Realization of User-Defined HVDC Converter Models for RTDS using Simulink Real-Time Embedded Coder

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11th Oct 2018 RTDS European User's Group Meeting

Outlines

- Reason
  - Why user-defined MMC model
- Development process
  - Half-bridge MMC
  - Switching function model
  - Realization in Matlab/Simulink
- Validation of user-defined model against MMC5 model
  - Three-Phase-to-Ground AC Fault
  - Pole-to-pole DC Fault
- Conclusion

User-defined MMC model

MMC models from library:

- Processor based model
  - MMC5
  - CHAINV5
- GTFPGA based model
  - The Unified Model (U5)
  - The Generic Model (GM)

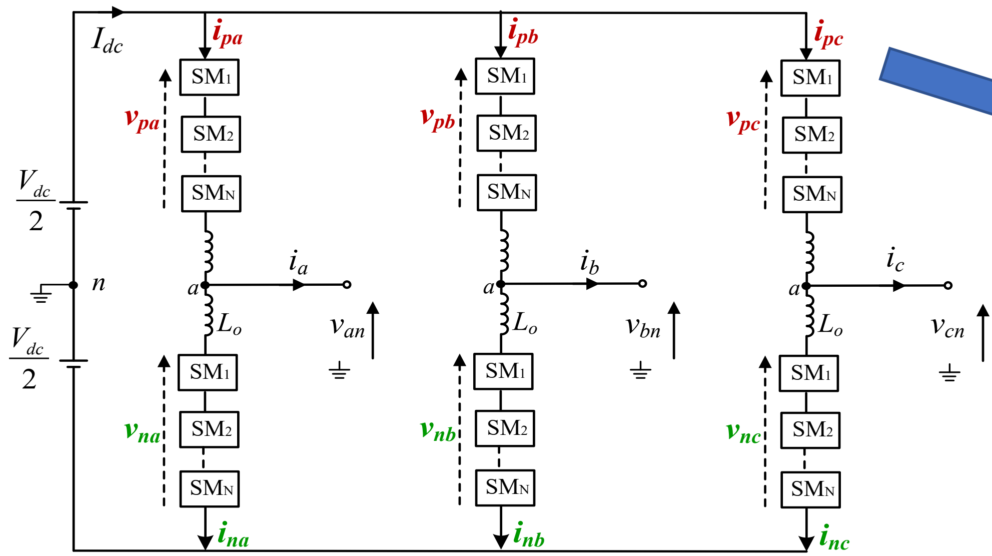
User-defined MMC model:

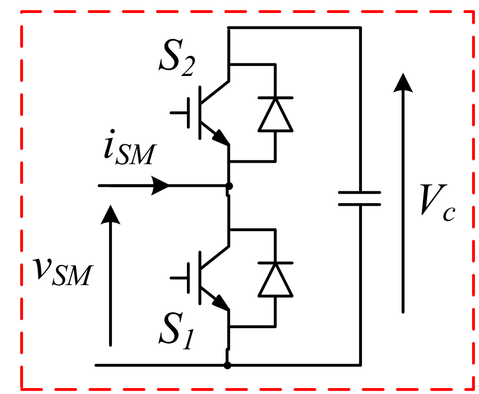
- Flexibility
  - Modelling methods
  - Topologies
  - Configurations
  - Parameters
  - Control strategies
  - Processor assignment

A user-defined processor-based half-bridge MMC model is developed.

Simulation Challenges of MMC

- Large number of SM per arm – modular design & good scalability
- Generate near sinusoidal AC output using low switching frequency





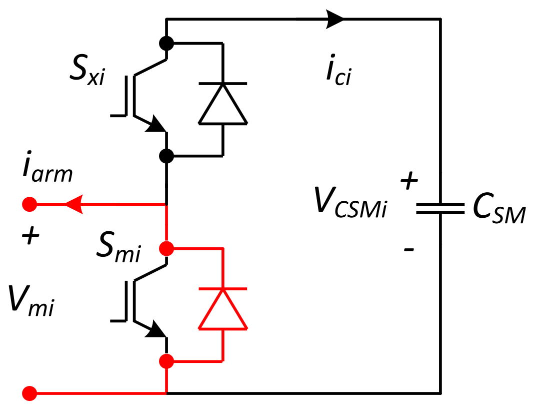
Detailed Model

Switches → Nodes → Matrix → **Simulation challenges**

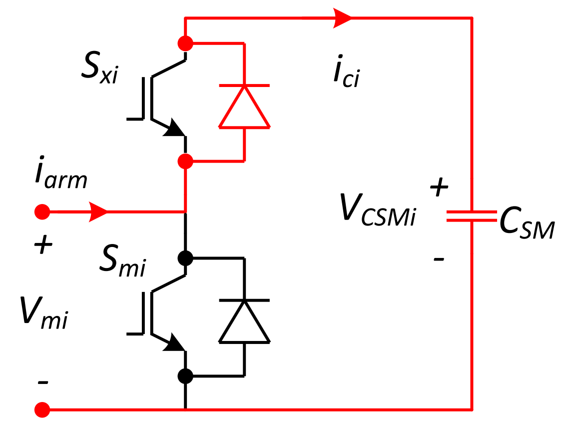
Switching Function Model

- The semiconductor switching devices are represented by ideal switches, where the ON and OFF states are denoted by 1 and 0 respectively.
- Capacitor voltage and current dynamics are expressed in terms of switching functions *Sxi*:

