MODELING OF HVDC-MMC TRANSMISSION SYSTEM FOR ELECTROMAGNETIC TRANSIENTS

June 21st 2013

Hani SAAD
Ph.D. student

Director: Prof. J. Mahseredjian, École Polytechnique de Montréal, Canada
Co-director: Prof. X. Guillaud, École Centrale de Lille, France

Industrial partner: RTE-France
Co-directors of project: S. Nguefeu and S. Dennetière
Plan:

1. Introduction
2. MMC topology overview
3. MMC models
4. Control system
5. HVDC-MMC model in EMTP-RV
1. Introduction

VSC based HVDC transmission system is expanding rapidly.
The recent Modular Multilevel Converter (MMC) topology offers significant benefit compared to previous VSC technologies

Advantages of Modular Multilevel Converter (MMC):
• Low frequency modulation
• Lower transient peak voltages on IGBT, which will lead to a lower losses
• Very low THD, hence no need for High-pass filters or very small size
• Modular structure, scalable to different power and voltage levels
2. MMC topology overview

At normal operation, S1 and S2 are complementary.

- The sub-module consist of two states:
  - $S_u \rightarrow \text{on}$ and $S_l \rightarrow \text{off}$
  - $S_u \rightarrow \text{off}$ and $S_l \rightarrow \text{on}$
3. MMC models

Depending on the type of study different type of modeling are presented:
- Model 1 – Model based on nonlinear IGBT models
- Model 2 – Model based on simplified switchable resistance
- Model 3 – Switching Function of Arm (SF-arm)
- Model 4 – Average Value Model of MMC (AVM-MMC)
3. MMC models

Model 1 - Models based on nonlinear IGBT models

- In this case IGBT/diode are modeled by nonlinear resistor and an ideal switch.

![Diagram of IGBT model]

Advantages:
- Very easy to achieve, it preserve the main structure of the IGBT
- The V-I curve of the IGBT/diode is modeled.

Inconvenient:
- Computation time is high
3. MMC models

Total IGBT/diode in the HVDC-MMC 401 Level system: 
2(IGBT/SM) * 400(SM/arms) * 2(arms/phase) * 3(phases) * 2(converters) 
= 9 500 IGBTs/diodes
3. MMC models

Model 2 - Models based on simplified switchable resistance
IGBT and diodes are represented by two-value resistors (Ron and Roff). A reduction is performed to reduce the number of electrical nodes that describe converter.

Advantages:
➢ Reduction of electrical nodes to 3 nodes, without losing the variable information of each SM.
➢ Low computation time

Inconvenient:
➢ The model is hard-coded, hence the user has no more access to SM circuits
➢ The V-I curve of IGBT/diode is not modeled
3. MMC models

**MMC Model 2**

**DLL block**

**Fortran 95 code**

Detailed Equivalent-Circuit-based Model (DECM)

MMC 401Levels

Capa.

Voltages

Gate

signals

Current

Arms
3. MMC models

Model 3 – Switching function of Arm

- Each MMC arm are modeled as controlled current and voltage sources for ON/OFF states and half diode bridge for Blocked state.
- These models can be used to study harmonics generated and control system which account for energy regulation of MMC-arm.
- It suppose that Capacitor voltages balancing control operate correctly

Assuming that: $\bar{v}_{C1} = \bar{v}_{C2} = ... = \bar{v}_{Ci} = \frac{v_{Ctot}}{N}$

\[
\begin{align*}
 v_{arm} &= s_n \cdot v_{Ctot} + (NR_{ON}) i_{arm} \\
 i_{Ctot} &= s_n \cdot i_{arm}
\end{align*}
\]

where: $s_n = \left( \frac{\sum_{i=1}^{N} S_i}{N} \right)$

$S_i = 1 \rightarrow$ For ON state
$S_i = 0 \rightarrow$ For OFF state
3. MMC models

- MMC Model 3
- DLL block
- Fortran 95 code
3. MMC models

Model 4 – AVM (Average Value Model)

- The AC and DC side characteristics are modeled as controlled current and voltage sources.
- These models can be used to study harmonics generated by such converters.
- AVM model suppose that internal variables of MMC (Capacitor voltages and current of each arm) are controlled correctly.

