**COURSE OBJECTIVES**

Academic Year : 2012-2013

Semester : II

Name of the Program: B.Tech IV Year: ………………. Section: A / B

Course/Subject: HVDC TRANSMISSION Course Code: 58008

Name of the Faculty: J.SRIDEVI Dept.: EEE

Designation: ASSOCIATE PROFESSOR

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

<table>
<thead>
<tr>
<th>S.No</th>
<th>Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>To deal with the importance of HVDC Transmission and HVDC Converters</td>
</tr>
<tr>
<td>2</td>
<td>To deal with power conversion between Ac to DC and DC to AC.</td>
</tr>
<tr>
<td>3</td>
<td>To deal with firing angle of HVDC System</td>
</tr>
<tr>
<td>4</td>
<td>To deal with Reactive power control of HVDC system</td>
</tr>
<tr>
<td>5</td>
<td>To deal with Power factor improvement of HVDC system</td>
</tr>
<tr>
<td>6</td>
<td>To deal with the protection of HVDC system</td>
</tr>
</tbody>
</table>

Signature of HOD Signature of faculty

Date: Date:

Note: Please refer to Bloom’s Taxonomy, to know the illustrative verbs that can be used to state the objectives.
COURSE OUTCOMES

Academic Year : 2012-2013

Semester : II

Name of the Program: B.Tech

IV Year: ……………….. Section: A / B

Course/Subject: HVDC TRANSMISSION

Course Code: 58008

Name of the Faculty: J.SRIDEVI

Dept.: EEE

Designation: ASSOCIATE PROFESSOR

The expected outcomes of the Course/Subject are:

<table>
<thead>
<tr>
<th>S.No</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Students will be able to understand the importance of Transmission power through HVDC</td>
</tr>
<tr>
<td>2</td>
<td>Ability to calculate power conversion between Ac to DC and DC to AC.</td>
</tr>
<tr>
<td>3</td>
<td>Ability to discuss 6 pulse, 12 pulse circuits.</td>
</tr>
<tr>
<td>4</td>
<td>Ability to discuss firing angle control.</td>
</tr>
<tr>
<td>5</td>
<td>Ability to control reactive power through HVDC.</td>
</tr>
<tr>
<td>6</td>
<td>Ability to discuss power flow analysis HVDC.</td>
</tr>
<tr>
<td>7</td>
<td>Ability to discuss protection of HVDC.</td>
</tr>
</tbody>
</table>

Signature of HOD

Signature of faculty

Date: 

Date:

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

Program Educational Objectives:
This programme is meant to prepare our students to professionally thrive and to lead. During their progression:

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

PEO 2: Graduates will be able to acquire, use and develop skills as required for effective professional practices.
PEO 3: Graduates will be able to attain holistic education that is an essential prerequisite for being a responsible member of society.

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

Program outcomes.

a) Ability to apply knowledge of mathematics, science, and engineering.
b) Ability to design and conduct experiments, as well as to analyze and interpret data.
c) Ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.
d) Ability to function on multi-disciplinary teams.
e) Ability to identify, formulates, and solves engineering problems.
f) Understanding of professional and ethical responsibility.
g) Ability to communicate effectively.
h) Broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.
i) Recognition of the need for, and an ability to engage in life-long learning.
j) Knowledge of contemporary issues.
k) Ability to utilize experimental, statistical and computational methods and tools necessary for engineering practice.
l) Graduates will 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.

Name of the Course: HVDC Transmission

Course educational objectives:

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

1. To deal with the importance of HVDC Transmission and HVDC Converters
2. To deal with power conversion between Ac to DC and DC to AC.
3. To deal with firing angle of HVDC System
4. To deal with Reactive power control of HVDC system
5. To deal with Power factor improvement of HVDC system
6. To deal with the protection of HVDC system
Course outcomes:

At the end of the course student will have ability to

1. Students will be able to understand the importance of Transmission power through HVDC.
2. Ability to calculate power conversion between Ac to DC and DC to AC.
3. Ability to discuss 6 pulse,12 pulse circuits.
4. Ability to discuss firing angle control.
5. Ability to control reactive power through HVDC.
6. Ability to discuss power flow analysis HVDC.
7. Ability to discuss protection of HVDC.

Assessment methods:

1. Regular attendance to classes.
2. Written tests clearly linked to learning objectives
3. Classroom assessment techniques like tutorial sheets and assignments.
4. Seminars

1. Program Educational Objectives (PEOs) – Vision/Mission Matrix (Indicate the relationships by mark “X”)

<table>
<thead>
<tr>
<th>PEOs</th>
<th>Mission of department</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Higher Learning</td>
</tr>
<tr>
<td>Graduates will have a successful technical or professional careers, including supportive and leadership roles on multidisciplinary teams</td>
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<tr>
<td>Graduates will be able to acquire, use and develop skills as required for effective professional practices</td>
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<tr>
<td>Graduates will be able to attain holistic education that is an essential prerequisite for being a responsible member of society</td>
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</tr>
<tr>
<td>Graduates will be engaged in life-long learning, to remain abreast in their profession and be leaders in our technologically vibrant society.</td>
<td>X</td>
</tr>
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</table>
2. **Program Educational Objectives (PEOs)-Program Outcomes (POs) Relationship Matrix** (Indicate the relationships by mark “X”)

<table>
<thead>
<tr>
<th>P-Outcomes</th>
<th>a</th>
<th>b</th>
<th>c</th>
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3. **Course Objectives-Course Outcomes Relationship Matrix** (Indicate the relationships by mark “X”)

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<tr>
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4. **Course Objectives-Program Outcomes (POs) Relationship Matrix** (Indicate the relationships by mark “X”)

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<th>P-Outcomes</th>
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</table>
5. Course Outcomes-Program Outcomes (POs) Relationship Matrix (Indicate the relationships by mark “X”)

<table>
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</table>

6. Courses (with title & code)-Program Outcomes (POs) Relationship Matrix (Indicate the relationships by mark “X”)

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<th>c</th>
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7. Program Educational Objectives (PEOs)-Course Outcomes Relationship Matrix (Indicate the relationships by mark “X”)

<table>
<thead>
<tr>
<th>P-Objectives (PEOs)</th>
<th>1</th>
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8. **Assignments and Assessments - Program Outcomes (POs) Relationship Matrix** (Indicate the relationships by mark “X”)

<table>
<thead>
<tr>
<th>P-Outcome Assessments</th>
<th>a</th>
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7. **Assignments and Assessments – Program Educational Objectives (PEOs) Relationship Matrix** (Indicate the relationships by mark “X”)

<table>
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<tr>
<th>P-Objectives (PEOs) Assessments</th>
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**RUBRIC TEMPLATE**

**Objective:** ____________________________

**Student Outcome:** ____________________________

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<th>S.No.</th>
<th>Name of the Student</th>
<th>Performance Criteria</th>
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<th>Scale (Numeric /descriptor)</th>
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### EXAMPLE OF FILLED RUBRIC

**OBJECTIVE:** Work effectively with others

**STUDENT OUTCOME:** Ability to function in a multi-disciplinary team

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Student Name</th>
<th>Performance Criteria</th>
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<th>Developing</th>
<th>Satisfactory</th>
<th>Exemplary</th>
<th>Score</th>
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</thead>
<tbody>
<tr>
<td>1.</td>
<td>Research &amp; Gather Information</td>
<td>Does not collect any information that relates to</td>
<td>Collects very little information -- some relates</td>
<td>Collects some basic information -- most</td>
<td>Collects a great deal of information -- all relates</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Filled by Team</td>
<td>Role’s Duty</td>
<td>Share Equally</td>
<td>Listen to Other Team Mates</td>
<td>Average Score</td>
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<tr>
<td></td>
<td>the topic.</td>
<td>to the topic.</td>
<td>relates to the topic.</td>
<td>to the topic.</td>
<td></td>
<td></td>
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</tr>
<tr>
<td><strong>Fulfill team role’s duty</strong></td>
<td>Does not perform any duties of assigned team role.</td>
<td>Performs very little duties.</td>
<td>Performs nearly all duties.</td>
<td>Performs all duties of assigned team role.</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Share Equally</td>
<td>Always relies on others to do the work.</td>
<td>Rarely does the assigned work--often needs reminding.</td>
<td>Usually does the assigned work--rarely needs reminding.</td>
<td>Always does the assigned work without having to be reminded.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Listen to other team mates</td>
<td>Is always talking--never allows anyone else to speak.</td>
<td>Usually doing most of the talking--rarely allows others to speak.</td>
<td>Listens, but sometimes talks too much.</td>
<td>Listens and speaks a fair amount.</td>
<td></td>
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</table>

Average score: 3.5
Assessment process and Relevant Surveys conducted:

10. Constituencies - Program Outcomes (POs) Relationship Matrix (Indicate the relationships by mark “X”).

<table>
<thead>
<tr>
<th>Constituencies</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
<th>G</th>
<th>h</th>
<th>i</th>
<th>j</th>
<th>k</th>
<th>l</th>
<th>m</th>
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<tbody>
<tr>
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<td></td>
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</tr>
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</table>

Assessment Process and Areas of improvements:

Prepare the following Matrix:

11. The improvements Matrix are summarized below and described in the text that follows.

Hint:

Example:

<table>
<thead>
<tr>
<th>Proposed Change</th>
<th>Year Proposed</th>
<th>Year Implemented</th>
<th>Old Version</th>
<th>New Version</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Add new real time applications</td>
<td>2013-2014</td>
<td></td>
<td>No real time applications in curriculum</td>
<td>Real time applications</td>
<td>To address need for additional material for applications</td>
</tr>
</tbody>
</table>
GUIDELINES TO STUDY THE COURSE / SUBJECT

Academic Year : 2012-2013

Semester : II

Name of the Program: B.Tech IV Year: ……………….. Section: A / B

Course/Subject: HVDC Transmission                                      Course Code: 58008

Name of the Faculty: J.SRIDEVI                                      .Dept.: EEE

Designation: ASSOCIATE PROFESSOR.

Guidelines to study the Course/ Subject: HVDC Transmission

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

Signature of HOD                                      Signature of faculty

Date:                                              Date:
### COURSE SCHEDULE

**Academic Year**: 2012-2013  
**Semester**: II  
**Name of the Program**: B.Tech IV  
**Year**: …………..  
**Section**: A / B  
**Course/Subject**: HVDC TRANSMISSION  
**Course Code**: 58008  
**Name of the Faculty**: J.SRIDEVI  
**Dept.**: EEE  
**Designation**: ASSOCIATE PROFESSOR

The Schedule for the whole Course / Subject is:

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Description</th>
<th>Duration (Date)</th>
<th>Total No. Of Periods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>56 Hours / Periods</td>
</tr>
<tr>
<td>1.</td>
<td>Basic Concepts</td>
<td>21/12/12 - 29/12/12</td>
<td>8</td>
</tr>
<tr>
<td>2.</td>
<td>Analysis of HVDC Converters</td>
<td>4/01/13 - 25/01/13</td>
<td>10</td>
</tr>
<tr>
<td>3.</td>
<td>Converter and HVDC System Control</td>
<td>01/02/13 - 22/02/13</td>
<td>12</td>
</tr>
<tr>
<td>4.</td>
<td>Reactive power control in HVDC</td>
<td>23/02/13 - 08/03/13</td>
<td>6</td>
</tr>
<tr>
<td>5.</td>
<td>Power flow analysis in AC/DC Systems</td>
<td>09/03/13 - 16/03/13</td>
<td>6</td>
</tr>
<tr>
<td>6.</td>
<td>Converter Fault and Protection</td>
<td>22/03/13 - 30/03/13</td>
<td>6</td>
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<tr>
<td>7.</td>
<td>Harmonics</td>
<td>05/04/13 - 05/04/13</td>
<td>4</td>
</tr>
<tr>
<td>8.</td>
<td>Filters</td>
<td>06/04/13 - 06/04/13</td>
<td>4</td>
</tr>
</tbody>
</table>

Total No. of Instructional periods available for the course: 56 Hours / Periods
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

<table>
<thead>
<tr>
<th>Know</th>
<th>Understand</th>
<th>Analyze</th>
<th>Generate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comprehend</td>
<td>Apply</td>
<td>Design</td>
<td>Evaluate</td>
</tr>
</tbody>
</table>

ILLUSTRATIVE VERBS FOR STATING SPECIFIC OBJECTIVES/OUTCOMES:

A. COGNITIVE DOMAIN (KNOWLEDGE)

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge</td>
<td>Comprehension Understanding</td>
<td>Application of knowledge &amp; comprehension</td>
<td>Analysis Of whole w.r.t. its constituents</td>
<td>Synthesis</td>
<td>Evaluation</td>
</tr>
<tr>
<td>Define</td>
<td>Convert</td>
<td>Change</td>
<td>Breakdown</td>
<td>Categorize</td>
<td>Appraise</td>
</tr>
<tr>
<td>Identify</td>
<td>Defend</td>
<td>Compute</td>
<td>Differentiate</td>
<td>Combine</td>
<td>Compare</td>
</tr>
<tr>
<td>Label</td>
<td>Describe (a Procedure)</td>
<td>Demonstrate</td>
<td>Discriminate</td>
<td>Compose</td>
<td>Conclude</td>
</tr>
<tr>
<td>List</td>
<td>Distinguish</td>
<td>Deduce</td>
<td>Distinguish</td>
<td>Compose</td>
<td>Contrast</td>
</tr>
<tr>
<td>March</td>
<td>Manipulate</td>
<td>Separate</td>
<td>Create</td>
<td>Criticize</td>
<td></td>
</tr>
<tr>
<td>Reproduce</td>
<td>Estimate</td>
<td>Modify</td>
<td>Subdivide</td>
<td>Devise</td>
<td>Justify</td>
</tr>
<tr>
<td>Select</td>
<td>Explain why/how</td>
<td>Predict</td>
<td>Design</td>
<td>Interpret</td>
<td></td>
</tr>
<tr>
<td>State</td>
<td>Extend</td>
<td>Prepare</td>
<td>Generate</td>
<td>Support</td>
<td></td>
</tr>
<tr>
<td>Generalize</td>
<td>Relate</td>
<td>Organize</td>
<td>Plan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Give examples</td>
<td>Show</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Illustrate</td>
<td>Solve</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summarize</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

B. AFFECTIVE DOMAIN (ATTITUDE)

<table>
<thead>
<tr>
<th>Adhere</th>
<th>Resolve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assist</td>
<td>Select</td>
</tr>
<tr>
<td>Attend</td>
<td>Serve</td>
</tr>
<tr>
<td>Change</td>
<td>Share</td>
</tr>
<tr>
<td>Develop</td>
<td></td>
</tr>
<tr>
<td>Help</td>
<td></td>
</tr>
<tr>
<td>Influence</td>
<td></td>
</tr>
</tbody>
</table>

C. PSYCHOMOTOR DOMAIN (SKILLS)

<table>
<thead>
<tr>
<th>Bend</th>
<th>Dissect</th>
<th>Insert</th>
<th>Perform</th>
<th>Straighten</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibrate</td>
<td>Draw</td>
<td>Keep</td>
<td>Prepare</td>
<td>Strengthen</td>
</tr>
<tr>
<td>Compress</td>
<td>Extend</td>
<td>Elongate</td>
<td>Remove</td>
<td>Time</td>
</tr>
<tr>
<td>Conduct</td>
<td>Feed</td>
<td>Limit</td>
<td>Replace</td>
<td>Transfer</td>
</tr>
<tr>
<td>Connect</td>
<td>File</td>
<td>Manipulate</td>
<td>Report</td>
<td>Type</td>
</tr>
<tr>
<td>Convert</td>
<td>Grow</td>
<td>Move Precisely</td>
<td>Reset</td>
<td>Weigh</td>
</tr>
<tr>
<td>Decrease</td>
<td>Increase</td>
<td>Paint</td>
<td>Set</td>
<td></td>
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</table>
## SCHEDULE OF INSTRUCTIONS
### COURSE PLAN

**Academic Year**: 2012-2013  
**Semester**: II  
**UNIT NO.**: I  
**Name of the Program**: B.Tech IV  
**Year**: ………………..  
**Section**: A / B  
**Course/Subject**: HVDC TRANSMISSION  
**Course Code**: 58008  
**Name of the Faculty**: J.SRIDEVI  
**Dept.**: EEE  
**Designation**: ASSOCIATE PROFESSOR.