$$v_{mi}(t) = s_{xi} V_{CSMi}(t) \qquad i_{ci}(t) = s_{xi} I_{arm}(t)$$



Bypass



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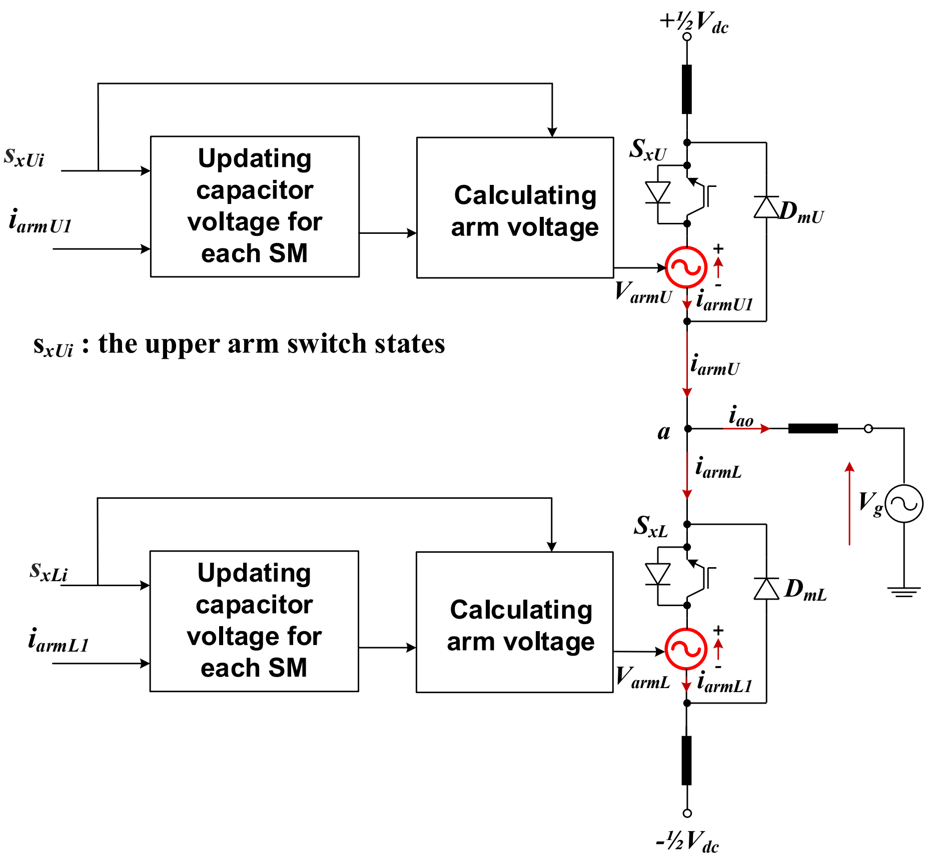
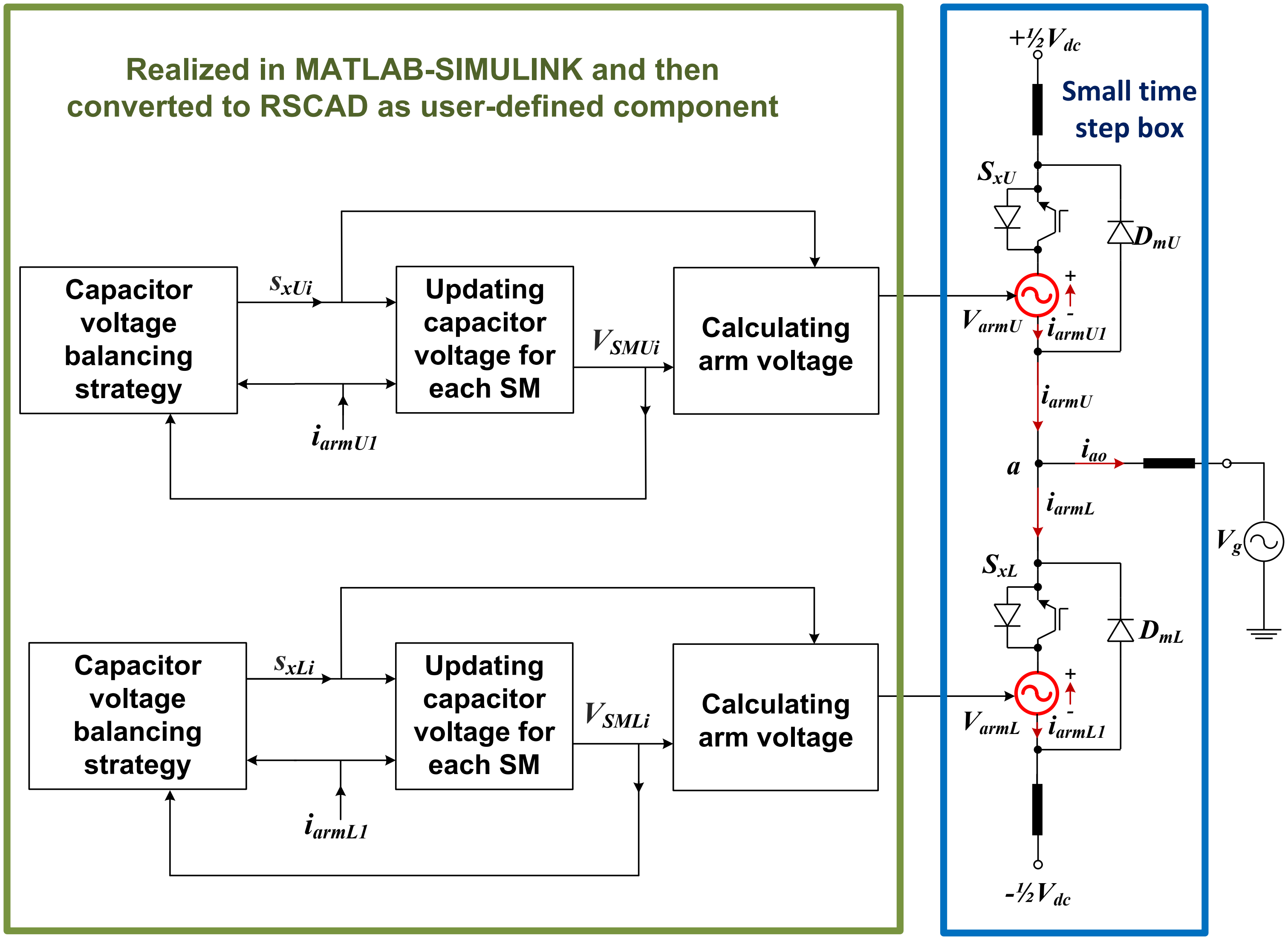
Switching Function Model

