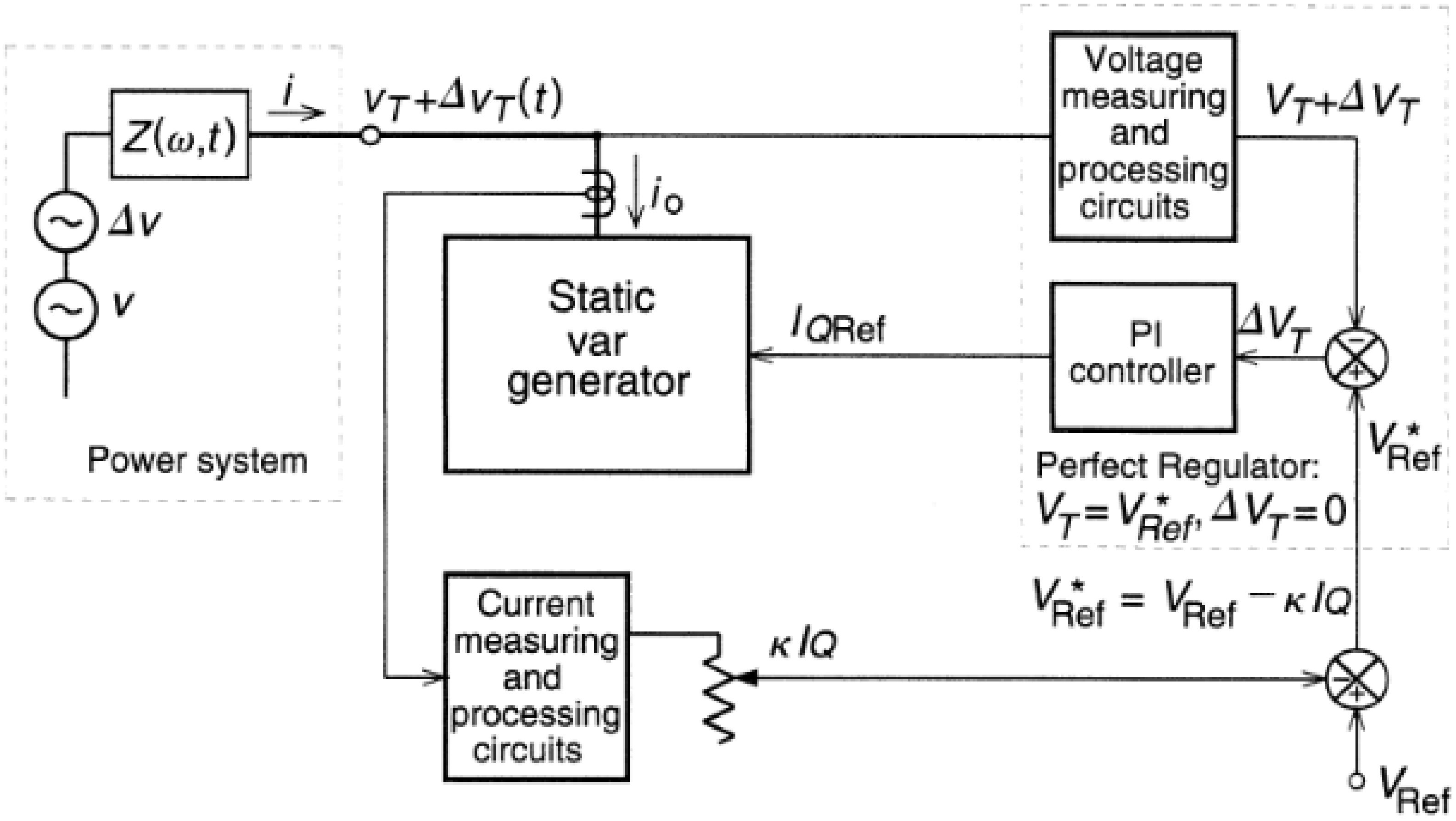
- The Regulation slope
- Transfer function and dynamic performance
- Transient Stability Enhancement and Power Oscillation damping
- Comparison between STATCOM and SVC

# THE REGULATION SLOPE

- When static compensator is employed, the terminal voltage is varied in proportion with compensating current. This is because
- The linear operating range of a compensator with maximum capacitive and inductive ratings can be extended if a regulation "droop" is allowed.
- Regulation "droop" means the terminal voltage is allowed to be smaller than the nominal no load value at full capacitive compensation and conversely, it is allowed to be higher than the nominal value at full inductive compensation.

Perfect regulation could result in poorly defined operating point, and a tendency of oscillation, if the system impedance exhibited a "flat“ region in the operating frequency range of interest.

A regulation "droop" or slope tends to enforce automatic load sharing between static compensators and other voltage regulating devices employed to control transmission voltage.



Implementation of *V-I* slope by a minor control loop changing the reference voltage in reference to the line current

The effective reference Voltage is

$$V_{ref}^{*} = V_{ref} + kI_Q$$

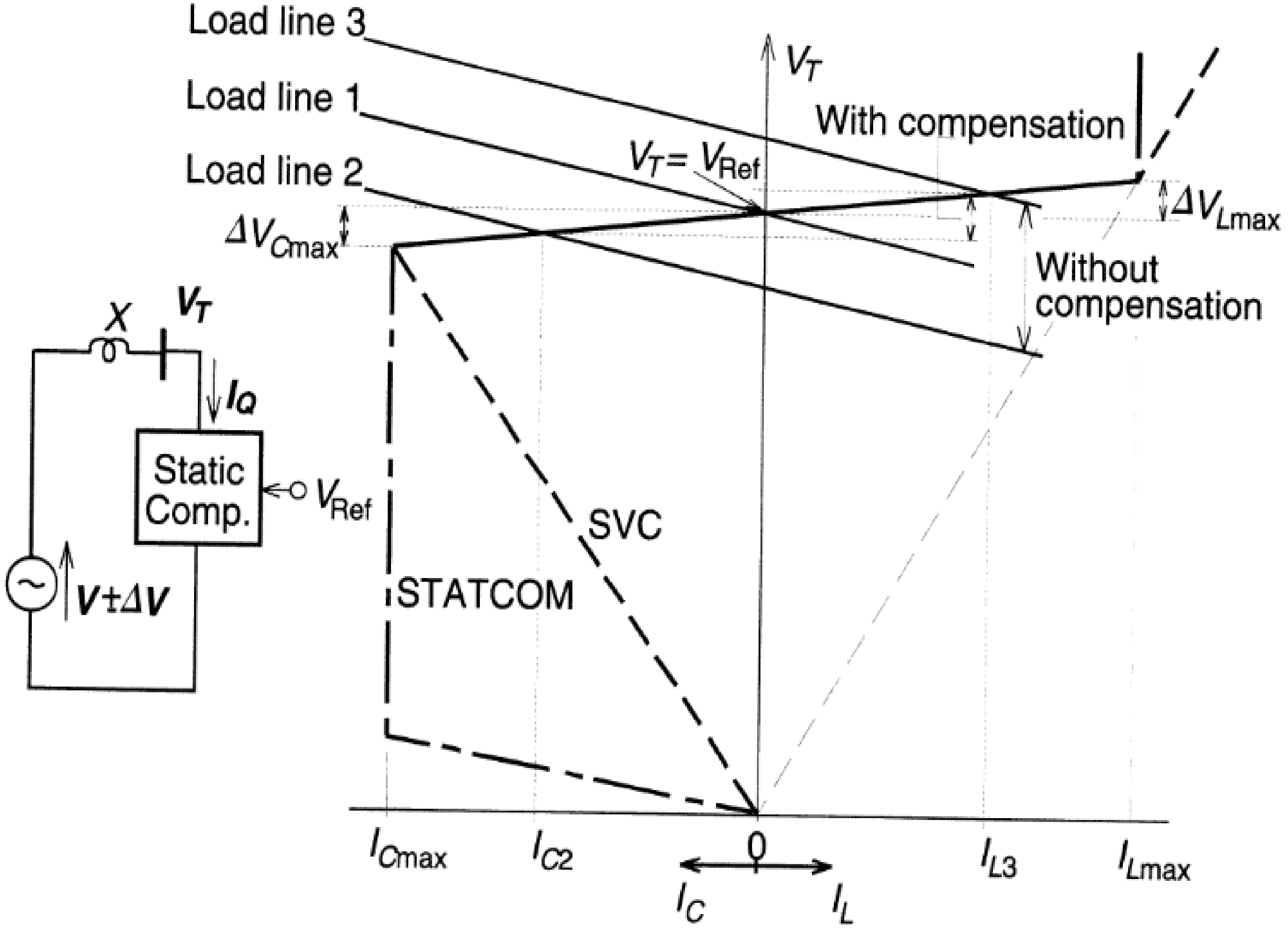
Here k is the regulation slope defined by

$$k = \frac{\Delta V_{c\max}}{I_{c\max}} = \frac{\Delta V_{L\max}}{I_{L\max}}$$

Equations indicate the effective ref voltage controlled to decrease from the nominal value with increasing capacitive compensating current and conversely, it is controlled to increase with increasing inductive compensating current until the maximum capacitive or inductive compensating current is reached.

The amplitude of the terminal voltage is regulated along a set linear slope over the control range of compensator.

For change of terminal voltage outside control range, the output current is determined by the basic *V-I* characteristic of the var generator.

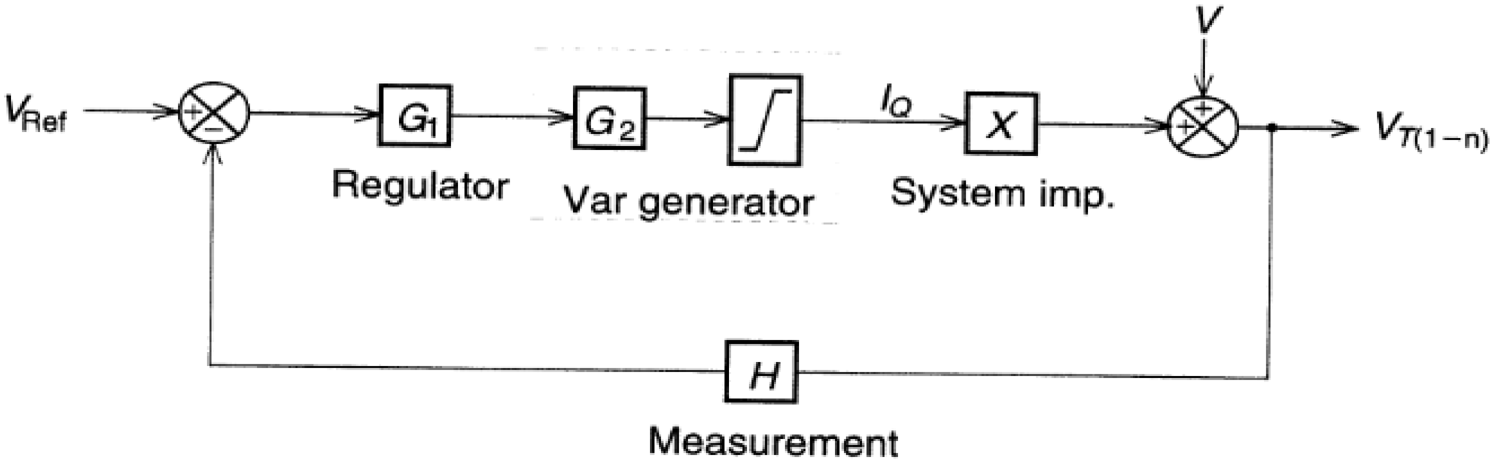


# V-I characteristics of SVC and STATCOM

# TRANSFER FUNCTION AND DYNAMIC PERFORMANCE

The dynamic performance can be characterized by the basic transfer function.

Basic transfer function block diagram is shown below which is derived from basic control scheme.



From the block diagram the terminal voltage $V_T$ can be derived as

$$V_T = V\frac{1}{1+G_1G_2HX} + V_{ref}\frac{G_1G_2X}{1+G_1G_2HX}$$

Let $V_{ref}$ = 0 and consider small variation in terminal voltage $\Delta V_T$. Then transfer function can be expressed as

$$\frac{\Delta V_T}{\Delta V} = \frac{1}{1+G_1G_2HX} = \frac{1}{1+GHX} \qquad \text{----------------------(1)}$$

where,

$$G_1 = \frac{1/k}{1+T_1s} \qquad G_2 = e^{-T_ds}$$

$$G = G_1G_2 = \frac{1/k}{1+T_1s}e^{-T_ds} \qquad H = \frac{1}{1+T_2s}$$

Here, T1 is the main time constant of PI controller, T2 is the amplitude measuring circuit time constant, Td is the transport lag of var generator, X is the reactive part of system impedance and k is the regulation slope.

Under steady state conditions, as ‘s’ tends to 0,

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

From the equation as the slope becomes smaller, the terminal voltage becomes constant independent of system voltage variation.

Similarly, with increase in slope the terminal voltage becomes unregulated.

From equation (1) **the dynamic behavior of the compensator is the function of system impedance.**

Also the time response and stability depend on system impedance.

# TRANSIENT STABILITY ENHANCEMENT

Transient stability indicates the ability of power system to recover from a major disturbance.

A static compensator can regulate the terminal voltage and can increase the transient stability by maintaining the transmission voltage.

Transient stability can be illustrated from power angle characteristics in the figure on next slide

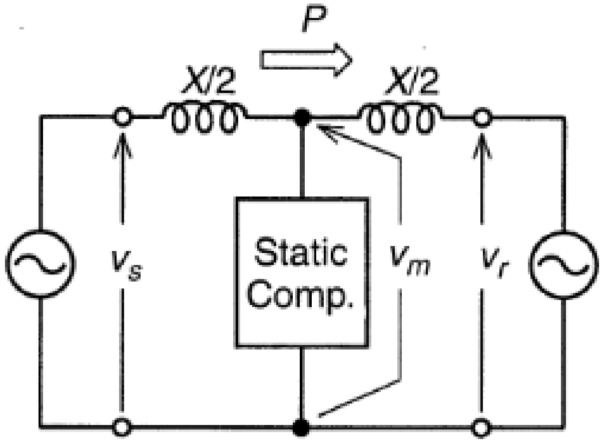
Plots marked SVC and STATCOM are represented with a given rating insufficient to maintain constant midpoint voltage over the total range of power angle.

Till $\delta=\delta_i$, characteristics are identical of STATCOM and SVC to that of an ideal compensator.

At $\delta=\delta_i$, SVC becomes fixed capacitor and STATCOM becomes a constant current source.

Angle smaller than $\delta_i$ the transmission line is over compensated

This over compensation capability of the compensator can be exploited to enhance the transient stability by increasing the var output to the maximum value after the fault clearing and thereby match the areas.

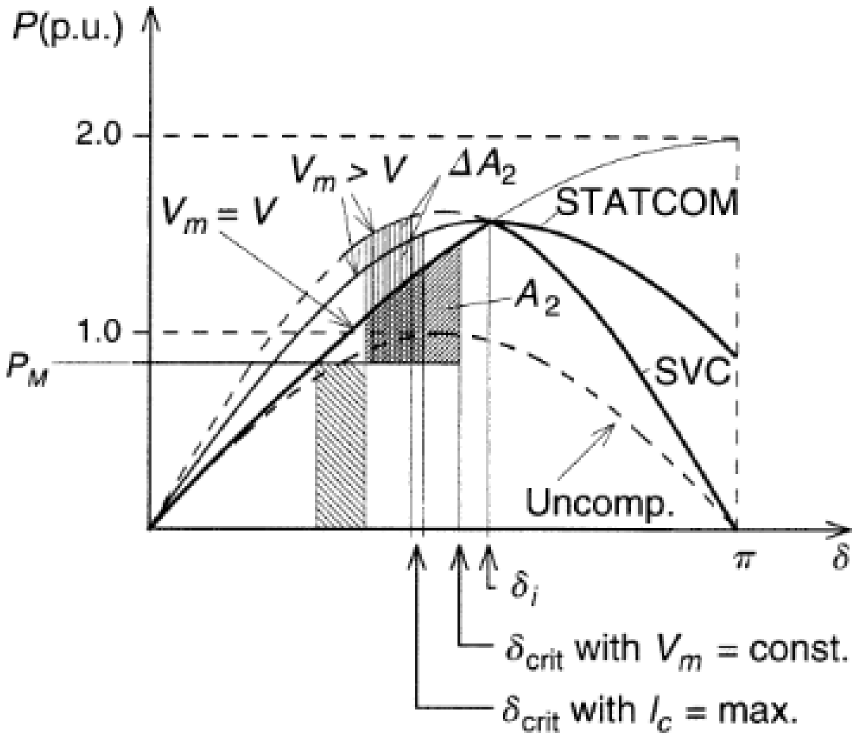


$v_s = V\sin(\omega t + \frac{\delta}{2})$ $v_r = V\sin(\omega t + \frac{\delta}{2})$

$v_m = V_m \sin \omega t$

For $V = V$: $\boxed{p = 2\frac{V^2}{X}\sin\frac{\delta}{2}}$

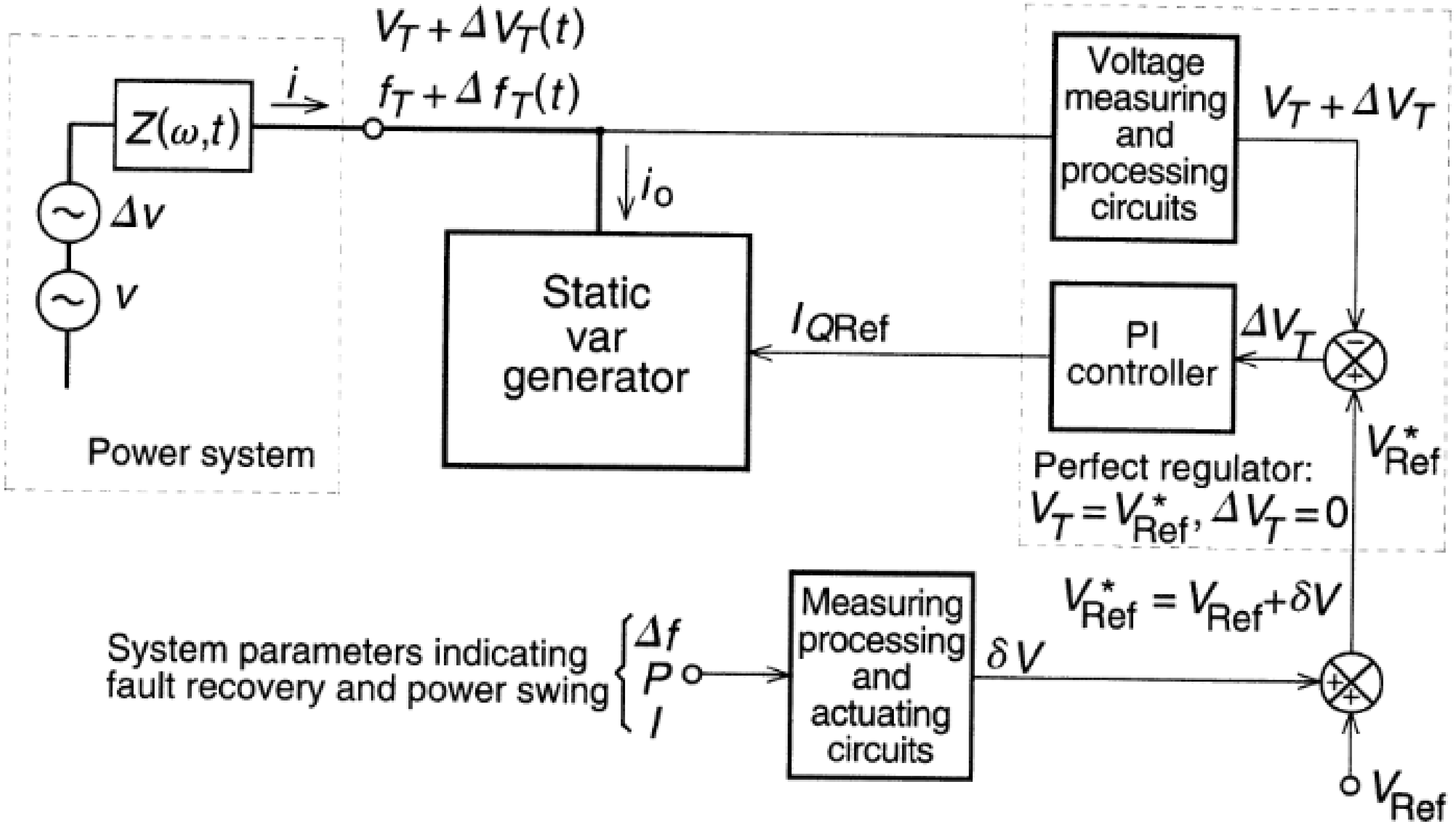
For uncompensated line: $P = \frac{V^2}{X}\sin\delta$