### Reference Textbooks

<table>
<thead>
<tr>
<th>S.No</th>
<th>Reference Textbooks</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>EHV-AC, HVDC Transmission and Distribution Engineering</td>
<td>S.Rao</td>
</tr>
<tr>
<td>2.</td>
<td>HVDC Power Transmission Systems</td>
<td>K.R. Padiyar</td>
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</tbody>
</table>

### Unit Plan

<table>
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<tr>
<th>Unit No.</th>
<th>Lesson No.</th>
<th>Date</th>
<th>No. of Periods</th>
<th>Topics / Sub-Topics</th>
<th>Objectives &amp; Outcomes Nos.</th>
<th>References (Text Book, Journal…) Page Nos.: ____to ____</th>
</tr>
</thead>
</table>
| 1.       | 1.         | 21/12/12   | 2              | Types of DC links   | 1,2                       | 1. Pg.no: 22-31  
|          |            |            |                |                     |                           | 2. Pg.no: 8-12 |
| 1.       | 2.         | 22/12/12   | 2              | Apparatus required for HVDC systems | 1,2                       | 1. Pg.no: 22-31  
|          |            |            |                |                     |                           | 2. Pg.no: 12-14 |
| 1.       | 3.         | 28/12/12   | 2              | Comparison of AC and DC Transmission | 1,2                       | 1. Pg.no: 43-47  
|          |            |            |                |                     |                           | 2. Pg.no: 15-18 |
| 1.       | 4.         | 29/12/12   | 2              | Applications of DC Transmission System | 1,2                       | 1. Pg.no: 47-49  
|          |            |            |                |                     |                           | 2. Pg.no: 18-19 |
| 2.       | 5.         | 4/01/13    | 2              | Choice of Converter Configuration | 1,2                       | 2. Pg.no: 43-46 |
|          |            |            |                |                     |                           |            |
| 2.       | 6.         | 11/01/13   | 2              | Analysis of 6 pulse Graetz Circuit | 1,2                       | 1. Pg.no: 84-97  
|          |            |            |                |                     |                           | 2. Pg.no: 46-61 |
| 2.       | 7.         | 18/01/13   | 2              | Analysis of 6 pulse Graetz Circuit | 1,2                       | 1. Pg.no: 84-97  
|          |            |            |                |                     |                           | 2. Pg.no: 46-61 |
| 2.       | 8.         | 19/01/13   | 2              | Analysis of 6 pulse Graetz Circuit | 1,2                       | 1. Pg.no: 84-97  
|          |            |            |                |                     |                           | 2. Pg.no: 46-61 |
| 2.       | 9.         | 25/01/13   | 2              | Analysis of 12 pulse Graetz Circuit | 1,2                       | 2. Pg.no: 61-65  |
|          |            |            |                |                     |                           |            |
| 3.       | 10.        | 01/02/13   | 2              | Principle of DC link Control | 1,2,3,4                   | 1. Pg.no: 66-68  
|          |            |            |                |                     |                           | 2. Pg.no: 76-79 |
| 3.       | 11.        | 08/02/13   | 2              | Converter control characteristics | 1,2,3,4                   | 1. Pg.no: 68-75  
|          |            |            |                |                     |                           | 2. Pg.no: 79-84 |
| 3.       | 12.        | 09/02/13   | 2              | Converter control characteristics | 1,2,3,4                   | 1. Pg.no: 68-75  
<p>|          |            |            |                |                     |                           | 2. Pg.no: 79-84 |</p>
<table>
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<tr>
<th>No.</th>
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<th>Topic</th>
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<tr>
<td>3.</td>
<td>13. 15/02/13</td>
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<td>Firing angle control</td>
<td>1,2,3</td>
<td>Pg.no: 341-346</td>
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<td>2,3,4</td>
<td>Pg.no: 84-89</td>
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<tr>
<td>3.</td>
<td>14. 16/02/13</td>
<td>2</td>
<td>Current and extinction angle control</td>
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<td>2,3,4</td>
<td>Pg.no: 89-90</td>
</tr>
<tr>
<td>3.</td>
<td>15. 22/02/13</td>
<td>2</td>
<td>Effect of source inductance on the system, Starting and stopping of DC link</td>
<td>1,2,3</td>
<td>Pg.no: 90-94</td>
</tr>
<tr>
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<td>2,3,4</td>
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<tr>
<td>4.</td>
<td>16. 23/02/13</td>
<td>2</td>
<td>Reactive power requirements in steady state, Conventional Control Strategies</td>
<td>3,4,5</td>
<td>Pg.no: 200-208</td>
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<td>Pg.no: 130-132</td>
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<tr>
<td>4.</td>
<td>17. 01/03/13</td>
<td>2</td>
<td>Alternate Control Strategies</td>
<td>3,4,5</td>
<td>Pg.no: 132-136</td>
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<tr>
<td>4.</td>
<td>18. 08/03/13</td>
<td>2</td>
<td>Sources of Reactive power</td>
<td>3,4,5</td>
<td>Pg.no: 136-144</td>
</tr>
<tr>
<td>5.</td>
<td>19. 09/03/13</td>
<td>2</td>
<td>Modelling of DC link</td>
<td>3,4,5</td>
<td>Pg.no: 188-191</td>
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<td>Pg.no: 193-194</td>
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<td>5.</td>
<td>20. 15/03/13</td>
<td>2</td>
<td>P.U system for d.c quantities</td>
<td>3,4,5</td>
<td>Pg.no: 194-196</td>
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<tr>
<td>5.</td>
<td>21. 16/03/13</td>
<td>2</td>
<td>Solution of AC- DC load flow</td>
<td>3,4,5</td>
<td>Pg.no: 194-196</td>
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<tr>
<td>6.</td>
<td>22. 22/03/13</td>
<td>2</td>
<td>Protection against over current and overvoltage in converter station</td>
<td>6,7</td>
<td>Pg.no: 387-389</td>
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<td>Pg.no: 97-108</td>
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<td>6.</td>
<td>23. 23/03/13</td>
<td>2</td>
<td>Surge arrestors, Smoothing Reactors</td>
<td>6,7</td>
<td>Pg.no: 395-416,512-525</td>
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<td>Pg.no: 110-113</td>
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<td>6.</td>
<td>24. 30/03/13</td>
<td>2</td>
<td>DC Breakers, Corona effects on DC lines</td>
<td>6,7</td>
<td>Pg.no: 274-278,842-845</td>
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<td>Pg.no: 113-118,122-126</td>
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<td>7.</td>
<td>25. 05/04/13</td>
<td>2</td>
<td>Generation of Harmonics, Characteristic harmonics</td>
<td>5,6,7</td>
<td>Pg.no: 135-147</td>
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<td>Pg.no: 145-147</td>
</tr>
<tr>
<td>7.</td>
<td>26. 05/04/13</td>
<td>2</td>
<td>Calculation of AC Harmonics, Non Characteristics harmonics</td>
<td>5,6,7</td>
<td>Pg.no: 152-159</td>
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<td></td>
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<td>Pg.no: 147-149</td>
</tr>
<tr>
<td>8.</td>
<td>27. 06/04/13</td>
<td>2</td>
<td>Types of AC filters</td>
<td>5,6,7</td>
<td>Pg.no: 178-181</td>
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<td></td>
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<td>Pg.no: 151-156</td>
</tr>
<tr>
<td>8.</td>
<td>28. 06/04/13</td>
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<td>Design of Single tuned filters, High pass filters</td>
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</table>

Signature of HOD          Signature of faculty

Date:

Note: 1. ENSURE THAT ALL TOPICS SPECIFIED IN THE COURSE ARE MENTIONED.
2. ADDITIONAL TOPICS COVERED, IF ANY, MAY ALSO BE SPECIFIED IN BOLD
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COURSE COMPLETION STATUS

Academic Year : 2012-2013
Semester : II
Name of the Program: B.Tech IV Section: A / B
Course/Subject: HVDC Course Code: 58008
Name of the Faculty: J. SRI DEVI .Dept.: EEE
Designation: ASSOCIATE PROFESSOR.

<table>
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<th>Remarks</th>
<th>No. of Objectives Achieved</th>
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<td>Basic Concepts</td>
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<td>Unit 2</td>
<td>Analysis of HVDC Converters</td>
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<td>Unit 3</td>
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<td>Unit 5</td>
<td>Power flow analysis in AC/DC Systems</td>
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Signature of HOD          Signature of faculty
Date:                     Date:
Note: After the completion of each unit mention the number of Objectives & Outcomes Achieved.
Gokaraju Rangaraju Institute of Engineering and Technology
(Autonomous)
Bachupally, Kukatpally, Hyderabad – 500 090, A.P., India. (040) 6686 4440

SYLLABUS

Academic Year : 2012-2013

Semester : II

Name of the Program: B.Tech IV Section: A / B

Course/Subject: HVDC Course Code: 58008

Name of the Faculty: J.SRIDEVI Dept.: EEE

Designation: ASSOCIATE PROFESSOR.

UNIT I  BASIC CONCEPTS

UNIT II  ANALYSIS OF HVDC CONVERTERS

UNIT III  CONVERTER & HVDC SYSTEM CONTROL
Principal of DC Link Control – Converters Control Characteristics – Firing angle control – Current and extinction angle control – Effect of source inductance on the system; Starting and stopping of DC link: Power Control.

UNIT IV  REACTIVE POWER CONTROL IN HVDC
Reactive Power Requirements in steady state-Conventional control strategies-Alternate control strategies-sources of reactive power-AC Filters – shunt capacitors-synchronous condensers.

UNIT V  POWER FLOW ANALYSIS IN AC/DC SYSTEMS

UNIT VI  CONVERTER FAULT & PROTECTION
Converter faults – protection against over current and over voltage in converter station – surge arresters – smoothing reactors – DC breakers –
Audible noise-space charge field-corona effects on DC lines-Radio interference.

UNIT - VII  HARMONICS
Generation of Harmonics - Characteristics harmonics, calculation of AC Harmonics, Non-Characteristics harmonics, adverse effects of harmonics - Calculation of voltage & Current harmonics - Effect of Pulse number on harmonics

UNIT-VIII  FILTERS
Types of AC filters, Design of Single tuned filters - Design of High pass filters.
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# SCHEDULE OF INSTRUCTIONS
## UNIT PLAN

**Academic Year**: 2012-2013  
**Semester**: II  
**UNIT NO.**: I  
**Name of the Program**: B.Tech IV  
**Year**: ………………..  
**Section**: A / B  
**Course/Subject**: HVDC TRANSMISSION  
**Course Code**: 58008  
**Name of the Faculty**: J.SRIDEVI  
**Dept.**: EEE  
**Designation**: ASSOCIATE PROFESSOR.

<table>
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<th>Date</th>
<th>No. of Periods</th>
<th>Topics / Sub - Topics</th>
<th>Objectives &amp; Outcomes Nos.</th>
<th>References (Text Book, Journal…)</th>
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<td>1.</td>
<td>21/12/12</td>
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<td>Applications of DC Transmission System</td>
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**References:**

1. EHV-AC, HVDC Transmission and Distribution Engineering - S.Rao  
2. HVDC Power Transmission Systems - K.R. Padiyar

**Signature of HOD**  
**Signature of faculty**

**Date:**  
**Date:**

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Introduction

• The network of transmission and distribution lines is formed by three phase alternating current system.
• For longer lines and higher power transfer, higher transmission voltages are necessary.
• The Electrical Power System (Network) is formed by a 3 phase, 50 Hz, AC System with several AC voltage levels for generation, transmission, distribution and utilisation.
• Choice of transmission voltage depends on power and distance.
AC power transformers are installed in various transmission and distribution substations and near load points to step-up or step down AC Voltages to required levels.

The entire AC Network operates synchronously at common prevailing frequency (50 Hz, ± 3%).

3 Phase AC System has a tendency to operate naturally in synchronism and the operation and control is very easy.

Power transfer through an AC transmission link is given by

\[ P_{ac} = \frac{|V_1| \cdot |V_2|}{X} \sin \delta \]
• In an AC Network AC Power transfer through a particular AC line cannot be controlled easily, quickly and accurately.
• The sin δ causes transient stability limit which is almost 50% of steady state limit.
• Reactive power flow causes additional (I^2 Rt) transmission losses and voltage regulation problems.
• For very long, high power transmission lines (> 800 km; > 1000 MW), for System Interconnections between two or more independently controlled AC Networks (Regional Grids) and for long submarine cables.
High Voltage Direct Current Transmission (HVDC) links are preferred due to technical and economic superiority over equivalent EHV AC transmission links for same power/distance.

Nominal Power transfer through an HVDC Link is given by:

\[ P_{dc} = U_d \cdot I_d = \left( \frac{(U_{d1} - U_{d2})}{R} \right) U_d \]

The HVDC power transfer can be controlled quickly and accurately by thyristor control and tap changer control.

There are no problems of reactive power flow, voltage fluctuations and high transmission losses.
• However HVDC voltages cannot be easily stepped up or stepped down.
• HVDC requires costly and complex substations, high technology, complex controls.
• The Modern Transmission Network continues to be of 3 phase 50 Hz, AC System with a few specific HVDC links integrated with the 3 phase AC Network.
• HVDC links are considered only for specific projects such as:
  • A few long high power, point to point, 2 terminal HVDC Transmission Systems. (e.g. ± 500 kV, 1500 MW, 820 km, Rihand-Deihi Bipolar 2T HVDC System (UP, India, 1992): ± 500 MW 1500 MW, 850 km Chandrapur-Padaghe Bipolar 2T HVPC System (Maharashtra, India, 1997)
• Back to Back Interconnecting HVDC Coupling Systems between Regional Grids (e.g. Vindhyachal sack-to-Back, 500 MW Link between Western Region and Northern Region, India (1989); Chandrapur Back-to-Back, 1000 MW Link between Western Region and Southern Region, India, 1996)
• Multi-terminal HVDC Interconnecting Systems (e.g. 5-Terminal Hydro-Quebeck : New England, USA/Canada, 1987-96)
• High Voltage long high power Cable transmission. (e.g. UK? France submarine Link, 2000 MW, 65 km).
• First commercial High Voltage Direct Current transmission system (HVDC) was introduced during 1953.

• With the successfully development of high power thyristor valves in early 1970’s, the HVDC transmission systems have become a technically and commercially viable alternative to EHVAC transmission particularly for (1) long distance bulk power transmission; (2) Submarine cable transmission and (3) system interconnection.

• For these three applications HVDC transmission systems have a distinct superiority over EHVAC and are being increasingly preferred.
Choice of a Transmission System

- The choice of the voltage is made from HVAC, EHV-AC, HVDC on the basis of the following economical and technical considerations.

**Economic Considerations**

- Capital cost of transmission systems:
  - Cost of line conductors, towers, insulators, installation land/right of way.
  - Capital cost of substations, intermediate substations, compensating substations, conversion substations, substation equipment like transformers, switchgear; substation area, buildings.
  - Cost of energy losses, maintenance.
• Needs of future expansion and associated cost.
• Economic aspects related with availability, reliability.
• Economic strategy for Energy Transmission.

Technical Considerations
• Length of the transmission line and total power to be transferred
• Control over Power Transfer, magnitude, rate of change.
• Existing network and long term plans.
• Choice of voltage considering power flow.
• Stability considerations related with power flow and frequency disturbances.
• Reliability and security of power flow. Availability of transmission link.
• Reactive power compensation and voltage control.
• Switching requirement.
• Right of way for transmission lines.
• Radial or Mesh.
• 21’ or 31’ or MT.
• Type of line:
  Overhead/underground/submarine cables.
• Network configuration, parallel lines, T-offs, multi-terminals etc.

**Application of EHV-AC Transmission**
• Voltage can be stepped-up or stepped-down in transformer substations to have economical transmission voltage.
• Lines can be tapped easily, extended easily.
• Parallel lines can be easily added.
• Control of Power flow in the Network is simple and natural.
• Power flow in a particular line cannot be controlled easily and quickly.
• Equipments are simple and reliable without need of high-tech.
• Operation is simple and adopts naturally to the synchronously operating AC systems.
• Generation and distribution is by AC.

**Special Features and Technical Consideration for EHVAC Lines**

• The most important requirement of an EHV-AC transmission line is power transfer ability based on transient stability limit.

\[ P_{ac} = \frac{|V_1| \cdot |V_2|}{X} \sin \delta \]
at $\delta = 30^\circ$, $\sin \delta = 0.5$. Hence AC line can transfer only 50% of its steady state power limit.

• EHV-AC line needs compensation of reactive power. This is provided by SVS; shunt reactors, Shunt capacitors, etc. installed in sub-stations. Intermediate substations are necessary at interval of 250 km to 400 km.

• Power transfer ability of EHV lines may be increased by using series capacitors or adding a parallel line. For high power lines several parallel circuits may be necessary.

• The line design is based on limits of corona, radio interference, TV interference, electrical field at ground level, etc.
• For EHV-AC lines the voltage stress at conductor surface should be kept below critical voltage. For achieving this, the use of bundled conductors is essential. Bundle conductors reduce the corona losses, Radio Interference, TV Interference.

• Switching surges occur during opening and closing of unloaded lines. Line insulation is designed on the basis of switching overvoltages. Appropriate circuit-breakers and compensation is necessary to limit switching surges. Insulation coordination is achieved with the use of suitable surge arresters.
• EHV-AC lines and Network have high short-circuit levels and associated protection problems. HVDC interconnection limits the short-circuit levels of both the AC networks.
• EHV-AC lines experience power swings during system disturbances, switching and faults. Protection of EHV-AC lines is designed to block during low power swings.
• EHV-AC lines transmit bulk power. Outage of a line causes stability problems in the network. Hence alternative transmission paths should be planned along with the protection system design. For each radial line, at least two three phase circuits are necessary.
• In large interconnected networks, the effect of a major fault in one of the networks can result in cascade tripping and a large scale blackout. To prevent this, the Network Segregation is carried out. HVDC interconnection eliminates the problem of cascade tripping.
Applications of HVDC transmission

- Long distance high Power transmission by overhead lines.
- Medium and long high power submarine or underground cables.
- System interconnection by means of overhead lines or underground/submarine cables or back to back HVDC coupling stations.
- Multi-Terminal HVDC System for interconnecting three or more 3 phase AC systems.
- Frequency conversion (60 Hz —50 Hz ; 50 Hz —25 Hz)
- Incoming lines in megacities.
An HVDC link has an AC system at each end.

The AC power is converted by thyristor-convertor valves into DC power.

The energy is transmitted in HVDC form to the other end.

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Schematic diagram of an HVDC Transmission System

Fig. 1-6. Schematic diagram of an HVDC Transmission System.

1, 2. AC systems at terminals, terminal AC substations
3. Convertor transformers
4. Thyristor valves of convertor
5. Smoothing reactor (HVDC)
6. HVDC transmission line (Bipolar)
7. Electrode line
8. Earth electrodes.
• At the other end the DC power is inverted in thyristor-convertor valves and fed into the receiving system.

• An 2-Terminal HVDC transmission system has an HVDC convertor substation at each end and an HVDC transmission line in between.

• In case of back-to-back coupling station, the rectifier and inverter are at the same place and there is no HVDC line.

• A back-to-back HVDC station provides an asynchronous tie between two adjacent AC Networks.
Choice of HVDC Transmission System

- **Long, high power transmission**
  - For long distance, high power transmission lines HVDC transmission systems are preferred due to their economic advantage and exact, fast and easy control of power flow from generating station to load centre.
  - Though HVDC system needs costly terminal substations, the line cost is lower than that of equivalent AC line.
  - Power flow can be controlled.
  - Line losses are low.
• The per km cost of HVDC line is lesser than that of an equivalent 3 phase double circuit AC line.
• For equal power transfer, the number of conductors for 3 phase AC line is 6 to 24 as against only 2 numbers required for Bipolar HVDC line.

Fig. 1.12. Economic comparison of long distance high power HVDC transmission and EHV-AC transmission.
• **System Interconnections**
  • Neighbouring independently controlled AC Networks are interconnected by system interconnections.
  • System interconnection is either by EHV-AC/HVAC or HVDC.
  • The basic function of an **interconnection** is to transfer energy from surplus zone to deficit zone.
  • When neighbouring AC Networks are connected by and AC interconnection they start operate synchronously at the same frequency. AC interconnection is called synchronous tie.
  • When neighbouring AC Networks are interconnected by HVDC interconnection, they can continue to have their independent load frequency control. (Asynchronous tie)
System interconnection has following major advantages.

