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July 2008

Dear participants,

Fast control of reactive power by means of shunt-connected static devices is a proven technology. **Working group I4** on Static Var Compensators of the High Voltage Power Electronics Stations Subcommittee has maintained a list of industrial and utility Static Var Compensator (SVC) installations around the world and found more than 500 of these installations still in service after 25 years of operation. SVCs are still considered today as a competitive solution to meet future needs of reactive power compensation.

Past tutorials offered on Static Var Compensators have focused mainly on power system aspects and on justifying the need for SVCs. This tutorial is focusing on equipment design and operations. A brief review of system aspects which justifies the need for fast reactive power compensation and a description of various applications are presented. It is intended to provide participants with a solid understanding of basic components and their integration in substation design, of control system and its dynamic performance and commissioning of SVCs.

This tutorial targets engineering personnel, plant and design engineers, and anyone responsible for: (1) validating the dynamic performance during the design stage and (2) ensuring reliable operations of Static Var Compensators.

Yours truly,

Hubert Bilodeau

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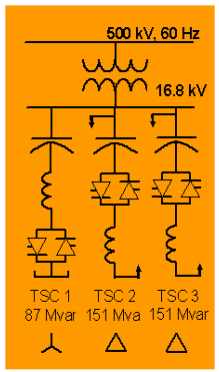

Tutorial on Static Var Compensators

PES General meeting, July 20-24 2008, Pittsburgh, PA

Presented by:

Hubert Bilodeau
Mikael Halonen
Chris Horwill
Dan Sullivan
Heinz Tyll
Rajiv K. Varma

Prepared by:

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Chris Horwill
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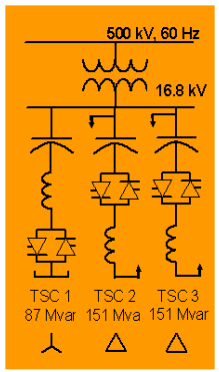

OUTLINE

- Module 1 - Reactive Power Compensation in Electrical Transmission Systems
- Module 2 - Basic characteristics of SVC
- Module 3 - SVC configurations and implications
- Module 4 - Main components in existing installations
- Module 5 - Thyristor valves
- Module 6 - Regulation, Control and Protection system
- Module 7 – Commissioning
- Module 8 – Standards
- Module 9 - Project Overview
- Module 10 - References

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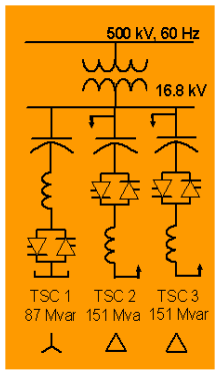


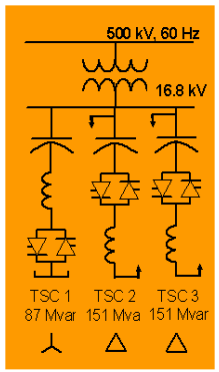
OUTLINE

- 8:00 -10:00 Module 1 - Reactive Power Compensation in Electrical Transmission Systems
  - » BREAK
- 10:15- 10:45 Module 2 - Basic characteristics of SVC
- 10:45 -11:30 Module 3 - SVC configurations and implications
- 11:30 -12:00 Module 4 - Main components in existing installations
  - » BREAK for lunch
- 13:00 -14:00 Module 5 - Thyristor valves
- 14:00 -15:00 Module 6 - Regulation, Control and Protection system
  - » BREAK
- 15:15 -15:45 Module 7 - Commissioning
- 15:45 -16:30 Module 8 and 9 - Standards and Project Overview
- 16:30 -16:40 Module 10 - References
- 16:40 -17:00 Open Discussion

Module 1

Reactive Power Compensation in Electrical Transmission Systems

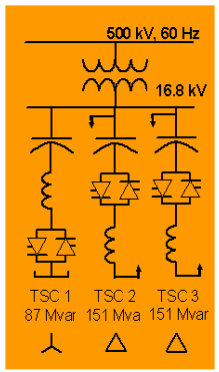
- Brief Review of Transmission Line Characteristics
- Power System Improvements With Var Control
- Applications of Static Var Compensator (SVC)
- Placement and Sizing of an SVC
- System Study Aspects for FACTS Controllers

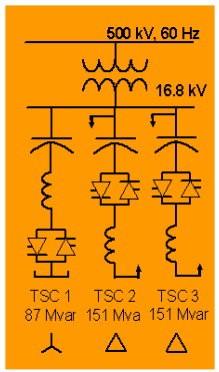


Module 2

Basic Characteristics of Static Var Compensator (SVC)

- How Var Control is achieved with SVC
- Basic Voltage-Current (V / I) characteristics