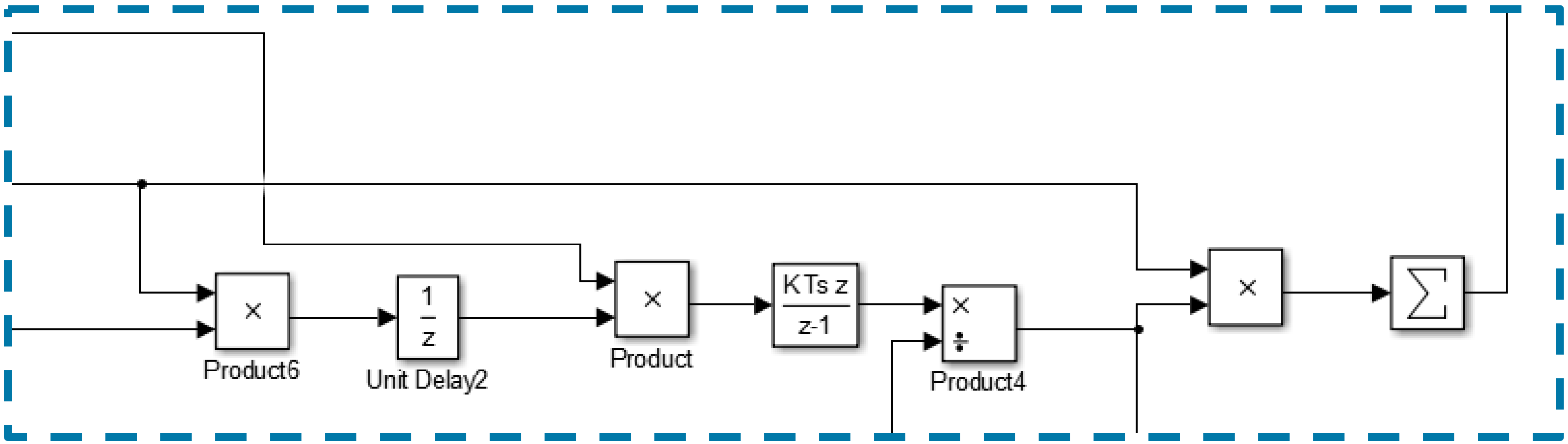
- At each time step, the capacitor voltages are updated and arm voltage calculated.
- Simulation speed increased.
- For dealing with converter blocking state, internal diodes and switches are added at each arm.



Switching Function Model



MATLAB/SIMULINK



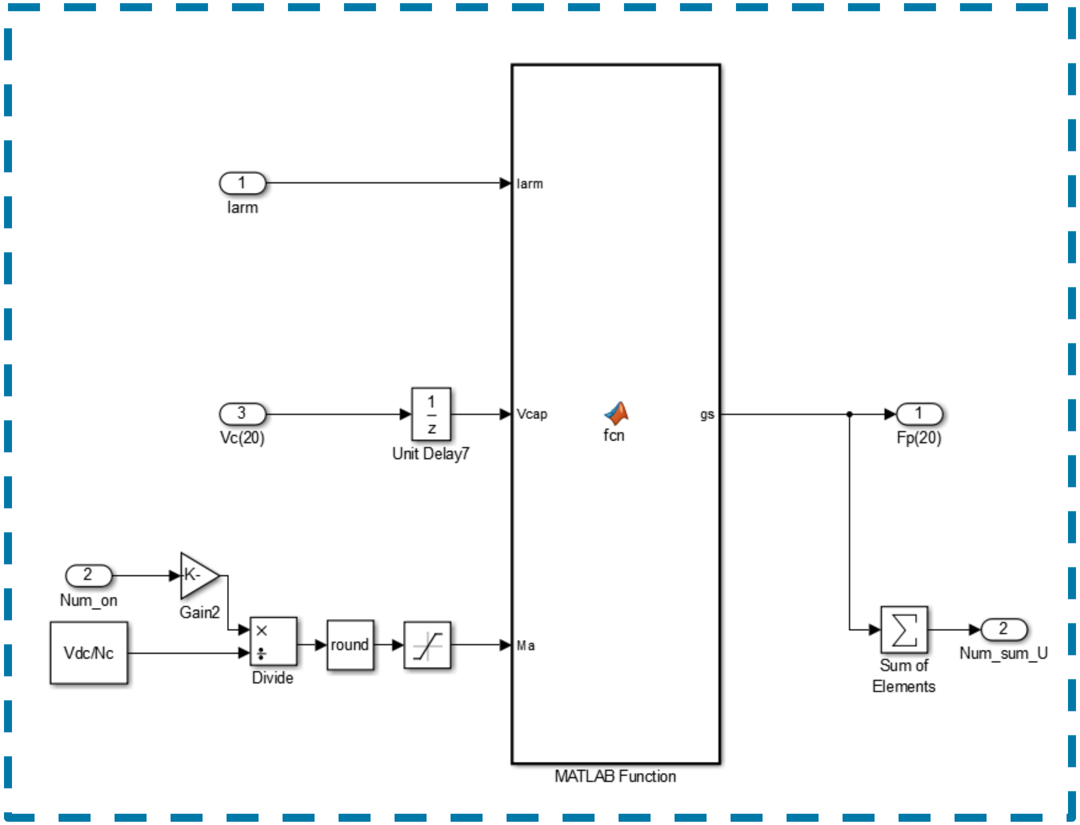
Matlab:

- R2015b
- Model configuration parameters are based on the Simulink-RSCAD conversion tutorial

Switching function modelling method:

- Components from Simulink library
  (multiply, delay, integrator)

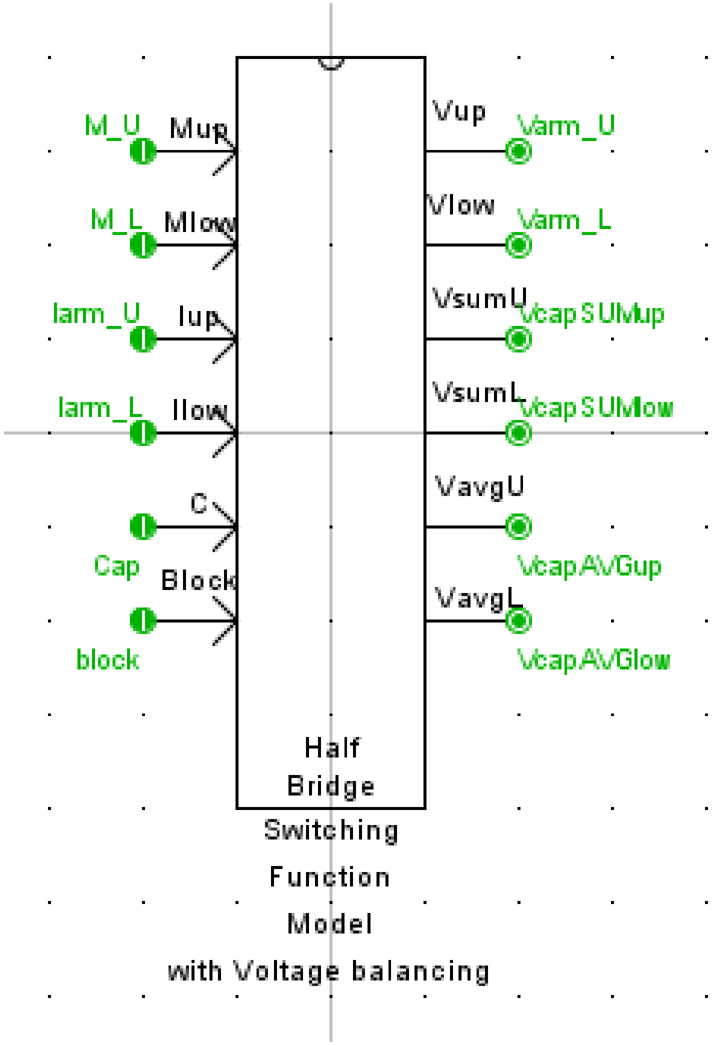
MATLAB/SIMULINK



Capacitor voltage balancing control:

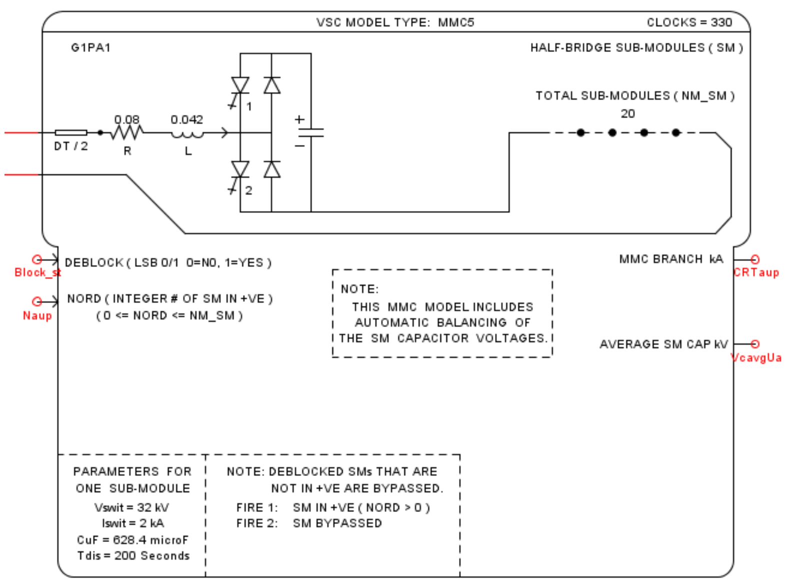
- Simple code(21 lines)
- Basic strategy: sort function
- Sorting all capacitor voltages every simulation time step

RSCAD Component Builder

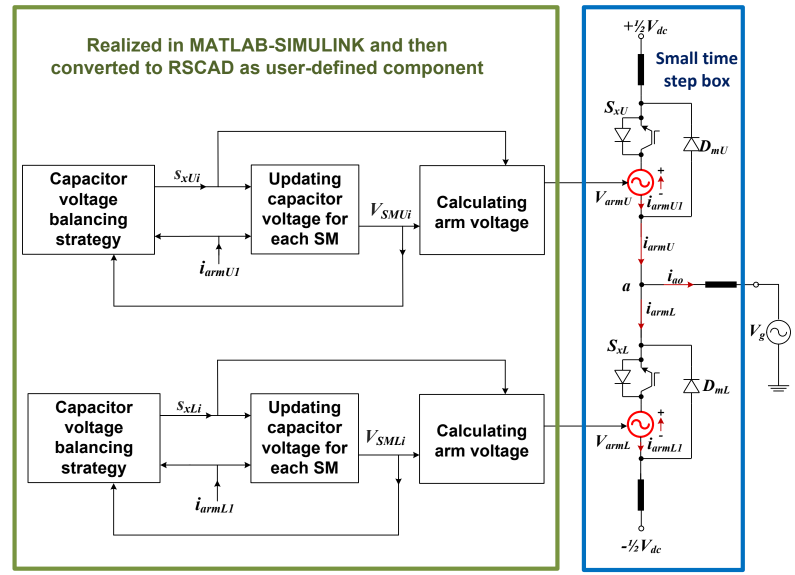


- Tool: Import Simulink model
- Component type: Control
- Inputs and outputs
- 50µs simulation time step