- Lesser overall installed capacity to meet the peak demand.
- Lesser spinning reserves.
- Overall economic generation by optimum use of high capacity economical generating plants.
- Better use of energy reserves such as hydro, thermal, nuclear.
- Better system support to weak network.
- Better system support to network having emergency due to outage of a plant or a line.
- Stronger grid with stable frequency.
EHV-AC interconnection:

- It is simple.
- Power flow adapts naturally to the needs and prevailing surplus deficit between interconnected networks.
- Voltages and connections can be made suitably by using transformer connection.

The limitations of EHV-AC interconnections include:

- It is synchronous tie.
- Frequency disturbance in one zone is quickly transferred to the other.
- Power swings in one network affect the other network. A weak tie link gets tripped due to such power swings.
- Large interconnected networks suffer from cascade tripping and overall black-outs in the event of major faults in any of the network.
HVDC interconnections:

- It is an asynchronous tie.
- Frequency disturbance from one AC Network is not transferred to the other.
- Direction and magnitude of power flow can be changed quickly and accurately by controlling the characteristics of rectifier/inverter.
- Power swings and frequency disturbances in connected AC Network can be quickly dampened by modulating the power flow through the HVDC interconnection.
- HVDC link can be used for interconnecting systems having different frequencies.
- HVDC link can be used for interconnection between two networks separated by sea or lake by using submarine cables.
• **Back-to-back asynchronous tie sub-stations**
  • In back-to-back HVDC coupling stations the interconnection is by a converter-substation without any transmission line.
  • The HVDC inverter and rectifier are installed in the same station.
  • Such a tie-link gives an asynchronous interconnection between two adjacent independently controlled AC networks.

• **Multi-terminal HVDC Interconnection**
  • Three or more AC networks can be interconnected asynchronously by means of a multi-terminal HVDC system.
  • Power flow from each connected AC Network can be controlled suitably.
  • Large power can be transferred.
  • Overall stability can be improved.
• **Cable Transmission**
  - HVDC is preferred for underground or submarine-cable transmission over long distance at high voltage.
  - The submarine cables are necessary to transfer power across oceans, lakes etc.
  - In case of AC cables, the temperature rise due to charging currents forms a limit for loading.
  - For each voltage rating there is a limit of length beyond which an AC cable cannot be used to transfer load current due to thermal limit.
  - HVDC cables have no continuous charging currents and can transfer bulk power over long distances.
Types of HVDC Systems

Monopolar HVDC system

- This system has, only one pole and the return path is provided by permanent earth or sea.
- The pole generally has negative polarity with respect to the earth.
- In monopolar HVDC system the full power and current is transmitted through a line conductor with earth or sea as a return conductor.
• The earth electrodes are designed for continuous full-current operation and for any overload capacity required in the specific case.
• The sea or ground return is permanent and of continuous rating.
• Monopolar HVDC systems are used only for low power rated links and mainly for cable transmission.

**Bipolar HVDC Transmission**
• This is most widely used of overhead long distance HVDC systems, for point-to-point power transfer.

• The HVDC substation and HVDC line has two poles, one positive and the other negative with respect to earth.
• The mid points of convertors at each terminal station are earthed via electrode line and earth electrode.
• Power rating of one pole is about half of bipole power rating.

![Diagram](image)

• During fault or trouble on one of the poles, the bipolar HVDC system is switched over automatically to monopolar mode.
• Thereby, the service continuity is maintained.
Homopolar HVDC System

- In such a system two transmission poles are of the same polarity and the return is through permanent earth.
- Two homopolar overhead lines feeding to a common monopolar cable termination.
- One overhead transmission tower carrying insulator strings supporting two homopolar transmission line conductors.
- Applications of homopolar transmission are limited.
Limitations of HVDC Transmission Systems

• HVDC system does not have step-up and step-down transformers.
• HVDC system does not have suitable HVDC circuit breakers.
• HVDC Transmission cannot be used economically for main transmission, subtransmission, distribution. It is used only for specific long distance/cable/interconnection projects.
• Cost of HVDC terminal substations is very high.
• Operation of HVDC transmission required continuous firing of thyristor valves. Controls of HVDC are complex. Several additional abnormal conditions are possible on DC side and in controls.
• HVDC substation require additional harmonic filters and shunt capacitors.

Converter station
• The major components of a HVDC transmission system are converter stations where conversions from AC to DC (Rectifier station) and from DC to AC (Inverter station) are performed.
• A point to point transmission requires two converter stations.
• The role of rectifier and inverter stations can be reversed (resulting in power reversals) by suitable converter control.
• The various components of a converter station are discussed below.
Fig. 1.5 Schematic diagram of a typical HVDC converter station.
Converter unit

- Each valve is used to switch in a segment of an AC voltage waveform.
- The converter is fed by converter transformers connected in star/star and star/delta arrangements.
- The valves are cooled by air, oil, water or freon.
- Liquid cooling using deionized water is more efficient and results in the reduction of station losses.

Fig. 1.6 A Twelve pulse converter unit
• The ratings of a valve group are limited more by the permissible short circuit currents than steady state load requirements.
• The design of valves is based on the modular concept where each module contains a limited number of sedes connected thyristor levels.
• Valve firing signals are generated in the converter control at ground potential and are transmitted to each thyristor in the valve through a fiber optic light guide system.
• The light signal received at the thyristor level is converted to an electrical signal using gate drive amplifiers with pulse transformers.
• The valves are protected using snubber circuits, protective firing and gapless surge arresters.
Converter Transformer
• The converter transformer can have different configurations - (i) three phase, two winding, (ii) single phase, three winding, (iii) single phase, two winding.
• The valve side windings are connected in star and delta with neutral point ungrounded.

• On the AC side, the transformers are connected in parallel with neutral grounded.
• The leakage reactance of the transformer is chosen to limit the short circuit currents through any valve.

• The converter transformers are designed to withstand DC voltage stresses and increased eddy current losses due to harmonic currents.
• One problem that can arise is due to the DC magnetization of the core due to unsymmetric firing of valves.
• In back to back links, which are designed for low DC voltage levels an extended delta configuration can result in identical transformers being used in twelve pulse converter units.

**Filters**

There are three types of filters used:

**AC filters** : These are passive circuits used to provide low impedance, shunt paths for AC harmonic currents. Both tuned and damped filter arrangements are used.

**DC filters** : These are similar to AC filters and are used for the filtering of DC harmonics.
High frequency (RFIPLC) filters: These are connected between the converter transformer and the station AC bus to suppress any high frequency currents. Sometimes such filters are provided on high-voltage DC bus connected between the DC filter and DC line and also on the neutral side.

Reactive power source
- Converter stations require reactive power supply that is dependent on the active power loading.
- Fortunately, part of this reactive power requirement is provided by AC filters.
- In addition, shunt (switched) capacitors, synchronous condensers and static var systems are used depending on the speed of control desired.
Smoothing reactor
• A sufficiently large series reactor is used on DC side to smooth DC current and also for protection.
• The reactor is designed as a linear reactor and is connected on the line side, neutral side or at intermediate location.

DC switchgear
• This is usually a modified AC equipment used to interrupt small DC currents.
• DC breakers or metallic return transfer breakers (MRTB) are used, if required for interruption of rated load currents.
• In addition to the equipment described above, AC switchgear and associated equipment for protection and measurement are also part of the converter station.
EHV-AC Versus HVDC Transmission

• **For backbone network.**
  Voltage can be easily stepped-up, stepped-down. The network has natural tendency to maintain synchronism. Load-frequency control is easy and simple. Network can be tapped at intermediate points to feed underlying subtransmission network.

• **Bulk power long distance transmission lines.**
  HVDC proves economical above breakeven point. Number of lines are less. No need of intermediate substation for compensation.

• **Stability of transmission system.**
  HVDC gives asynchronous tie and transient stability does not pose any limit. Line can be loaded up to thermal limit of the line or valves (whichever is lower).
• **Line loading.**
  The permissible loading of an EHV-AC line is limited by transient stability limit and line reactance to almost one third of thermal rating of conductors. No such limit exists in case of HVDC lines.

• **Surge impedance loading.**
  Long ERV-AC lines are loaded to less than 0.8 Pn. No such condition is imposed on HVDC line.

• **Voltage along the line.**
  Long EHV lines have varying voltage along the line due to absorption of reactive power. This voltage fluctuates with load. Such a problem does not arise in HVDC line. EHV-AC line remains loaded below its thermal limit due to the transient stability limit. Conductors are not utilized fully.
Number of lines.
EHVAC needs at least two three phase lines and generally more for higher power. HVDC needs only one bipole line for majority of application.

Intermediate substations.
EHV-AC transmission needs intermediate substations at an interval of 300 km for compensation.
HVDC line does not need intermediate compensating substation.

Asynchronous tie.
System having different prevailing frequencies or different rated frequencies can be interconnected. HVDC link provides asynchronous tie. Frequency disturbance does not get transferred large blackouts are avoided.
**Better control.**
Power flow through HVDC tie line can be controlled more rapidly and accurately than that of EHV-AC interconnector. HVDC-Power flow can be increased at a rate of 30 MW per minute. This is not possible with EHV-AC line.

**Corona loss and radio interference.**
For the same power transfer and same distance, the corona losses and radio interference of DC systems is less than that of AC systems, as the required d.c. insulation level is lower than corresponding a.c. insulation.

**Power Transfer and Reactive Power.**
The main difference between EHV-AC and HVDC transmission systems is in control of Real Power flow and Reactive Power Flow.
For AC line:

\[ Pac = \frac{|V_1| \cdot |V_2|}{X} \sin \delta \]

The AC line can be loaded up to transient stability limit which occurs at \( \delta = 30^0 \) and is given by

\[ Pac_{-\text{max}} = \frac{1}{2} \cdot \frac{|V_1| \cdot |V_2|}{X} \]

AC line power cannot be changed easily, quickly and accurately as \( |V_1| \) and \( |V_2| \) should be kept around rated voltage levels and angle \( \delta \) cannot be changed easily.

Secondly, the series reactance and shunt reactance of AC line result in reactive power flow, voltage regulation problems and additional transmission losses due to reactive component of current.
Power flow through HVDC link is given by

\[ P_{dc} = \frac{(U_{d1} - U_{d2})}{R} \cdot Ud \]

By varying \((U_{d1} - U_{d2})\) by means of thyristor converter control and tap-changer control; the power flow \(P_{dc}\) can be changed quickly, accurately and easily.

Secondly, HVDC transmission does not have series reactance and shunt reactance; reactive power flow. Hence voltage regulation problems and stability problems transmission losses etc. due to the flow of reactive power flow are absent in HVDC transmission systems. Transmission losses are low.

**Skin effect.**

This is absent in d.c. current. Hence current density is uniformly distributed across the cross-section of the conductor.
Charging current.
Continuous line charging currents are absent in HVDC lines. Reactive Power (MVAr) does not flow continuously. Hence transmission losses are low.

Tower size.
The phase-to-phase clearance, phase to ground clearances and tower size is smaller for d.c. transmission as compared to equivalent AC transmission for same power and distance. Tower is simpler, easy to install and cheaper.

Number of conductors.
Bipolar HVDC transmission lines require two-pole conductors to carry DC power. Hence HVDC transmission becomes economical over AC transmission at long distance when the saving in overall conductors cost, losses, towers etc. compensates the additional cost of the terminal apparatus such as rectifiers and converters.
Earth return.
HVDC transmission can utilize earth return and therefore does not need a double circuit. EHV-AC always needs a double circuit.

Reactive power compensation.
HVDC line does not need intermediate reactive power compensation like EHV-AC line.

Flexibility of operation.
Bipolar line may be operated in a monopolar mode by earth as a return path when the other pole develops a permanent fault.

Staging facility.
DC valves may be connected in series and parallel to get desired DC voltage and current. Multiterminal schemes are now possible.
Short-circuit level.
In AC transmission, additional parallel lines result in higher fault level at receiving end due to reduced equivalent reactance. When an exiting AC system is interconnected with another AC system by AC transmission line, the fault level of both the system increases. However, when both are interconnected by DC transmission, the fault level of each system remain unchanged.

Rapid power transfer.
The control of convertor valves permit rapid changes in magnitude and direction of power flow. Limitation is imposed by power generation and AC system conditions.
## SCHEDULE OF INSTRUCTIONS
### UNIT PLAN

**Academic Year**: 2012-2013  
**Semester**: II  
**Name of the Program**: B.Tech IV  
**Year**: ………………..  
**Section**: A / B  
**Course/Subject**: HVDC TRANSMISSION  
**Course Code**: 58008  
**Name of the Faculty**: J.SRIDEVI  
**Dept.**: EEE  
**Designation**: ASSOCIATE PROFESSOR.

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<th>No. of Periods</th>
<th>Topics / Sub - Topics</th>
<th>Objectives &amp; Outcomes Nos.</th>
<th>References (Text Book, Journal…)</th>
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<td>Analysis of 6 pulse Graetz Circuit</td>
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<td>Analysis of 12 pulse Graetz Circuit</td>
<td>1,2</td>
<td>2. Pg.no: 61-65</td>
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**References:**

1. EHV-AC, HVDC Transmission and Distribution Engineering - S.Rao  
2. HVDC Power Transmission Systems - K.R. Padiyar

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**Signature of HOD**  
**Signature of faculty**

**Date:**

**Note:**
1. ENSURE THAT ALL TOPICS SPECIFIED IN THE COURSE ARE MENTIONED.  
2. ADDITIONAL TOPICS COVERED, IF ANY, MAY ALSO BE SPECIFIED IN BOLD  
3. MENTION THE CORRESPONDING COURSE OBJECTIVE AND OUT COME NUMBERS AGAINST EACH TOPIC.
Static Power Conversion Adopted in HVDC Transmission

• A Bipolar HVDC transmission system has an HVDC terminal substation at each end. Each terminal substation has AC/DC convertor. The convertors change AC to DC or DC to AC.

• The convertor terminal operating in rectifier mode changes AC power to DC power. Delay angle $\alpha$ is held at 15 to 18°.

• The convertor terminal operating in inverter mode changes DC power to AC power. Extinction angle $\gamma$ is held at 15 to 18°.

• The complete HVDC Transmission transfers electric power from one AC Network to another AC Network in the form of high voltage direct current.
The convertor has two types of circuits:

- Main circuit through which high power flows. This comprises convertor transformers, thyristor valves, busbars, series reactor etc.
- Control and protection circuits for firing/blocking the valves in desired sequence, monitoring etc.

Fig. 2.9 Schematic diagram of an HVDC transmission system.
Six Pulse Converter Bridge (Graetz Bridge)

- A 6-pulse bridge has 6 valves arranged or 3 limbs for the vertical valve structure.
- AC supply is given from the three secondary leads of a converter transformer.
- The six valves are fired in a definite sequence (1, 2,...6).

![Diagram of Six-Pulse Converter Bridge](image-url)
• At any instant, two valves are conducting in the bridge, one from the upper commutation group and the second from the lower commutation group.
• The firing of the next valve in a particular group results in the turning off of the valve that is already conducting.
• The assumption is that there is no overlap between the two valves in a group.
• Thus the valve 2 is fired $60^0$ after the firing of valve 1 and valve 3 is fired $60^0$ after the firing of second valve.
• Each valve conducts for $120^0$ and the interval between consecutive firing pulse is $60^0$ in steady state.
Assumptions:
• The d.c current is constant.
• The valves can be modelled as ideal switches with zero impedance when ‘ON’ and with infinite impedance when ‘OFF’.
• The AC voltages at the converter bus are sinusoidal and remains constant.

DC voltage waveform
• The increase in the delay angle $\alpha$ causes corresponding delay in transfer from one valve arm to another, resulting in reduction of mean direct voltage. It is assumed that a large smoothing is connected on the DC side.
• With $\alpha = 0^\circ$ the commutation takes place naturally and the convertor acts as a rectifier.
• With increase in $\alpha$, the average value of DC voltage is reduced.
Fig. 4.11. Voltage waveforms for various values of $\alpha$. 

(a) Bridge Voltages  (b) Valve voltages
• When \( \alpha \) becomes more than 60°, some negative spikes begin to appear in the DC voltage. i.e. the energy will flow from DC system to AC system through the convertor without change in the direction of current.
• For \( \alpha = 90^0 \), the area of positive portion of DC voltage spikes and negative portion of DC voltage spikes per cycle are equal. The mean value of DC voltage per cycle of AC wave is zero. The convertor is acting neither as rectifier nor as inverter. Energy transfer is zero.
• For \( \alpha \) more than 90° , the negative pulses have more area than positive pulses, Mean value of DC voltage is negative i.e. the energy flows from DC system to AC systems indicating inversion mode.
• For \( \alpha = 180^\circ \), Full inversion is obtained.
Valve Voltage

• When the valve is conducting, this voltage is zero.
• When valve is not conducting, and the other valve arm of the same group is conducting, the voltage across the non-conducting valve arm corresponds to phase to phase voltage of transformer secondary terminals.

• **Definition of Delay Angle** $\alpha$. Delay angle $\alpha$ is the time expressed in electrical angle from the zero crossing(s) of the idealised sinusoidal commutating voltage and starting of forward current conduction(s).
• It can be conveniently understood as the angle between the Instant of natural commutation (zero crossing) and instant of delayed commutation, (C).
• By delaying the triggering pulses, the duration of conduction a cycle is reduced, thereby the average value of DC voltage is reduced.

• By varying $\alpha$ from zero to 90° elec., the no load direct voltage changes from maximum (at $\alpha = 0$) to zero (at $\alpha = 90^\circ$).

