Réseau de transport d'électricité

POLYTECHNIQUE MONTRÉAL

LE GÉNIE EN PREMIÈRE CLASSE

MODELING OF HVDC-MMC TRANSMISSION SYSTEM FOR ELECTROMAGNETIC TRANSIENTS

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Plan:

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

1. Introduction

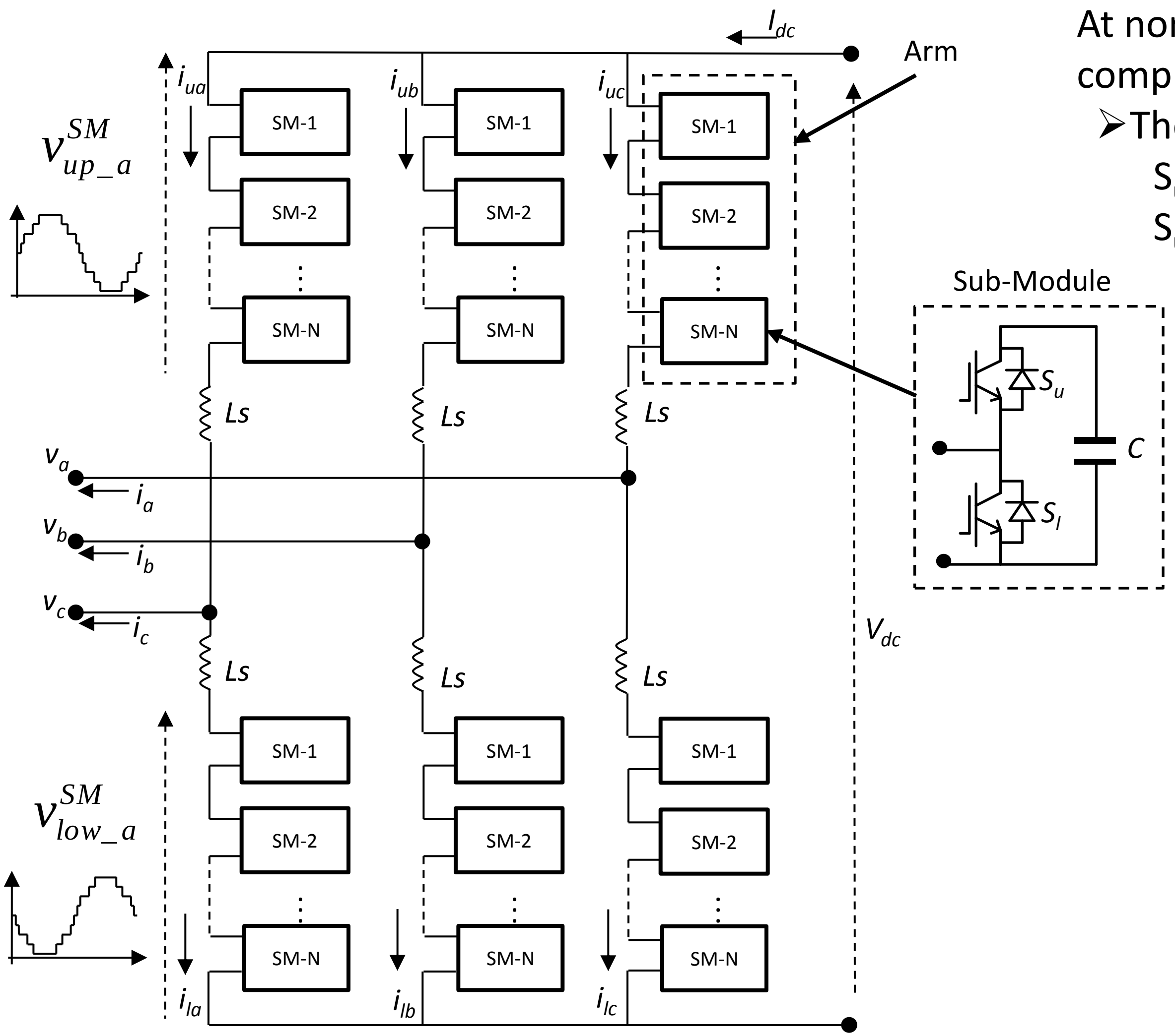
VSC based HVDC transmission system is expanding rapidly.

The recent Modular Multilevel Converter (MMC) topology offers significant benefit compared to previous VSC technologies

Advantages of Modular Multilevel Converter (MMC):

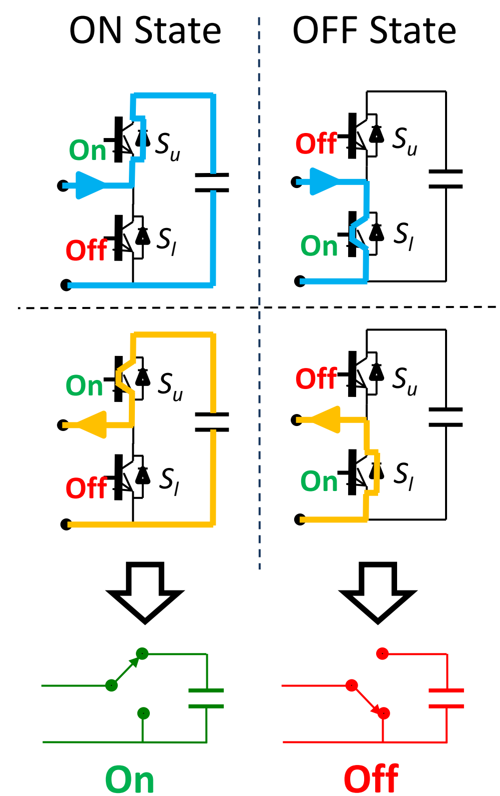
- Low frequency modulation
- Lower transient peak voltages on IGBT, which will lead to a lower losses
- Very low THD, hence no need for High-pass filters or very small size
- Modular structure, scalable to different power and voltage levels

2. MMC topology overview



At normal operation, S1 and S2 are complementary

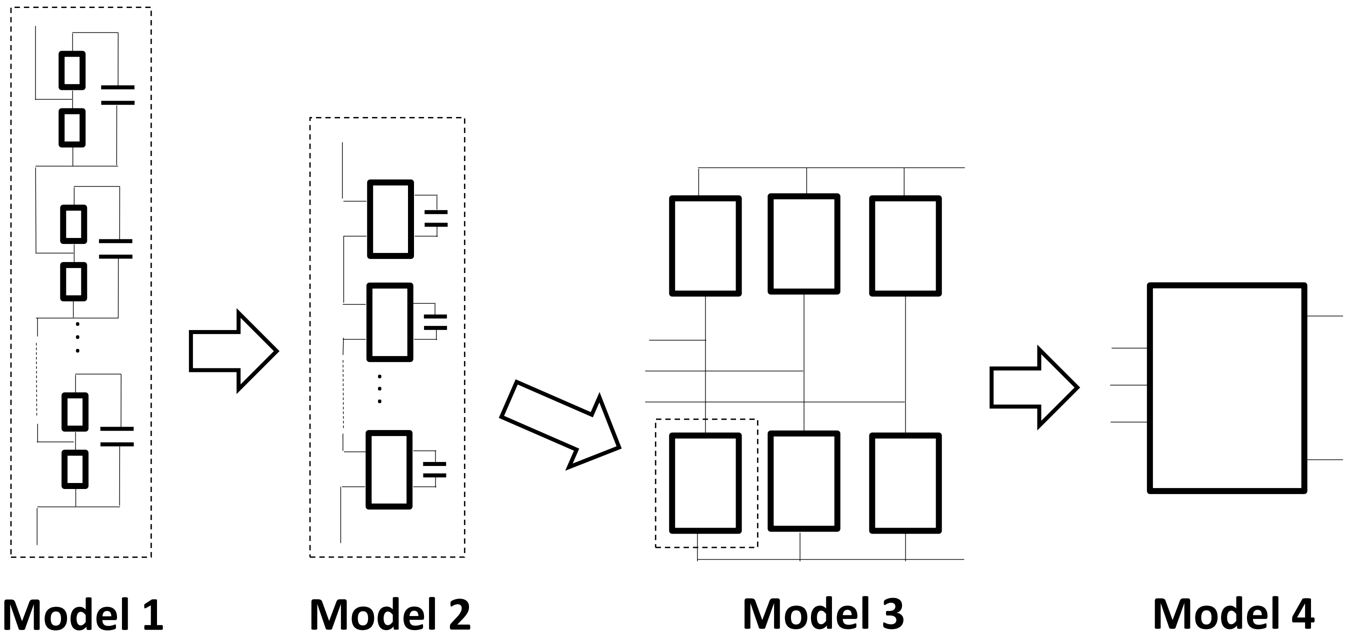
- The sub-module consist of two states:
  - S_u->on and S_l->off
  - S_u->off and S_l->on



