California ISO - STEP Meeting

March 9, 2004 - San Diego, CA

FACTS - STATCOM TECHNOLOGY

MITSUBISHI ELECTRIC POWER PRODUCTS, INC.

TM T&D
TM&D Corporation

Questions and Comments:

John J. Paserba; Manager
Power System Engineering Services Dept.
Power Systems Division,
530 Keystone Drive, Warrendale, PA 15086
Phone: (724) 778-5219, Fax: (724) 778-5149
john.paserba@meppi.com
Home Page: www.meppi.com

Mitsubishi Electric Power Products, Inc.

Headquarters, Operations, and Factories - Warrendale, PA

Our Mission:
To assist in the rebuilding of the electrical transmission system infrastructure through the supply of conventional equipment and systems, advanced transmission technologies, and technical services.

TMT&D Corporation

A Joint Venture Company of
Toshiba and Mitsubishi Electric

TMT&D Corporation

Introduction

Power Electronics Technologies

Strategic solutions to upgrading the Nation's electrical transmission system infrastructure by:

- Increasing Capacity
- Enhancing Reliability
- Improving Controllability
- Eliminating System Constraints
- Reducing T-Line Construction
- Preserving the Environment
- Value: Saving Time & Money, and Enabling Profitability

KEPCO Inuyama STATCOM - 1990

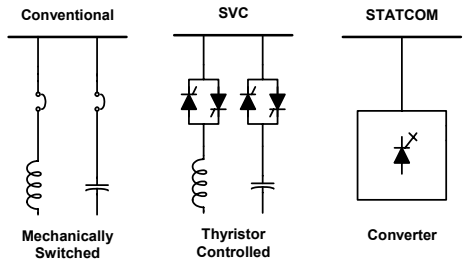
SDG&E Talega STATCOM/BTB - 2002

Power Electronics Transmission Applications

- Utilization/Expansion of Existing Transmission Grids
  - Enhanced Transmission System Reliability & Control
    - Higher Level of Power Quality and Security
    - Enhanced Voltage Control and Stability
    - Improved Power System Stabilization
    - Increased Power Flow Control
  - Power Transfer & Control
    - DC-Links for "seamless" interconnection
  - Improved Inter-tie Reliability & Control
    - Efficient Interconnection of ITC/RTO-type Systems
  - Increased Transmission System Capacity
    - Up to 40% increase in capacity can be realized
  - Optimized Transmission System Control & Operation

STATCOM TECHNOLOGY
BASIC DESIGN, OPERATION, & CONTROL

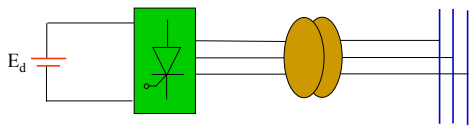
Shunt Compensation Evolution



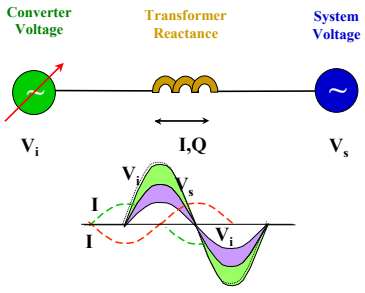
Slow VARs **Fast VARs** **Fast VARs**

STATCOM - Basic Configuration

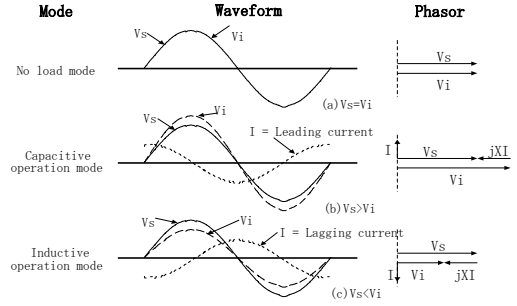
DC Voltage Source | IGBT/GCT Converter | Converter Transformer | Power System



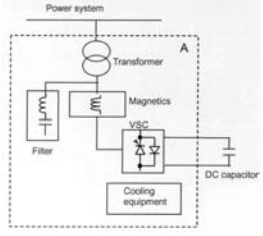
STATCOM - Basic Operation Principal



STATCOM - Principal Operation Modes

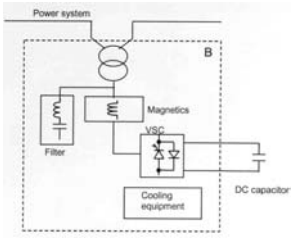


FACTS: VSC-Based Configurations (A)