• The following are noted: -
  • $\alpha = 0^\circ$ Rectifier mode maximum DC voltage
  • $\alpha = 15^\circ$ Rectifier mode reduced DC voltage
  • $\alpha = 90^\circ$ Rectifier mode No power transfer, Zero DC voltage
  • $\alpha > 90^\circ$ Inverter mode
  • $\alpha = 180^\circ$ Full inverter mode.
• The limits of delay angle $\alpha$ are 0 to $45^0$
• In practice, for normal rectifier operating mode, the delay angle $\alpha$ is held between 50 to $15^\circ$.
• The choice of $\alpha$ has two opposite constraints.
  (1) The reactive power demand of convertor valves reduces with reduction in delay angle $\alpha$. Hence smaller value of $\alpha$ is preferred with respect to reactive power requirements (AC shunt compensation)

(2) But with smaller value of $\alpha$ the possibility of further increase in DC voltage on rectifier side is reduced.
No-load Voltage Equation for Rectifier with Zero Delay Angle

(1) Phase to phase, 3 ph, AC waveforms (2) Corresponding DC output voltage. Fig. 5.3. No load voltage waveforms of a single six-pulse converter.
Secondary phase-to-phase voltage between terminals A and B of a six-pulse convertor bridge.
It is a sinusoidal voltage with an equation

\[ U_s = U_{sm} \cos \omega t \]

RMS value of the wave \( u_s \), is equal to \( U_s \), which corresponds to phase-to-phase secondary voltage of a convertor transformer which feeds a six-pulse convertor. The crest value (peak value) of the voltage waveform \( U_{sm} \) occurs at XX and is given by

\[ U_{sm} = \sqrt{2} U_s \]

where

\[ U_{sm} = \text{peak value of voltage } U_{AB} \text{ occurring at XX.} \]
\[ U_s = \text{rms value of phase-to-phase secondary voltage} \]
\[ \omega = 2\pi f \]
\[ f = \text{frequency of AC wave.} \]
• Integrating $u_s$ over segment ABCD between $-\pi/6$ and $+\pi/6$ as shown is Fig. and dividing by period $\pi/3$

$$U_{do} = \frac{1}{(\pi/3)} \int_{-\pi/6}^{+\pi/6} U_{sm} \cos \omega t \; d\omega t$$

$$= \frac{U_{sm}}{(\pi/3)} \left[ \sin \omega t \right]_{-\pi/6}^{+\pi/6}$$

$$= \frac{3}{\pi} U_{sm} \left[ \sin \left(\frac{\pi}{6}\right) - \sin \left(-\frac{\pi}{6}\right) \right]$$

$$U_{do} = \frac{3}{\pi} U_{sm}$$

where $U_{do}$ = Direct voltage between terminals of a six-pulse convertor, average value, no-load

$U_{sm}$ = Crest value of secondary phase to phase voltage.

Substituting,

$$U_{sm} = \sqrt{2} \cdot U_s$$

in Eqn. (5.2),

$$U_{do} = \frac{3}{\pi} \cdot \sqrt{2} \cdot U_s$$
where $U_s = \text{secondary, rms, phase to phase voltage}$

- This fundamental, important equation co-relates DC voltage with phase-to-phase secondary AC voltage for a six-pulse-bridge.

- For a six-pulse bridge

$$U_{do} = \frac{3}{\pi} \cdot \sqrt{2} \cdot U_s$$

$$U_{do} = 1.35 \cdot U_s$$

where $U_{do} = \text{No-load direct voltage with zero phase control, for a six pulse bridge}$

$U_s = \text{Phase to phase rms voltage for secondary.}$
Rectifier Voltage Equations with No-Load and Delay Angle $\alpha$

- The average value of DC voltage of a six-pulse convertor unit can be determined by finding average value of one segment between ($-\pi /6+\alpha$) and ($+\pi /6+\alpha$) with respect to peak phase to phase voltage at \textit{XX}.

\begin{figure}
\centering
\includegraphics[width=0.7\textwidth]{figure.png}
\caption{Analysis of no-load voltage with delay angle $\alpha$ present (neglecting reactance drop and over-lap angle).}
\end{figure}
• Each segment covers $\pi/3$ duration. Hence

$$U_d = \frac{1}{3} \int_{-\pi/6 + \alpha}^{\pi/6 + \alpha} U_{sm} \cdot \cos \omega t \cdot d\omega t$$

Where $U_{sm}$ = Crest value of phase to phase AC secondary voltage

$$= \sqrt{2} \ U_s$$

$U_s$ = Secondary phase to phase rms voltage

$U_d$ = Direct voltage between terminals of one six-pulse unit operating at no load with delay angle $\alpha$.

$$U_d = \frac{3}{\pi} \ U_{sm} \left(2 \sin \frac{\pi}{6} \cdot \cos \alpha\right)$$

$$= \frac{3}{\pi} \ U_{sm} \cdot \cos \alpha$$

$$= \frac{3}{\pi} \ \sqrt{2} \ U_s \cos \alpha$$

$$U_d = \left(\frac{3}{\pi} \cdot \sqrt{2}\right) \ U_s \cdot \cos \alpha$$
Comparing with delay angle $\alpha$, we get

$$ Ud = 1.35 U_s \cos \alpha $$

- The Direct voltage with delay angle $\alpha$ is proportional to $\cos \alpha$.
- By increasing delay angle $\alpha$, the average DC voltage reduces.
- Maximum DC voltage occurs at $\alpha = 0$ and is equal to $U_{do}$
Analysis of Graetz circuit with overlap

• Due to the leakage inductance of the converter transformers and the impedance in the supply network, the current in a valve cannot change suddenly.

• Thus commutation from one valve to the next cannot be instantaneous.

• For example, when valve 3 is fired, the current transfer from valve 1 to valve 3 takes a finite period during which both valves are conducting.

• This is called overlap and its duration is measured by the overlap (commutation) angle ‘μ’.
• Each interval of the period of supply can be divided into two subintervals
• In the first subinterval, three valves are conducting and in the second subinterval, two valves are conducting. This is based on the assumption that the overlap angle is less than 60°.
• As the overlap angle increases to 60°, there is no instant when only two valves are conducting.
• As the overlap angle increases beyond $60^0$, there is a finite period during an interval, when four valves conduct and the rest of the interval during which three valves conduct.

**Commutation**

• The process of transfer of direct current from one path to another with both paths carrying currents simultaneously is called commutation.
• The commutation process takes place sequentially between two consecutive valve arms of group A connected to positive terminal.
• In forced commutation process, the commutating reactance of the load circuit of two valves undergoing commutation causes the delay in the transfer from one path to another.
During commutation process, the current $i_s$ outgoing valve arm(1) reduces from full value $I_d$ to zero in a small time interval.

During the same interval of time, the current of incoming valve arm(3) rises from zero to full value($I_d$).

The time interval during which both the incoming and outgoing valves are conducting is measured in terms of electrical radians or degrees and is called angle of overlap.

**Commutating Reactance**

The commutating reactance is defined as the reactance of the circuit consisting of commutating arms and the commutating voltage source during the process of active commutation.
• The commutating reactance reduces the steepness of the fall in current \( i_1 \) in the outgoing valve arm.
• The commutating reactance also reduces the steepness of rise of current \( i_3 \) in incoming valve arm.
• Without commutating reactance the current transfer from one path to another path would have been instantaneous.

• But the transformer secondary winding has inherent reactance which prevents the step change in current.
• The commutating reactance is predominantly active due to the reactance of transformer winding.

Fig. 4.13. Explaining commutation between valve arm 1 and 3.
Fig. 4.14. Waveforms during commutation between valve arm 1 and 3 for rectifier mode.

Fig. 4.15. Waveforms during commutation between valve arms 1 and 3 for inverter mode.
• The angle of overlap ‘μ’ appears due to voltage drop in commutating reactance $X_c$.
• The path of $i_s$ is through commutating reactances $2X_c$ offered by the secondary windings and the conducting path.
• The flow of $i_s$ produces reactance voltage drop $i_s.X_c$ per phase.
• The waveform of mean voltage during commutation is shown in Fig.

![Diagram showing the waveform of mean voltage during commutation](image)

**Fig. 5.6.** Details of voltage waveform with delay angle $\alpha$ and overlap $\mu$ for RECTIFIER MODE.
**Voltage Equation.**

Let \( v_s \) be the voltage between secondary phases which is responsible for commutating current \( i_s \).

\[
v_s = U_{sm} \sin \omega t
\]

\[
v_s = \sqrt{2} U_s \sin \omega t
\]

Where \( U_{sm} = \) peak secondary ph. to ph. voltage

\( U_s = \) rms, ph. to. ph. secondary voltage

From basic circuit fundamentals, we know

\[
L \frac{di}{dt} = v
\]

In the local circuit of current \( i_s \) total inductance is \( 2L_c \) and current \( i_s \).

\[
2L_c \frac{di}{dt} = v_s = \sqrt{2} U_s \sin \omega t
\]

\[
di_s = \frac{\sqrt{2} U_s}{2L_c} \sin \omega t \, dt
\]
Where \( L_c \) = Inductance of commutating circuit per phase.

Integrating both sides,

\[
i_s = \frac{\sqrt{2} U_s}{2L_c} \cdot \cos \omega t + C
\]

Substituting initial condition, i.e. at \( \omega t = \alpha \); \( i_s = 0 \)

\[
C = \frac{U_s}{\sqrt{2} \omega L_c} \cdot \cos \alpha
\]

Therefore,

\[
i_s = \frac{U_s}{\sqrt{2} \omega L_c} \cdot (\cos \alpha - \cos \omega t)
\]

Substituting final commutating condition, i.e. at \( \omega t = \alpha + u; \) \( i_s = I_d \)

\[
I_d = \frac{U_s}{\sqrt{2} \omega L_c} \cdot [\cos \alpha - \cos (\alpha + u)]
\]

There is a small voltage drop due to area \( \delta A \) between \( \alpha \) and \( \alpha + \mu \) as shown in Fig.
\[ \delta A = \frac{1}{2} \int_{\theta}^{\theta+\pi} \sqrt{2} U_s \sin \omega t \, d\omega t \]
\[ = \frac{\sqrt{2}}{2} \left[ U_s \cos \omega t \right]_{\theta}^{\theta+\pi} \]
\[ = \frac{U_s}{\sqrt{2}} \left[ \cos \theta - \cos (\theta + u) \right] \]

Average value of voltage drop during the period \( \pi / 3 \) is

\[ \delta V = \frac{\delta A}{\pi / 3} \]
\[ = \frac{3}{\pi} \cdot \frac{U_s}{\sqrt{2}} \left[ \cos \theta - \cos (\theta + u) \right] \]

\[ \frac{3U_s}{\sqrt{2} \pi} = \frac{U_{do}}{2} \]

\[ \delta V = \frac{U_{do}}{2} \left[ \cos \theta - \cos (\theta + u) \right] \]
\[ Ud = U_{do} \cdot \cos \alpha - \delta V \]
\[ = U_{do} \cos \alpha - \frac{U_{do}}{2} [\cos \alpha - \cos (\alpha + u)] \]
\[ = \frac{U_{do}}{2} [\cos \alpha + \cos (\alpha + u)] \]
\[ \frac{U_d}{U_{do}} = \frac{1}{2} [\cos \alpha + \cos (\alpha + u)] \]

where \( U_{do} = \) No load direct voltage
\( U_d = \) Direct voltage on load with delay angle ‘\( \alpha \)’ and overlap angle ‘\( \mu \)’.

Therefore,
\[ I_d = \frac{U_s}{\sqrt{2} X_c} [\cos \alpha - \cos (\alpha + u)] \]

where \( X_c = 2\pi f L_c = \omega L_c \)

\[ \delta V = \frac{3}{\pi} \cdot \frac{U_s}{\sqrt{2}} [\cos \alpha - \cos (\alpha + u)] \]
\[ \delta V = \frac{3}{\pi} \cdot \omega L_c \cdot I_d \]
\[ \delta V = \frac{3X_c}{\pi} I_d \]
\[ U_d = U_{do} \cos \alpha - \delta V \]

\[ U_d = U_{do} \cos \alpha - \frac{3X_c}{\pi} I_d \]

**Equivalent Circuit of Rectifier**

![Equivalent Circuit of Rectifier](image)
Extinction angle $\gamma$, Angle of advance $\beta$

for $\alpha = 0$,

$$Id = \frac{U_s}{\sqrt{2} X_c} [1 - \cos (\alpha + u)]$$

for $\alpha$ present,

$$Id = \frac{U_s}{\sqrt{2} X_c} [\cos \alpha - \cos (\alpha + u)]$$

For same $Id$

$$1 - \cos (\alpha + u) = \cos \alpha - \cos (\alpha + u)$$
Definitions

1. **Delay angle** $\alpha$. The time expressed in electrical angular measure from zero crossing of idealised sinusoidal commutating voltage to starting instant of forward current.

2. **Angle of Advance** $\beta$. Time expressed in electrical angular measure from starting of current to zero crossing of idealised sinusoidal commutating voltage.

3. **Relation between $\beta$ and $\alpha$.** $\beta = \pi - \alpha$

4. **Angle of overlap** $\mu$. Time during which two consecutive converter arms carry current simultaneously.

5. **Extinction angle** $\gamma$ (Margin angle). Time from end of current conduction to zero crossing of idealized commutating sinusoidal voltage.

6. **Relationship between $\beta$, $\mu$, $\gamma$.** $\gamma = \beta - \mu$
Operation of inverter

• Consider a six pulse bridge working as a rectifier.

\[ Ud = \tilde{U}_{do} \cos \alpha \quad \text{(neglecting commutation overlap angle \(u\)).} \]

• The operation of the convertor in following modes:
  
  (1) \(\alpha < 90^\circ\), \(U_d\) positive. \(U_d I_d =\) positive, Rectifier mode
  
  (2) \(\alpha = 90^\circ\), \(U_d\) zero, \(U_d I_d =\) zero. No power flow
  
  (3) \(\alpha > 90^\circ\), \(U_d\) negative \(U_d I_d =\) Negative, Inversion.

• With \(\alpha\) above 90\(^\circ\), the average DC voltage per cycle of AC wave is negative and power flows from DC to AC resulting inversion.

• This needs a large smoothing reactor on DC side and power source on DC side.
• At \( \alpha = 180^\circ \), \( U_d = U_{do} \cos 180^\circ = -U_d \), i.e. polarity is reversed, current \( I_d \) continues in forward direction.

\[ \text{For rectifier, } U_d = U_{do} \cos \alpha \]

• When \( \alpha \) is more than 90°, it is more convenient to define angle of advance \( \beta \) such that

\[ \beta = \pi - \alpha \]

where

\[ \beta = \text{angle of advance} \]
\[ \alpha = \text{delay angle}. \]

We know,
\[ \cos (\pi - \alpha) = -\cos \alpha \]
\[ \cos \beta = -\cos \alpha \]

• Hence we can substitute \( \alpha = \pi - \beta \) resulting in the following relation for inverter.

\[ U_d = U_{do} \cos \beta \]
\[ \beta = \text{Angle of advance} \]
Equivalent circuit of inverter with $\cos\beta$
From Fig), it is observed that,

\[ \beta = \pi - \alpha \]
\[ \alpha = \pi - \beta \]

Where \( \beta \) = angle of advance (for inverter)
\( \alpha \) = delay angle (for rectifier)

\[ \gamma = \beta - \mu \]
\[ \mu = \beta - \gamma \]

Where \( \gamma \) = angle of extinction (for inverter)
\( \beta \) = angle of advance (for inverter)
\( \mu \) = angle of overlap (for rectifier)

By substituting the above equations,

\[ Ud = Udo \cos \alpha \text{ for rectifier, becomes} \]
\[ Ud = Udo \cos (\pi - \beta) \]
\[ = -Udo \cos \beta \text{ for inverter} \]

For inverter \( U_d \) is negative.
\[ Ud = \frac{U_{do}}{2} [\cos \alpha + \cos (\alpha + \mu)] \text{ for rectifier.} \]

\[ Ud = \frac{U_{do}}{2} [\cos (\pi - \beta) + \cos (\pi - \beta + \beta - \gamma)] \]

\[ = \frac{U_{do}}{2} [-\cos \beta + \cos (\pi - \gamma)] \]

\[ = \frac{U_{do}}{2} [-\cos \beta - \cos \gamma] \]

\[ = -\frac{U_{do}}{2} [\cos \beta + \cos \gamma] \]

For inverter \( U_d \) is negative.

\[ Ud = U_{do} \cos \alpha - Id \cdot \frac{3X_c}{\pi} \text{ ...for rectifier} \]

\[ Ud = U_{do} \cos (\pi - \beta) - Id \cdot \frac{3X_c}{\pi} \]

\[ = -U_{do} \cos \beta - Id \cdot \frac{3X_c}{\pi} \text{ ...for inverter} \]

\[ -U_d = \left[ U_{do} \cos \beta + Id \cdot \frac{3X_c}{\pi} \right] \]
\[ Id = \frac{U_s}{\sqrt{2} X_c} [\cos \alpha - \cos (\alpha + u)] \]
\[ = \frac{U_s}{\sqrt{2} X_c} [\cos (\pi - \beta) - \cos (\pi - \beta + \beta - \gamma)] \]
\[ = \frac{U_s}{\sqrt{2} X_c} [- \cos \beta + \cos \gamma] \]
\[ Id = \frac{U_s}{\sqrt{2} X_c} [\cos \gamma - \cos \beta] \]

**Equation for Inverter**

- \( Ud = Udo \cos \beta \)
- \( Ud = \frac{Udo}{2} (\cos \beta + \cos \gamma) \)
- \( \frac{Ud}{Udo} = \frac{1}{2} (\cos \beta + \cos \gamma) \)
- \( Ud = [Udo \cos \beta + Id \cdot \frac{3X_c}{\pi}] \)
- \( Id = \frac{U_s}{\sqrt{2} X_c} (\cos \gamma - \cos \beta) \)

**Equation for Rectifier**

- \( Ud = Udo \cos \alpha \)
- \( Ud = \frac{Udo}{2} (\cos \alpha + \cos (\alpha + u)) \)
- \( \frac{Ud}{Udo} = \frac{1}{2} [(\cos \alpha + \cos (\alpha + u)) \]
- \( Ud = Udo \cos \alpha - Id \cdot \frac{3X_c}{\pi} \)
- \( Id = \frac{U_s}{\sqrt{2} X_c} [\cos \alpha - \cos (\alpha + u)] \)

\( \pi - \beta = \alpha \)
\( \gamma = \beta - u \)
\( \beta = \text{Angle of Advance} \)
\( \gamma = \text{Extinction angle} \)
\( \alpha = \text{Delay angle} \)
\( \beta - u = \text{Overlap angle} \)
Equivalent circuit of inverter with \( \cos \gamma \)

Equivalent circuit of HVDC link
# SCHEDULE OF INSTRUCTIONS
## UNIT PLAN

**Academic Year**: 2012-2013  
**Semester**: II  
**UNIT NO.**: III  
**Name of the Program**: B.Tech IV  
**Year**: ………………..  
**Section**: A / B  
**Course/Subject**: HVDC TRANSMISSION  
**Course Code**: 58008  
**Name of the Faculty**: J. SRIDEVI  
**Dept.**: EEE  
**Designation**: ASSOCIATE PROFESSOR.