3. MMC models

Depending on the type of study different type of modeling are presented:

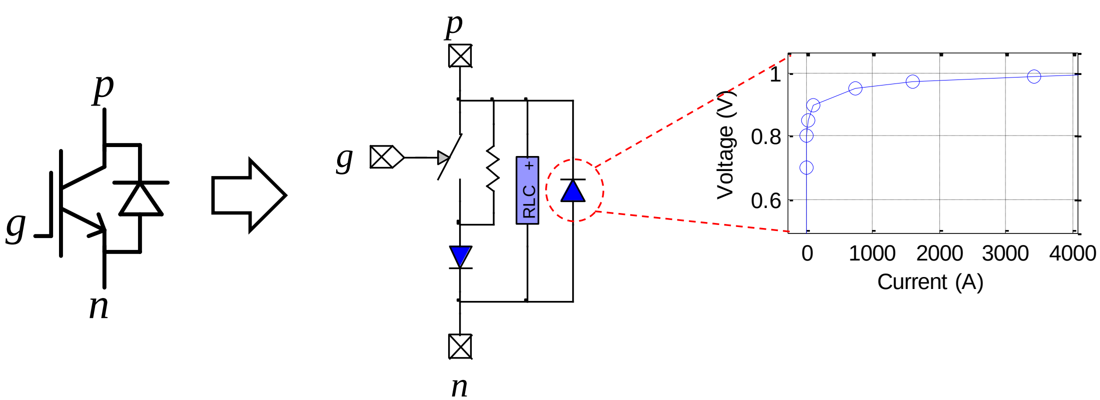
- Model 1 – Model based on nonlinear IGBT models
- Model 2 – Model based on simplified switchable resistance
- Model 3 – Switching Function of Arm (SF-arm)
- Model 4 – Average Value Model of MMC (AVM-MMC)

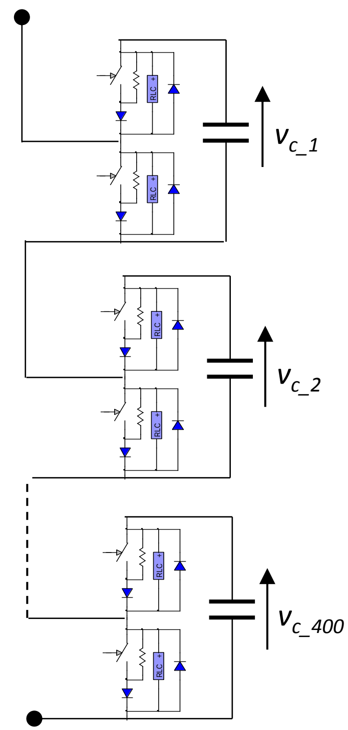


3. MMC models

Model 1 - Models based on nonlinear IGBT models

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





<u>Advantages:</u>

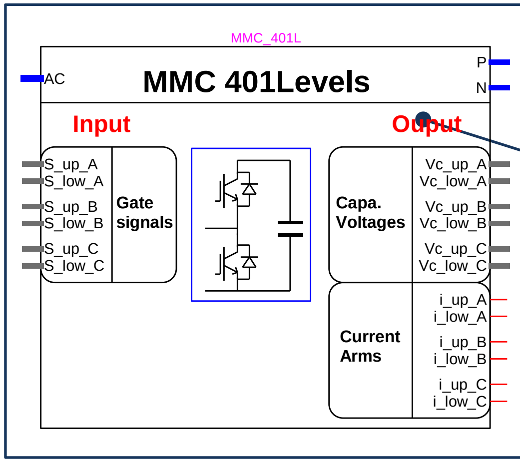
➢Very easy to achieve, it preserve the main structure of the IGBT

➢The V-I curve of the IGBT/diode is modeled.

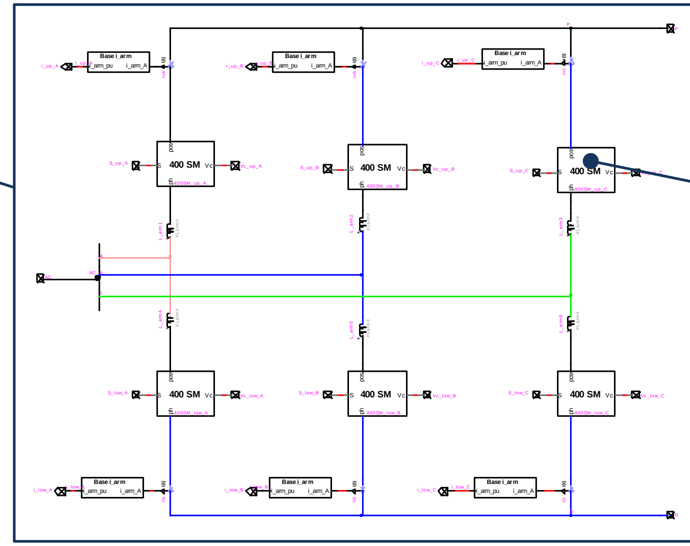
<u>Inconvenient:</u>

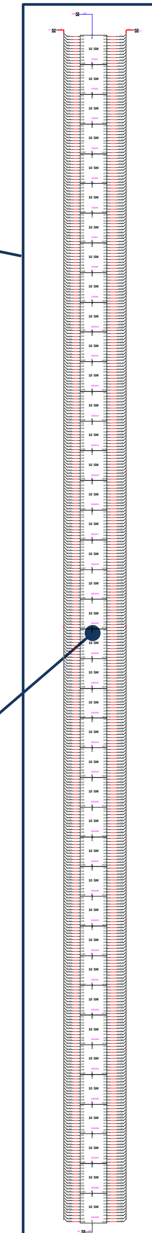
➢Computation time is high

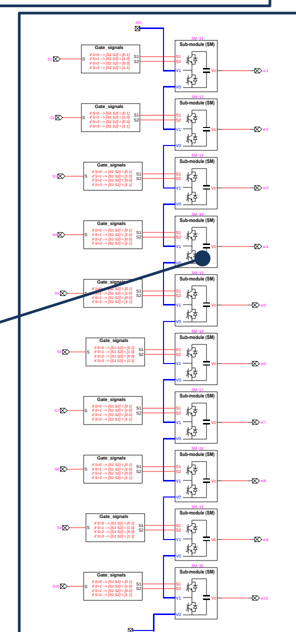
3. MMC models



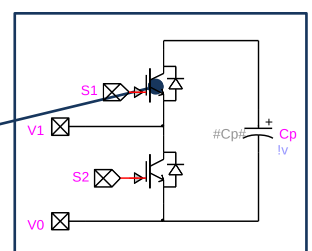
VSC-MMC 401 levels
Model 1

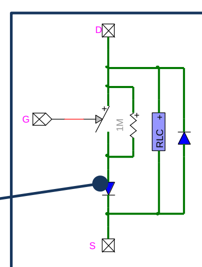


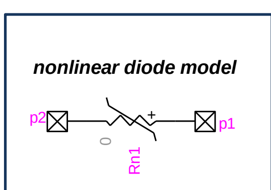




Total IGBT/diode in the HVDC-MMC 401 Level system:
2(IGBT/SM)*400(SM/arms)*2(arms/phase)*3(phases)*2(converters)
= 9 500 IGBTs/diodes