$A_2$ = area with $V_m = V$ (regulated voltage)

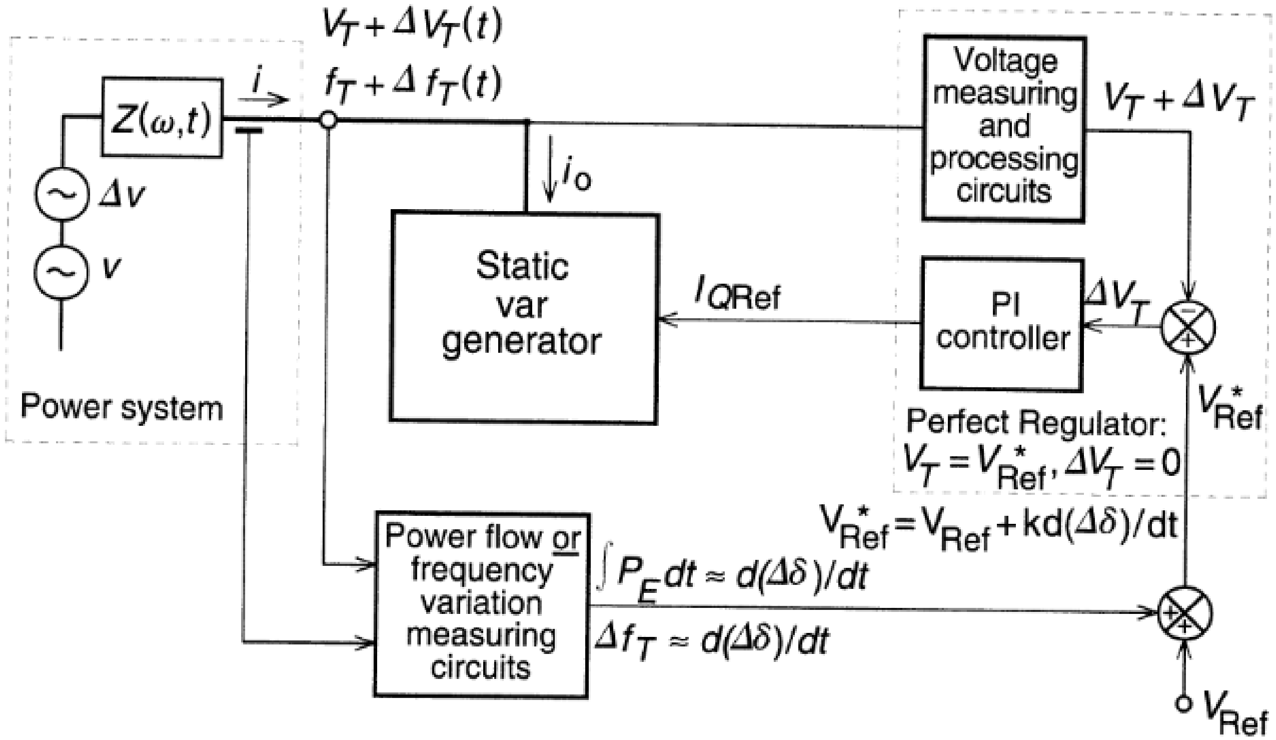
$\Delta A_2$ = additional area with maximum capacitive output ($V_m > V$)

# Implementation of transient stability enhancement concept by increasing the reference voltage during the first swing of a major disturbance.



# POWER OSCILLATION DAMPING

Power oscillation damping generally requires the variation of the voltage at the terminal of the compensator in proportion to the rate of change of the effective rotor angle. If rotor angle changes, frequency changes and real power is varied.



Implementation of power oscillation damping by modulating the reference voltage according to frequency or power variations

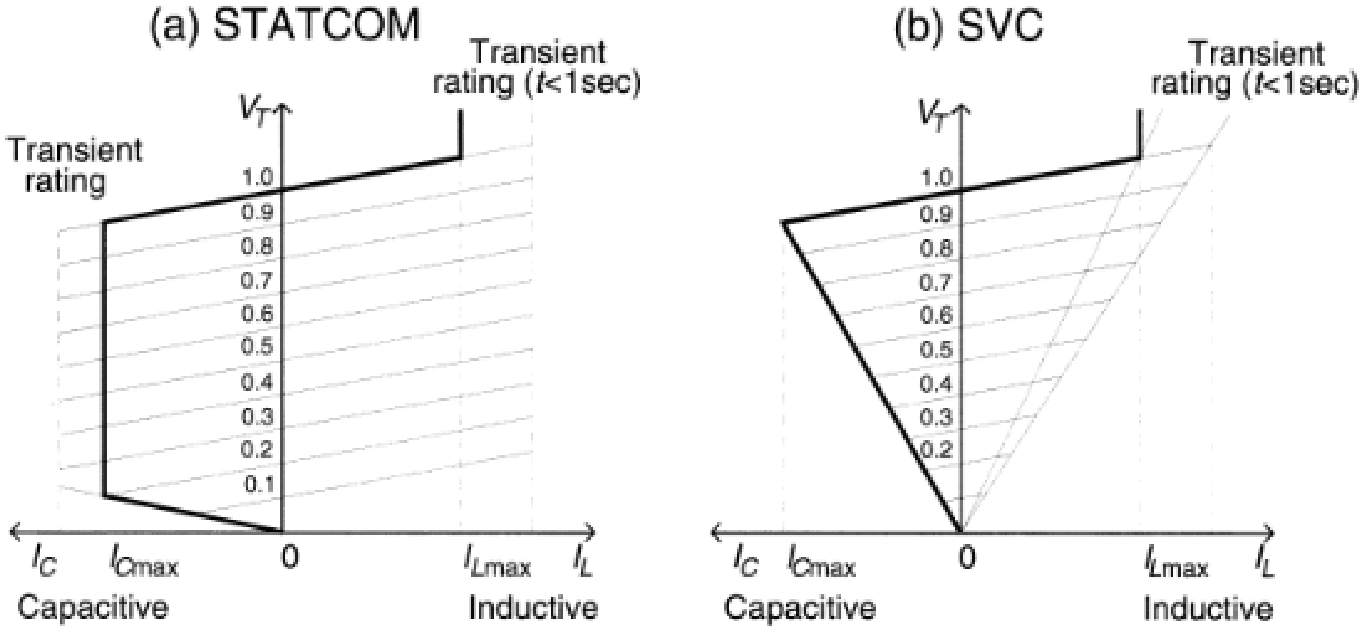
# COMPARISION BETWEEN  STATCOM AND SVC

In the linear operating range the *V-I* characteristic and functional compensation capability of the STATCOM and the SVC are similar.

Basic operational difference (voltage source v/s reactive admittance) accounts for the STATCOM's overall superior functional characteristics, better performance, and greater application flexibility than those attainable with the SVC.

STATCOM can be compared with SVC in different applications like Transient Stability, Response Time, Capability to Exchange Real Power, Operation with Unbalanced AC System, Loss Versus Var Output Characteristics.

# V-I and V-Q characteristics



*V-I* characteristics show that the STATCOM can be operated full output current range even at very low (theoretically zero), typically about 0.2 p.u system voltage levels.

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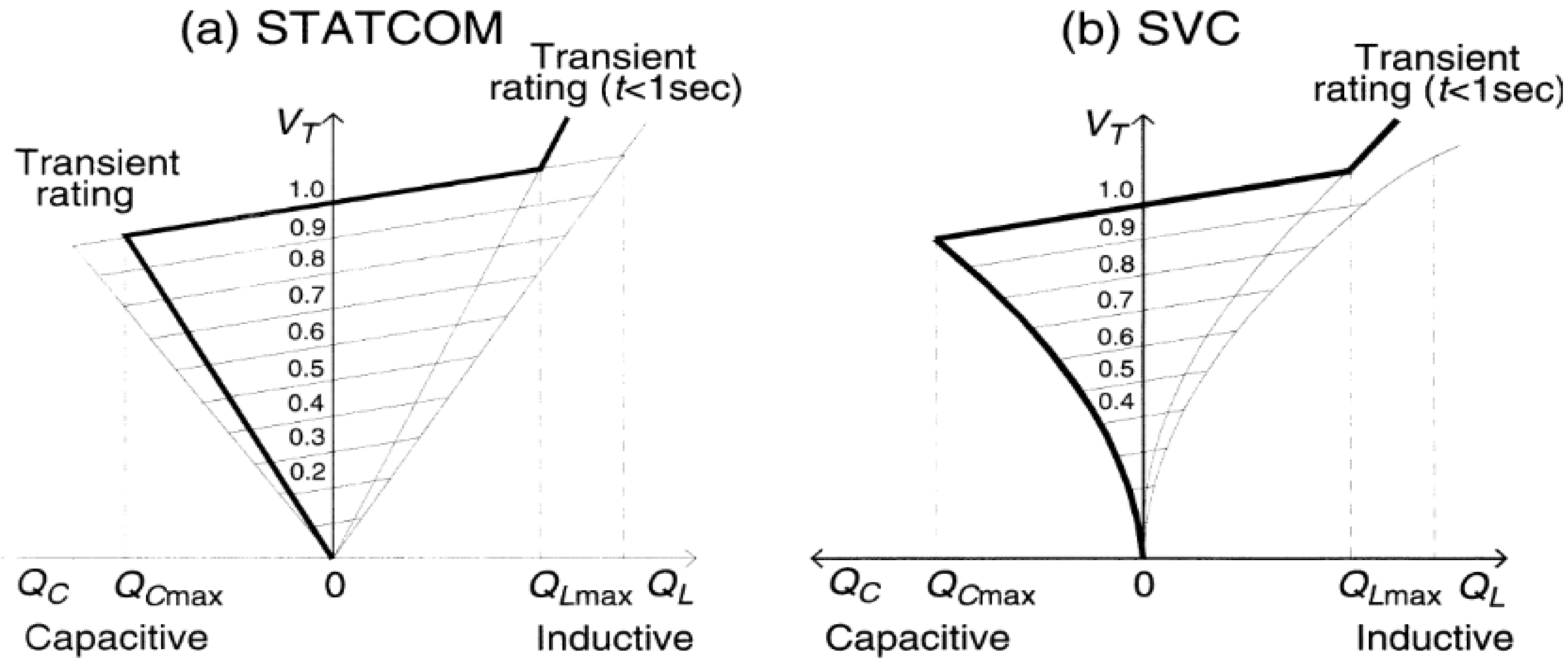
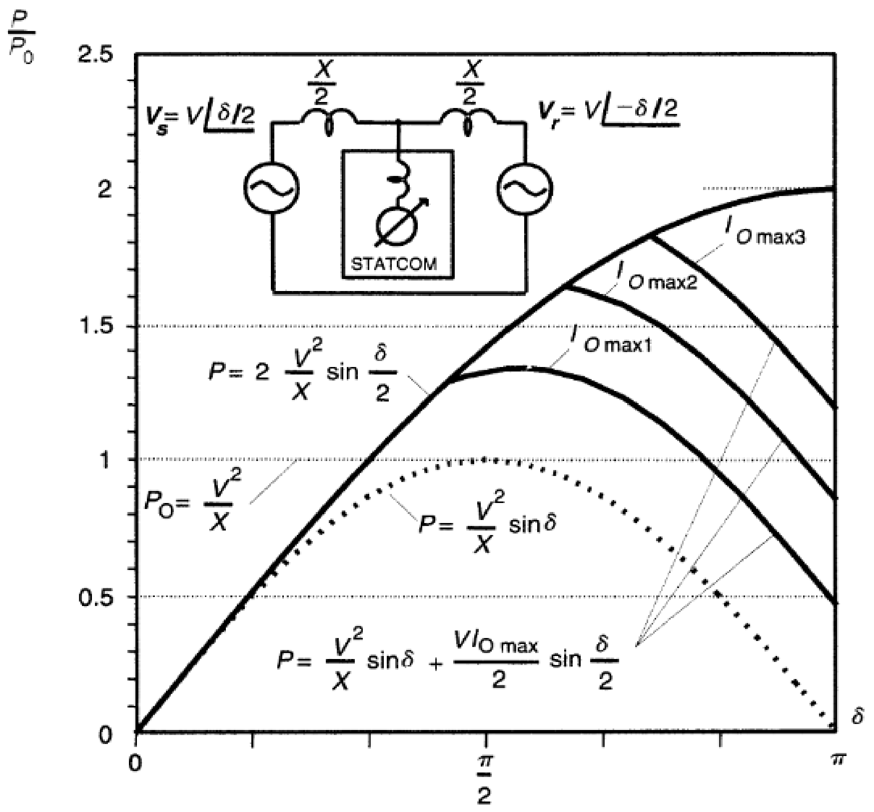


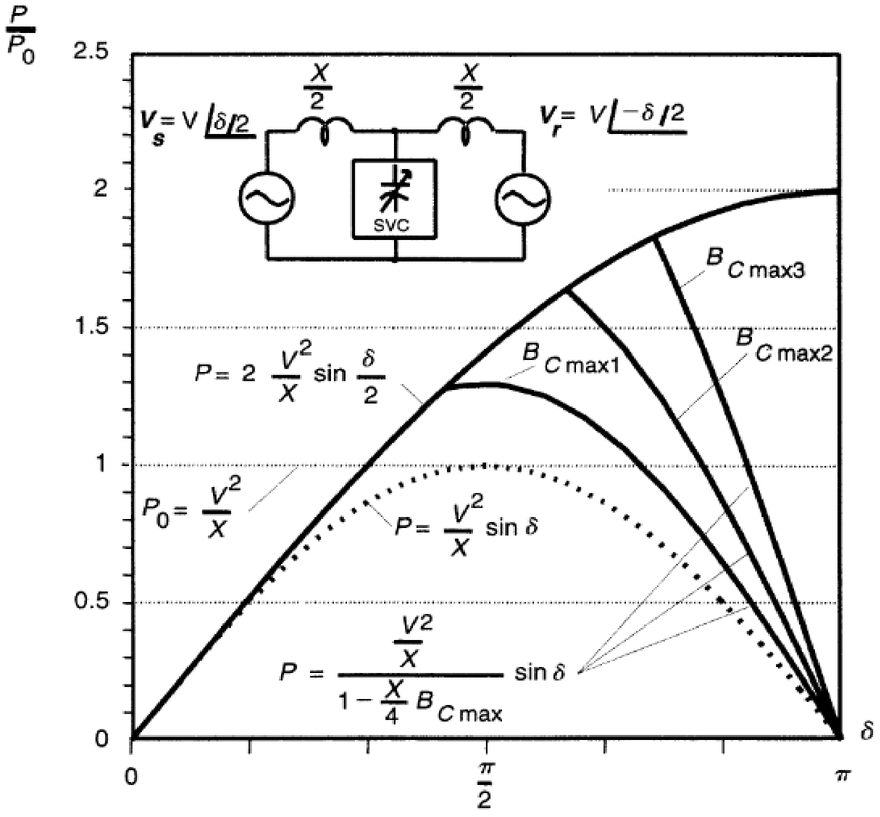
*V*-*Q* characteristics shows that STATCOM has maximum var generation or absorption which changes linearly with the ac system voltage. SVC gives maximum var output which decreases with the square of this voltage.

The capability of providing maximum compensating current at reduced system voltage enables the STATCOM to perform in a variety of applications the same dynamic compensation as an SVC of considerably higher rating.

# TRANSIENT STABILITY

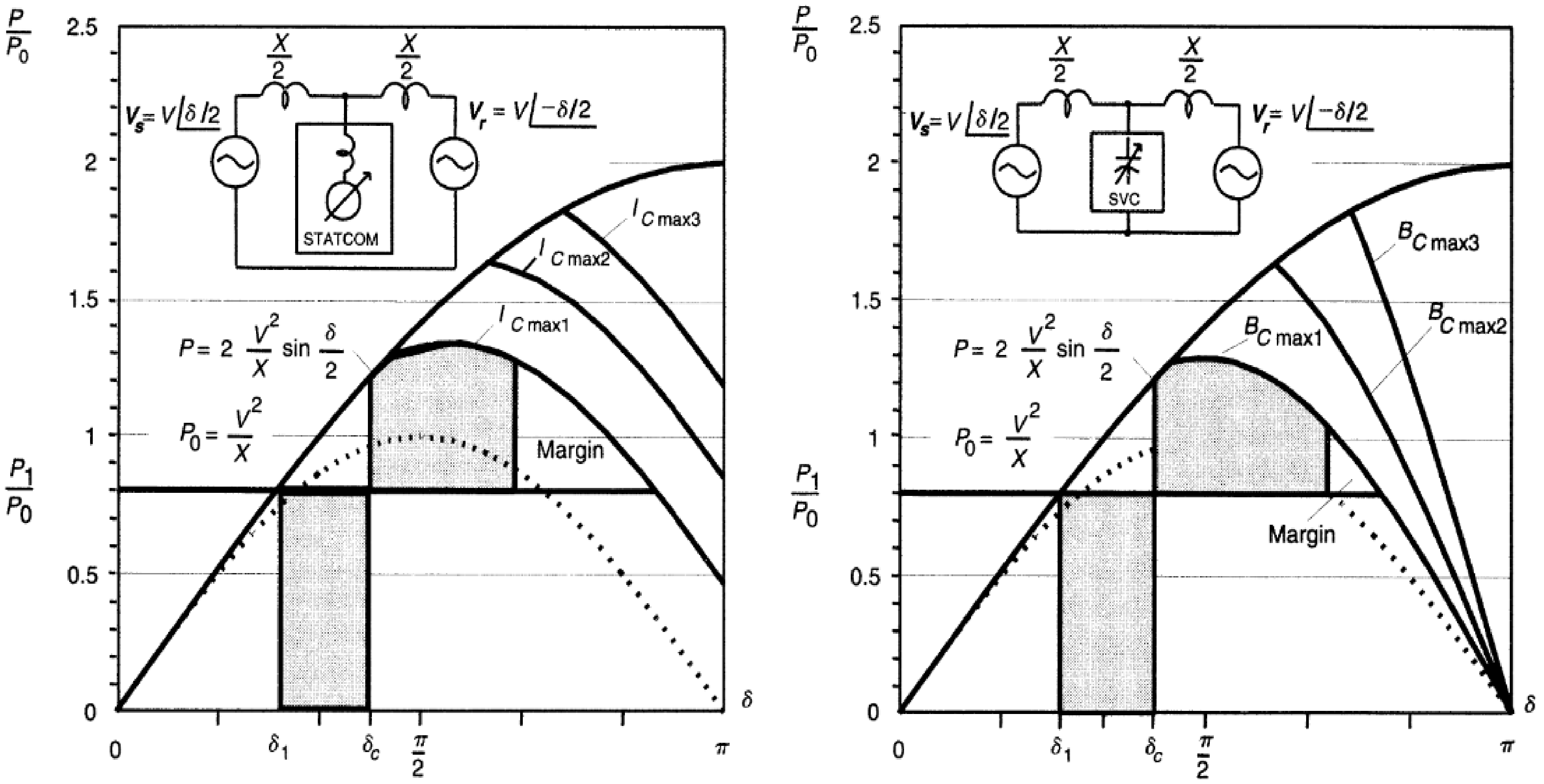


**STATCOM**



**SVC**

The ability of the STATCOM to maintain full capacitive output current at low system voltage also makes it more effective than the SVC in improving the transient(first swing) stability.