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</table>

**References:**
1. EHV-AC, HVDC Transmission and Distribution Engineering - S. Rao  
2. HVDC Power Transmission Systems - K.R. Padiyar

**Signature of HOD**  
**Signature of faculty**

**Date:**  

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Converter & HVDC System Control

• Principles of DC Link Control

Steady state equivalent circuit of a 2-terminal DC link

Schematic of a DC link showing transformer ratios
• The control of power in a DC link can be achieved through the control of current or voltage.

• From minimization of loss considerations, it is important to maintain constant voltage in the link and adjust the current to meet the required power.

• This strategy is also helpful for voltage regulation in the system from the considerations of the optimal utilization of the insulation.

• It is to be noted that the voltage drop along a DC line is small compared to the AC line, mainly because of the absence of the reactive voltage drop.

• Consider the steady state equivalent circuit of a two terminal DC link shown in Fig.
• The number of series connected bridges \((n_b)\) in both stations (rectifier and inverter) are the same.
• The voltage sources \(E_{dr}\) and \(E_{di}\) are defined by

\[
E_{dr} = (3\sqrt{2/\pi}) n_b E_{vr} \cos \alpha_r
\]
\[
E_{di} = (3\sqrt{2/\pi}) n_b E_{vi} \cos \gamma_i
\]

where \(E_{vr}\) and \(E_{vi}\) are the line to line voltages in the valve side windings of the rectifier and inverter transformer respectively.
• These voltages can be obtained as

\[
E_{vr} = \frac{N_{sr} E_r}{N_{pr} T_r}, \quad E_{vi} = \frac{N_{si} E_i}{N_{pi} T_i}
\]

where \(E_r\) and \(E_i\) are the AC (line to line) voltages of the converter buses on the rectifier and the inverter side. \(T_r\) and \(T_i\) are the off-nominal tap ratios on the rectifier and inverter side.
where $A_r$ and $A_i$ are constants.

- It is to be noted that $E_{di}$ is defined in terms of the extinction angle $\gamma_i$ rather than $\beta_i$.

- $E_{di}$ can also be written as

$$E_{di} = (A_i E_i / T_i) \cos \gamma_i$$

- where $X_{cr}$ and $X_{ci}$ are the leakage reactances of the converter transformers in the rectifier and inverter station respectively.

- The steady-state current $I_d$, in the DC link is obtained as

$$I_d = \frac{(E_{dr} - E_{di})}{R_{cr} + R_{ci} - R_d}$$
• It is to be noted that the control variables are $T_r$, $T_i$, and $\alpha_r, \beta_i$.  
• However, for maintaining safe commutation margin, it is convenient to consider $\gamma_i$ as control variable instead of $\beta_i$.  
• The denominator is small, even small changes in the voltage magnitudes $E_r$ or $E_i$ can result in large changes in the DC current, if the control variables are held constant.

\[
I_d = \frac{(A_r E_r / T_r) \cos \alpha_r - (A_i E_i / T_i) \cos \gamma_i}{R_{cr} + R_d - R_{ci}}
\]
• It is desirable to have current control at the rectifier station under normal conditions.

  • The increase of power in the link is achieved by reducing $\alpha_r$, which improves the power factor, at the rectifier for higher loadings and minimizes the reactive power consumption.

  • The inverter can now be operated at minimum $\gamma_i$, thereby minimizing the reactive power consumption at the inverter also.

• It is to be noted that the current control at the inverter worsens the power factor at the higher loadings as $\gamma$ has to be increased. Increased $\gamma$ also implies higher losses in the valve snubber circuits.
• The operation at minimum extinction angle at the inverter and current control at the rectifier results in better voltage regulation than the operation with minimum delay angle at the rectifier and current control at the inverter.

• The currents during line faults are automatically limited with rectifier station in current control.

• While there is a need to maintain a minimum extinction angle of the inverter to avoid commutation failure, it is economical to operate the inverter at constant extinction angle (CEA) which is slightly above the absolute minimum required for the commutation margin.
• However, the main drawback of CEA control is the negative resistance characteristic of the converter which makes it difficult to operate stably when the AC system is weak.

• Under normal conditions, the rectifier operates at constant current (CC) control and inverter at the CEA control.

• Under conditions of reduced AC voltage at the rectifier, it is necessary to shift the current control to the inverter to avoid run down of the DC link when the rectifier control hits the minimum limit.

• This implies that current controller must also be provided at the inverter in addition to the CEA controllers.
Characteristics of rectifier and inverter

• Rectifier is equipped with constant current regulator.
• Inverter is equipped with a constant extinction angle regulator.
• Inverter characteristics is given by

\[-U_d = U_{do} \cos \gamma - I_d \frac{3X}{\pi}\]

• There has a ‘-’ve slope.

• At common point, there is only one voltage and current which is ‘E’.
Steady-state $U_d/I_d$ Characteristic of an HVDC Convertor

• The horizontal segment RS has certain slope representing voltage drop in the DC line resistance ($I_d R$).
• The slope of vertical segment $I_{ds}$ is due to actual characteristic of constant current controller.
• Horizontal segment RS representing constant value of $U_d$ as obtained by natural voltage characteristic of a convertor.

• Vertical segment ST representing constant value of current $I_d$ as obtained by constant current controller fitted to the convertor control system.

• Control functions are so arranged as to shift the horizontal segment RS for voltage change and shift the vertical segment ST for current change.
• If inverter voltage is changed, the rectifier voltage should also be appropriately changed to satisfy the equation

\[ Ud_1 = Ud_2 + Id.R \]

**Intersecting Characteristics of Rectifier and Inverter Under Normal Operating Mode**

• For stable operation, the operating point should lie on the \( U_d/I_d \) characteristic of Rectifier and Inverter simultaneously.

• The idealised steady state characteristic of Rectifier (1) and inverter (2) drawn on a common diagram, assuming higher DC voltage on rectifier-end than that at the inverter end.

• This diagram is applicable for the normal operating mode of the HVDC link, NVC of rectifier \( (R_1 S_1) \) is above NVC of inverter \( (R_2 S_2) \).
Point A lies on the constant current characteristic (CCC) (1) of rectifier and natural voltage characteristic (NVC) of the inverter.

For this operating point, the current ($I_d$) is determined by the constant current setting of the rectifier.

The voltage $U_{d2}$ is determined by the natural voltage characteristic of the inverter.

Hence for stable operation with normal steady state operation mode.
• The operating point A moves naturally on segment $S_1T_1$ for changing load requirements.
• $R_1$, $S_1$, $T_1$, represents rectifier characteristic (1) ; $R_2$, $S_2$, $T_2$ represents the inverter characteristic (2) as seen from rectifier end i.e., the voltage drop of line is taken into account such that

\[ Ud_1 = Ud_2 + Id \cdot R. \]

• The constant current segment of inverter characteristic ($S_2T_2$) has a current margin ($\Delta i_d$) with respect to constant current segment of rectifier characteristic ($S_1T_1$).
Intersecting Characteristic under Steady Condition with Current Margin Control

• This is not for a normal situation but for contingency arising in the event of fall of rectifier DC voltage due to say a fall in AC side voltage at rectifier end.
• Under such eventuality, the operating point A should remain on constant current segment and should be on point of intersection.
To fulfil these conditions, the inverter is also provided with a constant current control (Segment $S_2T_2$) with a current margin ($\Delta I$) with respect to current setting of rectifier ($S_1T_1$).

- This control mode is called current margin control.
- In this mode of control, the rectifier-end has a lower DC voltage than the inverter-end.
- The direct current $I_d$ in the link is determined by inverter constant current controller setting ($I_{d2}$).
- The voltage of the inverter is adjusted along the natural voltage characteristic passing through point A.
Reversal of Power Through an HVDC Link

Necessity of Reversal of Power

• Normal operation of an interconnecting HVDC line in which power flow is scheduled in either forward or reverse direction.
• Sudden need of power for AC system at sending end due to deficit power generation and drop in frequency.
• Fault on HVDC line pole during which the line is temporarily de-energized by changing over the rectifier to inverter. After a certain lapse of time attempts are made to re-energized the line by changing the same to rectifier. These operations require ability of each convertor to operate as a rectifier or an inverter.
• During frequency oscillations in AC system, the power flow through DC line is modulated to dampen the oscillations.
• The convertor at each terminal is provided with controls such that their delay angles $\alpha$ can be adjusted at desired value.
• For forward power flow, the convertor at Terminal 1 is operated as rectifier by setting angle $\alpha$ between $0^0$ to $90^0$ and convertor at Terminal 2 is operated as an inverter by setting angle $\alpha$ between $90^0$ and $180^0$. 
FORWARD POWER 1 TO 2

\[ P = U_d \times I_{ds} \]

REVERSE POWER 2 TO 1

\[ P = -U_d \times I_{ds} \]
ΔId - current Margin
FIRING ANGLE CONTROL

There are two basic firing schemes, namely:

- Individual phase control (IPC)
- Equidistant pulse control (EPC)

IPC was used in the past and has now been replaced by EPC for reasons that will be explained.

Individual phase control (IPC)

1. Current control, unit amplifier
2. Valves firing units pulse generator
3. Pulse distribution unit
4. Pulse transmission system
5. Current feed back
6. 6 pulse convertor unit
• This principle is applied for individual valve. Normally with zero delay angle, the valves will start conducting at respective zero crossing in a sequence.

• However by delaying the instant of firing pulse by delay angle $\alpha$, the start of conduction of individual valve is delayed with reference to phase angle of zero crossing.

• The control pulses are given to each valve at definite phase angle $\alpha$ with respect to earlier zero crossing.

• In individual phase control the control function for initiating the control pulse is derived from commutation voltage.

• Three phase alternating voltage $U_{AC}$ is supplied to valve firing control unit.
Control function ($U_c$) is derived from the feedback current control system which converts the summation of Reference current command $I_{REF}$, current margin $\Delta I$ and feedback current $I_{RES}$ to proportionate $U_c$.

The level of $U_c$ with reference to sinusoidally varying $U_{AC}$ determining angle $\alpha$ of output pulses.

Each valve gets firing pulse in a definite sequence.

Each pulse has angle $\alpha$ with reference to earlier zero crossing.

The instant of control pulse and the phase angle $\alpha$ for each valve depends on phase voltage $U_{AC}$ and control function $U_c$.

Control function ($U_c$) is governed by feed back current control system.
• By varying $U_c$, the instant of triggering of each individual valve is changed.
• But for all the valves, same delay $\alpha$ is used at a time.
• This method was used in earlier HVDC schemes and had a disadvantage that the distortion in AC supply waveform $U_{AC}$ causes variation in the delay angle $\alpha$.
• The distortion in angle $\alpha$ results in enhancing the disturbance.
• Hence this method is not used in new projects. Instead, the equidistance firing control is used.
Drawbacks of IPC Scheme

• Any distortion in the system voltage leads perturbations in the zero crossings which affect the instants of firing pulses in scheme.

• This implies that even when the fundamental frequency voltage component balanced, the firing pulses are not equidistant in steady-state. This in turn leads to generation of noncharacteristic harmonics.

• The problem of harmonic instability can be overcome by the following

  1. Use of filters in control circuit to filter out non characteristic harmonics

  2. The use of firing angle control independent of the zero crossings of the AC voltages.
Equidistant Firing Control (EFC)

• The pulses derived from control pulse generator are of nominal frequency $f_c$ proportional to $(6f_0)$ or $(12f_0)$ for 6 pulse and 12 pulse converter unit respectively.

  Where $f_0$ is the fundamental frequency of AC Network.

• The pulses of $(6f_0)$ or $(12f_0)$ are separated in pulse distribution unit and are supplied to individual valves.

• As frequency $f_0$ of AC system is always constant, the control pulses are with constant frequency and equidistant with respect to timing.
• The train of pulses is delivered to the six-pulse convertor unit or 12 pulse convertor unit via a six or twelve stage ring counter.

• The ring counter has 6 or 12 stages with only one stage ON at a time. The stages are made ON sequentially giving a short output pulse.

• The train of pulses is resolved by a ring counter, distributing them to the individual valves.

• They are also given to the proceeding valve in the other commutation group, in order to obtain the correct length of deblocked time.
• The voltage controlled oscillator gives a train of control pulses of frequency \( f_c \). The frequency of output pulses is by control function \( U_c \).

\[
f_c = k U_c (2\pi f_0/p)
\]
\( f_c \) = frequency of control pulses
\( k \) = constant of controller
\( U_c \) = voltage control function derived from feedback current control system. (Fig. 14-8).

• Further, there are two possible types of Commutation Margin control namely;

1. Feedback Control system or

2. Predictive system.

• The feedback control system receives response of current as a feedback and uses to vary the control function \( U_c \) as described earlier.
Predictive Control

• During disturbance in power flow, predictive control is preferred to obtain quick response of DC line current \( I_d \) and AC line voltage \( U_{AC} \).

• In the predictive control, based on instantaneous measurements of \( U_d \) and \( I_d \), the instant of firing of a valve is predicted (by using commutation margin area prediction \( A_p \)).

• Prediction is by calculation through on line microprocessor provided with a software.

• The actual firing instant for a valve (with actual commutation margin area \( A_m \)) is measured.

• The difference between predicted commutation margin \( A_p \) and actual commutation margin \( A_m \) is \( \Delta A \).

\[ \Delta A = A_p - A_m \]
• The difference $\Delta A$ calculated for the preceeding valve firing is used as a correction for the firing instant of a later valve e.g. one period later.

• This difference $\Delta A$ is added to the reference ($A_{m\text{.ref}}$). i.e. reference command commutation margin area ($A_{m\text{ ref.}}$).

• Thus the feedback system of valve firing control has a predictive loop which feeds of the difference $\Delta A$ form the preceeding valve to the firing control of the later valve (e.g. one cycle later).

• By using predictive principle, quick response of disturbances in $I_d$ and $U_d$ are fed to the valve firing unit and the corrective actions are taken one period earlier based on the predictions.
STARTING AND STOPPING OF DC LINK

• Consider N series connected bridges at a converter station.

• If one of the bridges is to be taken out of service, there is need to not only block, but bypass the bridge.

• This is because of the fact that just blocking the pulses does not extinguish the current in the pair of valves that are left conducting at the time of blocking.

• The continued conduction of this pair injects AC voltage into the link which can give rise to current and voltage oscillations due to lightly damped oscillatory circuit in the link formed by smoothing reactor and the line capacitance.

• The transformer feeding the bridge is also subjected to DC magnetization when DC current continues to flow through the secondary windings.
• The bypassing of the bridge can be done with the help of a separate bypass valve or by activating a bypass pair in the bridge (two valves in the same arm of the bridge).

• The bypass valve was used with mercury arc valves where the possibility of arc backs makes it impractical to use bypass pairs.

• With thyristor valves, the use of bypass pair is the practice as it saves the cost of an extra valve.
# SCHEDULE OF INSTRUCTIONS
## UNIT PLAN

**Academic Year**: 2012-2013  
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Functions of Smoothing Reactor

• A convertor bridge with a large smoothing reactor acts like a DC side current convertor.

• The functions of smoothing reactor:
  • Smoothens the ripple from DC current waveform.
  • Reduces the requirement of DC filters and AC filters.
  • Reduces current transients, during sudden changes in DC power flow.
  • Reduces steepness of voltage and current surges approaching from DC line. Thereby the stresses on convertor valve and valve surge arresters are reduced.
  • Reduces rate of rise transient short-circuit currents on DC side on valve side and on DC pole side.
  • Limits the short-circuit currents in DC line poles.
Disadvantages and limitations of smoothing reactors.
• Reactor has additional losses.
• The resonance frequency is reduced and current stabilization control becomes difficult.
• High stored energy causes high short-circuit currents on DC side between pole bus and earth.
• High inductance of smoothing reactor on DC side results in slowing down of response of current control of HVDC transmission systems.
Basic Principle of Inductance, Smoothing Effect

- Smoothing reactor functions are a pure inductance.
- From the basic principles of electromagnetic field theory a coil with a magnetic core has inductance $L$ given by flux linkage per unit current:
  \[ L = \frac{d(\phi N)}{dt} \]

- The behaviour of smoothing reactor is that of a high inductance coil.
- This behaviour is characterised as:
  - Energy is stored in magnetic circuit of inductance ($L$) whenever current ($I_d$) is present
    \[ W_m = \frac{1}{2} LI_d^2 \]

where $W_m$ = stored energy is inductance of reactor, Joule
$L$ = Inductance of reactor, Henry
$I_d$ = Current in reactor, Amp.
• Current $I_d$ in inductance of the reactor cannot change instantaneously.
• The current change takes finite time of the order of a few micro-seconds or milliseconds.
• Thereby steepness of current surges is reduced.
• Smoothing reactor gives damping effect.
• Under steady state DC, frequency ($f$) is zero, hence inductive reactance $X_L = (2\pi fL)$ at steady DC current is zero.
• Under changing current condition the emf is induced in the reactor coil given by
  \[ e = L \frac{di}{dt} \text{ volts} \]
  
  • This emf opposes the rate of change of current ($di/dt$).
Reactive Power Requirements of HVDC Convertor

- The HVDC converts AC Power to DC power.
- On AC side, U and I are not in phase. Hence I has quadrature component.
- The convertor requires reactive Power Compensation for satisfactory operation.
- AC system supplies active Power $P_0$ as well as some reactive power $Q_0$ to the convertor. However, this is not enough.
- Hence additional compensation is provided on AC side of convertor by means of AC Filter Capacitors, shunt capacitors, synchronous condensers, or Static VAr Sources (SVS).
Reactive Power Compensation Consumption of convertors vary mainly with the following:

- Active power $P_d$ ($Q$ increases with $P$)
- Delay angle $\alpha$ of rectifier (and extinction angle $\gamma$ of inverter). ($Q$ increases with $\alpha$ and $\gamma$)

Also the other conditions to be considered include

- AC busbar voltage, DC Pole Voltage.
- Reduction in DC voltage by increasing $\alpha$ or $\gamma$ results in increased $Q$.
- Conditions on AC network side with reference to connected generator transmission lines etc. which affect reactive power supplied by AC network.
- Commutating reactance of convertors
- Mode of operation of HVDC system viz, monopolar, bipolar
- Convertor characteristic ($P_d/Q$)
As a standard convention, we say, in AC Circuits
• Inductive loads take (absorb) reactive power $Q$ is positive.
• Capacitive loads give (supply) reactive power $Q$ is negative.
• Synchronous condensers or static VAr Sources (SVS) supply or absorb reactive power depending upon control-setting.
• In AC circuit; the reactive loads include transformers, reactors, AC machines, transmission lines (series inductive reactance) etc. They absorb reactive power (kVAr).
• Synchronous Generators have limited capability to supply reactive power requirements and therefore the reactive power requirement is supplied (compensated) by means of specially installed capacitor banks.
• The basic means of reactive power compensation used in AC substations and on AC side of AC substations are
  1. AC shunt capacitors or/and,
  2. AC Filter capacitors (for HVDC only)
  3. Synchronous condenser (synchronous machine with over-excitation)
  4. Static VAr sources (SVS). Thyristor controlled or switched capacitors/reactors).
• Synchronous condensers and SVS give variable, stepless control of reactive power required for dynamic compensation.
• Synchronous condensers also provide additional moment of inertia and short-circuit level to the AC Bus.
Reactive Power Requirements of HVDC Convertor

- The HVDC converts AC Power to DC power. On AC side, U and I are not in phase. Hence I has quadrature component.
- Hence convertor required reactive Power Compensation for satisfactory operation. AC system supplies active Power P as well as some reactive power Q to the convertor.
- However, this is not enough. Hence additional compensation is provided on AC side of convertor control reactive power automatically.
- The compensation on AC side is provided by one or more of the following means.
1. AC filter capacitors
2. AC shunt capacitors
3. Synchronous condensers
4. Static VAr sources (SVS).
• Shunt compensation is also required for AC transmission lines for voltage control.
• Reactive Power Demand of convertors varies between 20 to 60% of active power flow.
• Generally AC filter capacitors are arranged in suitable switchable banks such that the requirements of AC harmonic filters and reactive power compensation on AC side
• In case higher compensation is required additional shunt capacitors are installed.
• Synchronous condensers are used in special cases where the AC busbars needs compensation of reactive power as well as additional short-circuit level for satisfactory convertor operation and rotating inertia for improvement in dynamic stability.
Reactive Power Requirements In Steady State

The equations for the reactive power as a function of the active power are conveniently expressed in terms of per unit quantities. The following per unit system is used for convenience.