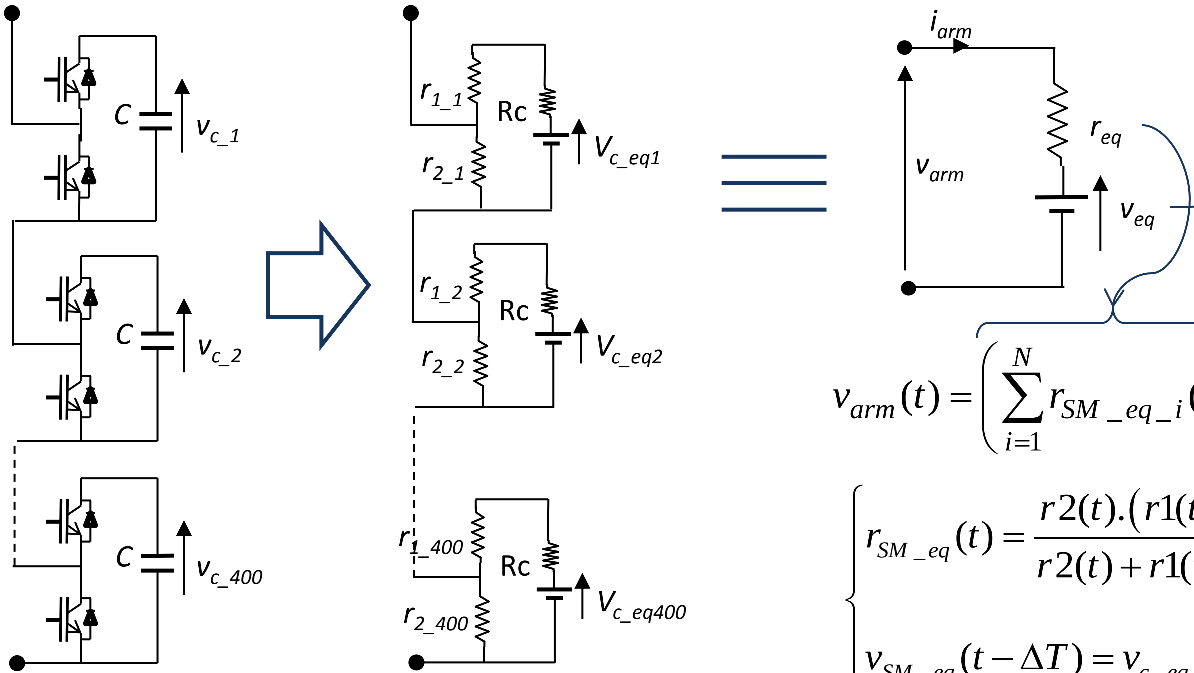




3. MMC models

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.



$$v_{arm}(t) = \left(\sum_{i=1}^{N} r_{SM\_eq\_i}(t)\right).i_{arm}(t) + \sum_{i=1}^{N} v_{SM\_eq\_i}(t-\Delta T)$$

$$\begin{cases} r_{SM\_eq}(t) = \dfrac{r2(t).\left(r1(t)+R_c\right)}{r2(t)+r1(t)+R_c)} \\ v_{SM\_eq}(t-\Delta T) = v_{c\_eq}(t-\Delta T).\left(\dfrac{r2(t)}{r2(t)+r1(t)+R_c}\right) \end{cases}$$

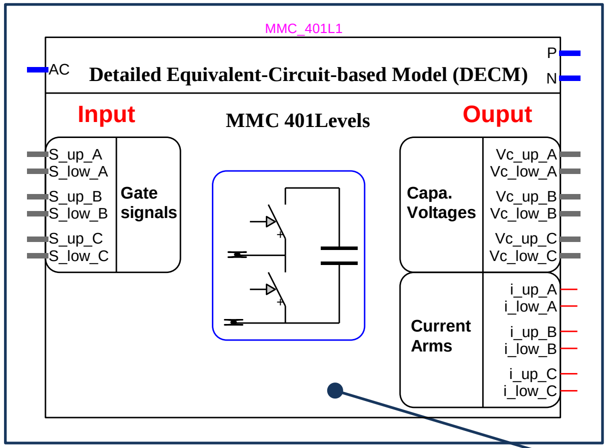
Advantages:

- Reduction of electrical nodes to 3 nodes, without loosing the variable information of each SM.
- Low computation time

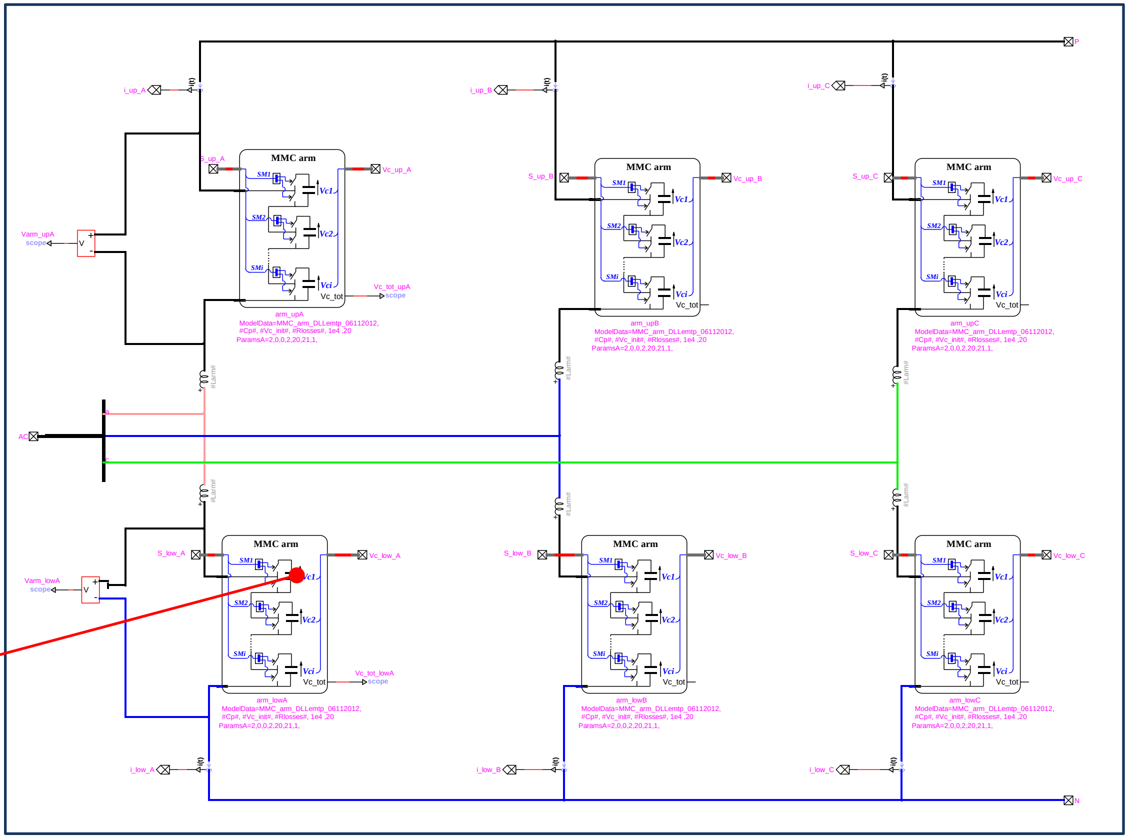
Inconvenient:

- 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

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

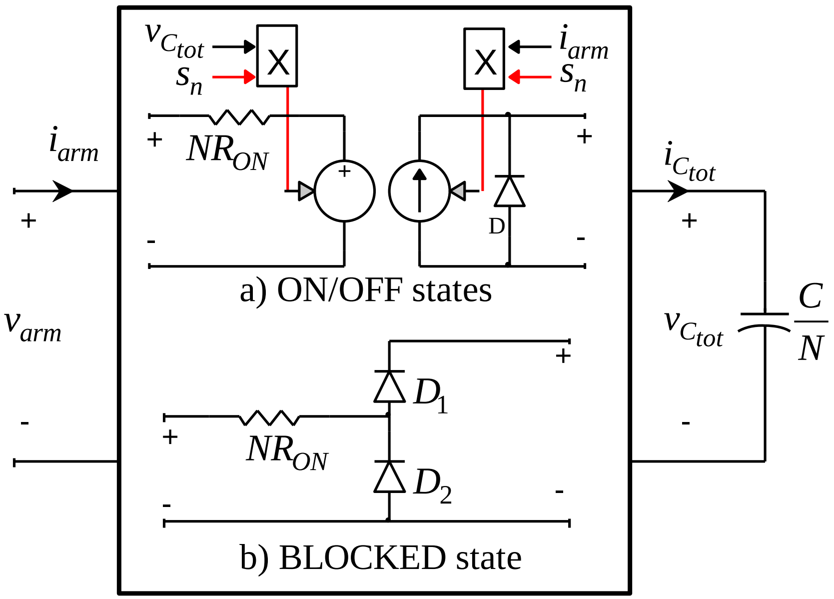
Assuming that: $\bar{v}_{C_1} = \bar{v}_{C_2} = \ldots = \bar{v}_{C_i} = \frac{v_{C_{tot}}}{N}$

$$\begin{cases} v_{arm} = s_n . v_{C_{tot}} + \left(NR_{ON}\right) i_{arm} \\ i_{C_{tot}} = s_n . i_{arm} \end{cases}$$

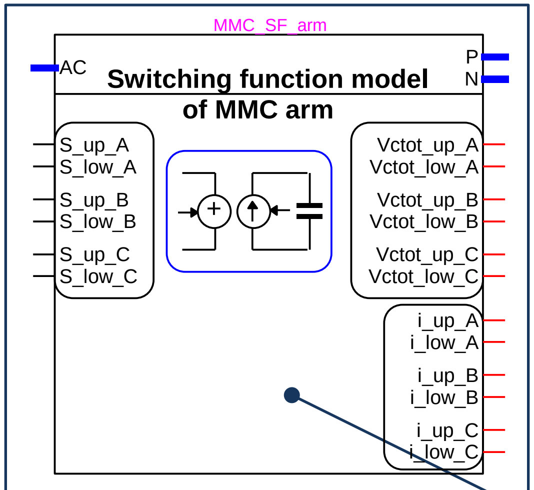
where: $s_n = \frac{\left(\sum_{i=1}^{N} S_i\right)}{N}$

$S_i = 1$ -> For ON state

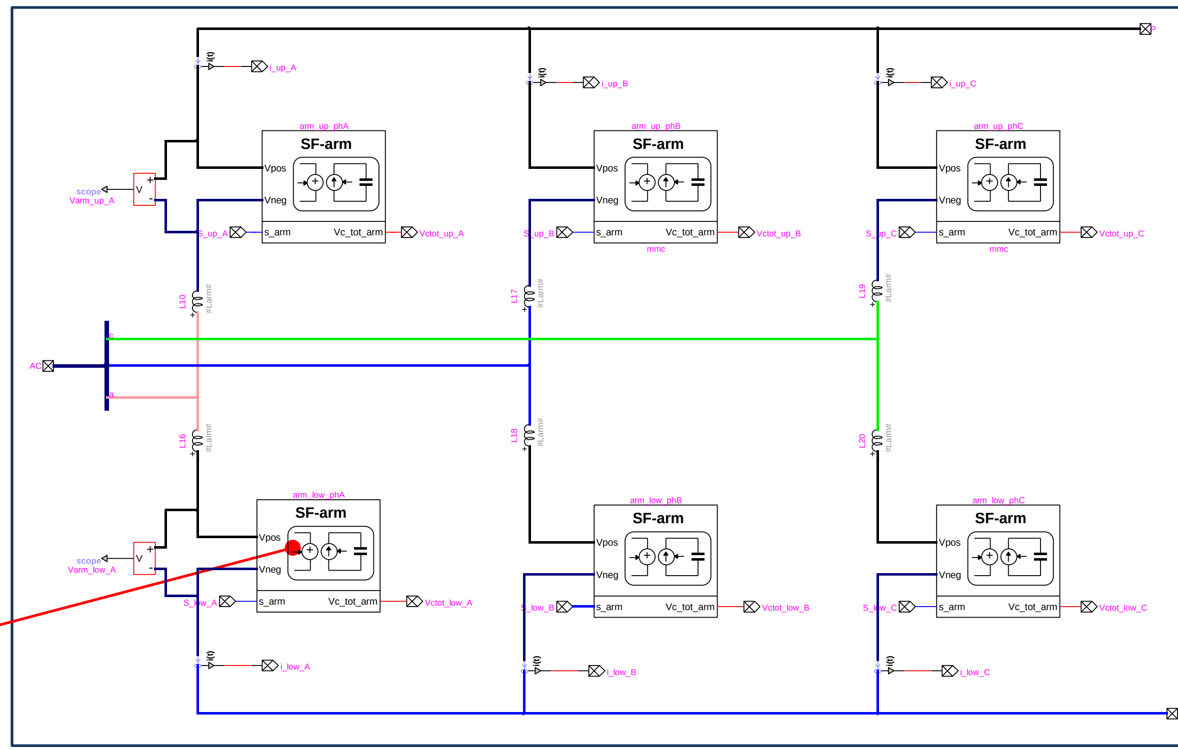
$S_i = 0$ -> For OFF state



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:

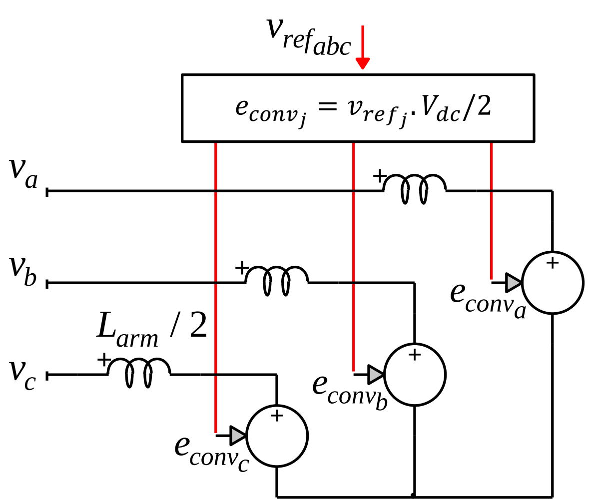
$$e_{conv_j} = \frac{L_{arm}}{2}\frac{di_j}{dt} - v_j \qquad i = a, b, c$$

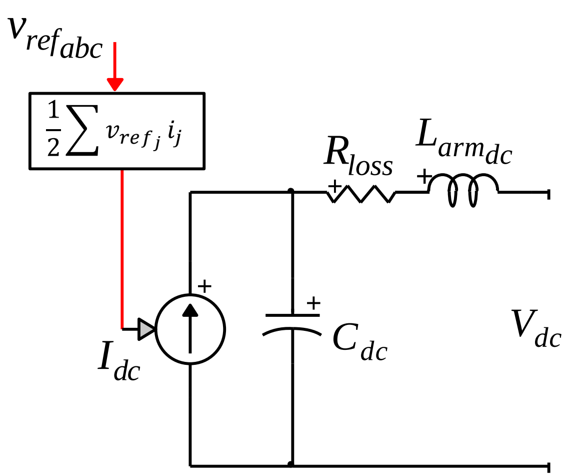
$$e_{conv_j} = v_{ref_j}\frac{V_{dc}}{2}$$

DC side:

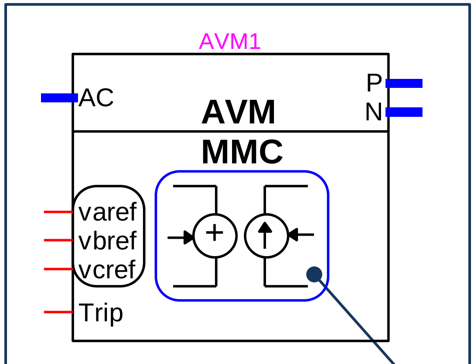
$$P_{AC} = P_{DC}$$

$$I_{dc} = \frac{1}{2}\sum_{j=a,b,c} v_{ref_j}\, i_j$$

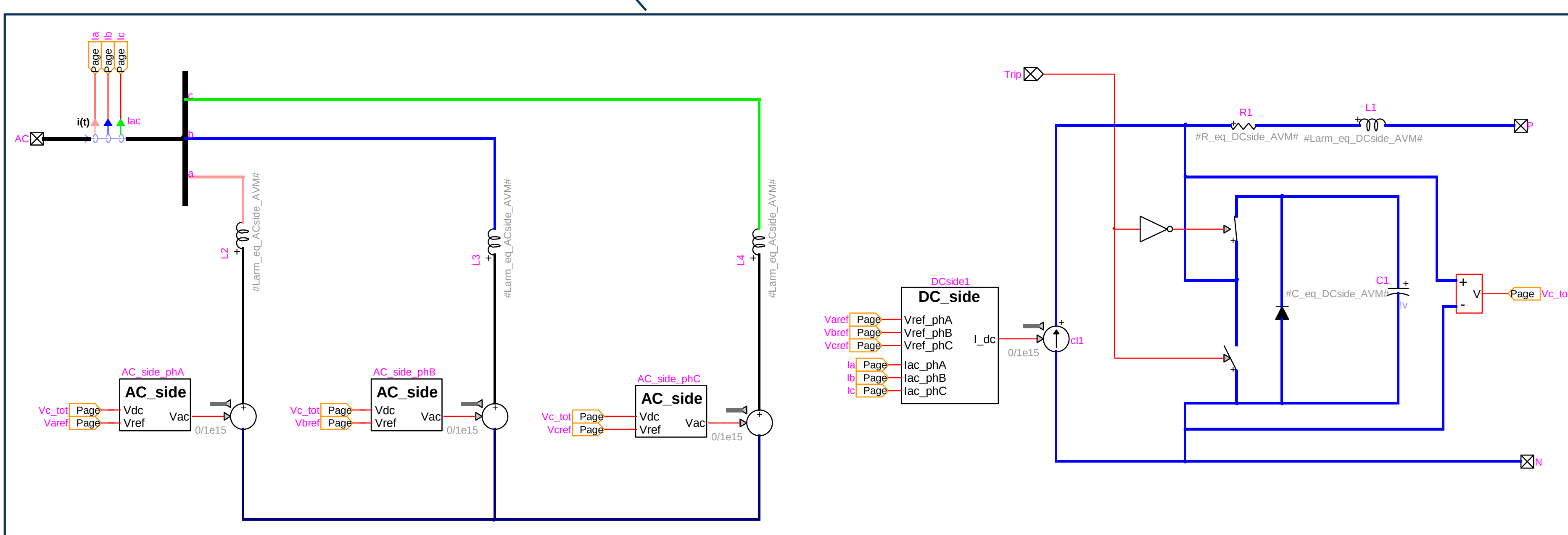




3. MMC models



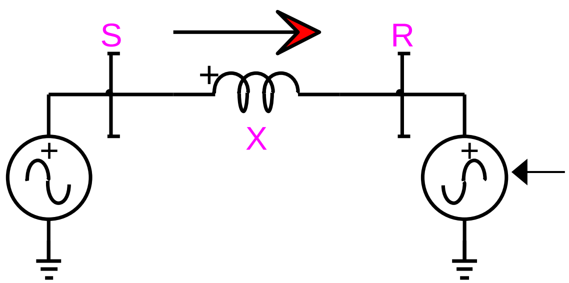
MMC Model 4



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



$$\begin{cases} P_R = \dfrac{V_S V_R}{X}\sin(\delta) \\ Q_R = \dfrac{V_S V_R \cos(\delta) - V_R^2}{X} \end{cases} \qquad \begin{matrix} \Leftrightarrow P_R = fct(\delta) \\ \Leftrightarrow Q_R = fct(V_R) \end{matrix}$$

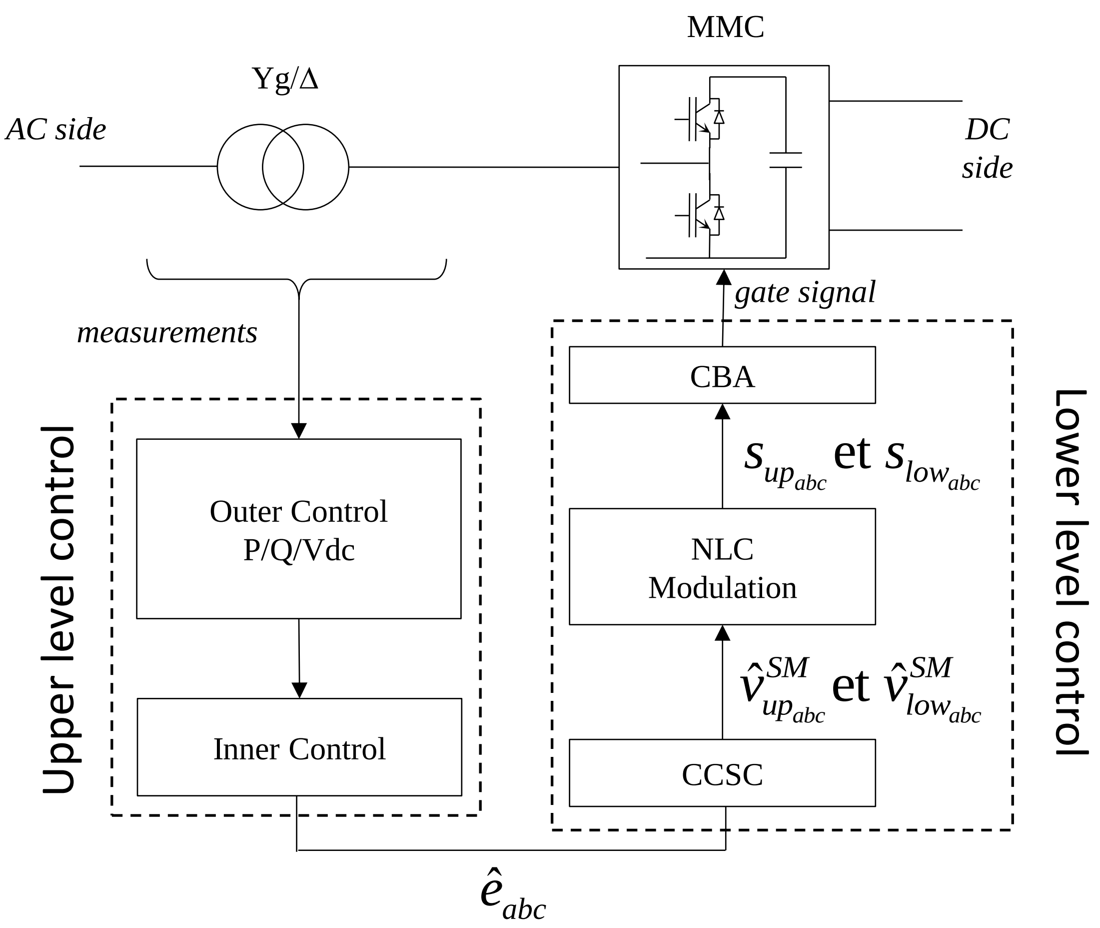
However the control system is much more complex

