Fundamental Concepts of Dynamic Reactive Compensation and HVDC Transmission

Brian K. Johnson
University of Idaho
b.k.johnson@ieee.org

Outline

• Objectives for this panel session
• Introduce Basic Concepts
  – Why Use Power Electronic Solutions
  – Dynamic Reactive Compensation on AC Systems
  – HVDC Transmission
• Phases for a Reactive Compensation Project
• Other Presentation Describe Technologies
Objectives for This Session

- Introduces fundamental concepts of both HVDC transmission and FACTS
  - First part of session FACTS, then HVDC
- The presentations are tutorial in nature
- Background material for more technically advanced presentations in this conference

Presentations

- Rajeev Varma → Elements of FACTS Controllers
- Wayne Litzenberger → HVDC Project Implementation
- Mike Bahrman → HVDC Technology: LCC
- Neil Kirby → HVDC Technology: VSC
Transmission Applications

Power Electronics

• Use of power electronics to change (improve) transmission performance

• Classes of devices
  – Variable Impedance Compensators
  – Switching Converter Based Compensators
  – HVDC: ac/dc conversion and dc transfer

Power Electronics for Solving AC Transmission Problems

• Transmission Bottlenecks have one or more of
  – Steady-state Stability Limits
  – Transient Stability Limits
  – Power System Oscillation Limit
  – Inadvertent Flows
  – Short Circuit Current Limits
  – Thermal Limits

• Bulk Power Transfer Over Long Distances
Some Conventional Solutions

- Series Capacitors
- Switched Shunt Capacitors or Reactors
- Power System Stabilizers
- Transformer Tap Changers
- Special Stability Controls
- Phase Angle Regulators
- Synchronous Condensers

When to Apply Power Electronic Solutions

- Apply where power converters matter
  - Dynamic reactive compensation
  - Conversion to/from DC for transmission
  - Interface to generation or storage
- Concerns: cost, losses, complexity, reliability
Why the Concern with Dynamic Reactive Compensation

• Why The Concern?
  – Reactive current impacts equipment ratings
  – Directly impacts the ability of the network to transport energy
  – Loads with rapid changing real or reactive power demand create voltage flicker

Possible Applications

• Mid Line Compensation
  – Increase Power Transfer by Supplying/Sinking Reactive Power to Support the Current Flow in Line

• Stability (Increase Power Transfer)
  – Power Oscillation Damping

• Voltage (PQ) Support
  – Arc Furnace (Flicker)
  – Load Compensation (Compressor Load)

• Avoid Causing, or Provide Damping for SSR
Implementation: Fast, Dynamic Variation Impedance

• Shunt Connection
  – Static VAR Compensator
  – Thyristor Controlled Reactor
  – Thyristor Switched Capacitor

• Series Connection
  – Thyristor Controlled Series Capacitor

Implementation: Controlled Voltage Source

• Controlled Voltage Magnitude and Angle

• Shunt Connection:
  – Static Synchronous Compensator (STATCOM)

• Series Connection:
  – Static Synchronous Series Compensator (SSSC)

• Combined Series Shunt
  – Unified Power Flow Controller
  – Convertible Static Compensator
Closed Loop Control

• Often Two Levels
  – Inner Control Loop Controls Switches
  – Outer Control Loop Tied to Specific Power System Objectives

• Possible Objectives
  – Regulate $|V|$ (local or remote), Q, or I injected
  – Control Power Flow on a Line
  – Damping of Oscillations

High Voltage Direct Current (HVDC) Transmission

• Update to Edison’s Vision

• AC Power Generation at Relatively Lower Voltage
  – Step Voltage Up to High Levels

• Convert From AC to DC and Back
  – DC Voltages Pole to Ground up to 800 kV
  – Currents up to about 3000A

• Most Systems Presently Point to Point—Evolving

• Multiterminal Grids
Basic Concept with HVDC

- Overhead Lines
  - Bulk Power Transfer Over Long Distances
  - Possibly Connecting Asynchronous Systems
- Underwater or Underground Cables
  - Distance Limits Underwater Cables
  - Longer Distances Where Overhead Lines Infeasible
- Back-to-back interconnections
  - Asynchronous systems – same or different frequency

Fast Controls Again Available

- Control Power Flow on DC Link
  - Control DC Voltage
  - Control DC Current
- Damp AC Power Systems Oscillations
- VSC HVDC Converters Can Control AC Side Voltage or Reactive Power
Development History

• First “Static” VAR Compensator (1930’s)
  – saturated reactors in combination with capacitors

• First HVDC projects (Mercury Arc Valves):
  – Berlin-Charlottenburg early 1940’s
  – Moscow early 1950’s
  – Gotland Island: 1954 (first operating project)

Development History (continued)