Module 3

SVC configurations and implications

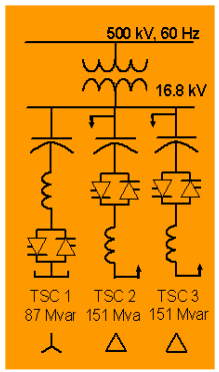
- Typical SVC Configuration
- Thyristor Controlled Reactor (TCR)
  - TCR – Firing Angle Control
  - TCR Harmonics
- Thyristor Switched Capacitor (TSC)
  - Coordinated switching
- Common Configurations
- Loss Comparison

Module 4

Main components in existing installations

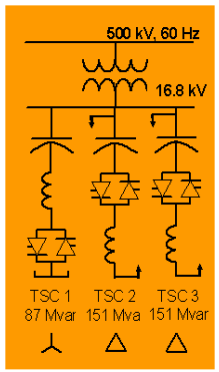
Objective:

Present the main components through existing installations

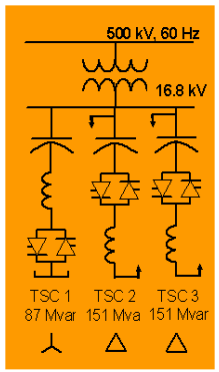


Module 5

Heart of the system: the thyristor valves



- *Thyristor – the device and its performance*
- *Thyristor manufacturing*
- *Thyristor valve components*
- *Thyristor valve losses and valve cooling*
- *Thyristor triggering and monitoring*
- *Thyristor valve control*
- *Hardware examples*



Module 6

SVC Control, Monitoring and Protection

I- Station Control Hierarchies

II- Plant control and monitoring

III- Closed-loop control and Regulation

- a) Voltage Control Structure - Regulation
- b) Additional control functions and other options
- c) Control loop analysis
  - -Linearity
  - -Demodulation effect of voltage measurement
  - -SVC Response in open-loop and closed-loop
- d) Case study – SVC Response
  - -Voltage reference step
  - -Reactor switching

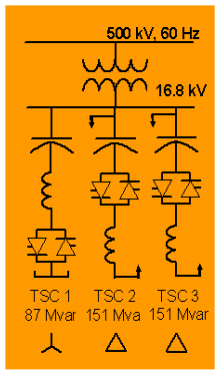
IV- Valve Base Electronic

V- Protection system

Module 7

Commissioning an SVC

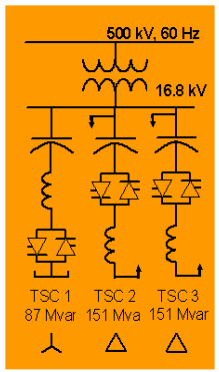
- The commissioning process
- Pre-commissioning tests
- System and operational considerations
- Commissioning tests
- Standards and guides



Module 8

Standards

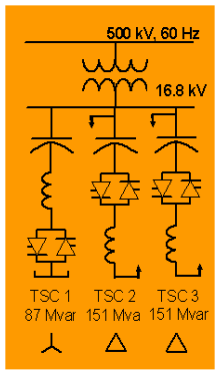
- Functional Specification IEEE 1031
- Field Tests for Static Var Compensator IEEE 1303
- Test Standard for thyristor valves IEC 61954



Module 9

Project Overview

- *Provide an Overview of a "Typical" SVC Project*
- *Key Tasks and Durations for "Typical" SVC Project*
- *Major Steps in the Project Process*
- *"Typical" SVC Project Schedule*



HUBERT BILODEAU

Senior Control Engineer, HVDC and FACTS
TransÉnergie, Hydro-Québec

Hubert Bilodeau (SM, 2000) graduated from École Polytechnique, Université de Montréal in 1975. After graduation, he joined General Electric in Peterborough, Canada and worked as a designer of static excitation and DC Rectifier equipment. In 1981, he joined BBC Brown Boveri Co. in Montreal as a technical coordinator for the HVDC/SVC Châteauguay project. At the end of the project he joined the parent company in Switzerland. Since 1989, he is working with Hydro-Quebec in Montreal as a control specialist for Static Compensator, series compensation and HVDC. He is registered professional in the province of Quebec and Ontario. He is a senior member of IEEE Power Engineering Society and currently Secretary of the High Voltage Power Electronics Stations Subcommittee of the Substations Committee and Chair of Working Group (WG) I4 on Static VAR Compensators.

MIKAEL HALONEN

System Design Manager, FACTS
ABB AB, Västerås, Sweden

Mikael Halonen (M'2006) was born in Västerås, Sweden, in 1970. He received his M.Sc. degree in Electrical Engineering from the Royal Institute of Technology, Stockholm, Sweden in 1996. He currently is working for ABB AB within its FACTS Division where he is involved in projects concerning reactive power compensation for voltage stability and control. He has been involved in many SVC projects, and has been responsible for design of systems in the area of FACTS, including commissioning and testing of system performance in field. He has performed numerous systems and design studies to determine SVC size, component rating and SVCs interaction with power systems. At present he is one of the managers of the ABB FACTS System Design Group in Sweden.

