Introduction to HVDC

VSC HVDC

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System Design

GRID

ALSTOM
The Voltage Sourced Converter
Single Phase
The Voltage Sourced Converter
Three Phase

VSC

Steady DC Voltage Input

Grid ALSTOM
AC/DC System Schematic – Ideal Load Flow

- **Line-to-Ground AC System Voltage**: $V_1$
- **Line-to-Ground Transformer Secondary Voltage**: $V_2$
- **Line-to-Ground Valve Voltage**: $V_3$
- **DC Voltage**

**Power Calculation**

\[
P = \frac{V_3 \cdot \sin(\delta)}{X} \cdot V_1
\]

\[
Q = \frac{V_3 \cdot \cos(\delta) - V_1}{X} \cdot V_1
\]
VSC Synthesis of a Sine Wave

Voltage Waveforms

Ideal Waveform

Simplest Possible Waveform

Acceptable Approximation if Sufficient Steps are Used
The Voltage Sourced Converter
Single Phase, 2-level

Steady DC Voltage Input

VSC

Alternating Voltage Output
VSC: Three Main Classes

- **Complex Transformer + Simple Converters**
  - Reduction in Harmonic Distortion
  - Increased Rating

- **Simple Transformer + Complex, "Multi-level" Converters**

- **Simple Transformer + Simple Converters with PWM**
Complex Transformer + simple converters
Simple Transformer, Simple Converter + PWM

Simple VSC

Output Voltage

Output Voltage, filtered
Multi-Level Converter

Multi-level
VSC

Output Voltage
What is a multi-level converter?

Total Flexibility
VSC Converter: phase arm

DC Transmission System

$\frac{1}{2}U_{dc}$

$U$

VSC Phase Unit

AC Terminal

Line-Neutral voltage (ideal)

$+\frac{1}{2}U_{dc}$

$-\frac{1}{2}U_{dc}$
Semiconductors for VSC

Voltage-Sourced Converters require semiconductors which can carry current in both directions and withstand voltage in the positive direction.

The following types of device have the appropriate properties:

Thyristor derivatives:
- GTO: Gate Turn-Off thyristor
- GCT: Gate Commutated Thyristor (= a GTO with a better gate drive)
- IGCT: Integrated Gate Commutated Thyristor (= a GCT with the gate drive “integrated” into the semiconductor package)

Transistor derivatives:
- BJT: Bipolar Junction Transistor (only for low power and low frequency)
- MOSFET: Metal-Oxide Semiconductor Field Effect Transistor (only for low power)
- IGBT: Insulated Gate Bipolar Transistor
- IEGT: Injection Enhanced Gate Transistor – similar to an IGBT

Do not confuse IGBT and IGCT!!
Basic 2-level inverter
One phase arm

DC Transmission System

\[ \frac{1}{2}U_{dc} \]

\[ + \frac{1}{2}U_{dc} \]

\[ - \frac{1}{2}U_{dc} \]

Line-Neutral voltage

U

VSC Valve V1

VSC Valve V2

=VSC Valve
VSC Valves of the ‘Controllable Voltage Source’ type
Circuit Types
Neutral-point clamped inverter
One phase arm (3 level)
Neutral-point clamped inverter
Three-phase circuit (3 level)
Neutral-point clamped inverter
One phase arm (5 level)

DC Transmission System

$\frac{1}{4}U_{dc}$

$\frac{1}{4}U_{dc}$

$\frac{1}{4}U_{dc}$

$\frac{1}{2}U_{dc}$

Line-Neutral voltage

V1

V2

V3

V4

V5

V6

V7

V8

= Diode Valve

= VSC Valve

U

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Flying Capacitor inverter
One phase arm (3 level)
VSC with series-connected chain link modules
a.k.a. Modular MultiLevel Converter
VSC-HVDC
2 Basic Approaches

Series-Connected IGBTs
✓ Conceptually simple circuit
✗ Requires PWM
✗ High switching losses
✗ Harmonic and EMC problems from PWM

Multi-level circuit
✓ Low switching losses
✓ Easily “scaleable”
✓ Virtually no harmonics
✗ More complex controls

= “Chain-Link” Module
Valve Design
VSC with series-connected half-chain links

Cannot electronically suppress faults on the DC side. Need to open the AC circuit breaker instead.
VSC with series-connected full-chain links

Can suppress faults on the DC side by blocking the chain links (or putting them “in reverse”)
Circuit Topology

- Line reactance (L) split
- Becomes a means of protection

- The number of modules = the number of devices in a conventional circuit
  - Requires twice the number of devices
VSC Valves - Sub-module Components

- IGBT
- Inter Sub-module Connector
- Bypass Switch
Main Components in ‘Half Bridge’

- IGBT (x2)
- Capacitor +ve Test Connection
- Main Terminal 1
- Capacitor -ve Main Terminal
- Thyristor and Clamp
- Bleed Resistor (x2)
- Laminated Bus-Bar
- Capacitor

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Main Components in ‘Full Bridge’

- IGBT (x4)
- Capacitor +ve Test Connection
- Main Terminal 1
- Main Terminal 2
- Capacitor -ve Test Terminal
- Laminated Bus-Bar
- Capacitor
- Bleed Resistor (x2)