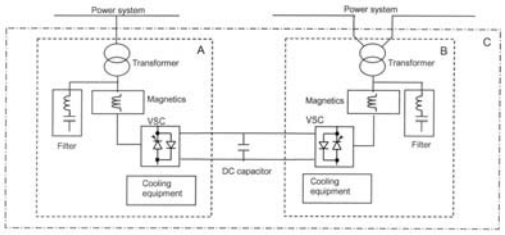
STATCOM Configuration

FACTS: VSC-Based Configurations (B)



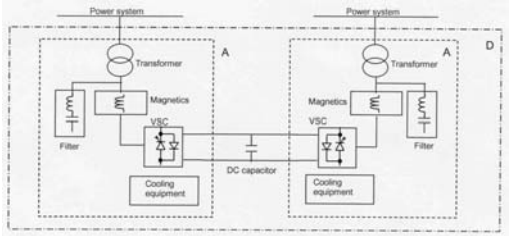
SSSC Configuration

FACTS: VSC-Based Configurations (C)



UPFC Configuration

FACTS: VSC-Based Configurations (D)



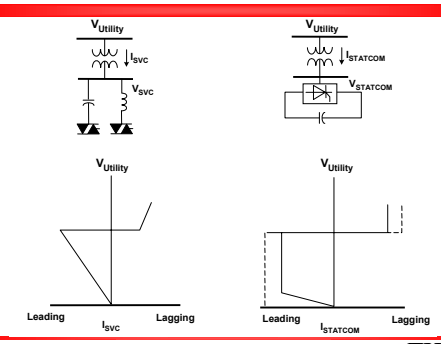
BTB Configuration

FACTS: VSC-Based Systems

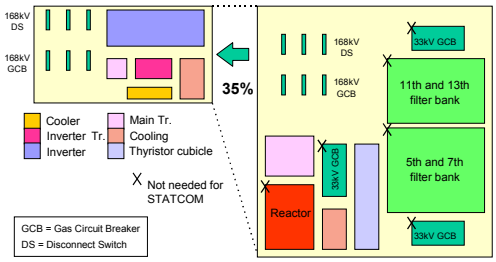
Application Systems of VSC Technology

FACTS Application	VSC Configuration	VSC Composition
STATCOM	A	A
SSSC	B	B
UPFC	C	A + B = C
BTB	D	A + A = D

Comparison of V-I Characteristics for SVC vs. STATCOM



Layout Arrangement Comparison of STATCOM vs. SVC



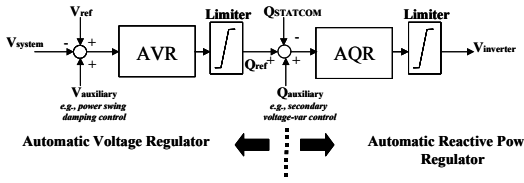
Typical STATCOM footprint is smaller than SVC footprint

COORDINATED CONTROL OF LOCAL AND REMOTE CAPACITOR BANKS

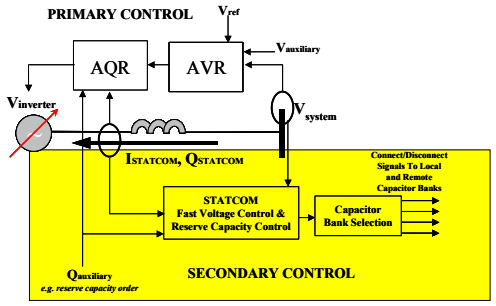
Coordinated Control

- The main purpose of coordinated (or secondary) controls applied to PE equipment is to ensure that adequate range of dynamic capability is available for major system disturbances
- The output of the coordinated controls calls for the switching of capacitor banks to "reset" the reactive power output of the STATCOM to a pre-specified level
  - After a system event (long term)
  - During the course of a daily load cycle (long term)
  - During an event for voltage control (fast)