Base converter voltage \((V_{db}) = (3\sqrt{2/\pi}) V_n\) where \(V_n\) is the rated (line to line) voltage at the valve side winding.

Base DC current \((I_{db}) = \) rated DC current \((I_{dn})\)

Base DC power \((P_{db}) = n_b V_{db} I_{db}\)

Where \(n_b\) is the number of bridges connected in series.

Base AC voltage (on the valve side) \((V_b) = V_n\)

Base AC power = Base DC power = \((\sqrt{18/\pi}) V_n I_{db} n_b\)
The average DC voltage across a converter bridge is given by

\[ \bar{V}_d = \dot{V} \cos \alpha - \bar{R}_c \dot{I}_d \]

Where

\[ \bar{V}_d = V_a / V_{db}, \dot{I}_d = I_d / I_{db}, \bar{V} = V / V_b \]
\[ \bar{R}_c = X_c / 2 \]
\[ X_c = \text{p.u. leakage reactance of the transformer on its own base.} \]

The power factor is given by

\[ \cos \phi \approx (\bar{V}_d / V_{dc}) = (\bar{V}_d / \bar{V}) = \cos \alpha - (\bar{R}_c \dot{I}_d / \bar{V}) \]

The power and reactive power in per unit are given by the following equations

\[ P_d = \bar{V} \dot{I}_d \cos \phi \]
\[ Q_d = \bar{V} \dot{I}_d \sin \phi \]
For typical values of the variation of $Q_d$ versus $P_d$.

\[
\alpha = 15^\circ, \quad X_c = 0.2, \quad \bar{V} = 1.0
\]

Fig. 7.1 Variation of $Q_d$ with $P_d$. 

(\(\alpha\) \(\gamma\) = 15°).
• Fig. 7.1 shows that $Q_d$ increases by about 60% at the rated power.
• This shows the importance of maintaining low firing angles in steady state. However, too low values of $\alpha$ can result increased frequency of mode shifts (transfer of current control from rectifier to inverter) and too low values of $\gamma$ can result in increased incidence of the commutation failure.
• The reactive power is also affected by the magnitude of the AC voltage.
• The reduction in $V$ leads to increase in $Q_d$
• However, on-load tap changer can control $V$ within limits.
• A 10% reduction of voltage from 1.0 p.u. To 0.9 p.u. requires about 15% increased current at rated power, which results in over 30% increase in the losses.
Alternate Control Strategies

• The region of operation of a converter bridge is bounded by the limits on the DC current and the firing angle.
• Neglecting the minimum current limit, the operating region of a bridge in $P_d$-$Q_d$ plane is shown.

![Diagram showing the region of operation of a converter bridge.](image)

• This region is bounded by
  (i) minimum $\alpha$ characteristic
  (ii) minimum $\gamma$ characteristic
  (iii) constant rated DC current.
• The operation at constant DC voltage implies constant power factor characteristic at the converter bus, (if the valve side AC voltage is kept constant through the action of the tap-changer).

• At the rectifier, the characteristic is that of a load with lagging power factor, while at the inverter, this can be viewed as a generator with leading power factor operation.

• If there is no voltage support provided at the converter bus, the stability limit is considerably reduced.
From the phasor diagram

The power expression is given by

\[ P = VEB \sin \delta \]

\[ P = \frac{E^2 B \cos (\delta + \phi) \sin \delta}{\cos \phi} \]
• It can be shown that the maximum power transfer is obtained when

\[ \delta = 45^\circ - \phi/2 \]

• The maximum power (for \( \Phi = 30^\circ \)) is given by

\[ P_{\text{max}} = 0.2887 \, E^2B \]

i) \( \phi = 0 \), \( P_{\text{max}} = 0.5 \, E^2B \)

ii) \( \phi = -30^\circ \), \( P_{\text{max}} = 0.866 \, E^2B \)

iii) \( V = E \), \( P_{\text{max}} = E^2B \)

• It is to be noted that the provision of a shunt capacitor (of susceptance, \( B_c \)) at the converter bus results in the modification of the maximum power
For $B = 3.0$ p.u. $B = 0.5$ p.u., this results in an increase of 20% in the maximum power.

The above analysis shows that there is a need to modify the reactive power characteristics of the converter station by either:

- choice of the reactive power sources or
- adjusting the converter control characteristics.

When the DC link involves long distance transmission, the minimization of power losses in the line dictates operation at constant DC voltage and flexibility of converter operation is not feasible.
• The alternate converter control strategies can be adopted. These are:
i) constant reactive power characteristic \((ab, a'b)\)
ii) constant leading power factor characteristic \((ac, a'c)\)
It is to be noted that by providing a constant reactive power source of $Q_n$ at the converter bus, the characteristic ab or a’b results in unity power factor operation of the converter. Similarly, by providing a reactive source of 2 $Q_n$, the power factor angle is changed from $\Phi$ to $-\Phi$. The expressions for the DC current and voltage for the two characteristics are given by

\[
\begin{align*}
 i_d &= \left( \frac{p_{dn}}{\nu} \right) \left[ \tan^2 \phi_n + \left( \frac{P_d}{P_{dn}} \right)^2 \right]^{\frac{1}{2}} \\
 i_d &= \left( 2 \frac{q_{dn}}{\nu} \right) \left[ 1 - \left( \frac{P_d}{P_{dn}} \right) + \left( \frac{P_d}{2P_{dn} \sin \phi_n} \right)^2 \right]^{\frac{1}{2}}
\end{align*}
\]

\[
v_d = \frac{P_d}{i_d}
\]
SCHEDULE OF INSTRUCTIONS
UNIT PLAN

Academic Year : 2012-2013
Semester : II
UNIT NO.: V

Name of the Program: B.Tech IV
Year: ………………..
Section: A / B

Course/Subject: HVDC TRANSMISSION
Course Code: 58008

Name of the Faculty: J.SRIDEVI
Dept.: EEE

Designation: ASSOCIATE PROFESSOR.

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References:
1. EHV-AC, HVDC Transmission and Distribution Engineering - S.Rao
2. HVDC Power Transmission Systems - K.R. Padiyar

Signature of HOD
Signature of faculty

Date: Date:

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3. MENTION THE CORRESPONDING COURSE OBJECTIVE AND OUT COME NUMBERS AGAINST EACH TOPIC.
Power Flow Analysis in AC/DC Systems

• Power flow analysis is an essential component of system studies carried out for planning, design and operation of power systems.

• The GaussSeidel method has given way to the use of Newton’s method which results in fast convergence.

• The computations are further simplified using fast decoupled load flow method in which the corrections to the bus voltage estimates are found from solving the following equations

\[
\Delta P/V = [B']\Delta \theta \\
\Delta Q/V = [B'']\Delta V
\]
MODELLING OF DC LINKS

• DC link

• The DC network consisting of DC links, smoothing reactors and converters can be viewed as a resistive network excited by current or voltage sources in steady state.
• Depending on the series or shunt connections of converters, it may be appropriate to consider loop resistance or nodal conductance matrix.
• The converters are not ideal sources, but are described by the converter and controller equations.
• The converters can be divided into either tree branches or links. The equations describing the DC network are:
where $[g]$ is the matrix of element conductances (diagonal), $v_g$ and $i_g$ are the voltage and current vectors corresponding to conductances. $i_{dL}$ and $i_{dT}$ are currents through the converters that are included in the links and the tree respectively. $V_{dL}$ and $V_{dT}$ are the corresponding converter voltages. $B'_{Lg}$ and $B'_{LT}$ are the components of the fundamental cutset matrix.
**DC Converter**

It is assumed that $N$ converters can be put into $m$ groups such that for all the converters in a group, the AC converter bus is identical. Normally, all the converters in a station can be grouped together. The number of converters in $i$th group is $n_i$. It is obvious that

$$\sum_{i=1}^{m} n_i = N$$
The voltage equation for the converter “j” in group “σ” is

\[ V_{dj} = (3 \sqrt{2/\pi}) \left( \frac{N_{sj}}{N_{pj}} \right) \left( \frac{E_{\sigma}}{T_j} \right) V_{b\sigma} \cos \alpha_j - (3/\pi) X_{cj} I_{dj} \]

\( X_{cj} \) is the leakage reactances of the transformer referred to the secondary in ohms,
\( N_{pj} \) and \( N_{sj} \) are the nominal turns of the primary and the secondary windings,
\( T_j \) is the off-nominal turns ratio of the transformer,
\( V_{bo} \) is the base voltage at the converter bus \( \sigma \) and \( E_{\sigma} \) is the per unit AC voltage at the converter bus.

\[ V_{dj} - \left[ \frac{(K_j E_{\sigma} \cos \alpha_j)}{T_j} \right] - R_{cj} I_{dj} = 0 \]

where

\[ K_j = (3\sqrt{2/\pi}) \left( \frac{N_{sj}}{N_{pj}} \right) V_{b\sigma} \quad R_{cj} = (3/\pi) X_{cj} \]
The power and reactive power injections into the AC bus ‘σ’ are

\[
P_\sigma = - \sum_{j=1}^{n_a} V_{dj} I_{dj}
\]

\[
Q_\sigma = - \sum_{j=1}^{n_a} V_{dj} I_{dj} \tan \phi_j
\]

Where

\[
\cos \phi_j = \frac{V_{dj} T_j}{K_j E_\sigma}, \ 0 < \phi_j < \pi
\]

It is to be noted that for an inverter station, both \(V_{dj}\) and \(\tan \phi_j\) are negative.

This results in \(P_\sigma\) being positive while \(Q_\sigma\) is negative.

For each converter, the extinction angle is obtained from

\[
I_d = (K_j E_\sigma / T_j R_{cj}) \left[ \cos \alpha_j + \cos \gamma_j \right]
\]

Where \(\gamma_j\) is the extinction angle of converter \(j\).
Controller Equations

• At each converter, the angle ($\alpha$ or $\gamma$) and the transformer tap ($T$) can be controlled directly within limits to achieve
  • current control,
  • DC voltage control,
  • power control or
  • control of reactive power.
• Generally, the angle control is continuous while the tap changer control (which is mechanically operated) is discrete.
• Theoretically, if the taps are continuous and unlimited, it is possible to control (in steady state) the current! power or voltage/reactive power with the tap changer control alone.
• In a two terminal DC system, the tap changer at the inverter is normally used to control the DC voltage while the tap changer at the rectifier controls the delay angle.
• The discrete nature of the controller results in the delay angle or DC voltage lying within narrow bounds rather than at fixed values.
• At a station, the converters may be series (or parallel) connected and are fed from the same AC bus.
• In such cases, it is appropriate to specify the total power at the station.
• Although, usually each converter in a station carries the same power, it is possible to have a situation where the power is shared unequally by different converters.
• In such cases, the converter control will be used to establish a certain proportion among voltage or current in series or parallel connected converters of a station.

• This will result in the control equations of the following type:

\[
F_{dj} = C_j F_{d\sigma} \\
\sum_{j=1}^{n_a} C_j = 1
\]

• If the N converter DC system is connected to the AC system at m stations (buses), it is obvious that the power can be specified only at (m—1) stations at the most.
• It is possible to have one of the control variables in a converter (angle or tap) kept fixed, which will then imply that only one variable can be specified.
• Sometimes, instead of specifying the angle at current (or power) controlled converters, it is usual to specify a voltage margin (of usually 3%).
• In this case, the following equation applies:

\[
V_{dj} = 0.97 \left( K_j E \sigma \cos \theta_{j, \min} / I_j \right) - R_{cj} I_{dj}
\]
Solution of DC load flow

• A simple approach to the load flow analysis of a parallel connected (monopolar) multiterminal DC system and which is also applicable for a two terminal system is described below.

• Choosing the last converter (by relabelling, if necessary) as the reference converter with voltage control, the voltage at the remaining converters is given by

\[
V'_d = [R] I'_d + E V_{dN} S_N \\
V'_d = [S] V_d, I'_d = [S] I_d
\]

• If power is specified at converter \( j \), the initial estimate of current at that converter is obtained from

\[
I_{dj(0)} = \frac{P_d}{V_{dN}}
\]
• It is assumed that \( P_{dj} \) is positive for the rectifier and negative for the inverter.
• The use of above equations iteratively, solves for \( V_d \) and \( I_d \).
• If the tap limits are violated, then the voltage \( V_{dN} \) has to be rescheduled and the DC load flow solution repeated.
• The violation of the control angle may require mode shift with the converter having the angle limit violation taking over voltage control. This is indicated when at a converter \( j \),

\[
\frac{K_j \cdot E_j \cdot \cos \theta_{j (\text{min})}}{T_{j (\text{min})}} - R_{cj} \cdot I_{dj} - V_{dj}^{\text{spec}} = d_j < 0
\]

• The converter with the largest absolute value of \( d_j \) is set at voltage control with minimum angle control.
• The concept of optimal power flow can also be extended to the DC load flow where it can be considered that the specifications for powers (and reactive powers if any) at a converter station are set by consideration of minimizing an objective function.
• Assuming that the specifications are set by optimization at a higher level, the solutions of power flow equations can be viewed as the solution of the following optimization problem.

$$\min J = \sum_{\sigma=1}^{m} \left[ W_{\sigma 1} \left( P_{\sigma} - P_{\sigma}^{\text{spec}} \right)^2 + W_{\sigma 2} \left( Q_{\sigma} - Q_{\sigma}^{\text{spec}} \right)^2 \right]$$

Subject to the constraints

$$u_{\text{min}} \leq u \leq u_{\text{max}}$$
$$x_{\text{min}} \leq x \leq x_{\text{max}}$$
$$g(x, u) = 0$$
• Theoretically, the optimization problem can be complex as some of the control variables (transformer taps) are discrete.
• However, the solution of the optimization problem can be simplified using iterative linear or quadratic programming technique.

PER UNIT SYSTEM FOR DC QUANTITIES
In general, it is possible to choose independently the base voltage and current in a converter as follows:
Base DC voltage \((V_{db}) = \text{nominal (rated) value of DC voltage per converter}\)
Base DC current \((I_{db}) = \text{nominal (rated) value of current}\).

If the converters are not identical, then, it is necessary to choose a common base which may refer to the largest converter.
The base resistance for a converter is then defined as

\[ R_{\text{base}} = \frac{V_{db}}{I_{db}} \]

The voltage equation for a converter is then obtained as

\[ V_d = K_v \left( \frac{E}{T} \right) \cos \alpha - R_c I_d \]

where \( V_d \), \( I_d \) and \( R_c \) are expressed in per unit. It is to be noted that the AC voltage is always expressed in p.u. \( K_v \) is defined as

\[ K_v = (3\sqrt{2/\pi}) \left( \frac{N_s}{N_p} \right) \left( \frac{V_p}{V_{db}} \right) \]

If all the converters are identical, then it is convenient to choose the base DC voltage such that

\[ K_v = (3\sqrt{2/\pi}) \left( \frac{N_s}{N_p} \right) \left( \frac{V_p}{V_{db}} \right) = 1 \]
\[ I_{db} = \frac{S_{AC(\text{base})}}{V_{db}} \]

\[ R_b = Z_b \left( \frac{18}{\pi^2} \right) \left( \frac{N_s^2}{N_p^2} \right) \]

\[ R_c = \frac{X_c}{2} \]
### SCHEDULE OF INSTRUCTIONS

#### UNIT PLAN

**Academic Year**: 2012-2013  
**Semester**: II  
**Name of the Program**: B.Tech IV  
**Year**: ………………..  
**Section**: A / B  
**Course/Subject**: HVDC TRANSMISSION  
**Course Code**: 58008  
**Name of the Faculty**: J.SRIDEVI  
**Dept.**: EEE  
**Designation**: ASSOCIATE PROFESSOR.

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**References**:

1. EHV-AC, HVDC Transmission and Distribution Engineering - S.Rao  
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## SCHEDULE OF INSTRUCTIONS

### UNIT PLAN

**Academic Year**: 2012-2013  
**Semester**: II  
**UNIT NO.**: VII  
**Name of the Program**: B.Tech IV  
**Course/Subject**: HVDC TRANSMISSION  
**Course Code**: 58008  
**Name of the Faculty**: J.SRIDEVI  
**Dept.**: EEE  
**Designation**: ASSOCIATE PROFESSOR.

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**References:**

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**Signature of HOD**  
**Signature of faculty**

**Date:**  
**Date:**

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# SCHEDULE OF INSTRUCTIONS
## UNIT PLAN

**Academic Year:** 2012-2013  
**Semester:** II  
**UNIT NO.:** VIII  
**Name of the Program:** B.Tech IV  
**Course/Subject:** HVDC TRANSMISSION  
**Course Code:** 58008  
**Name of the Faculty:** J.SRIDEVI  
**Dept.:** EEE  
**Designation:** ASSOCIATE PROFESSOR.