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

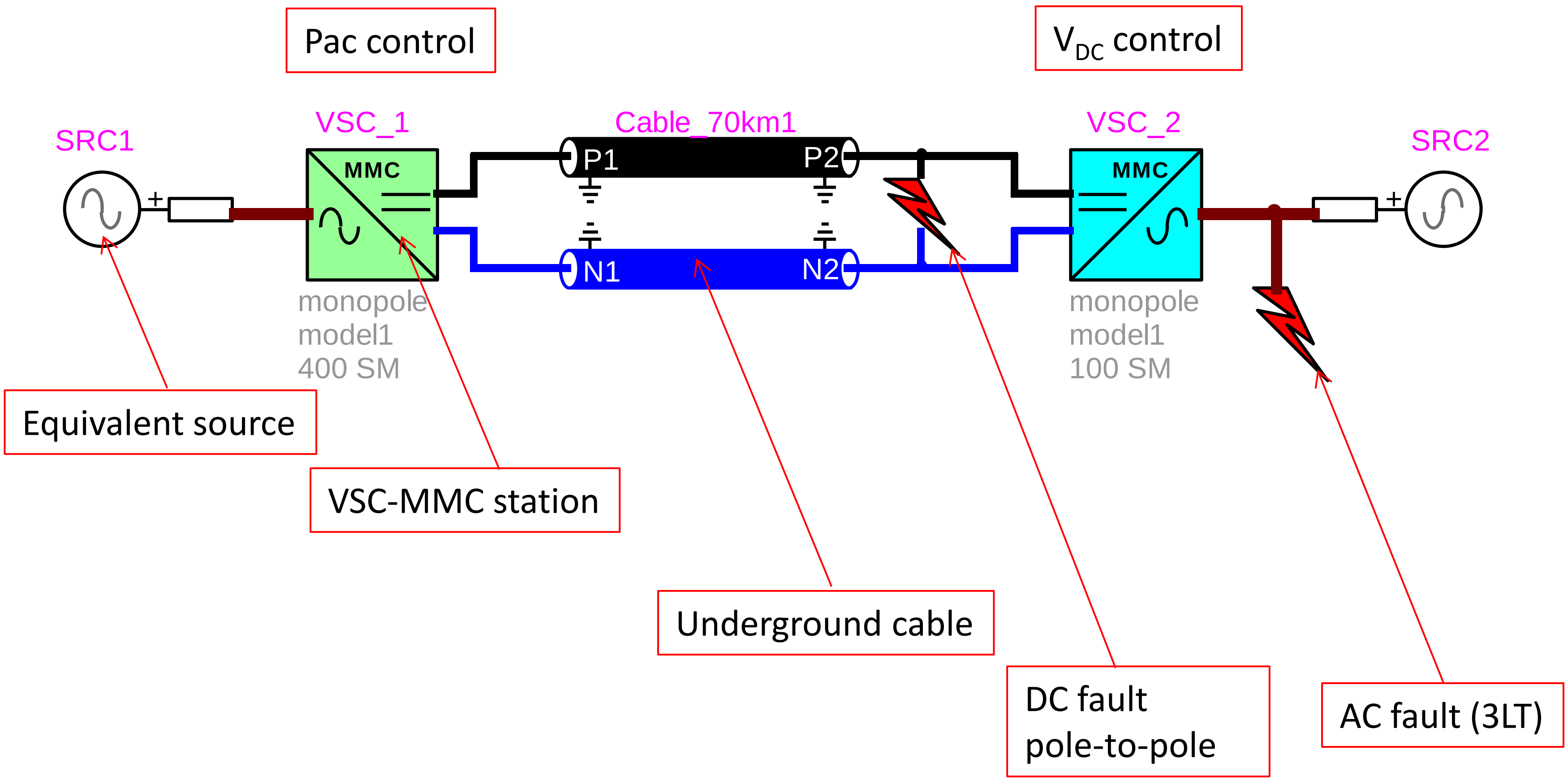
4. Control system

Control system structure



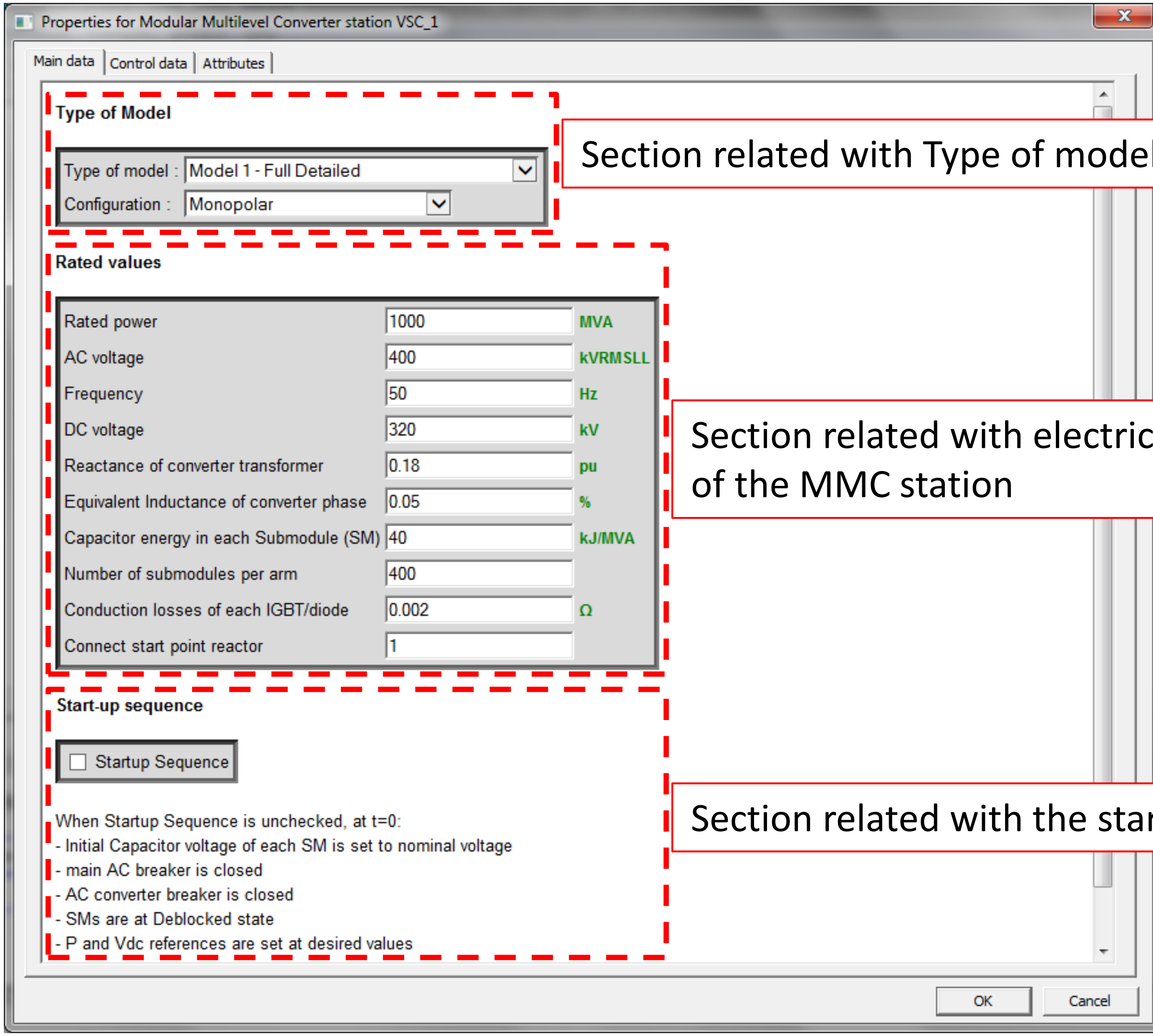
5. HVDC-MMC model in EMTP-RV

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

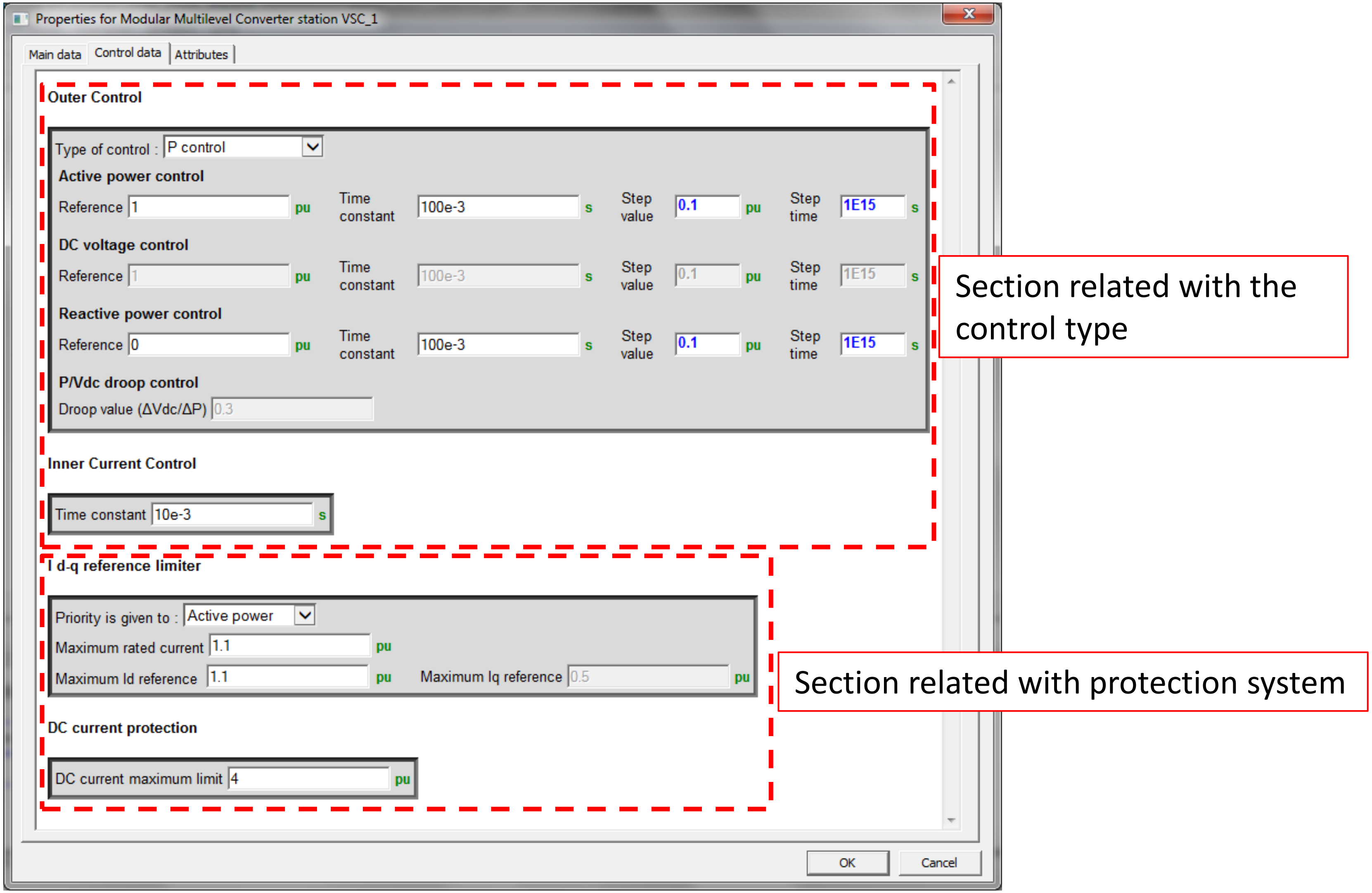


Section related with Type of model and circuit configuration