STATCOM

SVC

Improvement of transient stability with midpoint STATCOM and midpoint SVC

## RESPONSE TIME

The attainable response time and the bandwidth of the closed voltage regulation loop of the STATCOM are also significantly better than those of the SVC.

The time constant Td in the transfer function is about an order of magnitude smaller for the STATCOM than it is for the SVC.

The STATCOM can provide stable operation with respectable response over a much wider variation of the transmission network impedance than is possible with an SVC.

## CAPABILITY TO EXCHANGE REAL POWER

STATCOM, in contrast to the SVC, can interface a suitable energy storage with the ac system for real power exchange.

The reactive and real power exchange between the STATCOM and the ac system can be controlled independently of each other and any combination of real power generation and absorption with var generation and absorption is achievable.

# LOSS VS VAR OUTPUT CHARACTERISTICS

Both types of compensator have relatively low losses (about 0.1 to 0.2%) at and in the vicinity of zero var output.

The loss contribution of power semiconductors and related components to the total compensator losses is higher for the STATCOM than for the SVC.

This is due to available power semiconductor devices with internal turn-off capability have higher conduction losses than conventional thyristors.

Switching losses with forced current interruption tend to involve more losses than natural commutation.

***Thank you!***

# FACTS

# (Flexible AC Transmission Systems)

## Unit - 4

## SVC & STATCOM

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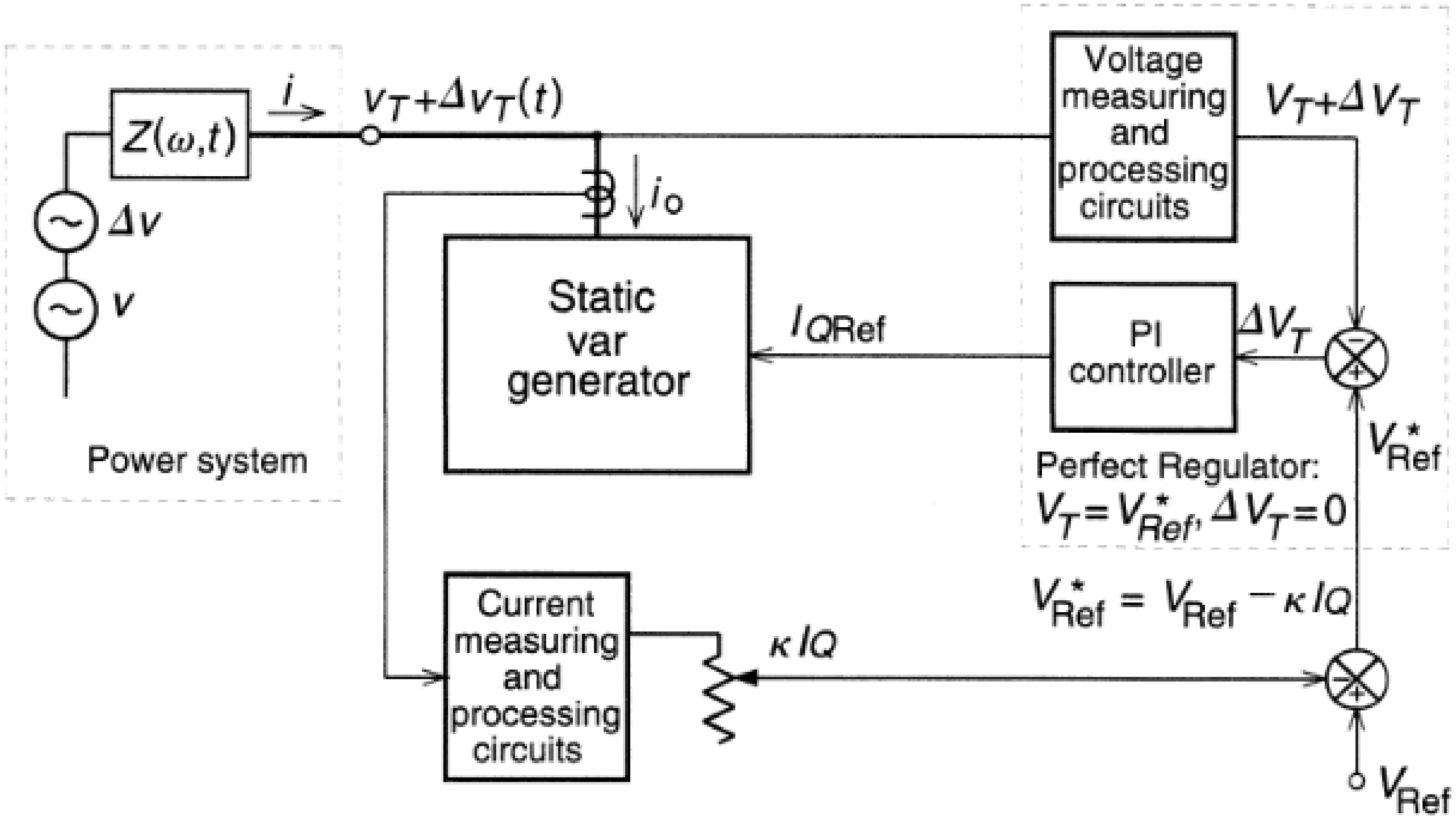

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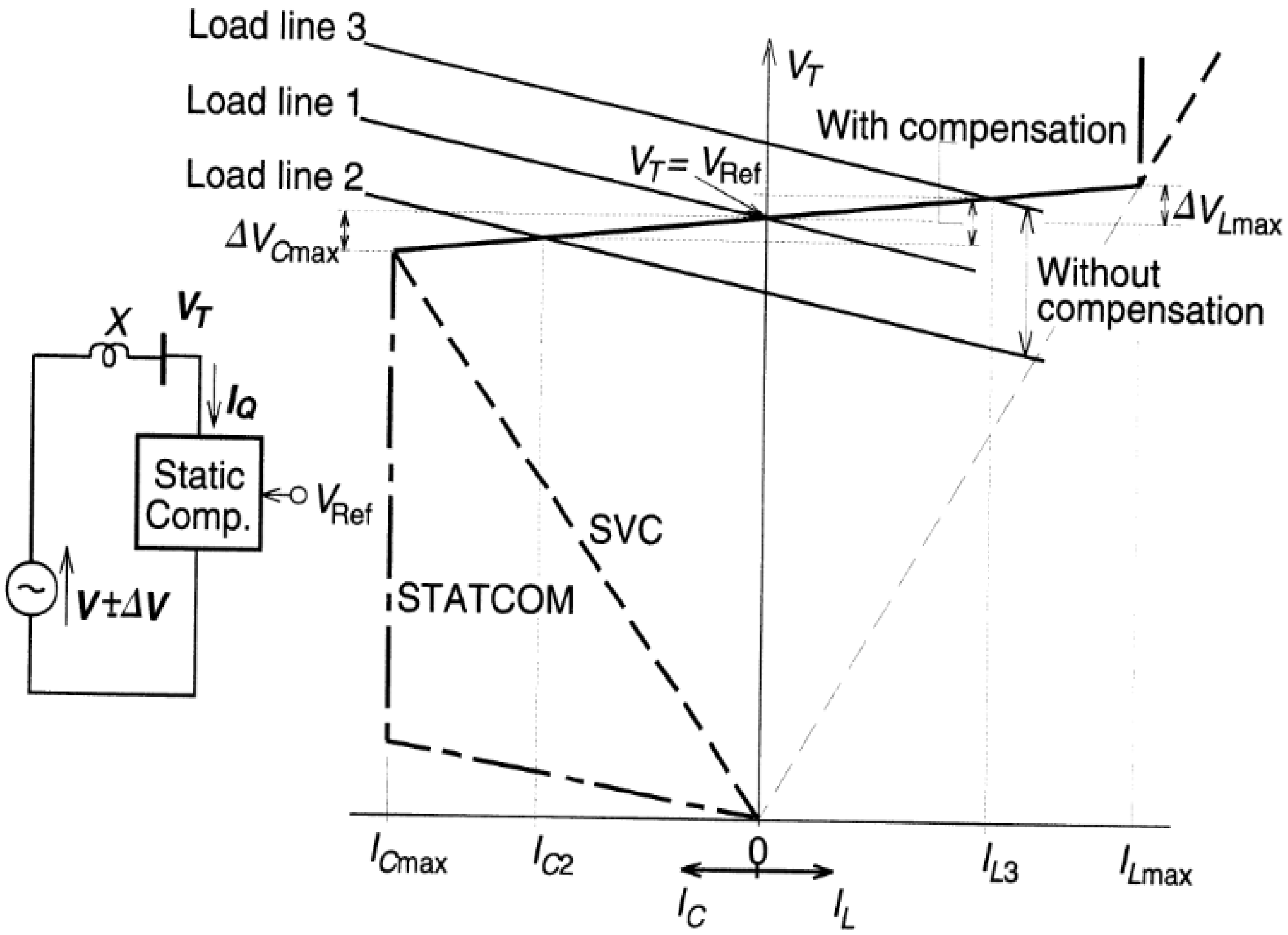

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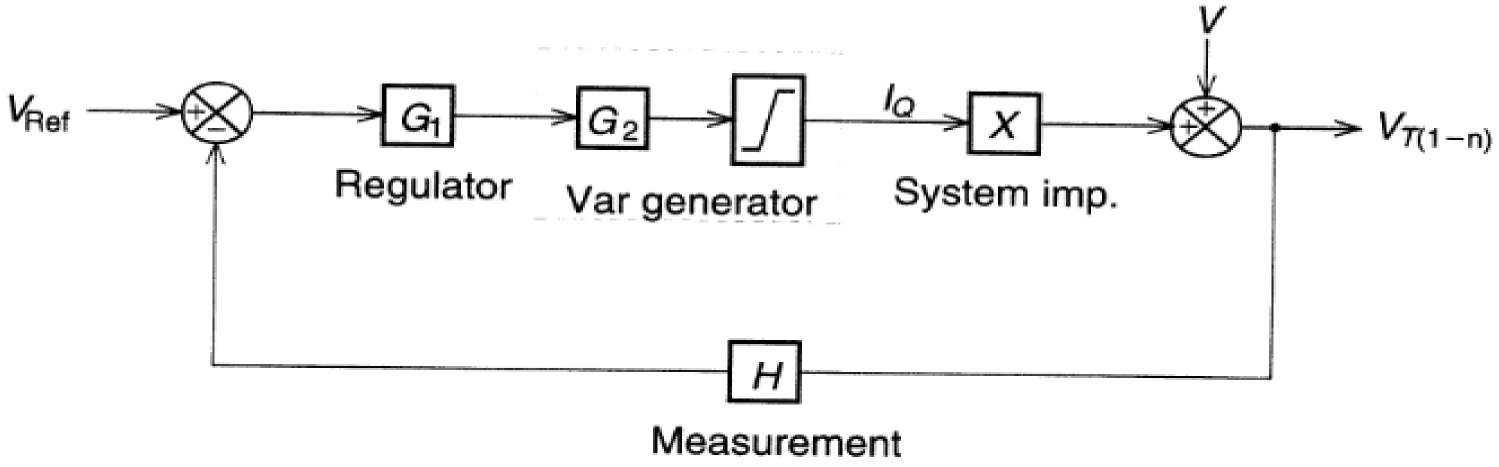

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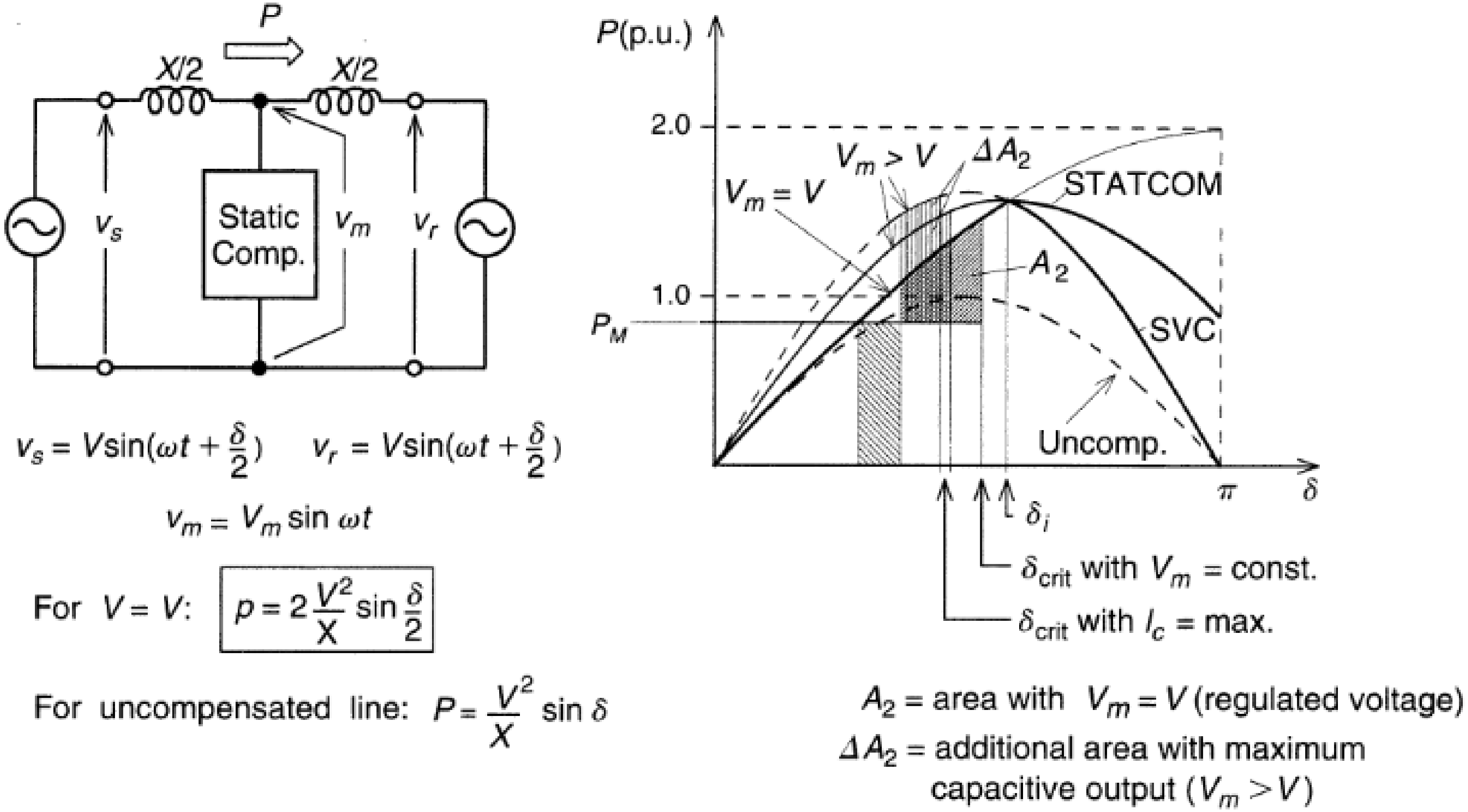

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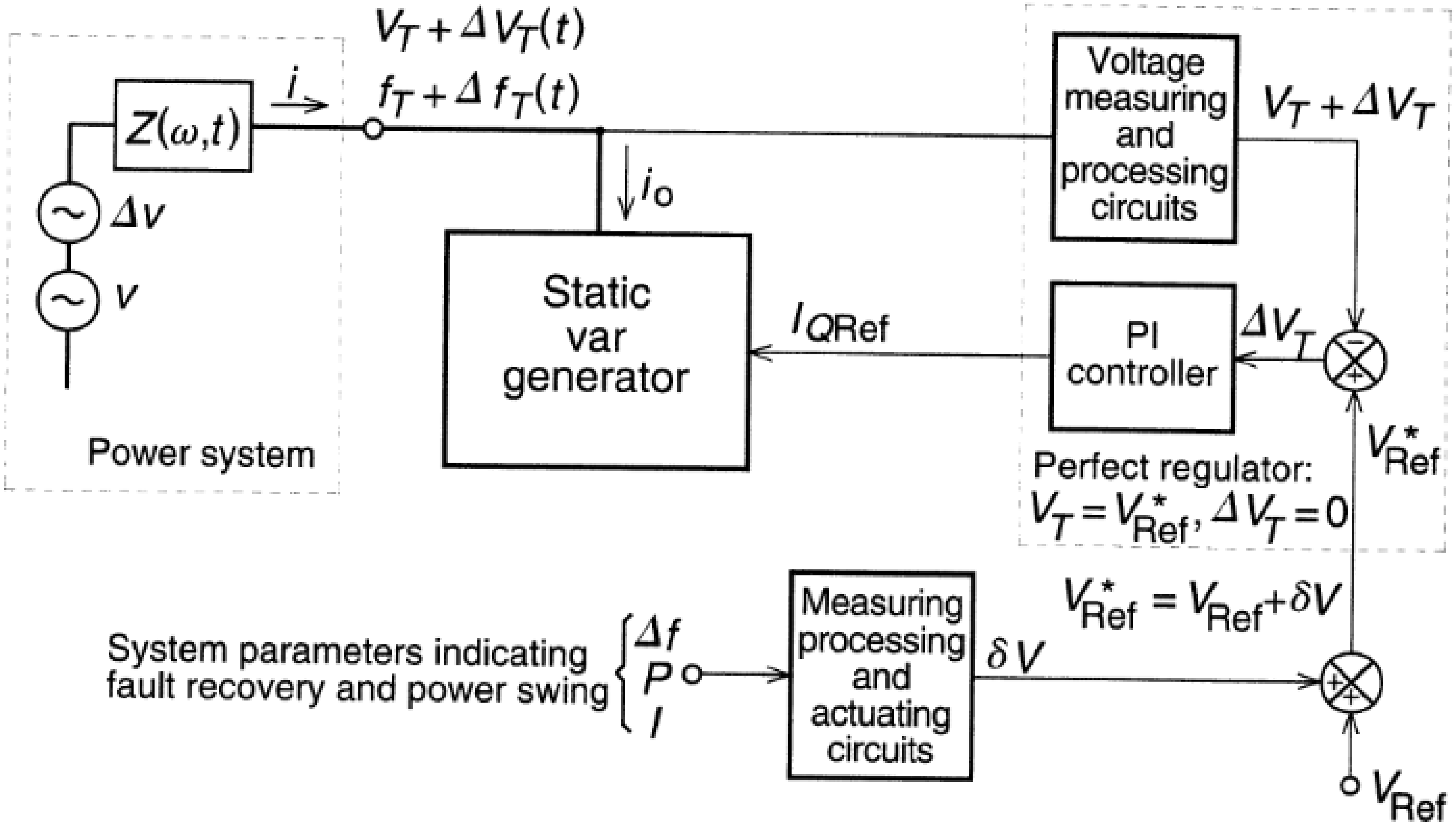