CHRIS HORWILL

Christopher Horwill (M'2001, SM'2004) was born in Royston England in 1948 and received his B Sc from the University of Leeds in 1971. Since then he has worked for AREVA T&D on the application engineering of SVC projects in the UK and worldwide. He is currently the Project Engineer for the de-icer project. He is the vice chair of the Power Electronic Stations Subcommittee (I0) of the IEEE PES Substations Committee as well as holding various posts in some of the Working Groups (I1, I4 and I5) of the Subcommittee.

DANIEL J. SULLIVAN, P.E.

Mitsubishi Electric Power Products, Inc.
Senior Engineer, Power Systems Engineering Services

Daniel Sullivan joined Mitsubishi Electric Power Products Inc, (MEPPI) in April of 2002. He earned a Bachelors of Science Degree in Electrical Engineering Technology from the Pennsylvania State University in 1995, Master of Science Degree in Electrical Engineering from the University of Pittsburgh in 2006, and is registered as a Professional Engineer in the Commonwealth of Pennsylvania.

At MEPPI, Mr. Sullivan has lead and conducted a wide array of power system analysis and engineering design studies associated with transmission systems and equipment applications. System analysis study works include areas associated with system dynamic performance, short-term voltage stability, powerflow, voltage stability, electromagnetic transients, insulation coordination, transmission line switching, temporary overvoltages, and current transformer saturation. Dan leads and conducts application and engineering studies associated with Static Var Compensators (SVC), Flexible AC Transmission Systems (FACTS), and gas insulated substation (GIS) equipment. Mr. Sullivan has taught various modules on Power System Transients and Surge Protection, and modules of an IEEE Tutorial on Static Var Compensators. He has been a member of IEEE since 1992, and contributes to various task forces and working groups within IEEE/PES, including his current appointment as Secretary of Substation Committee Working Group (WG) I4 on Static VAR Compensators. Dan is currently an active member of the Western Electricity Coordinating Council (WECC) SVC Modeling Task Force. Mr. Sullivan is a primary contributor for system analysis, engineering, design, modeling, and technical specification of SVC and FACTS controllers, including application studies, software model development/testing, evaluation of reactive power coordinated control strategies, and SVC control strategy development. He works closely with Mitsubishi Electric Corporation (MELCO) power electronics engineers and designers in Japan, in addition to providing technical support throughout the various stages of SVC projects from technical specification, design, testing, and commissioning stages. Dan also leads and conducts various engineering studies associated with gas-insulated substation (GIS) applications, such as insulation coordination, lightning surge analysis, very fast transient investigation, grounding analysis, surge arrester application, and GIS enclosure current investigations associated with multi-point bonding and grounding.

Prior to joining MEPPI, Mr. Sullivan was part of an engineering and construction team responsible for implementing large capital projects for a municipal utility. His primary responsibility was to plan and assist in the design and construction of all electrical distribution, generation, and operating equipment, including testing, training, and start-up.

HEINZ TYLL

Heinz Karl Tyll (M'88, SM'93) graduated in 1968 in Electrical Engineering from Coburg Polytechnikum. In 1974 he received the Diplom degree from the Technical University of Berlin. After joining Siemens AG, he worked in their High Voltage Transmission Engineering Department since 1975 in the field of network and SVC system analysis with transient network analyzer and digital programs. In 1988 he transferred to the System Engineering Group of the HVDC and SVC Sales Department. Since 1996 he is responsible for Basic Design of SVC, SC and FACTS applications. He contributed to CIGRE WG 38 TFs and to relevant IEEE WG. He is member of IEEE and VDE.

RAJIV K. VARMA

Associate Professor and Associate Chair-Graduate
The University of Western Ontario (UWO), London, Canada

Rajiv K. Varma obtained B.Tech. and Ph.D. degrees in Electrical Engineering from Indian Institute of Technology (IIT), Kanpur, India, in 1980 and 1988, respectively. He is currently an Associate Professor and Associate Chair-Graduate at The University of Western Ontario (UWO), London, Canada. Prior to this appointment, he was a faculty member at the Indian Institute of Technology, Kanpur, India, for 12 years from 1989-2001. He performed the first static var compensator (SVC) simulation study in India on the HVDC simulator at Central Power Research Institute, Bangalore. While in India, he was awarded the Government of India BOYSCAST Young Scientist Fellowship in 1992-93 to conduct research on Flexible AC Transmission System (FACTS) at the UWO. He also received the Fulbright grant of the U.S. Educational Foundation in India, to conduct research in FACTS at Bonneville Power Administration (B.P.A.), Portland, Oregon, USA, during May-Aug. 1998. He is the co-author of the book "Thyristor Based FACTS Controllers in Electrical Transmission Systems" published by Wiley/IEEE Press in 2002. Dr. Varma is an Editor of the IEEE Transactions on Power Delivery. He is the Chair of IEEE Working Group on "FACTS and HVDC Bibliography" and is active on a number of other IEEE working groups. He has received several Teaching excellence awards at the Faculty of Engineering and University level at UWO. His research interests include FACTS, Power systems stability, and Grid integration of wind power generation systems.