Validation against MMC5 model



MMC5 model

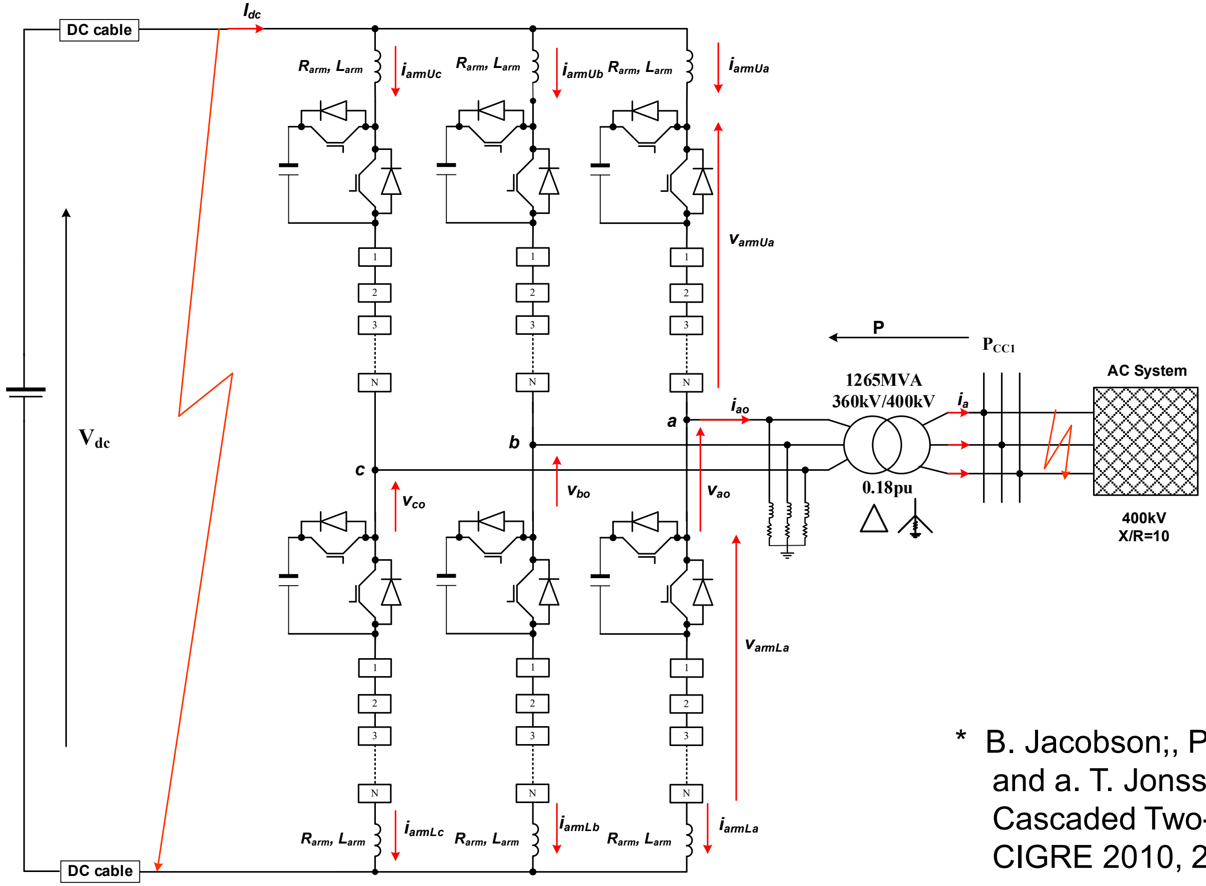


User-defined switching function model

- MMC5 model from RSCAD library is used as the benchmark
- Half-bridge
- 20 SMs per arm
- Same test system

Test System

- Simple one terminal MMC supplied by a DC source
- Converter is in active power control mode
- The SM capacitances are calculated based on the recommended value of 30 kJ/MVA (by ABB*)



* B. Jacobson;, P. Karlsson;, G.Asplund;, L.Harnnart; and a. T. Jonsson, "VSC-HVDC Transmission with Cascaded Two-level Converters," presented at the CIGRE 2010, 2010.