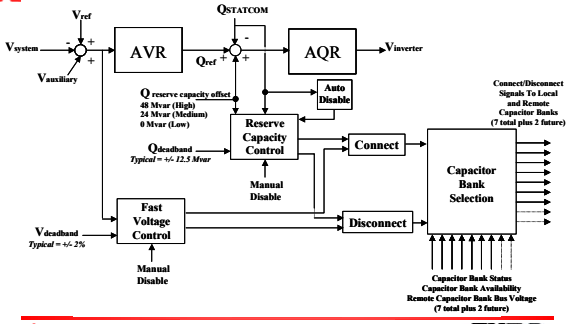
Functional Diagram for a Primary Control For a STATCOM



Functional Diagram for Coordinated Control



Detailed Control Diagram of One Method of Coordinated Control



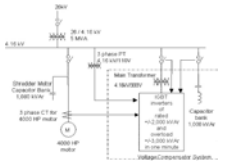
For Further Details on Secondary/Coordinated Voltage-Var Control Refer to:

http://www.meppi.com/mepssd/FACTS.html

SELECTED MEPPI/TMT&D FACTS-STATCOM PROJECTS

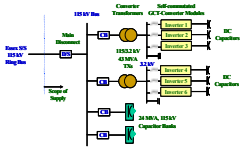
Seattle Iron & Metals D-STATCOM Project

- **Project Highlights**
  - **Ratings**
    - 0 to + 5 MVAr Dynamic Range VSC
    - Overload Rating of 150%
    - 4.16/ 26.4 kV-ac
  - **VSC Based Design**
    - Voltage Sourced Converters with Insulated Gate Bipolar Transistor (IGBT) Elements in Outdoor Weatherproof Encl.
  - **Voltage Flicker Suppression**
    - Dynamic Voltage Control of Shredder Motor for Steel Recycling Operation
  - **Air-Cooling Method**
    - Low-Loss Forced Air Cooling System
  - **Commissioned**
    - January 2000



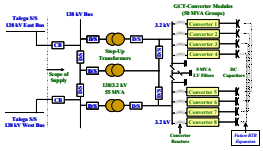
VELCO - Essex S/S STATCOM Project

- **Project Highlights**
  - **Ratings**
    - -41 to +133 MVAr Dynamic Range
    - 115 kV-ac
  - **VSC Based Design**
    - Voltage Sourced Converters with Gate Commutated Turn-Off Thyristors (GCT)
  - **Coordinated Control**
    - STATCOM System Control Coordinated with both Local and Remote Capacitor Banks
  - **Small Footprint / Low Noise**
    - Meets Site Installation Restrictions & Strict Environmental Requirements
  - **Commissioned**
    - May 2001



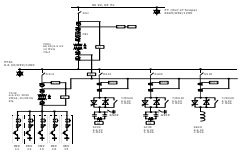
SDG&E - Talega S/S STATCOM/BTB Project

- **Project Highlights**
  - **Ratings**
    - -100 to +100 MVAr (STATCOM)
    - 50 MW BTB DC-Link (future option)
    - 138 kV-ac
  - **VSC Based Design**
    - Voltage Sourced Converters with Gate Commutated Turn-Off Thyristors (GCT)
  - **Auto-Reconfiguration Feature**
    - Control and Reliability Enhancement during Contingency Operation
  - **Low Noise / Small Footprint**
    - Strict Environmental Requirements
    - Modular Equipment Construction
  - **Commissioned**
    - February 2003

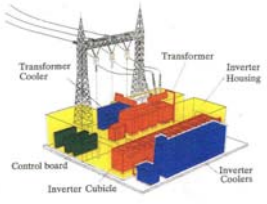


Manitoba Hydro - Bloodvein Hybrid SVS Project

- **Project Highlights**
  - **Ratings**
    - -4 to +12 MVAr
    - Hybrid STATCOM and SVC
    - 66 kV-ac
  - **Hybrid Design**
    - VSC STATCOM with IGBT Elements
    - SVC Components
      - High Speed Thy. Switched Capacitors
      - High Speed Thy. Switched Reactor
  - **Fast Track Project / Installation**
    - Remote Northern Manitoba Location
    - Limited Equip. Delivery, Installation, Testing, & Commissioning Windows
  - **Commissioned**
    - December 2003



KEPCO - Inuyama STATCOM



Kansai Electric - Inuyama S/S
+/-80 MVA, 154 kV STATCOM

The World's First Commercial VSC STATCOM Installation (In-Service: May, 1990)