AC side:

\[ e_{\text{conv}j} = \frac{L_{\text{arm}}}{2} \frac{di_j}{dt} - v_j \quad i = a, b, c \]

\[ e_{\text{conv}j} = v_{\text{ref}j} \frac{V_{dc}}{2} \]

DC side:

\[ P_{AC} = P_{DC} \]

\[ I_{dc} = \frac{1}{2} \sum_{j=a,b,c} v_{\text{ref}j} i_j \]
3. MMC models

MMC Model 4
4. Control system

**Basic idea:**
By linearizing the power equation, active and reactive power can be decoupled, thus:
- Regulating the phase angle -> active power is controlled
- Regulating the voltage amplitude -> reactive power is controlled

\[
\begin{align*}
\mathbf{P}_R &= \frac{V_S V_R}{X} \sin(\delta) \\
\mathbf{Q}_R &= \frac{V_S V_R \cos(\delta) - V_R^2}{X}
\end{align*}
\]

\( \iff \mathbf{P}_R = \text{fct}(\delta) \)
\( \iff \mathbf{Q}_R = \text{fct}(V_R) \)

However the control system is much more complex

**Upper control (VSC control)**
Since MMC topology is a VSC type, the generic Outer/Inner Control can be used

**Lower control (MMC control)**
Controller related to the MMC topology, in order to control internal variables
4. Control system

Control system structure

AC side

Yg/Δ

measurements

Outer Control
P/Q/Vdc

Inner Control

CBA

MMC

gate signal

DC side

NLC
Modulation

CCSC

\[ \hat{e}_{abc} \]

\[ s_{up_{abc}}, s_{low_{abc}} \]

\[ \hat{v}_{up_{abc}}, \hat{v}_{low_{abc}} \]
5. HVDC-MMC model in EMTP-RV

HVDC link modeled in EMTP-RV

NB: This test case is included in the examples folder of EMTP-RV 2.5
5. HVDC-MMC model in EMTP-RV

Section related with Type of model and circuit configuration

Section related with electrical parameters of the MMC station

Section related with the start-up sequence if checked
5. HVDC-MMC model in EMTP-RV

Section related with the control type

Section related with protection system
5. HVDC-MMC model in EMTP-RV

Subsystem structure of the VSC-MMC station

AC side

Power Transformer

MMC model 1 to 4

DC side

Control and Protection System

Scope:

Voltage

Current

Input

Output

Upper Level Control

Lower Level Control

MMC 21 Levels

Control and Protection System

Acquisition System
5. HVDC-MMC model in EMTP-RV

MMC model comparisons under AC fault

Simulation configuration:
MMC-401Level ($N = 400$SMs/arm)
Time-Step = 10us
Three-phase to ground fault of 200ms after 1sec of simulation

MMC-2 phase A current: $i_a$

MMC-2 phase A voltage: $v_a$

MMC-2 dc current: $I_{dc}$

MMC-2 dc voltage: $V_{dc}$
5. HVDC-MMC model in EMTP-RV

**MMC model comparison under DC fault**

**Simulation configuration:**
- MMC-401Level \((N = 400\text{SMs/arm})\)
- Time-Step = 10us
- Permanent Pole-to-pole DC fault at 1.9sec of simulation

![Graph showing MMC-1 ac current: \(i_a\)](image1)

![Graph showing MMC-1 dc current: \(I_{dc}\)](image2)

![Zoomed graph showing MMC-1 dc current: \(I_{dc}\)](image3)
5. HVDC-MMC model in EMTP-RV

**Computation performances**
- 401-levels MMC based HVDC link was tested for 1sec simulation.
- The simulation time is compared for all models
- The best computing performance is given by Model 4

<table>
<thead>
<tr>
<th>Model</th>
<th>Time step (μs)</th>
<th>Computation time (s) in function of SMs/arm</th>
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6. References


Questions?