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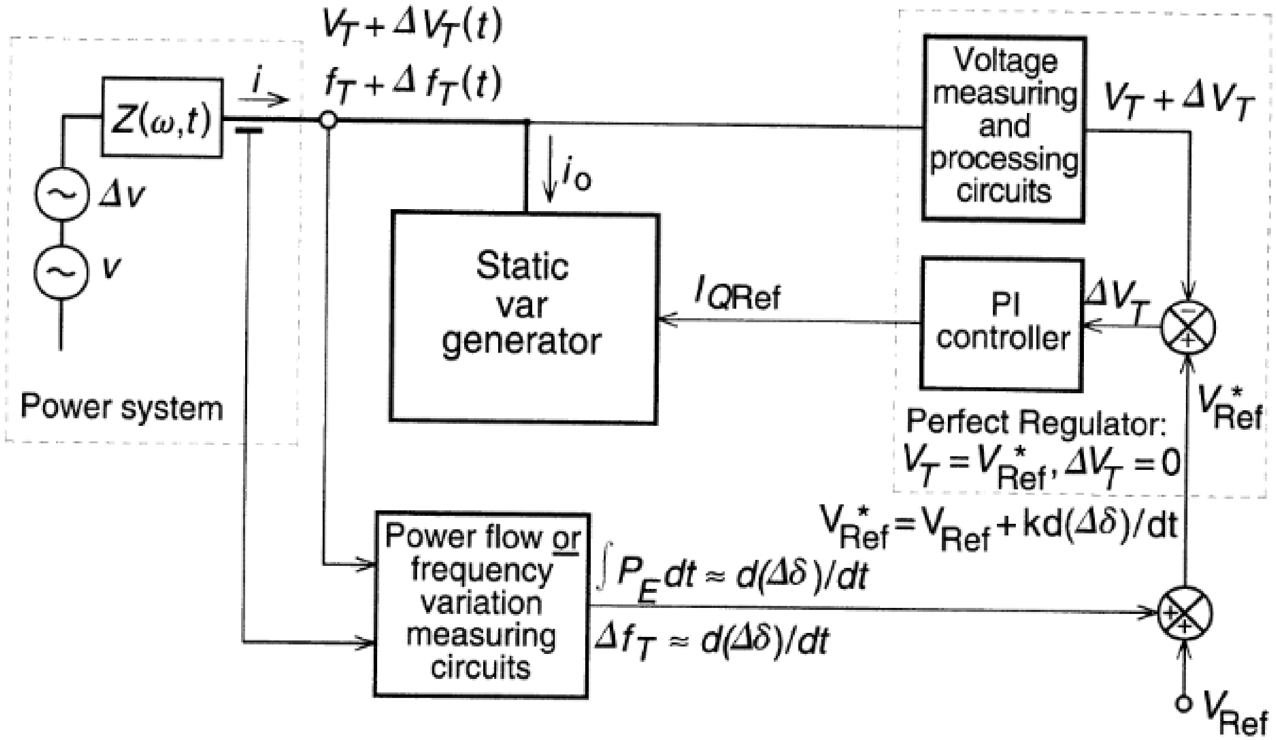

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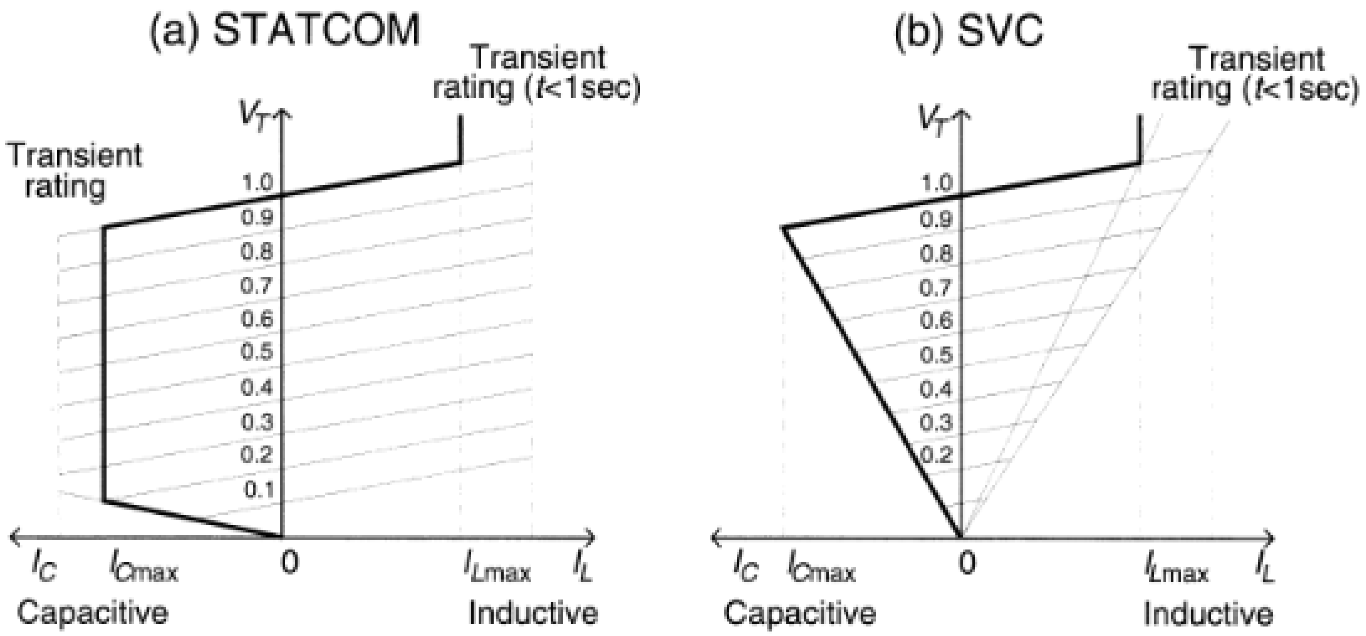
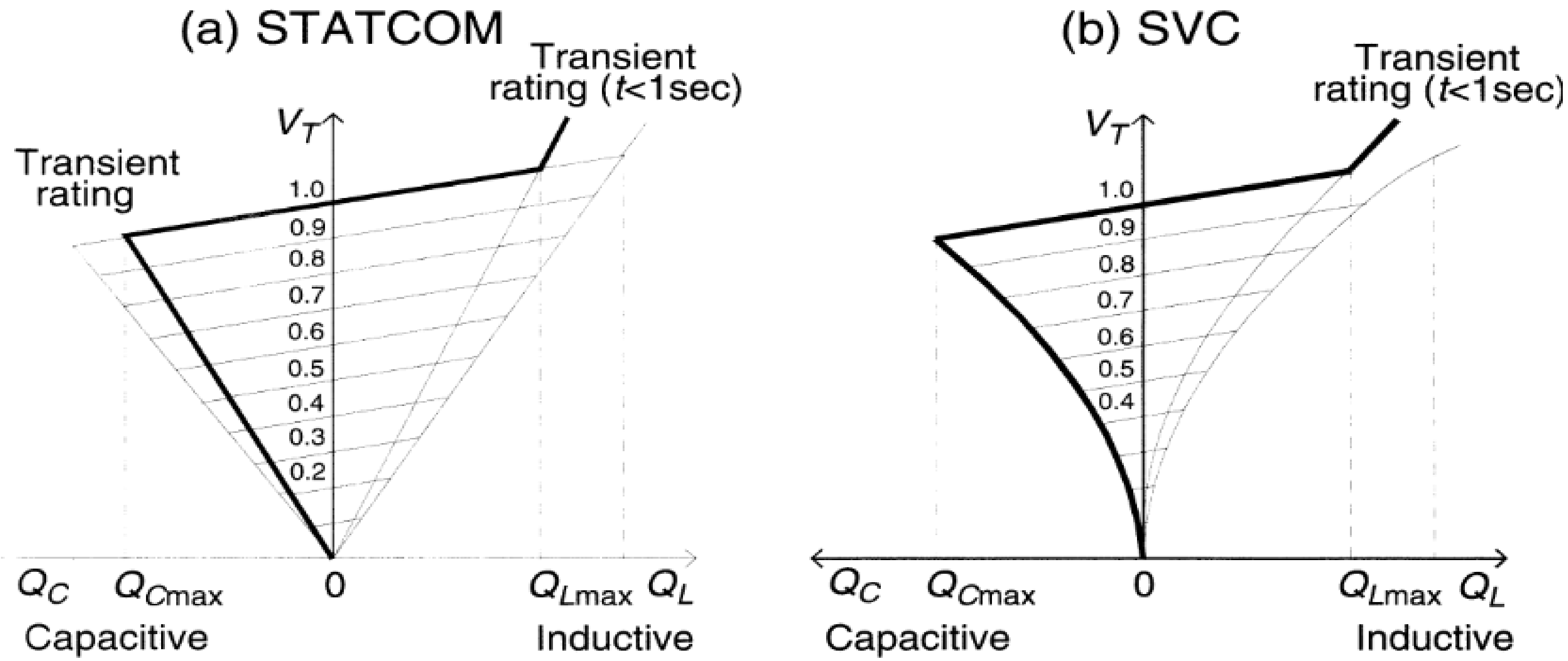


*V-I* characteristics show that the STATCOM can be operated full output current range even at very low (theoretically zero), typically about 0.2 p.u system voltage levels.

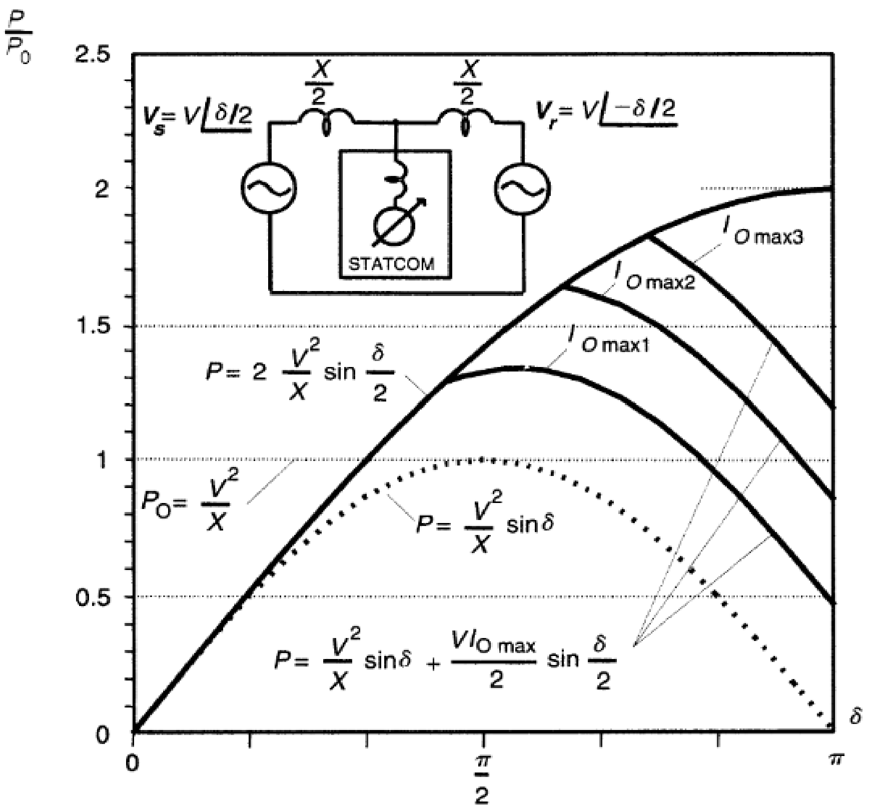
SVC becomes a fixed capacitive admittance at full output, the maximum attainable compensating current of the SVC decreases linearly with AC system voltage.



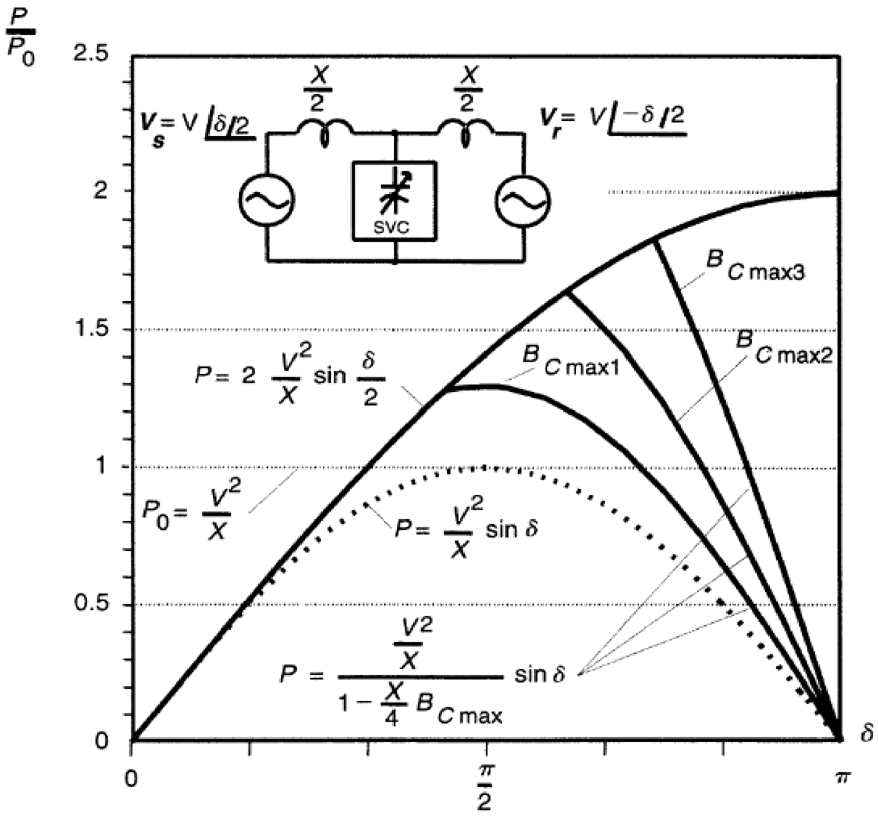
*V*-*Q* characteristics shows that STATCOM has maximum var generation or absorption which changes linearly with the ac system voltage. SVC gives maximum var output which decreases with the square of this voltage.

The capability of providing maximum compensating current at reduced system voltage enables the STATCOM to perform in a variety of applications the same dynamic compensation as an SVC of considerably higher rating.

# TRANSIENT STABILITY

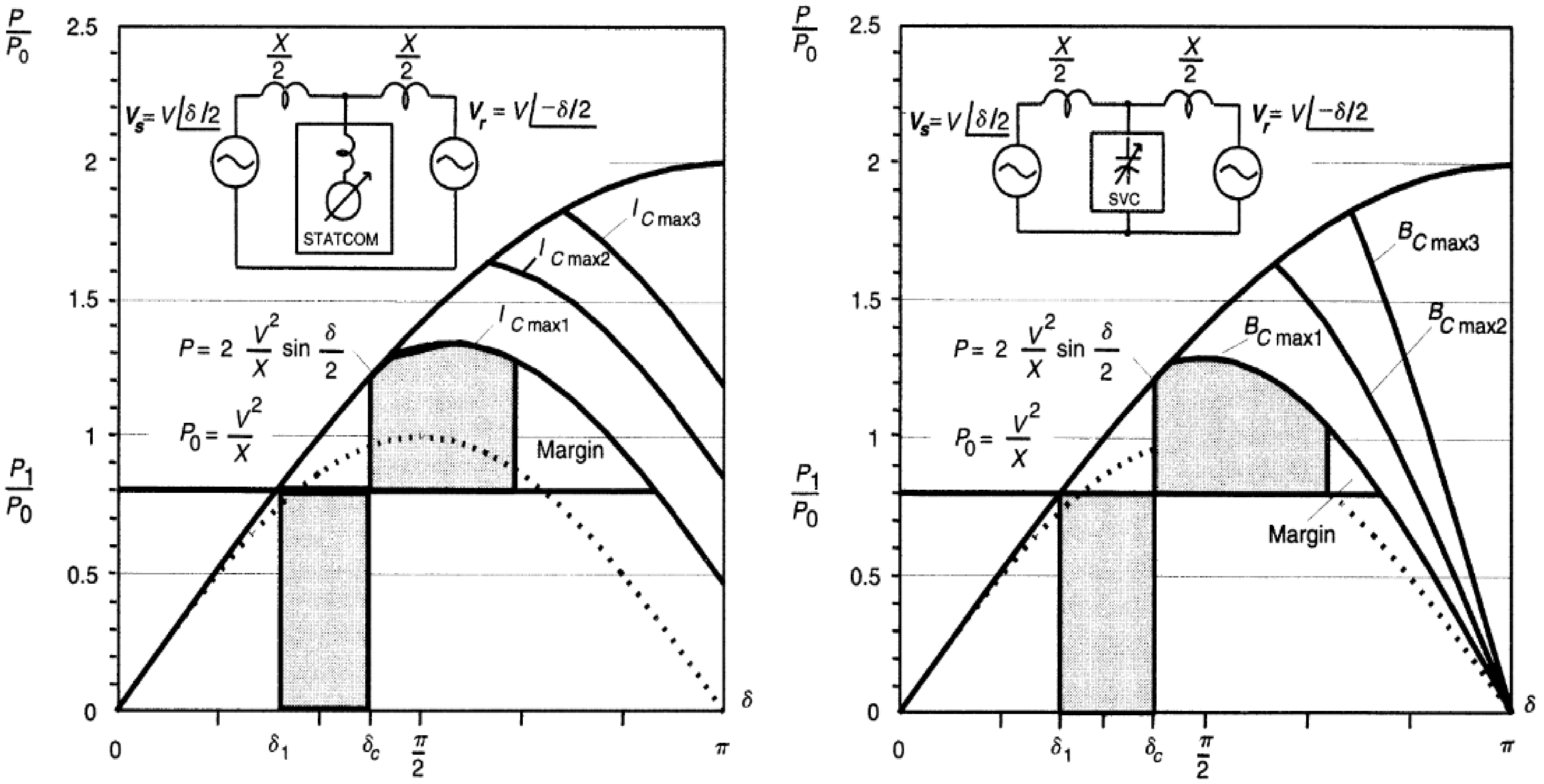


**STATCOM**



**SVC**

The ability of the STATCOM to maintain full capacitive output current at low system voltage also makes it more effective than the SVC in improving the transient(first swing) stability.