Test System

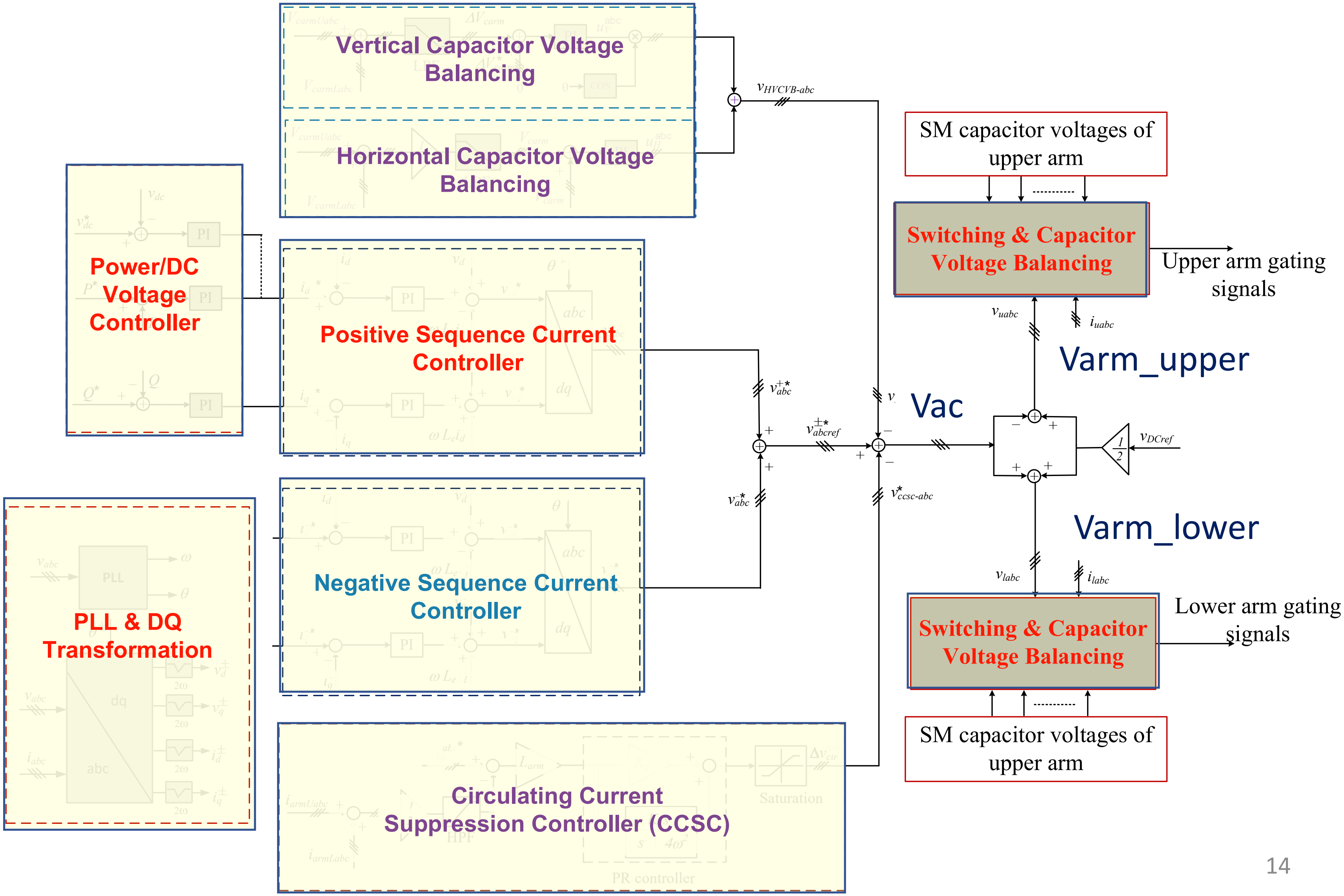
Table I: Simulation Parameters

Parameters		Value
MMC rated active power (P)		1200MW
MMC nominal dc Voltage (V_{dc})		640kV(±320kV)
MMC rated ac output voltage (L-L)		360kV
Arm inductance (L_{arm})		0.13pu
SM capacitance (C_{SM})	20-SM	628μF
Nominal Frequency		50Hz
Interfacing transformer voltage ratio		400/360kV
Transformer leakage reactance		0.18pu

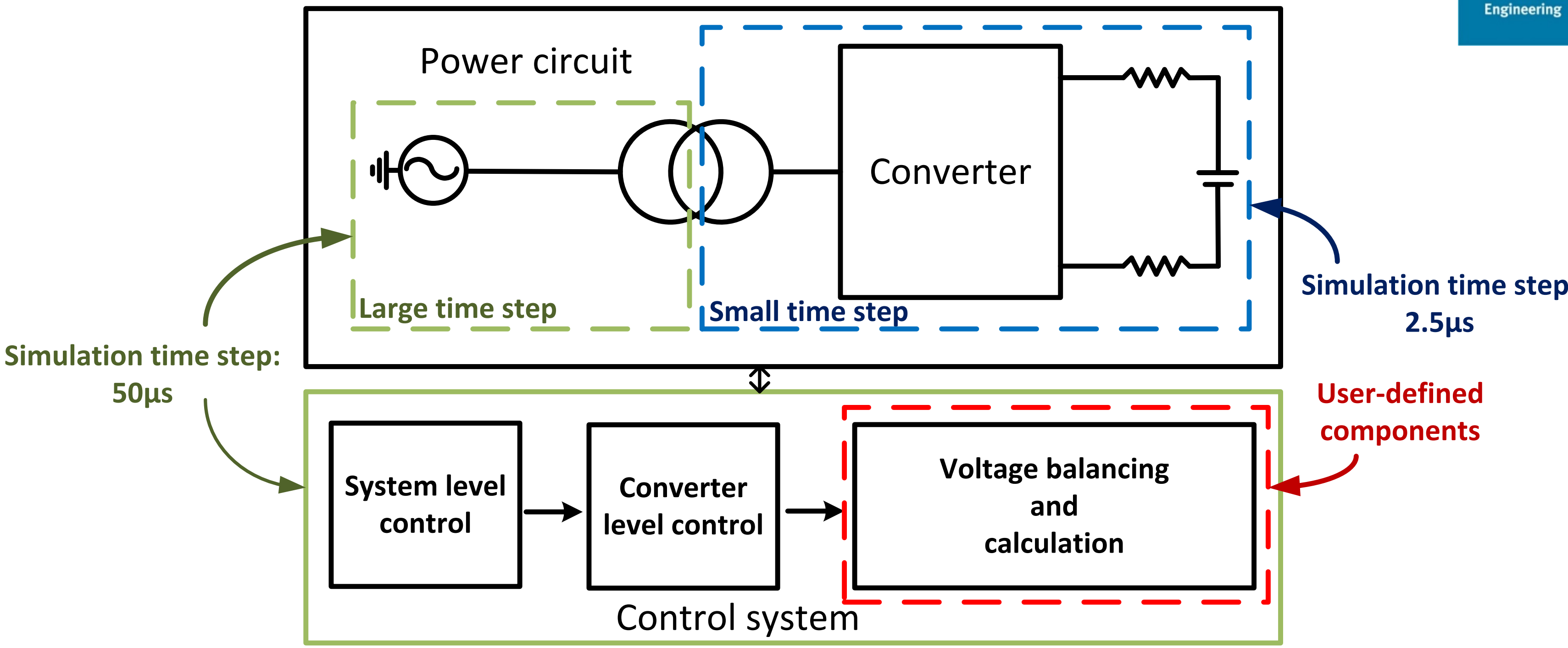
Simulation Scenarios:

1. Three-Phase-to-Ground AC Fault
2. Pole-to-pole DC Fault

MMC Control - Overall Control System



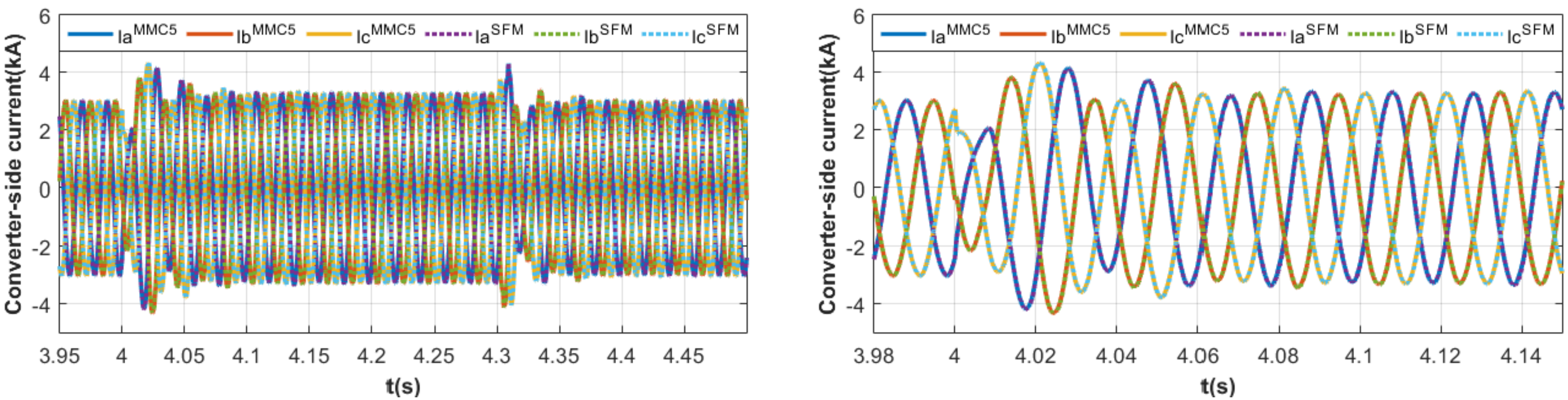
MMC Model Implementations in RTDS



- Part of the MMC models with the requirements of high switching frequency are built in small time step.
- The AC grid source is modelled in a large time step.
- These two parts of power circuit are connected by a interface transformer.
- The model is implemented on one RTDS rack, with one PB5 card and 2 GPC cards.