• Thyristor Based Converter Applications
  – HVDC Transmission (early 1970’s)
  – Static Var Compensators (early 1970’s)
  – Thyristor Controlled Series Capacitor (late 1980’s)

• Voltage Sourced Converter (VSC) Applications
  – FACTS Devices (late 1980’s)
  – VSC HVDC Transmission (late 1990’s)
Phases of a Dynamic Reactive Compensation Study

- Phase I: Feasibility Study
- Phase II: Determine type, location, size
- Phase III: Define equipment requirements
- Phase IV: Equipment design and verification
- Phase V: Commissioning and normal operation

Phase I: Characteristics of the system

- Identify System Performance Problems
  - Transient stability
  - Oscillatory stability
  - Voltage stability (steady-state)
  - Short term voltage instability (voltage collapse)
  - Steady-state power flow (thermal ratings)
Phase I: Characteristics of the system (cont.)

- Identify the compensation needs
  - Shunt compensation
  - Series Compensation
  - Speed of response (slow versus fast)
  - Can the problems be examined independently or will coordinated analysis be needed

- Type of compensation impacts location & rating
- Availability of space at site could be key

Phase I: Study Tools/Model Detail

- Programs
  - Load flow programs
  - Stability programs

- Model detail
  - Full system model
  - Positive sequence models
  - Simple, generic compensator models
Phase II: Determine Type of Compensator, Location, Ratings

- Identify solution options
  - Conventional
  - FACTS
  - Combinations
- Studies to evaluate the performance of these options

Phase II: Determine Type of Compensator, Location, Ratings

- Potential locations for the compensation
- Impact of compensator type, location & choice on:
  - System performance – varies with compensation
  - Ratings of the compensation
  - Losses
  - Cost versus value of compensation to system performance
Phase II: Study Tools and Model Detail

• Nearly the same as in phase I
  – Load flow programs
  – Stability programs

• Model detail
  – Full system model
  – Positive sequence models
  – Fairly simple, generic compensator models
    • Control models need more detail

Phase I and Phase II: Who performs the studies

• Transmission system owner
• Regional independent system operator
• Consultant hired by system owner/operator
• Possibly some involvement from vendors
Phase III: Defining Equipment Requirements

- Objective of the studies is to be prepared to write technical specifications and request for proposals for potential bidders
- Studies performed by combination of transmission owner/operator and consultants

Phase III: System Study Related Information

- MVA Rating of compensator
- Voltage interconnection ratings
- Operating Range for compensator
- Harmonic performance requirements
  - Limits
  - System characteristics
- Loss evaluation
Phase III: System Study Related Information

- System dynamic performance requirements
  - System characteristics
  - Control limits
  - Overload capability
    - Not automatic unless specified
- Control responses following faults and disturbances
Phase III: System Study Related Information

- Control response during daily load cycle
- Control response during an event
- Control response after a system response
  - Short term
  - Long term
- Identify possible interactions
  - Other control devices
  - Harmonics, SSR

Phase III: Resources for FACTS Applications

  - Many points useful for STATCOM as well
- IEEE Standard 1534: IEEE Recommended Practice for Specifying Thyristor Controlled Series Capacitors
- WECC/EPRI work on models for SVC –2010 T&D meeting panel session for PES web page
Phase IV: Equipment design and verification

- Generally conducted by equipment vendor
- Verify that device designed meets performance requirements
- Outcome is competed design

Phase IV: Stages

- Main equipment design: system and components
- Control software
- Dynamic performance studies
- Harmonic filter design and performance studies
- Audible noise study
Phase IV: Stages

- Electromagnetic transients studies
  - Transient response
  - Dynamic response
  - Overvoltage analysis
  - Insulation coordination
  - Component protection
- Possibly real time simulator studies

Phase V: Commissioning and normal operation

- Confirm performance within benchmark limits
  - Set up instrumentation
  - Obtain measurements during staged events or faults
  - Obtain measurements during actual faults and dynamic events
  - Compare results to simulation studies
Phase V: Conditions to check

• System load flows within specified limits
• Equipment effectively enhances network steady-state and dynamic performance
• Evaluate interactions with other system equipment
• Evaluate losses
• Harmonic performance
• Assess reliability and availability

Phase V: Commissioning and normal operation

• Commissioning stage will involve owner and vendor
• Post-commissioning studies by owner
Rest of Session

• Rajeev Varma → Elements of FACTS Controllers
• Wayne Litzenberger → HVDC Project Implementation
• Mike Bahrman → HVDC Technology: LCC
• Neil Kirby → HVDC Technology: VSC

PES HVDC and FACTS Subcommittee Web Page

• [http://www.ece.uidaho.edu/hvdcfacts/](http://www.ece.uidaho.edu/hvdcfacts/)