STATCOM

SVC

Improvement of transient stability with midpoint STATCOM and midpoint SVC

## RESPONSE TIME

The attainable response time and the bandwidth of the closed voltage regulation loop of the STATCOM are also significantly better than those of the SVC.

The time constant Td in the transfer function is about an order of magnitude smaller for the STATCOM than it is for the SVC.

The STATCOM can provide stable operation with respectable response over a much wider variation of the transmission network impedance than is possible with an SVC.

## CAPABILITY TO EXCHANGE REAL POWER

STATCOM, in contrast to the SVC, can interface a suitable energy storage with the ac system for real power exchange.

The reactive and real power exchange between the STATCOM and the ac system can be controlled independently of each other and any combination of real power generation and absorption with var generation and absorption is achievable.

# LOSS VS VAR OUTPUT CHARACTERISTICS

Both types of compensator have relatively low losses (about 0.1 to 0.2%) at and in the vicinity of zero var output.

The loss contribution of power semiconductors and related components to the total compensator losses is higher for the STATCOM than for the SVC.

This is due to available power semiconductor devices with internal turn-off capability have higher conduction losses than conventional thyristors.

Switching losses with forced current interruption tend to involve more losses than natural commutation.

# *Thank you!*

A Presentation On…..

# FACTS DEVICES

# FACTS

Flexible AC Transmission System (Facts) is a new integrated concept based on power electronic switching converters and dynamic controllers to enhance the system utilization and power transfer capacity as well as the stability, security, reliability and power quality of AC system interconnections.

# INTRODUCTION

- Flexible Alternating Current Transmission System.

- FACTS as they are generally known, are new devices that improve transmission systems.

- FACTS is a static equipment used for the AC transmission of electrical energy.

- It is generally a power electronics based device.

- Meant to enhance controllability and increase power transfer capability.

# BENEFITS OF FACTS DEVICES

- Regulation of power flows in prescribed transmission routes.
- Reduces the need for construction of new transmission lines, capacitors and reactors.
- Provides greater ability to transfer power between controlled areas.
- These devices help to damp the power oscillations that could damage the equipment.

- Improves the transient stability of the system.

- Controls real and reactive power flow in the line independently.

- Damping of oscillations which can threaten security or limit the usable line capacity.

- ✓ Better utilization of existing transmission system assets

- ✓ Increased transmission system reliability and availability (lower vulnerability to load changes, line faults)

- ✓ Increased dynamic and transient grid

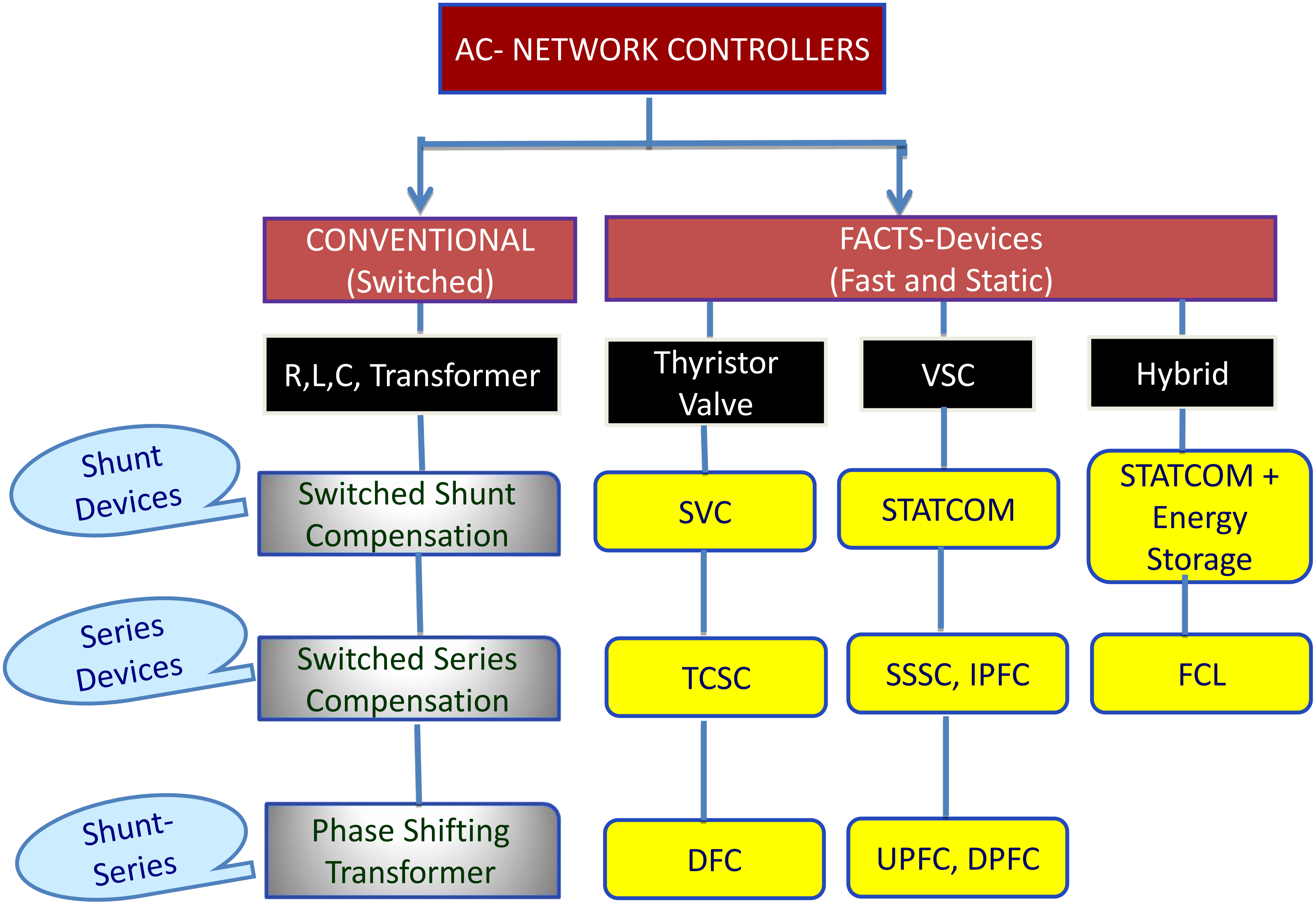
- ✓ Stability and reduction of loop flows

- ✓ Increased quality of supply for sensitive industries

  (through mitigation of flicker, frequency variations)

- ✓ Environmental benefits

**OVER VIEW OF FACTS**



AC- NETWORK CONTROLLERS

CONVENTIONAL (Switched)

FACTS-Devices (Fast and Static)

R,L,C, Transformer

Thyristor Valve

VSC

Hybrid

Shunt Devices

Switched Shunt Compensation

SVC

STATCOM

STATCOM + Energy Storage

Series Devices

Switched Series Compensation

TCSC

SSSC, IPFC

FCL

Shunt-Series

Phase Shifting Transformer

DFC

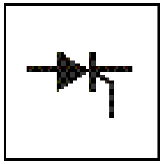
UPFC, DPFC

# Basic Types of FACTS Controllers

# Basic Types of FACTS Controllers

FACTS controllers are classified as

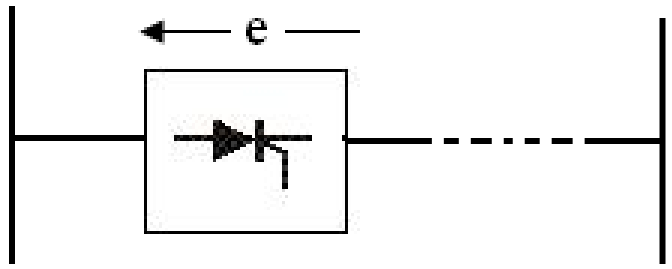
- Series Controllers
- Shunt Controllers
- Combined Series-Series Controllers
- Combined Series-Shunt Controllers



# Basic Types of FACTS Controllers

Series Controllers:

- It could be a variable impedance (capacitor, reactor, etc) or a power electronic based variable source of main frequency, subsynchonous and harmonic frequencies to serve the desired need.



# Basic Types of FACTS Controllers

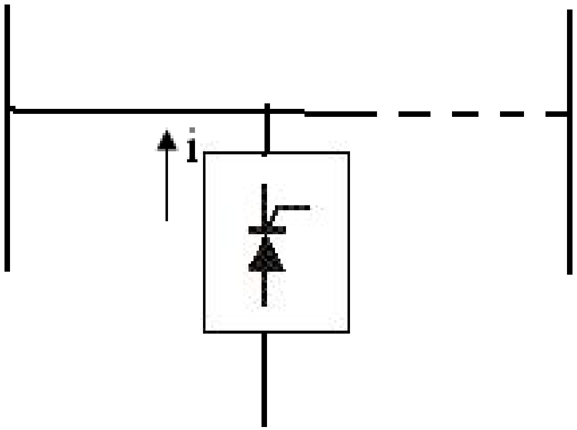
Series Controllers:

- Inject a voltage in series with the line.
- If the voltage is in phase quadrature with the current, controller supplies or consumes reactive power.
- Any other phase, involves control of both active and reactive power.

# Basic Types of FACTS Controllers

## Shunt Controllers:

- It could be a variable impedance (capacitor, reactor, etc) or a power electronic based variable source or combination of both.



# Basic Types of FACTS Controllers

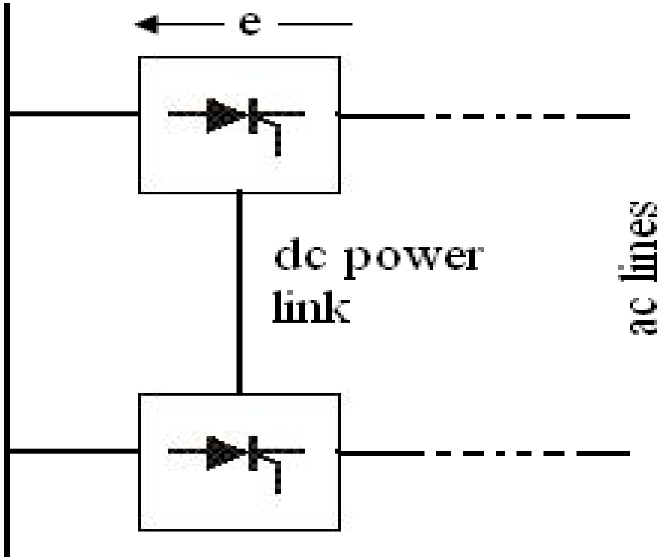
Shunt Controllers:

- Inject a current in the system.
- If the current is in phase quadrature with the voltage, controller supplies or consumes reactive power.
- Any other phase, involves control of both active and reactive power.

# Basic Types of FACTS Controllers

## Combined Series-Series Controllers:

- It could be a combination of separate series controllers or unified controller.



# Basic Types of FACTS Controllers

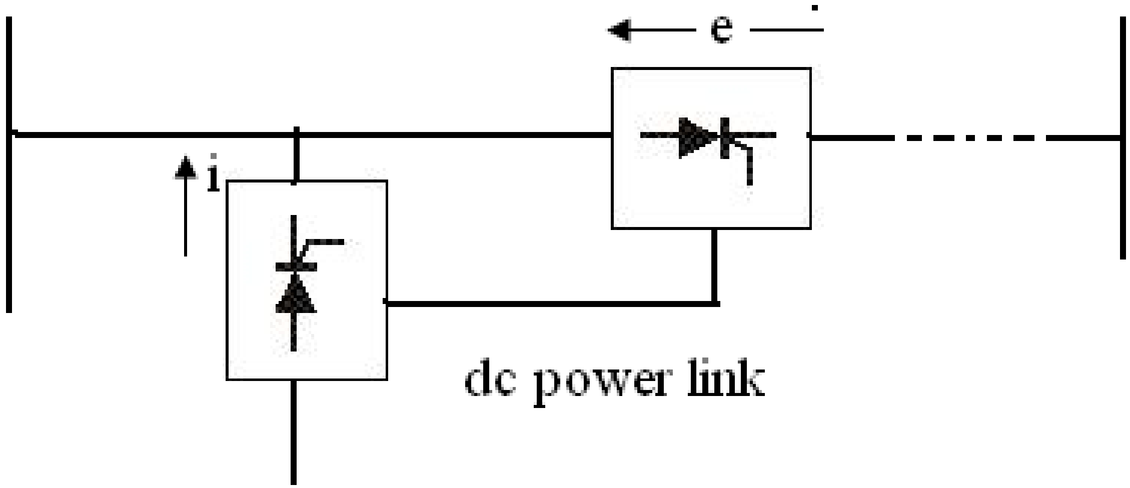
Combined Series-Series Controllers:

- Series controllers supply reactive power for each line and real power among lines via power link.
- Interline power flow controller balance real and reactive power flow in the lines.

# Basic Types of FACTS Controllers

Combined Series-Shunt Controllers:

- It could be a combination of separate series & shunt controllers or unified power flow controller.



# Basic Types of FACTS Controllers

Combined Series-Shunt Controllers:

- Inject current into the system with the shunt controller and voltage in series with the line with series controller.
- When the controllers are unified, exchange real power between series and shunt controllers via power link.

# Basic Types of FACTS Controllers

Choice of the controller:

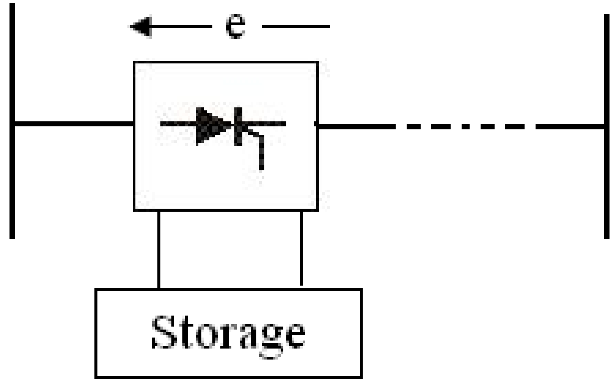
- Series controller controls the current/power flow by controlling the driving voltage.
- To control current/power flow and damp oscillations, series controller is several times more powerful than shunt controller.
- Shunt controller injects current in the line
- Thus it is used for more effective voltage control & damp voltage oscillations.

# Basic Types of FACTS Controllers

- Injecting the voltage in series with the line can improve the voltage profile.
- But shunt controller is more effective to improve the voltage profile at substation bus.
- For a given MVA, size of series controller is small compared to shunt controller.
- Shunt controllers cannot control the power flow in the lines.
- Series controllers should bypass short circuit currents and handle dynamic overloads.

# Basic Types of FACTS Controllers

- Controllers with gate turn off devices are based on dc to ac converters and exchange active/reactive power with ac lines.
- This requires energy storage device.



# Basic Types of FACTS Controllers

- Energy storage systems are needed when active power is involved in the power flow.
- A controller with storage is more effective for controlling the system dynamics.
- A converter-based controller can be designed with high pulse order or pulse width modulation to reduce the low order harmonic generation to a very low level.
- A converter can be designed to generate the correct waveform in order to act as an active filter.

# Static VAR Compensators (SVC)

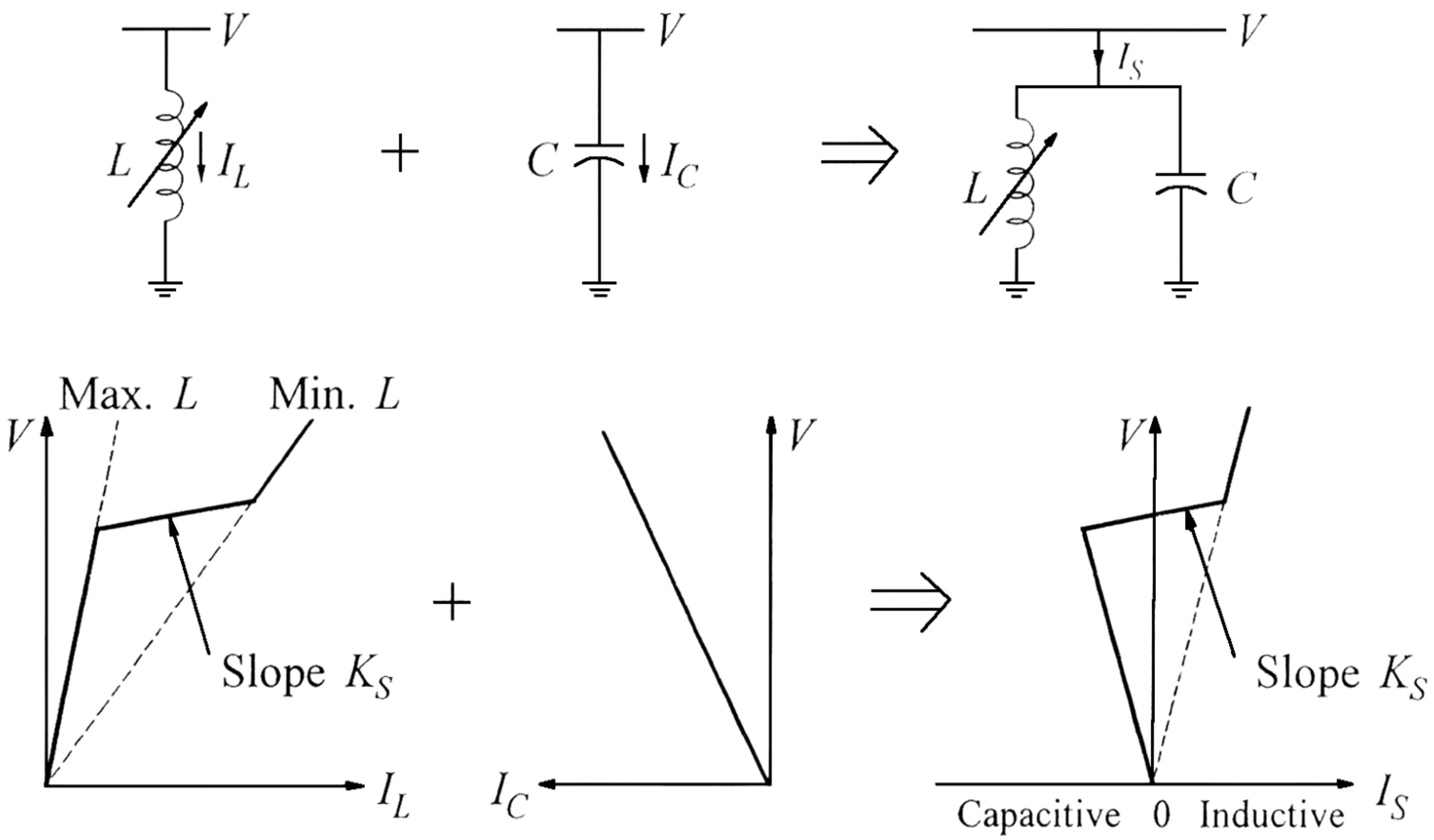
- Shunt connected static var generators and/or absorbers whose outputs are varied so as to control specific power system quantities