Chubu Steel - STATCOM Installation

Chubu Steel +/-24 MVA, 22 kV STATCOM
(Arc Furnace Flicker Suppression)

Mutsu Wind Farm STATCOM

(Static Synchronous Compensator)

Mutsu Windfarm

- **Rating**
  +/- 3 MVAr
  (6 x 500 kVAr unit)
- **IGBT**
  1200-V, 600-A
- **Switching frequency**
  4000 Hz
- **Air cooling**

For Further Details on
Mitsubishi/TMT&D Application
of FACTS Controllers
Refer to:

http://www.meppi.com/eng_analysis.html

Features/Benefits of FACTS Technology

- STATCOM, SVC, SSSC, BTB, UPFC Applications
  - Reactive Power Control & Voltage Control/Stability
    - Continuous Operation, Compensation, and Control
  - Rapid, Continuous Response & Coordinated Control
    - Dynamic Coordinated Control, Continuous Characteristics
  - Independent Control of Voltage and Power Flow
    - Dynamic Support for Power System Contingencies
  - Automatic Real and Reactive Power Control
    - Complete Dynamic and Steady-State Power System Control
  - Low Short Circuit Ratio Operation
    - Superior Performance for Weak System Applications

Features/Benefits of FACTS Technology

- STATCOM, SVC, SSSC, BTB, UPFC Applications
  - Modular Design, Redundancy, & Advanced Systems
    - *n* x VSC groups, *n* x VSC modules, 5-pulse PWM, etc.
  - Compact Size, System Layout Options
    - Solutions for Space Limitations & Installation Flexibility
  - Easily Expandable & Mobile
    - Flexibility & Mobility for Future System Considerations
  - Standard Interconnection Transformers
    - Typical Two/Three Winding Design (NOT multiplex or ϕ-shift)
  - Large Capacity GCT & LTT Technology
    - Low Losses, Fewer Components, and High Reliability

Features/Benefits of FACTS Technology

- STATCOM, SVC, SSSC, BTB, UPFC Applications
  - Low Operating Losses
    - Reduced Losses & Operating Costs using GCT / LTT
  - Low-Level Maintenance, Service
    - Static Systems with High Reliability, Easy Maintenance
    - Equipment Easily Accessible for Maintenance/Service
  - Rapid Implementation
    - Efficient Turnkey Project Capabilities and Proven Success
  - State-of-the-Art Technology
    - Converters, Control, Interface, Devices, Equipment, Expertise

Summary

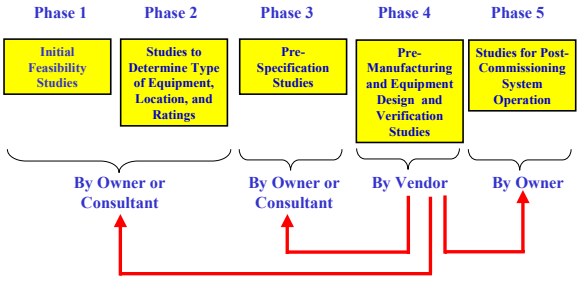
- Power Electronics Technologies
  - Strategic Solutions to Upgrading the Existing Electrical Transmission System Infrastructure
  - Proven Reliability and Performance for both Transmission & Distribution System Applications
  - Provides Optimal and Profitable Operation of Power Systems wrt Generation, Transmission, & Distribution
  - Increasing Needs in North America and Worldwide for:
    - Dynamic Voltage Support & Control
    - Power Flow Control & Transfer Capability
    - Improved Power System Stability & Control
    - Increased Transmission Capacity & Import Capability
    - Enhanced Power Quality & Interconnection Reliability

Appendix
FACTS APPLICATIONS: POWER SYSTEM PERSPECTIVE

FACTS Projects: Phases of System Studies

- Phase 1
  - Initial Feasibility Studies to Determine System Constraints and Reinforcement Needs
- Phase 2
  - Studies to Determine Type of Equipment, Location and Ratings
- Phase 3
  - Pre- Specification Studies for Defining Equipment Requirements
- Phase 4
  - Pre-Manufacturing and Equipment Design / Verification Studies
- Phase 5
  - Studies for Post-Commissioning System Operation

Studies for FACTS Projects



For Further Details on System Studies Aspects of FACTS Controllers Refer to:

http://www.meppi.com/mepssd/FACTS.html