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LEsson PLAN

Academic Year : 2012-2013

Semester : II

Name of the Program: B.Tech IV Year: ………………. Section: A / B

Course/Subject: HVDC Transmission Course Code: 58008

Name of the Faculty: J.SRIDEVI Dept.: EEE

Designation: ASSOCIATE PROFESSOR.

Lesson No: 1 Duration of Lesson: 1hr 30 Minutes

Lesson Title: Types of DC links

INSTRUCTIONAL/LESSON OBJECTIVES:

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

1. To deal with the importance of HVDC Transmission and HVDC Converters

2. To deal with power conversion between Ac to DC and DC to AC.

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about DC Links.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: Explain briefly about different types of HVDC links. (Obj:1,2/Out:1,2)

Signature of faculty
LESSON PLAN

Academic Year : 2012-2013
Semester : II
Name of the Program: B.Tech IV Year: .................. Section: A / B
Course/Subject: HVDC Transmission Course Code: 58008
Name of the Faculty: J.SRIDEVI Dept.: EEE
Designation: ASSOCIATE PROFESSOR.

Lesson No: 2 Duration of Lesson: 1hr 30 Minutes
Lesson Title: Apparatus required for HVDC systems

INSTRUCTIONAL/LESSON OBJECTIVES:

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

1. To deal with the importance of HVDC Transmission and HVDC Converters
2. To deal with power conversion between Ac to DC and DC to AC.

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker
TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about the apparatus required for HVDC systems.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: Draw a schematic diagram of typical HVDC converter station and describe the various components of the station. (Obj:1,2/Out:1,2)

Signature of faculty
LESSON PLAN

Academic Year : 2012-2013
Semester : II
Name of the Program: B.Tech IV Year: .................. Section: A / B
Course/Subject: HVDC Transmission Course Code: 58008
Name of the Faculty: J.SRIDEVI Dept.: EEE
Designation: ASSOCIATE PROFESSOR.
Lesson No: 3 Duration of Lesson: 1hr 30 Minutes
Lesson Title: Comparison of AC and DC Transmission

INSTRUCTIONAL/LESSON OBJECTIVES:

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

1. To deal with the importance of HVDC Transmission and HVDC Converters
2. To deal with power conversion between Ac to DC and DC to AC.

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker
TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about comparison of AC and DC Transmission.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: What is the need for interconnection of systems? Explain the merits of connecting HVAC systems by HVDC tie-lines (Obj:1,2/Out:1,2)
LESSON PLAN

Academic Year : 2012-2013

Semester : II

Name of the Program: B.Tech IV Year: ………………. Section: A / B

Course/Subject: HVDC Transmission Course Code: 58008

Name of the Faculty: J.SRIDEVI Dept.: EEE

Designation: ASSOCIATE PROFESSOR.

Lesson No: 4 Duration of Lesson: 1hr 30 Minutes

Lesson Title: Applications of DC Transmission System

INSTRUCTIONAL/LESSON OBJECTIVES:

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

1. To deal with the importance of HVDC Transmission and HVDC Converters

2. To deal with power conversion between Ac to DC and DC to AC.

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about the applications of HVDC systems.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: Explain the economic advantages of HVDC system. (Obj:1,2/Out:1,2)

Signature of faculty
LESION PLAN

Academic Year : 2012-2013

Semester : II

Name of the Program: B.Tech IV Year: .................... Section: A / B

Course/Subject: HVDC Transmission Course Code: 58008

Name of the Faculty: J.SRIDEVI Dept.: EEE

Designation: ASSOCIATE PROFESSOR.

Lesson No: 5 Duration of Lesson: 1hr 30 Minutes

Lesson Title: Choice of Converter Configuration

INSTRUCTIONAL/LESSON OBJECTIVES:

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

1. To deal with the importance of HVDC Transmission and HVDC Converters

2. To deal with power conversion between Ac to DC and DC to AC.

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Choice of Converter Configuration.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: What are the factors which help in deciding the number of pulse converters used in a systems. Classify them as economic, technical and describe. (Obj: 1, 2/Out: 1, 2)
LESSON PLAN

Academic Year : 2012-2013
Semester : II

Name of the Program: B.Tech IV Year: ……………….. Section: A / B
Course/Subject: HVDC Transmission Course Code: 58008

Name of the Faculty: J.SRIDEVI Dept.: EEE
Designation: ASSOCIATE PROFESSOR.

Lesson No: 6 Duration of Lesson: 1hr 30 Minutes

Lesson Title: Analysis of 6 pulse Graetz Circuit

INSTRUCTIONAL/LESSON OBJECTIVES:
On completion of this lesson the student shall be able to:

1. To deal with the importance of HVDC Transmission and HVDC Converters
2. To deal with power conversion between Ac to DC and DC to AC.

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker
TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Analysis of 6 pulse Graetz Circuit.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: Obtain expression for the output voltage and direct current of a converter working as a rectifier with delay angle `α' and commutation angle `γ'. (Obj:1,2/Out:1,2)

Signature of faculty
LESSON PLAN

Academic Year : 2012-2013

Semester : II

Name of the Program: B.Tech IV Year: .......................... Section: A / B

Course/Subject: HVDC Transmission Course Code: 58008

Name of the Faculty: J.SRIDEVI Dept.: EEE

Designation: ASSOCIATE PROFESSOR.

Lesson No: 7 Duration of Lesson: 1hr 30 Minutes

Lesson Title: Analysis of 6 pulse Graetz Circuit

INSTRUCTIONAL/LESSON OBJECTIVES:

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

1. To deal with the importance of HVDC Transmission and HVDC Converters

2. To deal with power conversion between Ac to DC and DC to AC.

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Analysis of 6 pulse Graetz Circuit.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: With the help of neat sketches, analyze a six pulse rectifier bridge circuit with an overlap angle greater than 60°. Deduce the relevant equations and draw the necessary graphs. (Obj:1,2/Out:1,2)

Signature of faculty
LESSON PLAN

Academic Year : 2012-2013

Semester : II

Name of the Program: B.Tech IV  Year: ……………… Section: A / B

Course/Subject: HVDC Transmission  Course Code: 58008

Name of the Faculty: J.SRIDEVI  Dept.: EEE

Designation: ASSOCIATE PROFESSOR.

Lesson No: 8  Duration of Lesson: 1hr 30 Minutes

Lesson Title: Analysis of 6 pulse Graetz Circuit

INSTRUCTIONAL/LESSON OBJECTIVES:

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

1. To deal with the importance of HVDC Transmission and HVDC Converters

2. To deal with power conversion between Ac to DC and DC to AC.

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Analysis of 6 pulse Graetz Circuit.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: Sketch a timing diagram for a 3phase Graetz's circuit considering with and without overlap angle less than 60°. (Obj:1,2/Out:1,2)

Signature of faculty
LESSON PLAN

Academic Year : 2012-2013
Semester : II
Name of the Program: B.Tech IV Year: .................. Section: A / B
Course/Subject: HVDC Transmission Course Code: 58008
Name of the Faculty: J.SRIDEVI Dept.: EEE
Designation: ASSOCIATE PROFESSOR.
Lesson No: 9 Duration of Lesson: 1hr 30 Minutes
Lesson Title: Analysis of 12 pulse Graetz Circuit

INSTRUCTIONAL/LESSON OBJECTIVES:

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

1. To deal with the importance of HVDC Transmission and HVDC Converters
2. To deal with power conversion between Ac to DC and DC to AC.

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker
TEACHING POINTS :

• 5 min.: Taking attendance
• 10 min.: Re collecting the contents of previous class.
• 70 min.: Explain in detail about Analysis of 12 pulse Graetz Circuit.
• 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: What is the reason for using star-star and star-delta transformer configurations for 12 pulse converter. Derive an equation for primary current using fourier analysis. (Obj:1,2/Out:1,2)

Signature of faculty
LESSON PLAN

Academic Year : 2012-2013
Semester : II

Name of the Program: B.Tech IV Year: ................. Section: A / B

Course/Subject: HVDC Transmission Course Code: 58008

Name of the Faculty: J.SRIDEVI Dept.: EEE

Designation: ASSOCIATE PROFESSOR.

Lesson No: 10 Duration of Lesson: 1hr 30 Minutes

Lesson Title: Principle of DC link Control

INSTRUCTIONAL/LESSON OBJECTIVES:

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

1. To deal with the importance of HVDC Transmission and HVDC Converters
2. To deal with power conversion between Ac to DC and DC to AC.
3. To deal with firing angle of HVDC System

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Principle of DC link Control.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: Derive the mathematical model of d.c. link controllers of a d.c. link.
(Obj:1,2,3/Out:2,3,4)

Signature of faculty
LESSON PLAN

Academic Year                : 2012-2013
Semester                              : II
Name of the Program: B.Tech IV     Year: .......................... Section: A / B
Course/Subject: HVDC Transmission        Course Code: 58008
Name of the Faculty: J.SRIDEVI        Dept.: EEE
Designation: ASSOCIATE PROFESSOR.

Lesson No: 11                   Duration of Lesson: 1hr 30 Minutes
Lesson Title: Converter control characteristics

INSTRUCTIONAL/LESSON OBJECTIVES:

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

1. To deal with the importance of HVDC Transmission and HVDC Converters
2. To deal with power conversion between Ac to DC and DC to AC.
3. To deal with firing angle of HVDC System

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker
TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Converter control characteristics.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: What are the basic characteristics of converter control? With the aid of V-I characteristics, explain how power ow control is achieved? (Obj:1,2,3/Out:2,3,4)

Signature of faculty
LESSON PLAN

Academic Year : 2012-2013
Semester : II

Name of the Program: B.Tech IV
Year: ………………..
Section: A / B

Course/Subject: HVDC Transmission
Course Code: 58008

Name of the Faculty: J.SRIDEVI
Dept.: EEE
Designation: ASSOCIATE PROFESSOR.

Lesson No: 12
Duration of Lesson: 1hr 30 Minutes

Lesson Title: Converter control characteristics

INSTRUCTIONAL/LESSON OBJECTIVES:

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

1. To deal with the importance of HVDC Transmission and HVDC Converters
2. To deal with power conversion between Ac to DC and DC to AC.
3. To deal with firing angle of HVDC System

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Principle of Converter control characteristics.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: What are the desired features of control? Explain in detail. (Obj:1,2,3/Out:2,3,4)

Signature of faculty
LESSON PLAN

Academic Year : 2012-2013
Semester : II
Name of the Program: B.Tech IV Year: .................. Section: A / B
Course/Subject: HVDC Transmission Course Code: 58008
Name of the Faculty: J.SRIDEVI Dept.: EEE
Designation: ASSOCIATE PROFESSOR.
Lesson No: 13 Duration of Lesson: 1hr 30 Minutes
Lesson Title: Firing angle control

INSTRUCTIONAL/LESSON OBJECTIVES:

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

1. To deal with the importance of HVDC Transmission and HVDC Converters
2. To deal with power conversion between Ac to DC and DC to AC.
3. To deal with firing angle of HVDC System

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker
TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Firing angle control.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: What is equivalent pulse control? What are the advantages of equivalent pulse contour over individual phase control? (Obj:1,2,3/Out:2,3,4)

Signature of faculty
LESSON PLAN

Academic Year : 2012-2013

Semester : II

Name of the Program: B.Tech IV Year: .................. Section: A / B

Course/Subject: HVDC Transmission Course Code: 58008

Name of the Faculty: J.SRIDEVI Dept.: EEE

Designation: ASSOCIATE PROFESSOR.

Lesson No: 14 Duration of Lesson: 1hr 30 Minutes

Lesson Title: Current and extinction angle control

INSTRUCTIONAL/LESSON OBJECTIVES:

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

1. To deal with the importance of HVDC Transmission and HVDC Converters

2. To deal with power conversion between Ac to DC and DC to AC.

3. To deal with firing angle of HVDC System

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Current and extinction angle control.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: What is the necessity of having constant ignition angle, constant current and constant extinction angle controllers at each converter station? (Obj:1,2,3/Out:2,3,4)

Signature of faculty
LESSON PLAN

Academic Year : 2012-2013

Semester : II

Name of the Program: B.Tech IV Year: ……………….. Section: A / B

Course/Subject: HVDC Transmission Course Code: 58008

Name of the Faculty: J.SRIDEVI Dept.: EEE

Designation: ASSOCIATE PROFESSOR.

Lesson No: 15 Duration of Lesson: 1hr 30 Minutes

Lesson Title: Effect of source inductance on the system, Starting and stopping of DC link

INSTRUCTIONAL/LESSON OBJECTIVES:

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

1. To deal with the importance of HVDC Transmission and HVDC Converters
2. To deal with power conversion between Ac to DC and DC to AC.
3. To deal with firing angle of HVDC System

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

• 5 min.: Taking attendance
• 10 min.: Re collecting the contents of previous class.
• 70 min.: Explain in detail about Effect of source inductance on the system, Starting and stopping of DC link.
• 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: Explain the working of working basic power controller using VDCOL (Voltage Dependent Current Order Limiter). (Obj:1,2,3/Out:2,3,4)

Signature of faculty
LESSON PLAN

Academic Year : 2012-2013

Semester : II

Name of the Program: B.Tech IV Year: ………………. Section: A / B

Course/Subject: HVDC Transmission Course Code: 58008

Name of the Faculty: J.SRIDEVI Dept.: EEE

Designation: ASSOCIATE PROFESSOR.

Lesson No: 16 Duration of Lesson: 1hr 30 Minutes

Lesson Title: Reactive power requirements in steady state, Conventional Control Strategies

INSTRUCTIONAL/LESSON OBJECTIVES:

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

1. To deal with firing angle of HVDC System.

2. To deal with Reactive power control of HVDC system

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Reactive power requirements in steady state, Conventional Control Strategies.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: What is meant by Reactive power control and also give different sources of reactive power. (Obj:3,4/Out:4,5)

Signature of faculty
LESSON PLAN

Academic Year : 2012-2013
Semester : II
Name of the Program: B.Tech IV Year: .................. Section: A / B
Course/Subject: HVDC Transmission Course Code: 58008
Name of the Faculty: J.SRIDEVI Dept.: EEE
Designation: ASSOCIATE PROFESSOR.
Lesson No: 17 Duration of Lesson: 1hr 30 Minutes
Lesson Title: Alternate Control Strategies

INSTRUCTIONAL/LESSON OBJECTIVES:

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

1. To deal with firing angle of HVDC System.
2. To deal with Reactive power control of HVDC system

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker
TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Alternate Control Strategies
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: Write a note on Alternate control strategies. (Obj:3,4/Out:4,5)

Signature of faculty
LESSON PLAN

Academic Year : 2012-2013
Semester : II
Name of the Program: B.Tech IV Year: ……………….. Section: A / B
Course/Subject: HVDC Transmission Course Code: 58008
Name of the Faculty: J.SRIDEVI Dept.: EEE
Designation: ASSOCIATE PROFESSOR.
Lesson No: 18 Duration of Lesson: 1hr 30 Minutes
Lesson Title: Sources of Reactive power

INSTRUCTIONAL/LESSON OBJECTIVES:

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

1. To deal with firing angle of HVDC System.
2. To deal with Reactive power control of HVDC system

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker
TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Sources of Reactive power
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: Give different sources of reactive power. (Obj:3,4/Out:4,5)

Signature of faculty
LESSON PLAN

Academic Year : 2012-2013
Semester : II
Name of the Program: B.Tech IV Year: ………………. Section: A / B
Course/Subject: HVDC Transmission Course Code: 58008
Name of the Faculty: J.SRIDEVI Dept.: EEE
Designation: ASSOCIATE PROFESSOR.
Lesson No: 19 Duration of Lesson: 1hr 30 Minutes
Lesson Title: Modelling of DC link

INSTRUCTIONAL/LESSON OBJECTIVES:

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

1. To deal with firing angle of HVDC System.
2. To deal with Reactive power control of HVDC system

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker
TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Modelling of DC link.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: Explain by means of a schematic diagram and with theoretical expression, how power ow through HVDC link, is controlled? (Obj:3,4/Out:4,5)

Signature of faculty
LESSON PLAN

Academic Year : 2012-2013

Semester : II

Name of the Program: B.Tech IV Year: .................... Section: A / B

Course/Subject: HVDC Transmission Course Code: 58008

Name of the Faculty: J.SRIDEVI Dept.: EEE

Designation: ASSOCIATE PROFESSOR.

Lesson No: 20 Duration of Lesson: 1hr 30 Minutes

Lesson Title: P.U system for d.c quantities

INSTRUCTIONAL/LESSON OBJECTIVES:

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

1. To deal with firing angle of HVDC System.
2. To deal with Reactive power control of HVDC system

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

• 5 min.: Taking attendance
• 10 min.: Re collecting the contents of previous class.
• 70 min.: Explain in detail about P.U system for d.c quantities.
• 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: Write a short notes on:
(a) Modeling of H.V.D.C. links
(b) P.U. system for d.c. quantities. (Obj:3,4/Out:4,5)

Signature of faculty
LESSON PLAN

Academic Year : 2012-2013

Semester : II

Name of the Program: B.Tech IV Year: ……………… Section: A / B

Course/Subject: HVDC Transmission Course Code: 58008

Name of the Faculty: J.SRIDEVI Dept.: EEE

Designation: ASSOCIATE PROFESSOR.

Lesson No: 21 Duration of Lesson: 1hr 30 Minutes

Lesson Title: Solution of AC- DC load flow

INSTRUCTIONAL/LESSON OBJECTIVES:

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

1. To deal with firing angle of HVDC System.

2. To deal with Reactive power control of HVDC system

TEACHING AIDS : PPTs, White Board, LCD Projector, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Solution of AC- DC load flow.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: What do you understand by a load flow? Is the load flow chart different for a DC Load flow as compared to AC load flow? (Obj:3,4/Out:4,5)

Signature of faculty
LESSON PLAN

Academic Year : 2012-2013
Semester : II
Name of the Program: B.Tech IV Year: ……………… Section: A / B
Course/Subject: HVDC Transmission Course Code: 58008
Course Code:
Name of the Faculty: J.SRIDEVI Dept.: EEE
Designation: ASSOCIATE PROFESSOR.
Lesson No: 22 Duration of Lesson: 1hr 30 Minutes
Lesson Title: Protection against over current and overvoltage in converter station

INSTRUCTIONAL/LESSON OBJECTIVES:
On completion of this lesson the student shall be able to:

1. To deal with the protection of HVDC system

TEACHING AIDS : White Board, Marker
TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Protection against over current and overvoltage in converter station.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: What are the basic principles of over current protection. (Obj:6/Out:7)

Signature of faculty
LESSON PLAN

Academic Year : 2012-2013
Semester : II

Name of the Program: B.Tech IV Year: …………….. Section: A / B
Course/Subject: HVDC Transmission Course Code: 58008

Name of the Faculty: J.SRIDEVI Dept.: EEE
Designation: ASSOCIATE PROFESSOR.