- The term static is used to denote that there are no moving or rotating components

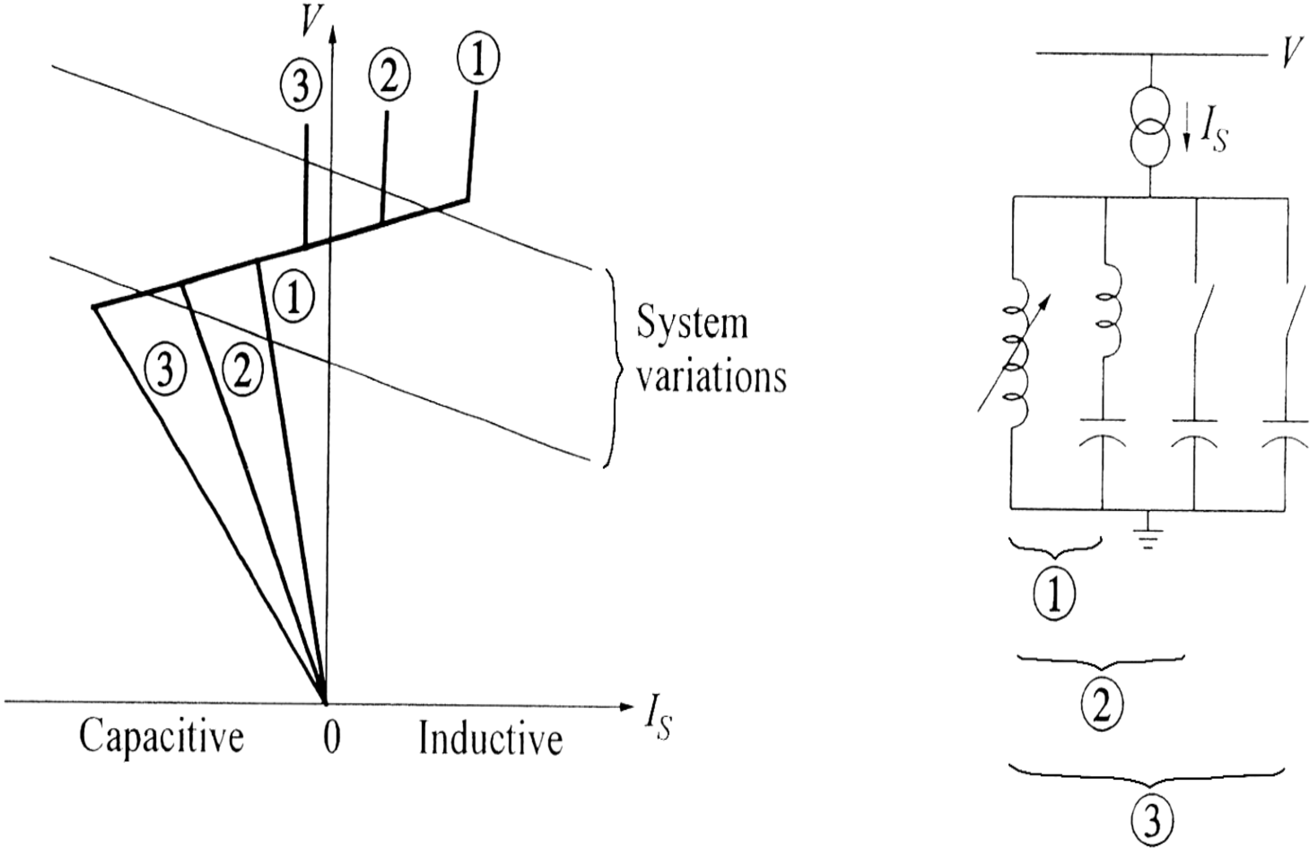
- Basic types of SVCs:
  - Thyristor-controlled reactor (TCR)
  - Thyristor-switched capacitor (TSC)
  - Saturated reactor

- A static var system (SVS) is an aggregation of SVCs and mechanically switched capacitors or reactors whose outputs are coordinated

- When operating at its capacitive limit, an SVC behaves like a simple capacitor

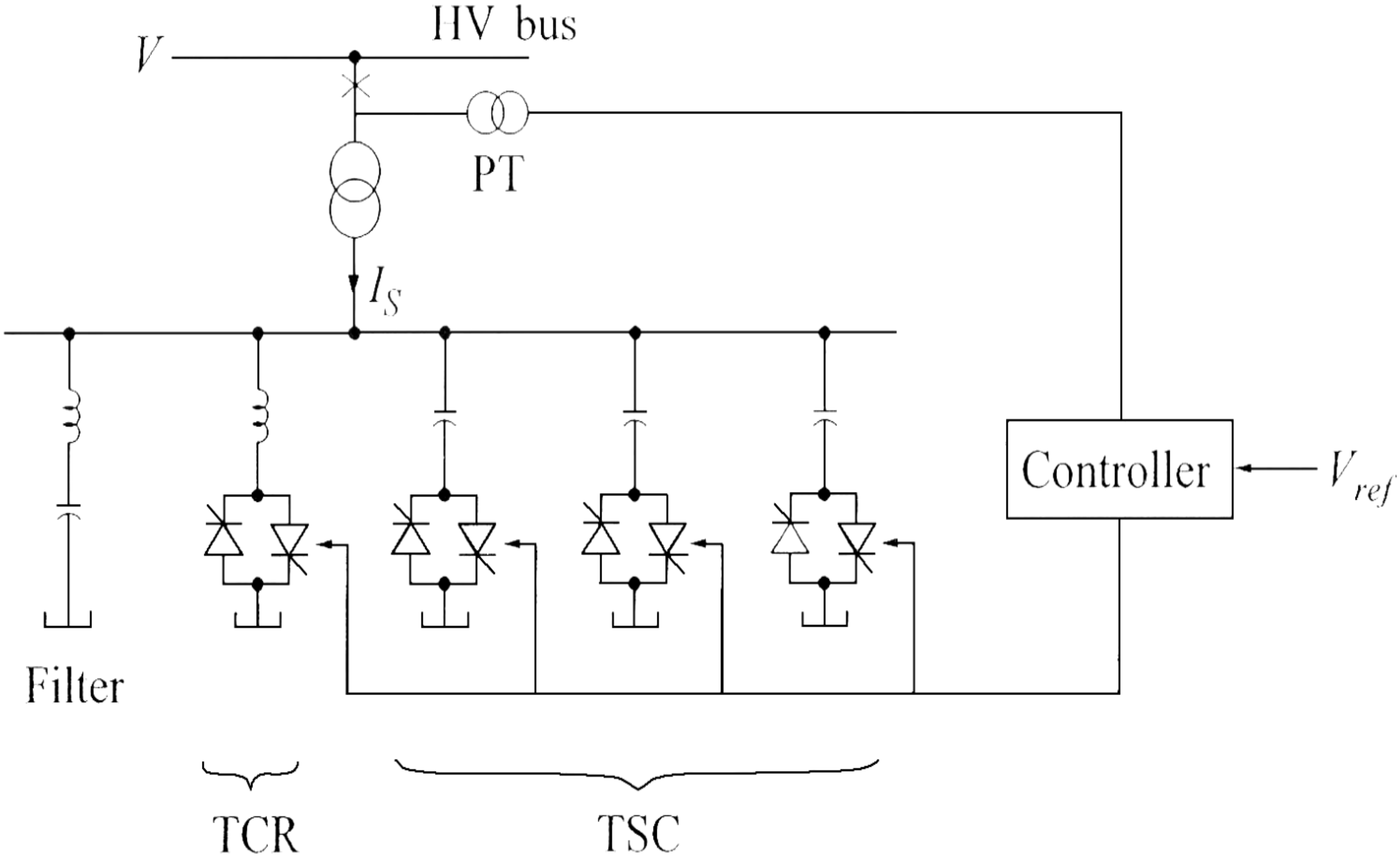


Composite characteristics of an SVS

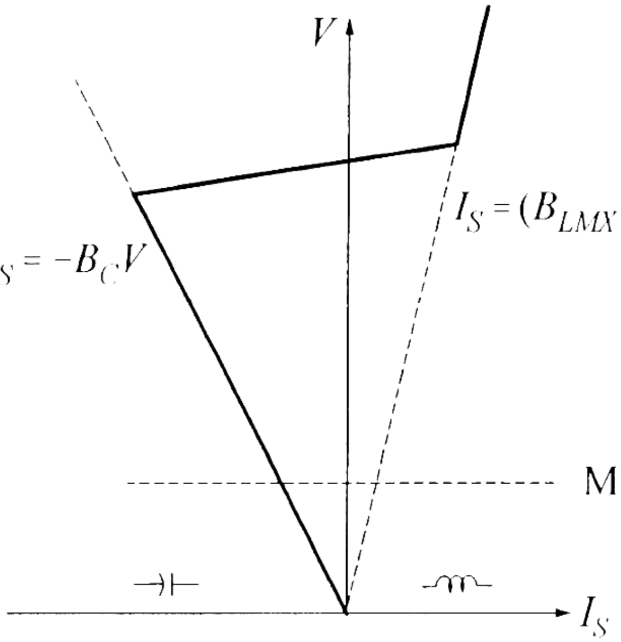


Use of switched capacitors to extend continuous control range

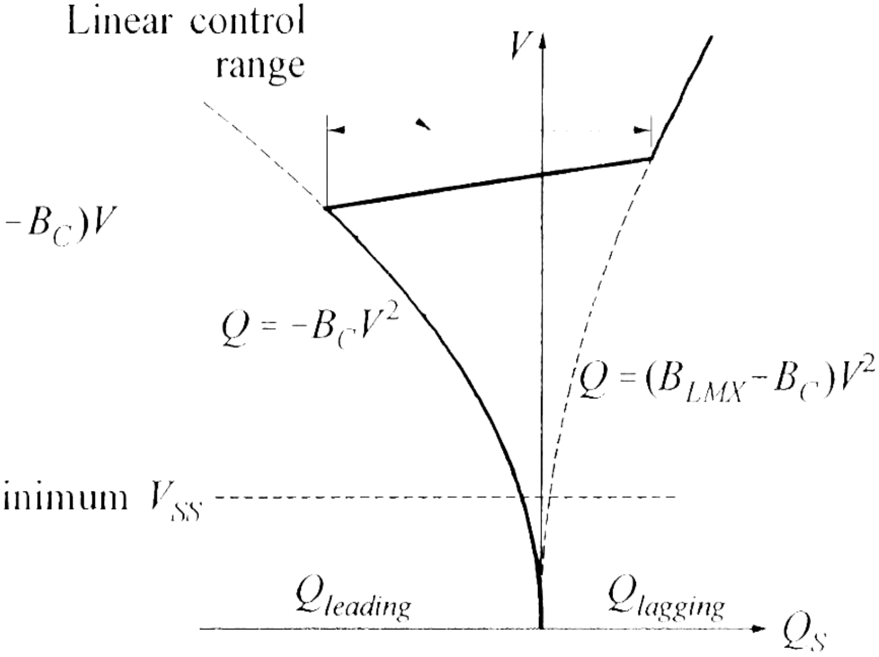
# A typical static var system



# SVS steady-state characteristics



(a) Voltage-current characteristic



(b) Voltage-reactive power characteristic

# Static Synchronous Compensator (STATCOM)

- This shunt connected static compensator was developed as an advanced static VAR compensator where a voltage source convertor (VSC) is used in- stead of the controllable reactors and switched capacitors.

- Although VSCs require self-commutated power semiconductor devices such as GTO, IGBT, IGCT, MCT, etc (with higher costs and losses) unlike in the case of variable impedance type SVC which use thyristor devices.

A STATCOM is comparable to a Synchronous Condenser (or Compensator) which can supply variable reactive power and regulate the voltage of the bus where it is connected. The equivalent circuit of a Synchronous Condenser (SC) is shown in Fig.1.

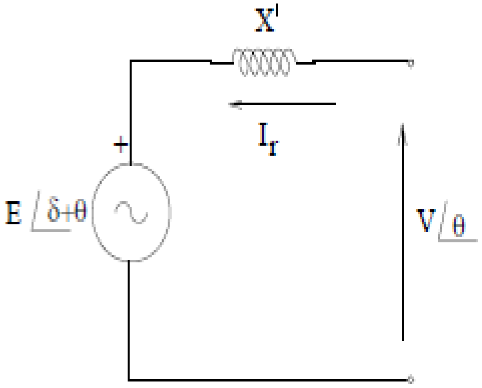


Fig.1. Synchronous condenser

A STATCOM (previously called as static condenser (STATCON) has a similar equivalent circuit as that of a SC. The AC voltage is directly proportional to the DC voltage (Vdc) across the capacitor (see Fig.2. which shows the circuit for a single phase STATCOM)

There are many technical advantages of a STATCOM over a SVC. These are primarily:

(a) Faster response

(b) Requires less space as bulky passive components (such as reactors) are eliminated

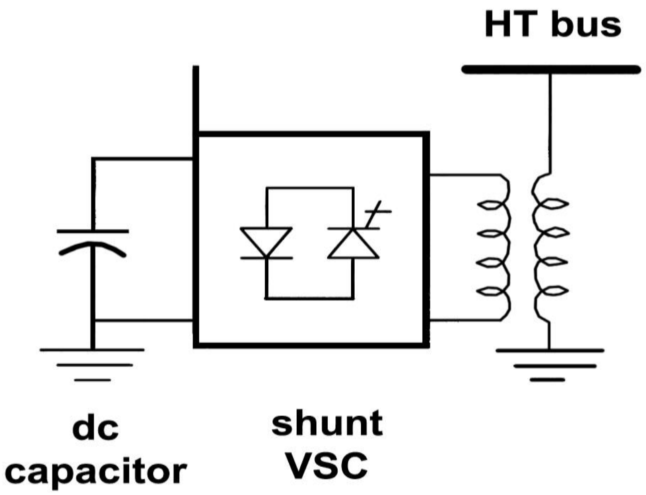
(c) Inherently modular and relocatable

(d) It can be interfaced with real power sources such as battery, fuel cell or SMES (superconducting magnetic energy storage)

(e) A STATCOM has superior performance during low voltage condition as the reactive current can be maintained constant (In a SVC, the capacitive reactive current drops linearly with the voltage at the limit (of capacitive susceptance). It is even possible to increase the reactive current in a STATCOM under transient conditions if the devices are rated for the transient overload. In a SVC, the maximum reactive current is determined by the rating of the passive components – reactors and capacitors.

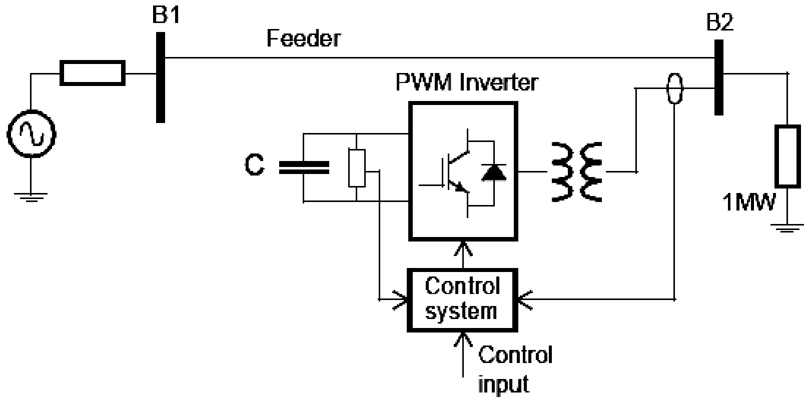
- STATCOM is a regulating(poor power factor and poor voltage) device.
- Based on a power electronics voltage-source converter and can act as either a source or sink of reactive AC power.
- If connected to a source of power it can also provide active AC power.
- STATCOM provides better damping characteristics than the SVC as it is able to transiently exchange active power with the system

- Can be based on a voltage-sourced or current-sourced converter
- Figure below shows one with voltage-sourced converter
  - driven by a dc voltage source: capacitor



- Effectively an alternating voltage source behind a coupling reactance
  - controllable in magnitude
- Can be operated over its full output current range even at very low (typically 0.2 pu) system voltage levels
- Requires fewer harmonic filters and capacitors than an SVC, and no reactors
  - significantly more compact

# Structure of STATCOM



- **Basically, the STATCOM system is comprised of Power converters, Set of coupling reactors or a step up transformer, Controller**

# Advantages of STATCOM

- The reactive components used in the STATCOM are much smaller than those in the SVC.
- The characteristics of STATCOM are superior.
- The output current of STATCOM can be controlled up to the rated maximum capacitive or inductive range.
- Reduction of the capacity of semiconductor power converter and capacitor bank to one half of those for the conventional SVC.
- Better transient response of the order of quarter cycle.
- Reduction of harmonic filter capacity.
- Reduction of size of high value air-cored reactor.
- Reduction of equipment volume and foot-print.