Section related with electrical parameters of the MMC station

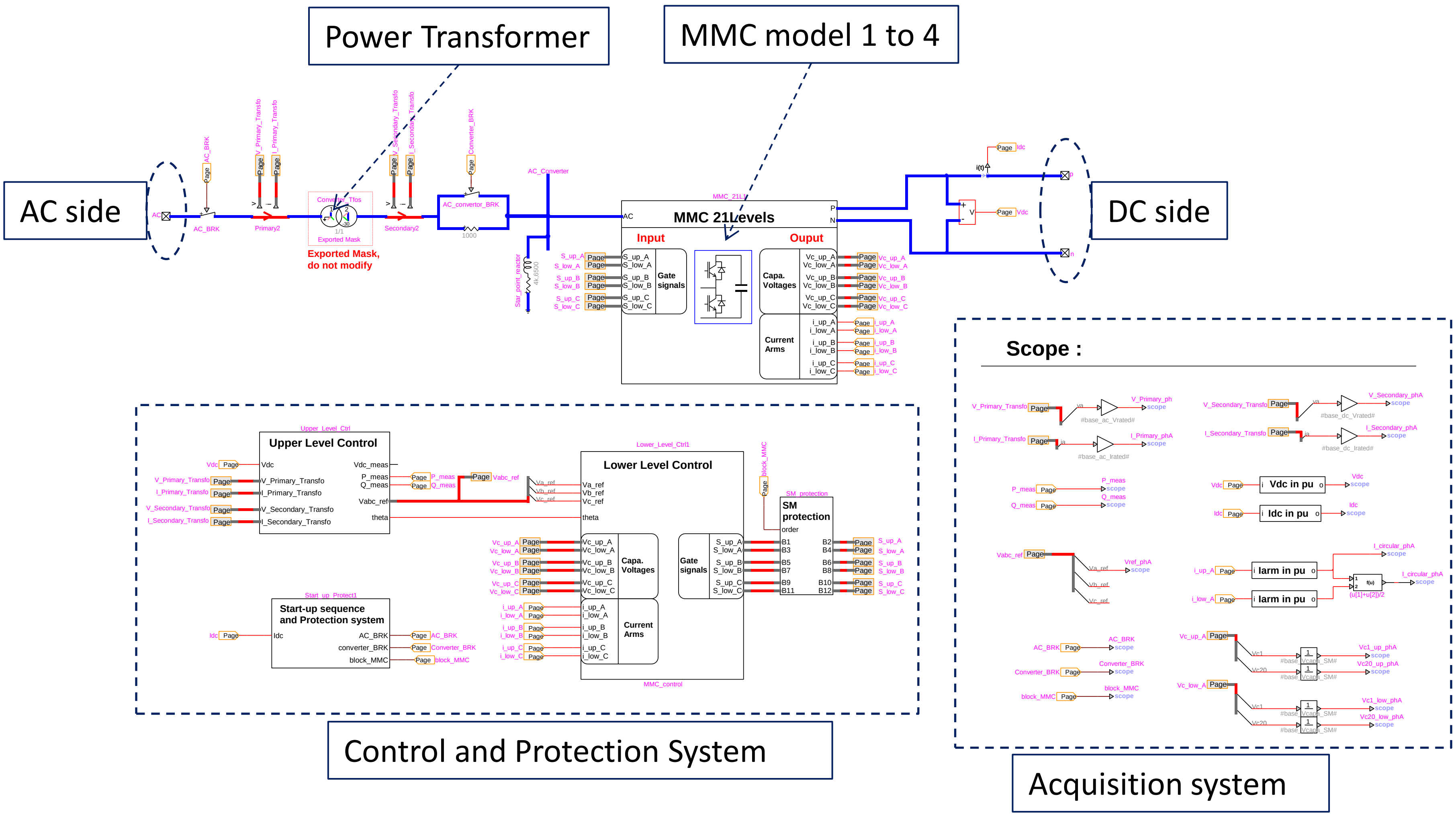
Section related with the start-up sequence if checked

5. HVDC-MMC model in EMTP-RV



5. HVDC-MMC model in EMTP-RV

Subsystem structure of the VSC-MMC station



5. HVDC-MMC model in EMTP-RV

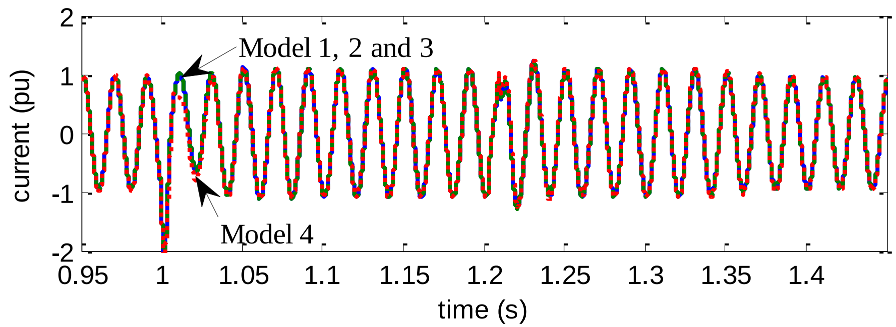
MMC model comparisons under AC fault

Simulation configuration:

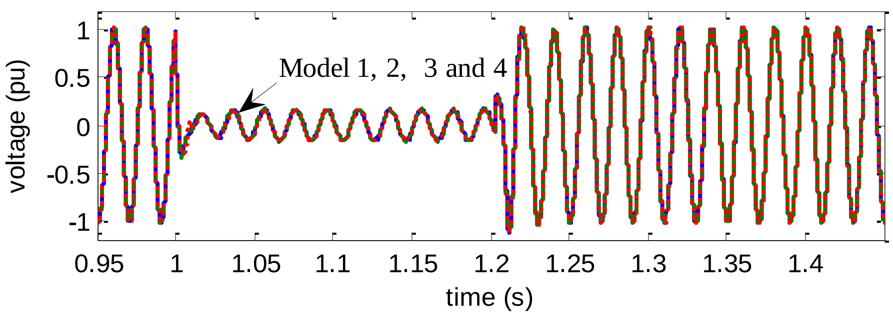
MMC-401Level (N = 400SMs/arm)

Time-Step = 10us

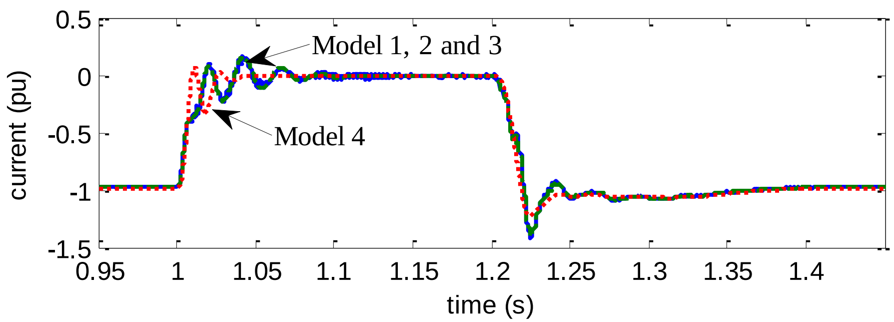
Three-phase to ground fault of 200ms after 1sec of simulation



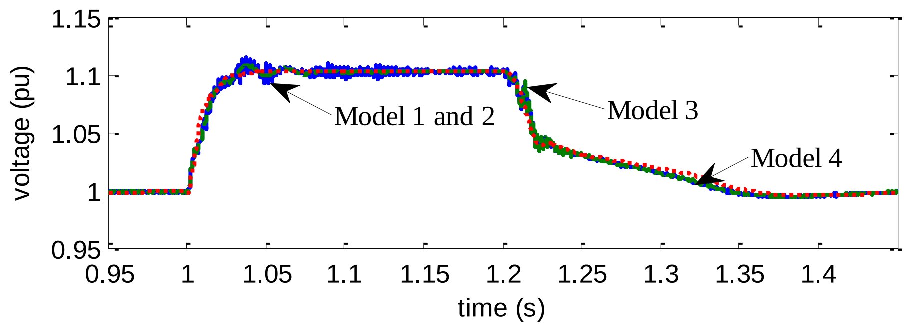
MMC-2 phase A current: i_a



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

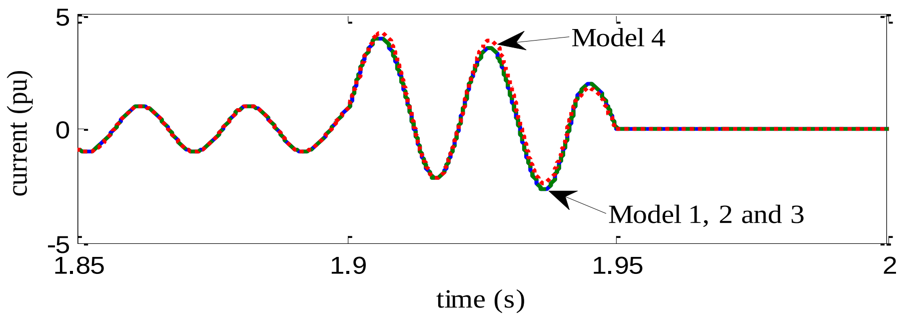
MMC model comparison under DC fault

Simulation configuration:

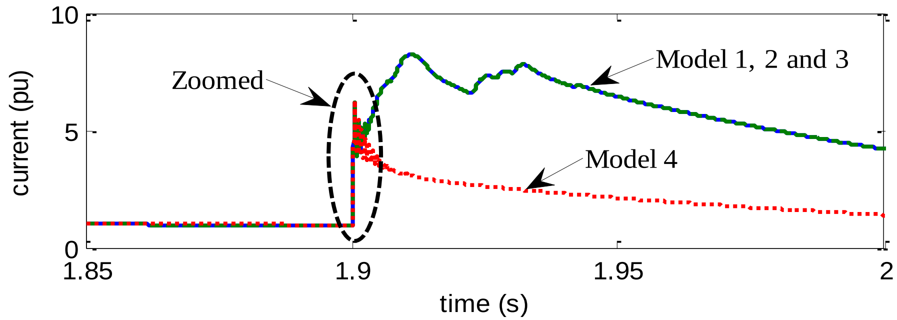
MMC-401Level (*N* = 400SMs/arm)

Time-Step = 10us

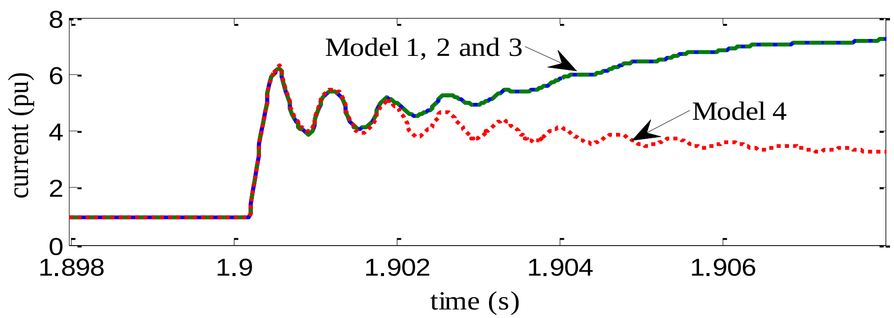
Permanent Pole-to-pole DC fault at 1.9sec of simulation



MMC-1 ac current: i_a



MMC-1 dc current: I_{dc}



Zoomed MMC-1 dc current: I_{dc}

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

Model	Time step (µs)	Computation time (s) in function of SMs/arm			
		20	50	100	400
# 1	10	258	822	2,106	13,459
# 2	10	37	65	114	441
# 3	10	18	18	18	18
# 4	10	15	15	15	15
# 4	100	2	2	2	2

6. References

- Saad H., Dennetière S., Mahseredjian J., Delaru P., Guillaud X., Peralta J., Nguefeu S., “Modular multilevel converter models for electromagnetic transients,” submitted to IEEE Trans. on Power Delivery, TPWRD-00396-2013
- Saad H., Dufour C, Dennetière S., Mahseredjian J., Nguefeu S., “Real Time simulation of MMCs using the State-Space Nodal Approach,” accepted in *IPST 2013, International Power System Transient Conference*
- Saad, H.; Peralta, J.; Dennetiere, S.; Mahseredjian, J.; Jatskevich, J. and al, "Dynamic Averaged and Simplified Models for MMC-Based HVDC Transmission Systems," Power Delivery, IEEE Transactions on , vol.PP, no.99, pp.1,10
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- Peralta J., Saad H., Dennetiere, S., Mahseredjian, J., "Dynamic performance of average-value models for multi-terminal VSC-HVDC systems," *Power and Energy Society General Meeting, 2012 IEEE*, pp. 1-8, 22-26 July 2012

Questions?