Lesson No: 23 Duration of Lesson: 1hr 30 Minutes
Lesson Title: Surge arrestors, Smoothing Reactors

INSTRUCTIONAL/LESSON OBJECTIVES:

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

1. To deal with the protection of HVDC system

TEACHING AIDS : White Board, Marker
TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Surge arrestors, Smoothing Reactors.
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: Give the necessity of smoothing reactor in a HVDC system and list out main functions of it. (Obj:6/Out:7)

Signature of faculty
LESSON PLAN

Academic Year : 2012-2013
Semester : II
Name of the Program: B.Tech IV Year: ……………… Section: A / B
Course/Subject: HVDC Transmission Course Code: 58008
Name of the Faculty: J.SRIDEVI Dept.: EEE
Designation: ASSOCIATE PROFESSOR.
Lesson No: 24 Duration of Lesson: 1hr 30 Minutes
Lesson Title: DC Breakers, Corona effects on DC lines

INSTRUCTIONAL/LESSON OBJECTIVES:
On completion of this lesson the student shall be able to:

1. To deal with the protection of HVDC system

TEACHING AIDS : White Board, Marker
TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about DC Breakers, Corona effects on DC lines
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: How is the effect of corona neglected in a HVDC system? Compare this with corona effect of a HVDC system. (Obj:6/Out:7)

Signature of faculty
LESSON PLAN

Academic Year : 2012-2013

Semester : II

Name of the Program: B.Tech IV Year: ……………….. Section: A / B

Course/Subject: HVDC Transmission Course Code: 58008

Name of the Faculty: J.SRIDEVI Dept.: EEE

Designation: ASSOCIATE PROFESSOR.

Lesson No: 25 Duration of Lesson: 1hr 30 Minutes

Lesson Title: Generation of Harmonics, Characteristic harmonics

INSTRUCTIONAL/LESSON OBJECTIVES:

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

1. To deal with Power factor improvement of HVDC system

TEACHING AIDS : White Board, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Generation of Harmonics, Characteristic harmonics
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: Why are harmonics generated in HVDC converter and what are the problems associated with the harmonics. Suggest some remedial measures. (Obj:5/Out:6, 7)

Signature of faculty
LESSON PLAN

Academic Year : 2012-2013
Semester : II
Name of the Program: B.Tech IV Year: .................. Section: A / B
Course/Subject: HVDC Transmission Course Code: 58008
Name of the Faculty: J.SRIDEVI Dept.: EEE
Designation: ASSOCIATE PROFESSOR.
Lesson No: 26 Duration of Lesson: 1hr 30 Minutes
Lesson Title: Calculation of AC Harmonics, Non Characteristics harmonics

INSTRUCTIONAL/LESSON OBJECTIVES:

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

1. To deal with Power factor improvement of HVDC system

TEACHING AIDS : White Board, Marker
TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Calculation of AC Harmonics, Non Characteristics harmonics
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: How is Total Harmonic Distortion estimated in a circuit? Explain the relevance of THD to a HVDC system. (Obj:5/Out:6, 7)

Signature of faculty
LESSON PLAN

Academic Year : 2012-2013

Semester : II

Name of the Program: B.Tech IV Year: ................. Section: A / B

Course/Subject: HVDC Transmission Course Code: 58008

Name of the Faculty: J.SRIDEVI Dept.: EEE

Designation: ASSOCIATE PROFESSOR.

Lesson No: 27 Duration of Lesson: 1hr 30 Minutes

Lesson Title: Types of AC filters

INSTRUCTIONAL/LESSON OBJECTIVES:

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

1. To deal with Power factor improvement of HVDC system

TEACHING AIDS : White Board, Marker

TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Types of AC filters
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: What are the various types of filters that are employed in HVDC converter station? Discuss them in detail. (Obj:5/Out:6, 7)

Signature of faculty
LESSON PLAN

Academic Year : 2012-2013
Semester : II
Name of the Program: B.Tech IV Year: ……………….. Section: A / B
Course/Subject: HVDC Transmission Course Code: 58008
Name of the Faculty: J.SRIDEVI Dept.: EEE
Designation: ASSOCIATE PROFESSOR.
Lesson No: 28 Duration of Lesson: 1hr 30 Minutes
Lesson Title: Design of Single tuned filters, High pass filters

INSTRUCTIONAL/LESSON OBJECTIVES:

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

1. To deal with Power factor improvement of HVDC system

TEACHING AIDS : White Board, Marker
TEACHING POINTS :

- 5 min.: Taking attendance
- 10 min.: Re collecting the contents of previous class.
- 70 min.: Explain in detail about Design of Single tuned filters, High pass filters
- 5 min.: Doubts clarification and Review of the class.

Assignment / Questions: Compare the schematics of a low pass filter and a high pass filter. What are the key elements common features and the dissimilarities. (Obj:5/Out:6, 7)

Signature of faculty
ASSIGNMENT SHEET – 1

Academic Year : 2012-2013

Date: 29.12.12.

Semester : II

Name of the Program: B.Tech IV Year: 

Section: A / B

Course/Subject: HVDC TRANSMISSION

Name of the Faculty: J.SRIDEVI

Dept.: EEE

Designation : ASSOCIATE PROFESSOR

This Assignment corresponds to Unit No. I

Q1. Explain briefly about different types of HVDC links

Q2. What is the need for interconnection of systems? Explain the merits of connecting HVAC systems by HVDC tie -lines

Q3. Explain the economic advantages of HVDC system

Q4. Draw a schematic diagram of typical HVDC converter station and describe the various components of the station.

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: 1,2

Outcome Nos.: 1,2

Signature of HOD

Signature of faculty

Date:

Date:
ASSIGNMENT SHEET – 2

Academic Year : 2012-2013
Semester : II
Name of the Program: B.Tech IV Year: Section: A / B
Course/Subject: HVDC TRANSMISSION
Name of the Faculty: J.SRIDEVI Dept.: EEE
Designation : ASSOCIATE PROFESSOR

This Assignment corresponds to Unit No. II

Q1. Draw a schematic of a 6 pulse converter circuit and derive from fundamentals, the expression for voltage and currents for the operation of converter as a rectifier and inverter with relevant waveforms.

Q2. Sketch a timing diagram for a 3phase Graetz's circuit considering with and without overlap angle less than 60°.

Q3. Draw the equivalent circuits of both rectifier and inverter.

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: 1,2.

Outcome Nos.: 1,2

Signature of HOD Signature of faculty
Date: Date:
ASSIGNMENT SHEET – 3

Academic Year : 2012-2013

Semester : I / II

Name of the Program: B.Tech IV Year: ……………… Section: A / B

Course/Subject: HVDC TRANSMISSION

Name of the Faculty: J.SRIDEVI Dept.: EEE

Designation : ASSOCIATE PROFESSOR

This Assignment corresponds to Unit No. III

Q1. Discuss the effect of source inductance on the HVDC converter system performance.

Q2. Explain in detail the converter control characteristics of a HVDC systems.

Q3. Explain the drawbacks in Individual phase control and equidistant pulse control schemes used in HVDC projects.

Q4. Write short notes on the following
   a) Constant Alpha control
   b) Inverse cosine control

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: 1,2,3

Outcome Nos.: 2,3,4

Signature of HOD

Signature of faculty

Date: 
ASSIGNMENT SHEET – 4

Academic Year : 2012-2013
Date: 08.03.13

Semester : II

Name of the Program: B.Tech ………IV……………… Year: ……………….. Section: A / B

Course/Subject: HVDC TRANSMISSION

Name of the Faculty: J.SRIDEVI
Dept.: EEE

Designation : ASSOCIATE PROFESSOR

This Assignment corresponds to Unit No. IV

Q1. What are the alternate reactive power control strategies?

Q2. Discuss the various sources of reactive power for HVDC converters.

Q3. Explain in detail, the concept of reactive power requirement in HVDC converters.

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: 3,4

Outcome Nos.: 4,5

Signature of HOD
Signature of faculty
Date: Date:
ASSIGNMENT SHEET – 5

Academic Year : 2012-2013  Date:16.03.13.

Semester : II

Name of the Program: B.Tech IV  Year: ……………… Section: A / B

Course/Subject: HVDC TRANSMISSION

Name of the Faculty: J.SRIDEVI Dept.:EEE.

Designation : ASSOCIATE PROFESSOR

This Assignment corresponds to Unit No. V

Q1. What is the condition for minimum reactive power requirement of a DC link under normal conditions?

Q2. Classify the solution methodology for AC-DC load flow and explain

Q3. Explain the per unit system for DC quantities.

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: 3,4

Outcome Nos.: 5,6

Signature of HOD Signature of faculty

Date: Date:
ASSIGNMENT SHEET – 6

Academic Year : 2012-2013 Date: 30.03.13.

Semester : II

Name of the Program: B.Tech ……IV……………… Year: ……………….. Section: A / B

Course/Subject: HVDC TRANSMISSION

Name of the Faculty: J.SRIDEVI Dept.: EEE

Designation : ASSOCIATE PROFESSOR

This Assignment corresponds to Unit No. VI

Q1. Classify the faults on a converter

Q2. Write a brief note on short circuits in a converter.

Q3. Explain the difference between the A.C. circuit breaker and H.V.D.C. circuit breaker.

Q4. Explain the causes of over voltages on D.C. side of H.V.D.C converter.

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: 6

Outcome Nos.: 7

Signature of HOD

Signature of faculty

Date:
ASSIGNMENT SHEET – 7

Academic Year : 2012-2013
Semester : II
Name of the Program: B.Tech IV Year: ................ Section: A / B
Course/Subject: HVDC TRANSMISSION
Name of the Faculty: J.SRIDEVI Dept.:EEE.
Designation : ASSOCIATE PROFESSOR
This Assignment corresponds to Unit No. VII

Q1. Derive the expression for a total harmonic distortion in a 12 pulse converter.

Q2. How the voltage and current harmonics are calculated.

Q3. Explain in detail the non characteristic harmonics

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: 5

Outcome Nos.: 6,7

Signature of HOD
Signature of faculty

Date:          Date:
ASSIGNMENT SHEET – 8

Academic Year : 2012-2013 Date: 06.04.13

Semester : II

Name of the Program: B.Tech IV Year: ……………… Section: A / B /C /D

Course/Subject: HVDC TRANSMISSION

Name of the Faculty: J.SRIDEVI Dept.:EEE.

Designation : ASSOCIATE PROFESSOR

This Assignment corresponds to Unit No. / Lesson …………………………………………………

Q1. How do you design a single tuned filter? Explain the precautions taken while designing.

Q2. Mention the configurations and impedance characteristics of various types of filters. Give design aspects of single tuned filter.

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: 5

Outcome Nos.: 6,7

Signature of HOD Signature of faculty

Date: Date:
TUTORIAL SHEET - 1

Academic Year : 2012-2013  Date: 29.12.12.

Semester : II

Name of the Program: B.Tech IV Year: Section: A / B

Course/Subject: HVDC TRANSMISSION

Name of the Faculty: J.SRIDEVI Dept.: EEE

Designation : ASSOCIATE PROFESSOR

This Tutorial corresponds to Unit No. I

Q1. What is the need of interconnection of systems?

Q2. Explain the merits of connecting HVAC systems by HVDC tie-lines?

Q3. Discuss the relative merits and demerits of using E.H.V.A.C transmission and HVDC transmission for bulk power transmission over long distances.

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: 1,2

Outcome Nos.: 1,2

Signature of HOD  Signature of faculty

Date:  Date:
TUTORIAL SHEET - 2

Academic Year : 2012-2013
Semester : II
Name of the Program: B.Tech IV Year:
Section: A / B
Course/Subject: HVDC TRANSMISSION
Name of the Faculty: J.SRIDEVI
Dept.: EEE
Designation : ASSOCIATE PROFESSOR

This Tutorial corresponds to Unit No. II

Q1. With the help of neat sketches, analyze a six pulse rectifier bridge circuit with an overlap angle greater than 600. Deduce the relevant equations and draw the necessary graphs.

Q2. With the help of neat sketches, analyze a six pulse rectifier bridge circuit with an overlap angle less than 600. Deduce the relevant equations and draw the necessary graphs.

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: 1,2
Outcome Nos.: 1,2

Signature of HOD
Signature of faculty
Date: Date:
TUTORIAL SHEET - 3

Academic Year : 2012-2013

Semester : II

Name of the Program: B.Tech IV Year:

Section: A / B

Course/Subject: HVDC TRANSMISSION

Name of the Faculty: J.SRIDEVI

Dept.: EEE

Designation : ASSOCIATE PROFESSOR

This Tutorial corresponds to Unit No. III

Q1. What are the limitations of manual control of a DC line operation?

Q2. Name the different types of Equidistant pulse control and explain them in detail.

Q3. Distinguish between constant voltage and constant current controls.

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: 1,2,3

Outcome Nos.: 2,3,4

Signature of HOD

Signature of faculty

Date:

Date:
Q1. With a neat sketch, explain about Thyristor Switched Capacitor.

Q2. What is a Static VAR system? How many types of SVS schemes are present and what are they?

Q3. Discuss the relative features of different reactive power control schemes in HVAC and HVDC systems.

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: 3, 4

Outcome Nos.: 4, 5

Signature of HOD

Signature of faculty

Date:
TUTORIAL SHEET - 5

Academic Year : 2012-2013 Date: 16.03.13.

Semester : II

Name of the Program: B.Tech IV Year: Section: A / B

Course/Subject: HVDC TRANSMISSION

Name of the Faculty: J.SRIDEVI Dept.: EEE

Designation : ASSOCIATE PROFESSOR

This Tutorial corresponds to Unit No. V

Q1. Write a short notes on:
(a) Modeling of H.V.D.C. links
(b) P.U. system for d.c. quantities.

Q2. Compare simultaneous and sequential methods of power flow analysis.

Q3. Draw the flow chart for AC/DC load flow.

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: 3,4

Outcome Nos.: 5,6

Signature of HOD

Signature of faculty

Date:

Date:
TUTORIAL SHEET - 6

Academic Year : 2012-2013 Date: 30.03.13.

Semester : II

Name of the Program: B.Tech IV Year: Section: A / B

Course/Subject: HVDC TRANSMISSION

Name of the Faculty: J.SRIDEVI Dept.: EEE

Designation : ASSOCIATE PROFESSOR

This Tutorial corresponds to Unit No. VI

Q1. Explain the effects of single commutation failure in converter.

Q2. Explain briefly the factors on which recovery from a commutation failure depends.

Q3. Explain the fault clearing process in H.V.D.C. poles. Explain how are the H.V.D.C. equipment protected against prolonged short circuit currents though there is no H.V.D.C. circuit breaker on H.V.D.C. pole side.

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: 6

Outcome Nos.: 7

Signature of HOD Signature of faculty

Date: Date:
TUTORIAL SHEET - 7

Academic Year : 2012-2013 Date: 05.04.13.

Semester : II

Name of the Program: B.Tech IV Year: Section: A / B

Course/Subject: HVDC TRANSMISSION

Name of the Faculty: J.SRIDEVI Dept.: EEE

Designation : ASSOCIATE PROFESSOR

This Tutorial corresponds to Unit No. VII

Q1. What are the various sources of harmonics generation in a HVDC line? Describe how a double tuned filter can be designed for a HVDC system.

Q2. How is Total Harmonic Distortion estimated in a circuit? Explain the relevance of THD to a HVDC system.

Q3. Explain the effect of firing angle errors on non characteristic harmonics.

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: 5

Outcome Nos.: 6,7

Signature of HOD                      Signature of faculty

Date:                                Date:
TUTORIAL SHEET - 8

Academic Year : 2012-2013                       Date: 06.04.13.

Semester : I

Name of the Program: B.Tech IV Year: Section: A / B

Course/Subject: HVDC TRANSMISSION

Name of the Faculty: J.SRIDEVI                      Dept.: EEE

Designation : ASSOCIATE PROFESSOR

This Tutorial corresponds to Unit No. VIII

Q1. What are the various types of filters that are employed in HVDC converter station? Discuss them in detail.

Q2. Draw the loci of Network impedance and filter impedance and analyze the impact of network impedance or admittance on the design of single tuned filter.

Please write the Questions / Problems / Exercises which you would like to give to the students and also mention the Objectives/Outcomes to which these Questions / Problems / Exercises are related.

Objective Nos.: 5

Outcome Nos.: 6,7

Signature of HOD

Signature of faculty

Date:
EVALUATION STRATEGY

Academic Year : 2012-2013

Semester : II

Name of the Program: B.Tech IV Year: ………………. Section: A / B

Course/Subject: HVDC TRANSMISSION

Name of the Faculty: J.SRIDEVI Dept.: EEE

Designation : ASSOCIATE PROFESSOR

1. TARGET:

   A) Percentage for pass: 100

   b) Percentage of class: 95

2. COURSE PLAN & CONTENT DELIVERY

   • PPT presentation of the Lectures
   • Solving exercise problems
   • Model questions

3. METHOD OF EVALUATION

   3.1 Continuous Assessment Examinations (CAE-I, CAE-II)
   3.2 Assignments/Seminars
   3.3 Mini Projects
   3.4 Quiz
   3.5 Semester/End Examination
   3.6 Others

Signature of HOD Signature of faculty

Date: Date:
RESULT ANALYSIS

Name of the Program: B.Tech IV Year                      Section: A / B
Course/Subject: HVDC TRANSMISSION

<table>
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<th>Academic Year</th>
<th>Subject</th>
<th>Total No. of students appeared</th>
<th>No. of students passed</th>
<th>No. of students failed</th>
<th>&lt; 60</th>
<th>60 to 70</th>
<th>&gt; 70</th>
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<td>09</td>
<td>01</td>
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This is an Elective subject. In 2010-11,2011-12 we have not taken as an elective subject.