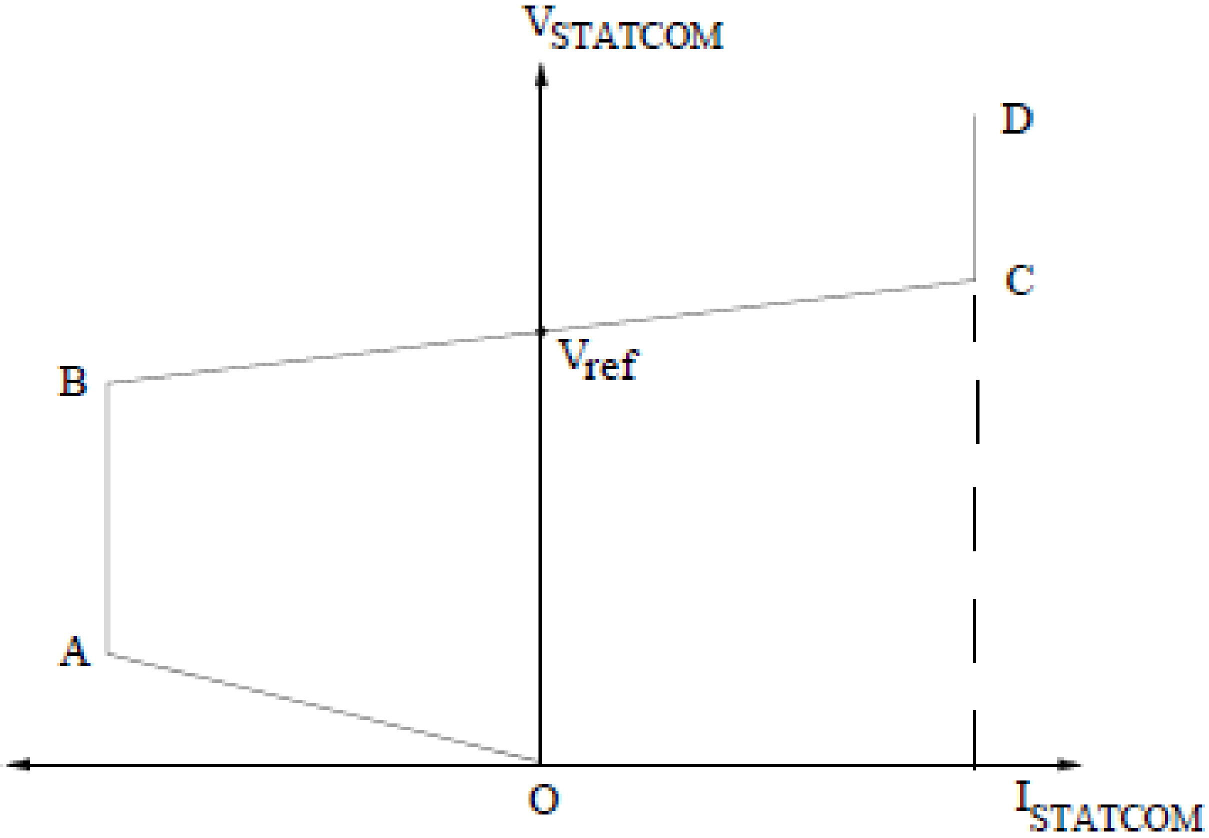
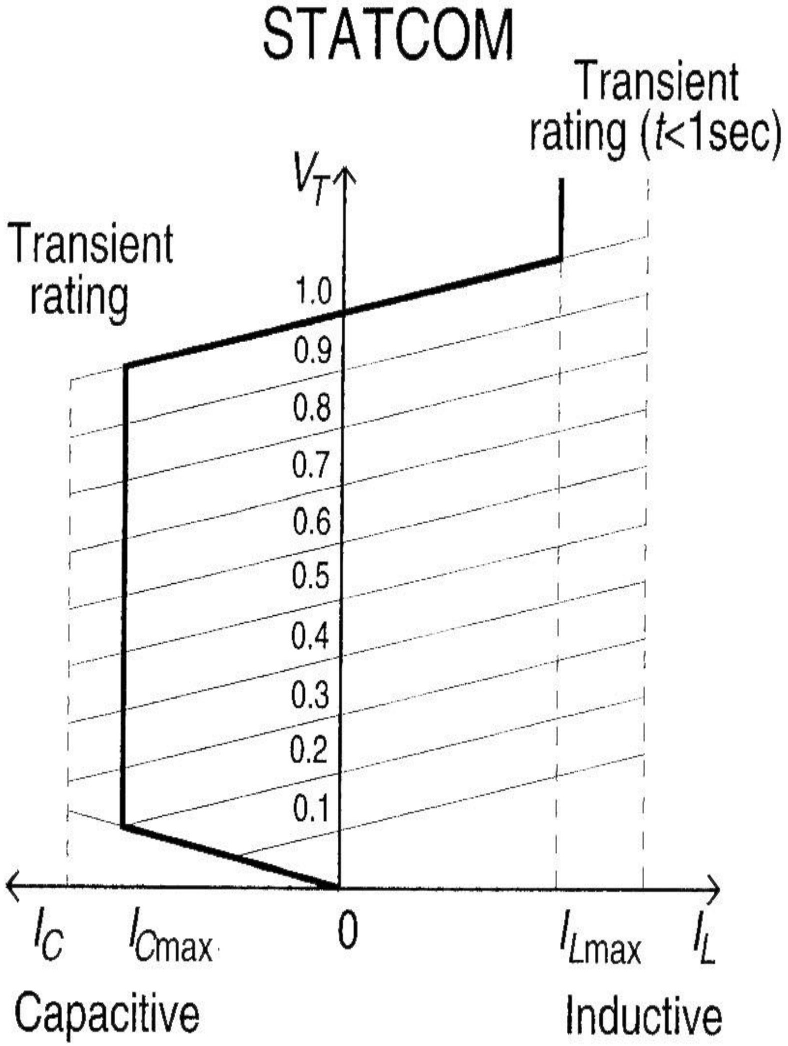
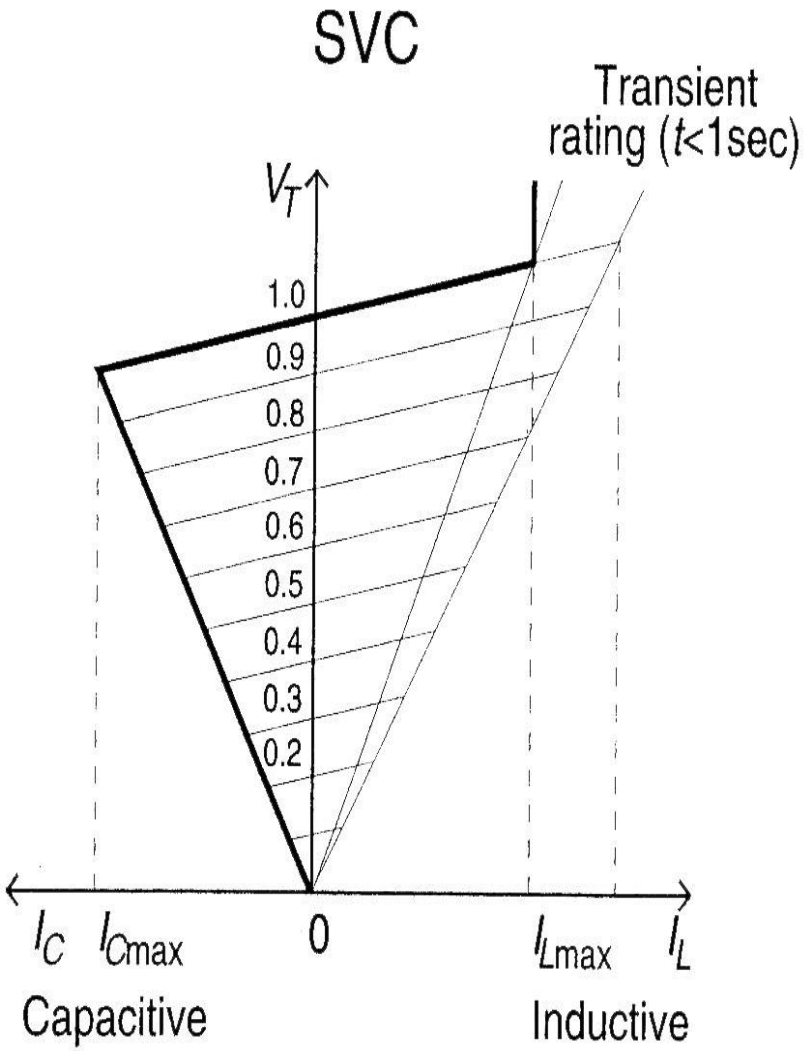


Figure 6.4: Control characteristics of a STATCOM

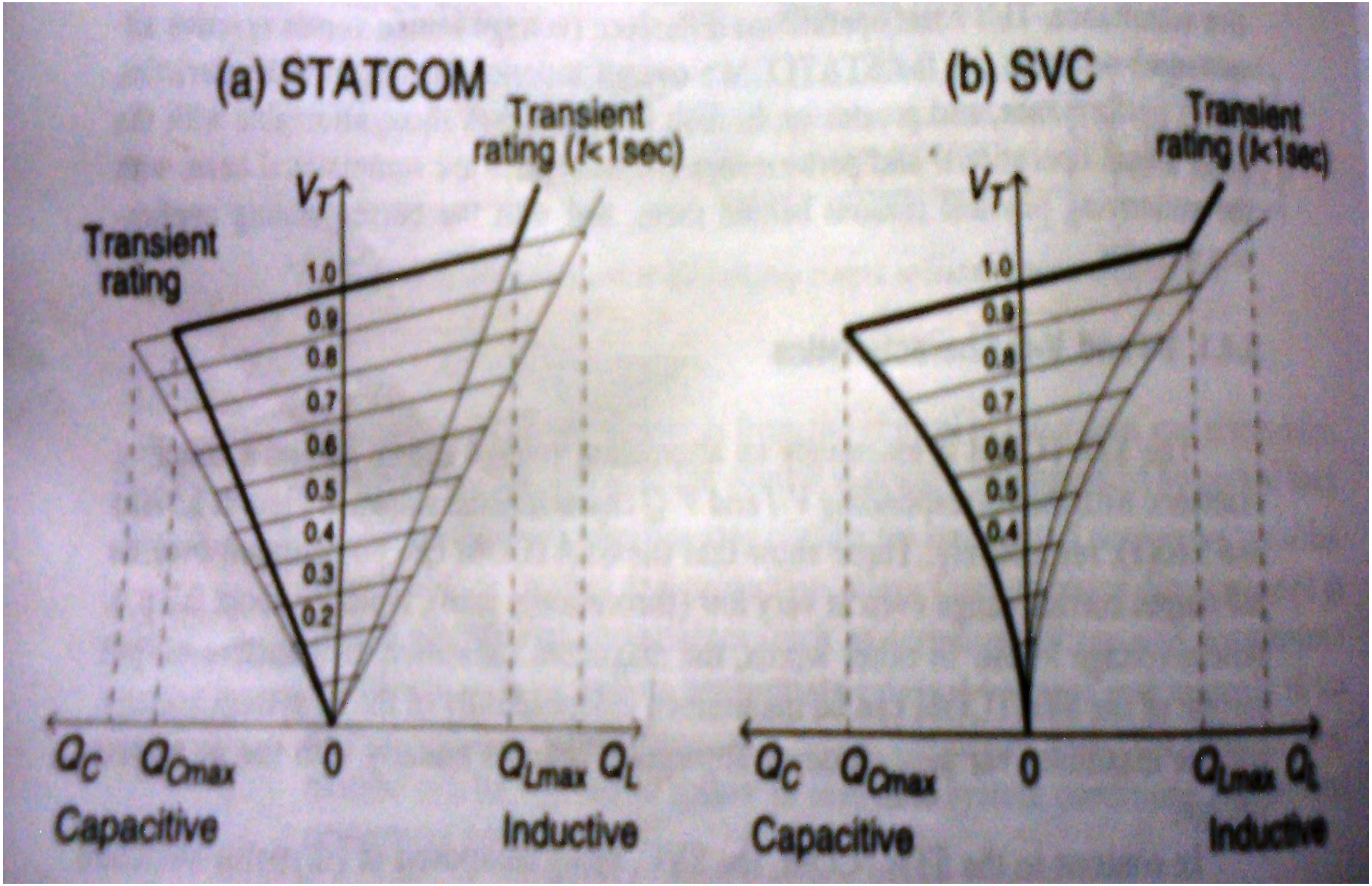
# COMPARISON
# OF
# STATCOM AND SVC CHARACTERISTICS

# (i) V-I characteristics

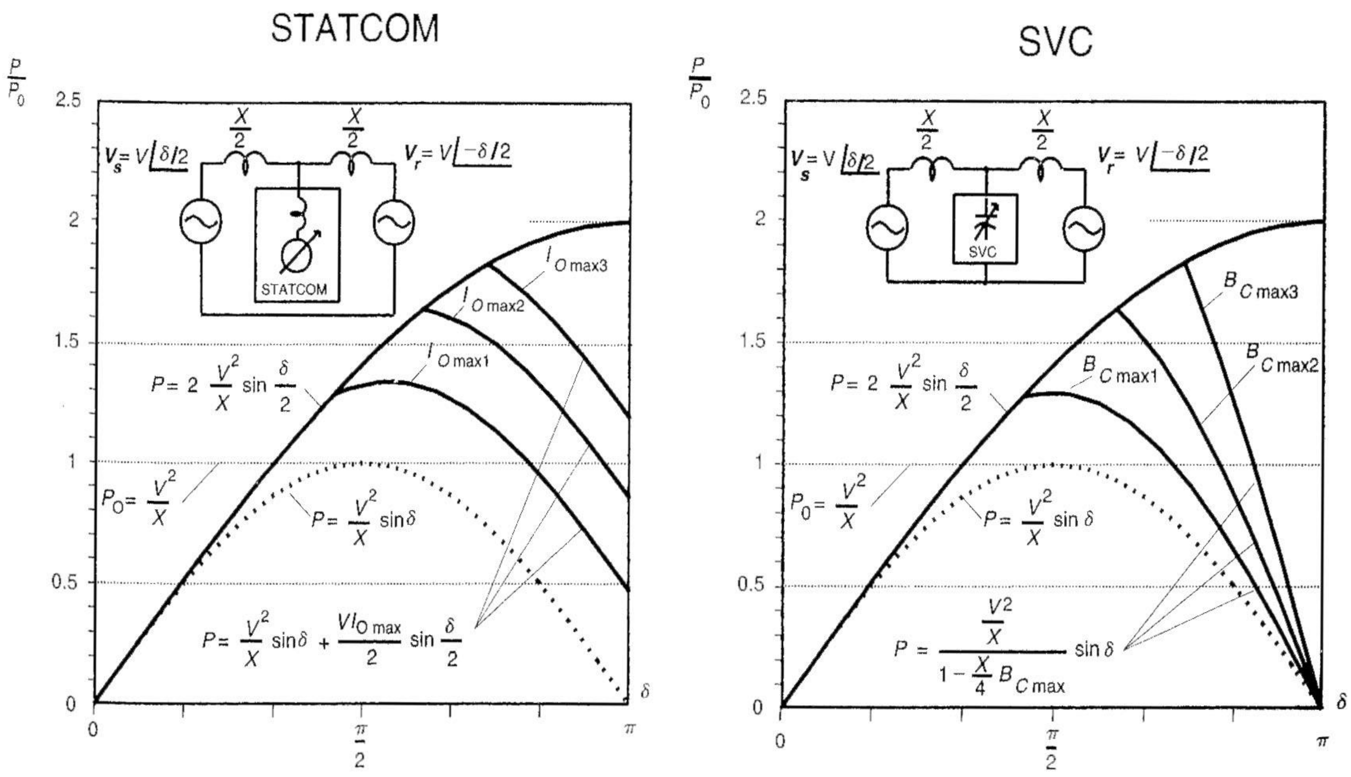




# (ii) V-Q Characteristics



# (iii) Transient stability



P- δ characteristics with mid-point compensation

# (iv) Response Time

Transport lag $e^{-T_d s}$

SVC- Between 2.5 ms to 5.0 ms
STATCOM- Between 200 µs to 300 µs

# (v) Capability to exchange real power

For applications requiring active (real) power compensation it is clear that the STATCOM, in contrast to the SVC, can interface a suitable energy storage with the AC system for real power exchange.

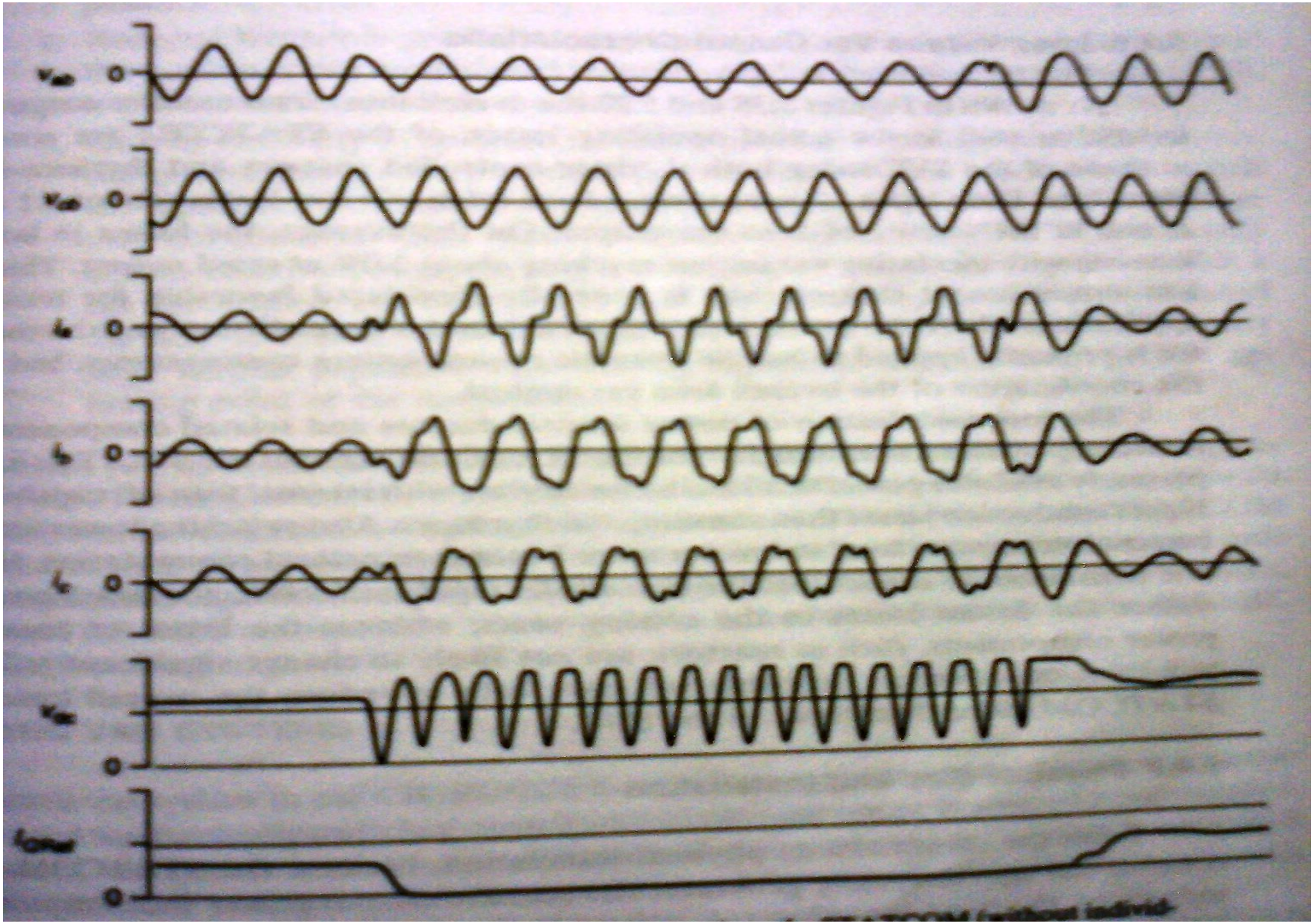
# (vi) Operation with unbalanced AC System

- **SVC** controls establishes three identical shunt admittances, one for each phase. Consequently, with unbalanced system voltages the compensating currents in each phase would become different . It is possible to control the three compensating admittances individually by adjusting delay angle of the TCRs so as to make the three compensating currents identical.

- However in this case triple-n harmonic content would be different in each phase and their normal cancellation through delta connection would not place. This operation mode thus would generally require the installation of the usually unneeded third harmonic filters.

- The operation of the **STATCOM** under unbalanced system conditions is different from that of the SVC, but the consequences of the such operation are similar.

- The STATCOM operation is governed by fundamental physical law requiring that the net instantaneous power at the ac and dc terminals of the voltage-sourced converters employed must be always be equal. This is because the converter has no internal energy storage and thus energy transfer through it is absolutely direct, and consequently the net instantaneous power at the ac and dc terminals must be equal.



Wave forms illustrating the operation of a STATCOM during LG Fault at the regulated bus

# (vii) Loss Versus Var output characteristics

❑The loss contribution of power semiconductors and related components to the total compensator losses is higher for the STATCOM than for the SVC. This is because presently available power semiconductor devices with internal turn-off capability have higher conduction losses than conventional thyristors.

❑ Thus the technological advances probably will have help to reduce the overall losses of the STATCOM more than those of the SVC.

# (viii) Physical size and installation

- From the stand point of physical installation, because the STATCOM not only controls but also internally generates the reactive output power, the large capacitor and reactor banks with their associated switchgear and protection, used in conventional thyristors controlled SVCs, are not needed.

- This results in a significant reduction in overall size (about 30 to 40 %) , as well as installation labor and cost.

## Gokaraju Rangaraju Institute of Eningeering & Technology

Department of Electrical & Electronics Engineering

B.Tech - IV Year I Sem A-Sec AY: 2018-19

Mid - I DoE: 05.02.2019

### Power Electronics - CO Attainment

| ***Question Numbers*** | ***1*** | ***2*** | ***3*** | ***4*** |
|---|---|---|---|---|
| ***Course Outcomes*** | ***1*** | ***2*** | ***2*** | ***3*** |
| *Roll Number* | | | | |
| 15241A0201 | 4 | 4 | | 5 |
| 15241A0202 | 4 | | 5 | 4 |
| 15241A0203 | 4 | | 5 | 5 |
| 15241A0204 | 4 | 4 | 3 | |
| 15241A0205 | 4 | 5 | 4 | |
| 15241A0206 | A | A | A | A |
| 15241A0207 | | 4 | 4 | 4 |
| 15241A0208 | 4 | 4 | 4 | |
| 15241A0209 | 4 | 4 | | 4 |
| 15241A0211 | 4 | 5 | 4 | |
| 15241A0212 | 5 | 5 | 4 | |
| 15241A0213 | 4 | | 5 | 4 |
| 15241A0214 | | 5 | 4 | 5 |
| 15241A0215 | 4 | 4 | | 4 |
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| 15241A0218 | 4 | 3 | 4 | |
| 15241A0219 | | 4 | 4 | |
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| 15241A0222 | 4 | | 4 | 5 |
| 15241A0224 | 4 | 3 | 2 | |
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| 15241A0227 | 4 | | 5 | 5 |
| 15241A0228 | 3 | 5 | | |
| 15241A0229 | | 5 | 4 | 5 |
| 15241A0230 | 3 | 4 | | 4 |
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| ***Question Numbers*** | ***1*** | ***2*** | ***3*** | ***4*** |
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| 15241A0259 | 4 | 3 | 4 | |
| 15241A0260 | 4 | 4 | 4 | |
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| 16245A0203 | | 5 | 4 | 5 |
| 16245A0204 | | 5 | 4 | 5 |
| 16245A0205 | 3 | 4 | | 3 |
| 16245A0206 | 3 | | 3 | 4 |
| 16245A0207 | | 5 | 4 | 3 |
| 16245A0208 | 5 | 4 | 3 | |
| 16245A0209 | | 4 | 5 | 5 |
| 16245A0210 | 2 | 5 | 3 | |
| 16245A0211 | | 4 | 4 | 5 |
| 16245A0212 | 5 | | | 5 |
| | | | | |
| | | | | |
| Grand Total | 194 | 231 | 189 | 166 |
| NSA | 50 | 53 | 49 | 39 |
| Attempt %=(NSA/Total no of students) * 100 | 72.5 | 76.8 | 71 | 56.5 |
| Average (attainment) = Total / NSA | 3.9 | 4.4 | 3.9 | 4.3 |
| Attainment % = (Total/no.of max marks*no.of students attempted)*100 | 77.6 | 87.2 | 77.1 | 85.1 |

| | |
|---|---|
| **CO 1** | **77.60** |
| **CO 2** | **82.20** |
| **CO 3** | **85.10** |

# Gokaraju Rangaraju Institute of Eningeering & Technology

Department of Electrical & Electronics Engineering

B.Tech - IV Year I Sem B-Sec AY: 2018-19

Mid - I DoE: 05.02.2019

## Power Electronics - CO Attainment

| ***Question Numbers*** | ***1*** | ***2*** | ***3*** | ***4*** |
|---|---|---|---|---|
| ***Course Outcomes*** | ***1*** | ***2*** | ***2*** | ***3*** |
| *Roll Number* | | | | |
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| 15241A0269 | 4 | 4 | | |
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| 15241A0276 | 4 | 5 | | 5 |
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| 15241A0280 | 4 | | 5 | 4 |
| 15241A0281 | 4 | 5 | 4 | |
| 15241A0282 | 5 | | 5 | 5 |
| 15241A0283 | 3 | | | |
| 15241A0284 | 5 | 5 | 4 | |
| 15241A0285 | | 5 | 4 | 5 |
| 15241A0286 | 5 | 4 | 2 | |
| 15241A0287 | | 5 | 3 | |
| 15241A0288 | 3 | 4 | | |
| 15241A0289 | 5 | 4 | 4 | |
| 15241A0290 | | 5 | | 4 |
| 15241A0291 | 4 | 4 | 3 | |
| 15241A0292 | 5 | 5 | | 5 |
| 15241A0293 | | 4 | 4 | 5 |
| 15241A0294 | | 3 | 4 | 4 |
| 15241A0295 | 2 | | 4 | 5 |
| 15241A0296 | 4 | | 4 | 4 |
| 15241A0297 | 4 | | 5 | 5 |
| 15241A0298 | 4 | 5 | 4 | |
| 15241A0299 | | 5 | 3 | 5 |
| 15241A02A0 | A | A | A | A |

| ***Question Numbers*** | ***1*** | ***2*** | ***3*** | ***4*** |
|---|---|---|---|---|
| ***Course Outcomes*** | ***1*** | ***2*** | ***2*** | ***3*** |
| *Roll Number* | | | | |
| 15241A02A1 | 4 | | 4 | 4 |
| 15241A02A2 | 5 | 5 | 2 | |
| 15241A02A3 | | 5 | 5 | 5 |
| | | | | |
| 15241A02A5 | 5 | 3 | | 3 |
| 15241A02A6 | 4 | 4 | | 3 |
| 15241A02A7 | | 5 | 5 | |
| 15241A02A8 | 4 | 5 | | |
| 15241A02A9 | 4 | | 4 | 5 |
| 15241A02B0 | 4 | 5 | | 3 |
| 15241A02B1 | 4 | | 5 | 5 |
| 15241A02B2 | 4 | 5 | | |
| 15241A02B3 | 5 | 5 | 3 | |
| 15241A02B4 | | 4 | 4 | 5 |
| 15241A02B5 | 4 | 5 | 3 | |
| 15241A02B6 | | 5 | 4 | 5 |
| 15241A02B7 | 3 | 5 | 4 | |
| 15241A02B8 | 4 | 5 | 3 | |
| 15241A02B9 | 3 | 5 | 3 | |
| 15241A02C0 | | 5 | 4 | 4 |
| 16245A0213 | 4 | 4 | | 5 |
| 16245A0214 | | 4 | 3 | 4 |
| 16245A0215 | 3 | 4 | 3 | |
| 16245A0216 | 3 | 4 | | 5 |
| 16245A0217 | 4 | 5 | 4 | |
| 16245A0218 | 4 | | 4 | 4 |
| 16245A0219 | 4 | 4 | | 4 |
| 16245A0220 | 3 | 4 | 3 | |
| 16245A0221 | | 4 | 3 | 5 |
| 16245A0222 | 4 | 4 | 4 | |
| 16245A0223 | 4 | | 5 | 5 |
| 16245A0224 | 5 | 5 | 3 | |
| | | | | |
| Grand Total | 213 | 250 | 190 | 176 |
| NSA | 53 | 56 | 49 | 39 |
| Attempt %=(NSA/Total no of students) * 100 | 74.6 | 78.9 | 69 | 54.9 |
| Average (attainment) = Total / NSA | 4.0 | 4.5 | 3.9 | 4.5 |
| Attainment % = (Total/no.of max marks*no.of students attempted)*100 | 80.4 | 89.3 | 77.6 | 90.3 |

| | |
|---|---|
| **CO 1** | **80.40** |
| **CO 2** | **83.40** |
| **CO 3** | **90.30** |

## Gokaraju Rangaraju Institute of Eningeering & Technology

Department of Electrical & Electronics Engineering

B.Tech - IV Year I Sem A-Sec AY: 2018-19

Mid - II DoE: 08.04.2019

### Power Electronics - CO Attainment

| ***Question Numbers*** | ***1*** | ***2*** | ***3*** | ***4*** |
|---|---|---|---|---|
| ***Course Outcomes*** | ***4*** | ***5*** | ***6*** | ***7*** |
| *Roll Number* | | | | |
| 15241A0201 | 5 | 4 | | 5 |
| 15241A0202 | 5 | 5 | | |
| 15241A0203 | 5 | | | |
| 15241A0204 | 5 | 5 | | 5 |
| 15241A0205 | 4 | 4 | | 5 |
| 15241A0206 | 4 | | 4 | 5 |
| 15241A0207 | 5 | 4 | | 5 |
| 15241A0208 | 4 | 3 | | 3 |
| 15241A0209 | 5 | 5 | 4 | |
| 15241A0211 | 5 | 5 | | 3 |
| 15241A0212 | 5 | 5 | | 4 |
| 15241A0213 | 5 | 4 | | 5 |
| 15241A0214 | 5 | 5 | | 5 |
| 15241A0215 | 5 | 4 | | 4 |
| 15241A0216 | 5 | 5 | | 2 |
| 15241A0217 | 5 | 4 | 4 | |
| 15241A0218 | 4 | 3 | | 4 |
| 15241A0219 | 5 | 5 | | 4 |
| 15241A0220 | 5 | 4 | 5 | |
| 15241A0221 | 5 | 5 | | 3 |
| 15241A0222 | 5 | 1 | | 4 |
| 15241A0224 | 4 | 3 | | 3 |
| 15241A0225 | 5 | 3 | | 4 |
| 15241A0226 | 5 | 4 | | 5 |
| 15241A0227 | 5 | 5 | | 5 |
| 15241A0228 | | | 3 | 5 |
| 15241A0229 | 5 | 4 | | 5 |
| 15241A0230 | 5 | 4 | 4 | |
| 15241A0231 | 5 | | 4 | 4 |
| 15241A0232 | 5 | 3 | | 4 |
| 15241A0233 | 5 | 5 | | 5 |
| 15241A0234 | 5 | 5 | | 5 |
| 15241A0235 | 5 | 4 | | 3 |
| 15241A0236 | 5 | 4 | | 4 |
| 15241A0237 | 5 | 3 | 5 | |
| 15241A0238 | 5 | 4 | | 4 |
| 15241A0239 | 5 | 4 | 4 | |
| 15241A0240 | 5 | 4 | 4 | |
| 15241A0241 | 5 | 4 | 3 | |

| ***Question Numbers*** | ***1*** | ***2*** | ***3*** | ***4*** |
|---|---|---|---|---|
| ***Course Outcomes*** | ***4*** | ***5*** | ***6*** | ***7*** |
| *Roll Number* | | | | |
| 15241A0242 | 5 | 4 | | 4 |
| 15241A0244 | 5 | | 4 | |
| 15241A0245 | 5 | | | 4 |
| 15241A0246 | 4 | 4 | 5 | |
| 15241A0247 | 5 | 5 | 2 | |
| 15241A0248 | 5 | 4 | | 5 |
| 15241A0249 | 5 | 5 | 5 | |
| 15241A0250 | 5 | 4 | 4 | |
| 15241A0251 | 4 | 5 | | |
| 15241A0252 | | | | |
| 15241A0253 | 5 | | 4 | |
| 15241A0254 | 5 | | | 4 |
| 15241A0255 | 5 | 5 | | 5 |
| 15241A0256 | 5 | 4 | | 4 |
| 15241A0257 | 5 | 5 | | 4 |
| 15241A0258 | | 4 | | 4 |
| 15241A0259 | 5 | 4 | | 4 |
| 15241A0260 | 4 | 5 | | |
| 16245A0201 | 4 | 4 | 3 | |
| 16245A0202 | 5 | 5 | 4 | |
| 16245A0203 | 5 | 4 | 4 | |
| 16245A0204 | 5 | 4 | | 4 |
| 16245A0205 | 5 | 3 | | 4 |
| 16245A0206 | 4 | 4 | | 3 |
| 16245A0207 | 5 | 4 | | 4 |
| 16245A0208 | 5 | 4 | 4 | |
| 16245A0209 | 4 | 5 | | 4 |
| 16245A0210 | 5 | | 3 | |
| 16245A0211 | 5 | 4 | 5 | |
| 16245A0212 | 5 | 4 | | 4 |
| | | | | |
| | | | | |
| Grand Total | 319 | 246 | 91 | 183 |
| NSA | 66 | 59 | 23 | 44 |
| Attempt %=(NSA/Total no of students) * 100 | 95.7 | 85.5 | 33.3 | 63.8 |
| Average (attainment) = Total / NSA | 4.8 | 4.2 | 4.0 | 4.2 |
| Attainment % = (Total/no.of max marks*no.of students attempted)*100 | 96.7 | 83.4 | 79.1 | 83.2 |

| | |
|---|---|
| **CO 4** | **96.70** |
| **CO 5** | **83.40** |
| **CO 6** | **79.10** |
| **CO 7** | **83.20** |

## Gokaraju Rangaraju Institute of Eningeering & Technology

Department of Electrical & Electronics Engineering

B.Tech - IV Year I Sem B-Sec

AY: 2018-19

Mid - II

DoE: 08.04.2019

### Power Electronics - CO Attainment

| ***Question Numbers*** | ***1*** | ***2*** | ***3*** | ***4*** |
|---|---|---|---|---|
| ***Course Outcomes*** | ***4*** | ***5*** | ***6*** | ***7*** |
| *Roll Number* | | | | |
| 15241A0261 | 5 | 5 | 2 | |
| 15241A0262 | | | | |
| 15241A0263 | 5 | | | |
| 15241A0264 | 4 | 4 | 3 | |
| 15241A0265 | 5 | 4 | 4 | |
| 15241A0266 | 5 | 5 | 4 | |
| 15241A0267 | 5 | 5 | 4 | |
| 15241A0268 | 5 | 4 | | 4 |
| 15241A0269 | 4 | 3 | 3 | |
| 15241A0270 | 5 | 4 | | 4 |
| 15241A0271 | 5 | 4 | | |
| 15241A0272 | 5 | 4 | | 4 |
| 15241A0273 | 5 | 4 | | 4 |
| 15241A0274 | 3 | | | |
| 15241A0275 | 5 | 5 | | 5 |
| 15241A0276 | 5 | 5 | | 4 |
| 15241A0277 | 5 | 4 | | |
| 15241A0278 | 5 | 4 | | 4 |
| 15241A0279 | | 5 | | 5 |
| 15241A0280 | 5 | 5 | | 3 |
| 15241A0281 | 5 | 5 | | 4 |
| 15241A0282 | 5 | 5 | | 4 |
| 15241A0283 | 5 | 5 | 4 | |
| 15241A0284 | 5 | 5 | 5 | |
| 15241A0285 | 5 | 5 | | 5 |
| 15241A0286 | 5 | 5 | 4 | |
| 15241A0287 | 4 | 4 | | |
| 15241A0288 | 4 | 4 | 2 | |
| 15241A0289 | 5 | 4 | | |
| 15241A0290 | 4 | 5 | | |
| 15241A0291 | | 5 | 4 | 4 |
| 15241A0292 | 5 | 5 | | 5 |
| 15241A0293 | 5 | 5 | | 4 |
| 15241A0294 | | | 4 | 4 |
| 15241A0295 | 5 | 5 | 3 | |
| 15241A0296 | 5 | 5 | | |
| 15241A0297 | 5 | 5 | 4 | |
| 15241A0298 | 5 | 4 | 5 | |
| 15241A0299 | 4 | 4 | | |
| 15241A02A0 | | | 3 | 3 |

| ***Question Numbers*** | ***1*** | ***2*** | ***3*** | ***4*** |
|---|---|---|---|---|
| ***Course Outcomes*** | ***4*** | ***5*** | ***6*** | ***7*** |
| *Roll Number* | | | | |
| 15241A02A1 | 5 | 5 | | 5 |
| 15241A02A2 | | 5 | 5 | |
| 15241A02A3 | 4 | 5 | | 4 |
| | | | | |
| 15241A02A5 | 5 | 4 | 3 | |
| 15241A02A6 | | 4 | 4 | 4 |
| 15241A02A7 | 5 | 5 | | 5 |
| 15241A02A8 | 5 | 5 | | |
| 15241A02A9 | 5 | 4 | | 5 |
| 15241A02B0 | 4 | 4 | | 3 |
| 15241A02B1 | 5 | 5 | | 4 |
| 15241A02B2 | 5 | 4 | | 4 |
| 15241A02B3 | 5 | 5 | | 5 |
| 15241A02B4 | 5 | 5 | | 5 |
| 15241A02B5 | 5 | 4 | | 4 |
| 15241A02B6 | 5 | 5 | | 5 |
| 15241A02B7 | 5 | 4 | | 4 |
| 15241A02B8 | 5 | 4 | | 4 |
| 15241A02B9 | 5 | 4 | | 3 |
| 15241A02C0 | 5 | 4 | | |
| 16245A0213 | 3 | 3 | | 4 |
| 16245A0214 | 5 | 5 | 4 | |
| 16245A0215 | 4 | 4 | | 4 |
| 16245A0216 | 5 | 5 | | 4 |
| 16245A0217 | 5 | 4 | | 5 |
| 16245A0218 | 5 | 5 | | |
| 16245A0219 | 5 | 5 | | 4 |
| 16245A0220 | 5 | 4 | | 4 |
| 16245A0221 | 5 | 4 | | 5 |
| 16245A0222 | 4 | 4 | | |
| 16245A0223 | 5 | 3 | | |
| 16245A0224 | 4 | 4 | | 4 |
| | | | | |
| Grand Total | 305 | 294 | 74 | 168 |
| NSA | 64 | 66 | 20 | 40 |
| Attempt %=(NSA/Total no of students) * 100 | 90.1 | 93 | 28.2 | 56.3 |
| Average (attainment) = Total / NSA | 4.8 | 4.5 | 3.7 | 4.2 |
| Attainment % = (Total/no.of max marks*no.of students attempted)*100 | 95.3 | 89.1 | 74.0 | 84.0 |

| | |
|---|---|
| **CO 4** | **95.30** |
| **CO 5** | **89.10** |
| **CO 6** | **74.00** |
| **CO 7** | **84.00** |