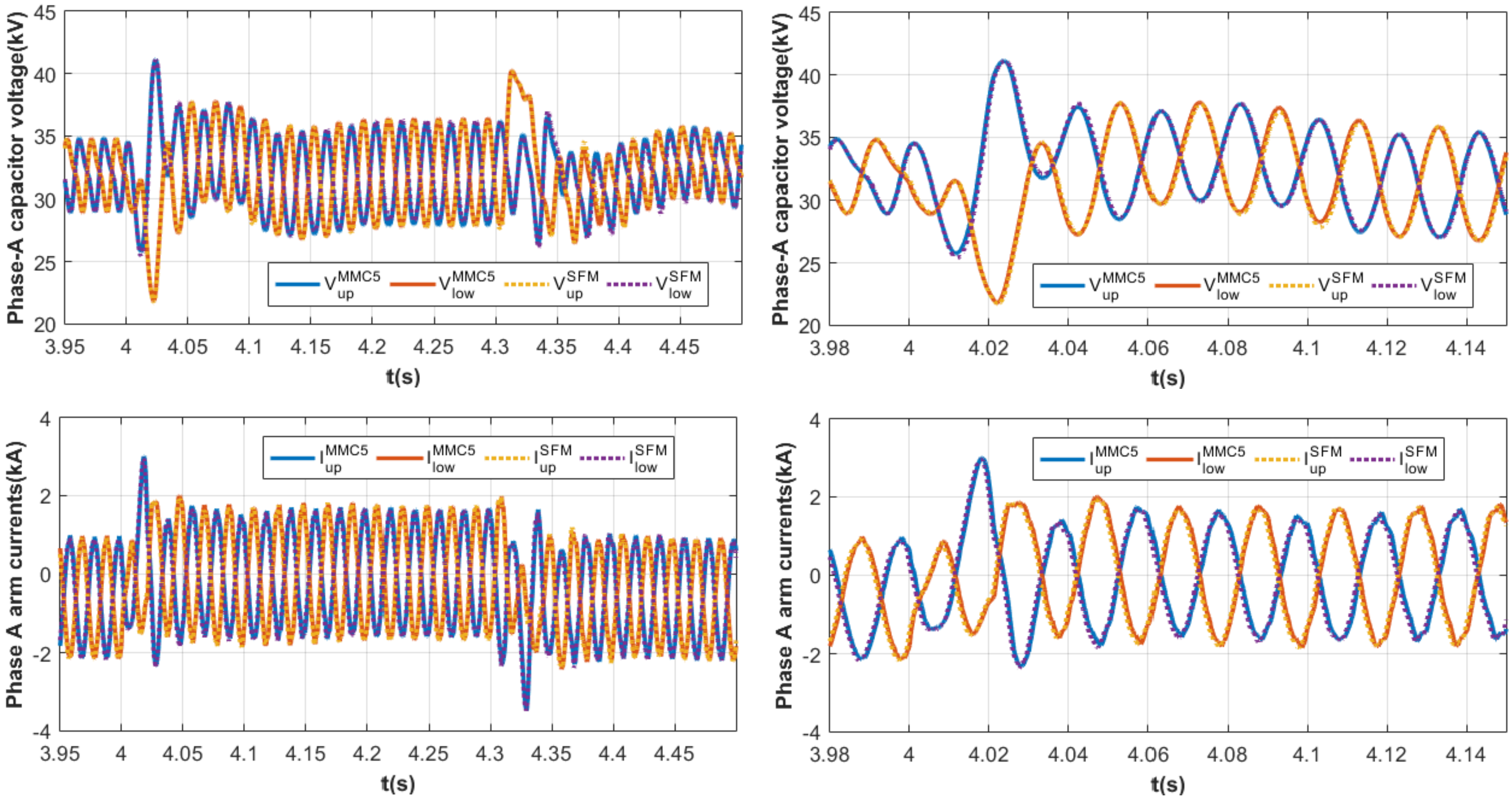
1. Three-Phase-to-Ground AC Fault

- Symmetrical three-phase AC fault happens at *t*=4s and the fault is cleared after 300ms
  - MMC5: MMC5 model
  - SFM: User-defined switching function model



- Converter-side AC currents are well agreed

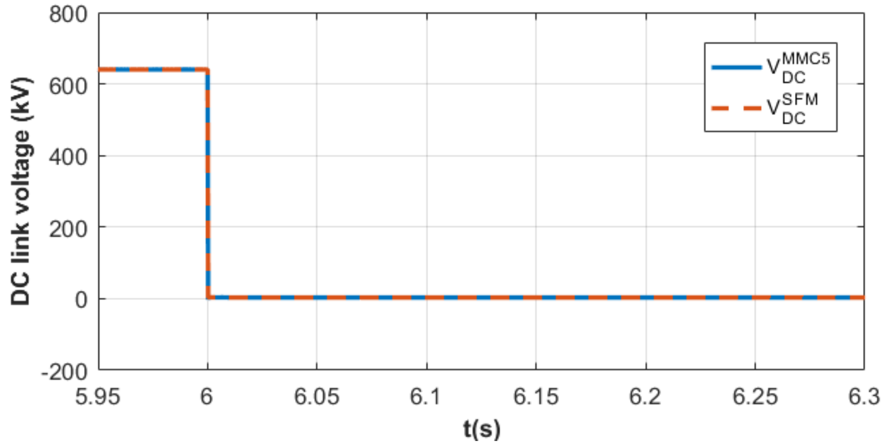
1. Three-Phase-to-Ground AC Fault

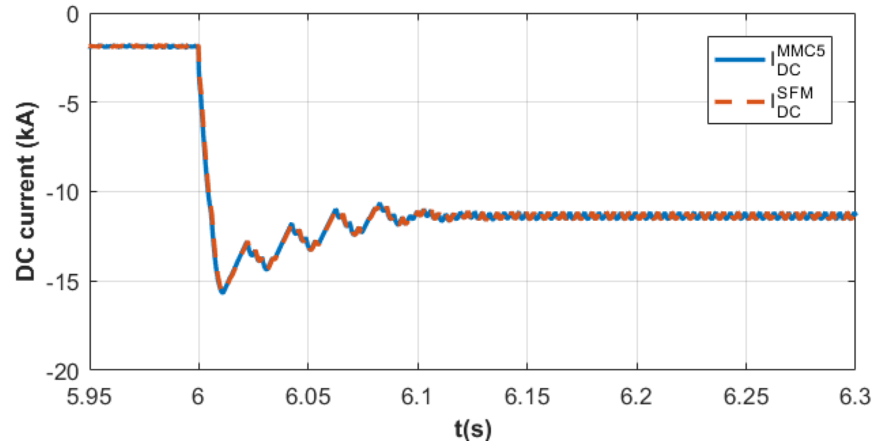


- Average value of capacitor voltages and arm currents are well agreed

2. Pole-to-pole DC Fault

- Fault is applied at t=6s
- Converter blocking is activated 50μs after fault inception

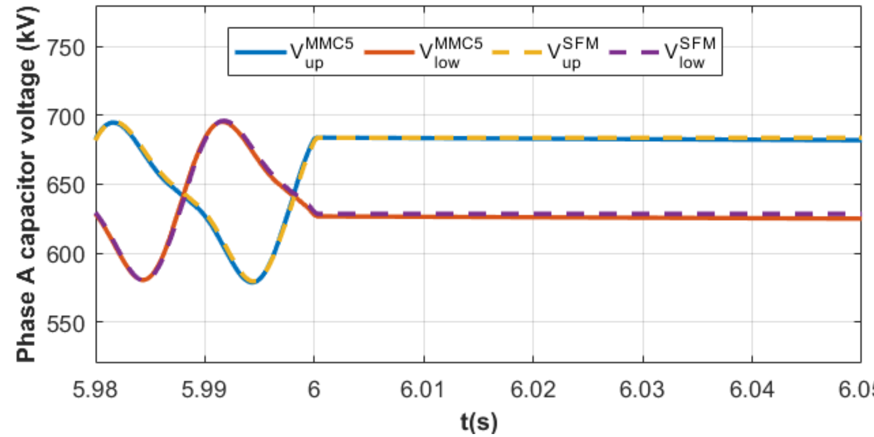


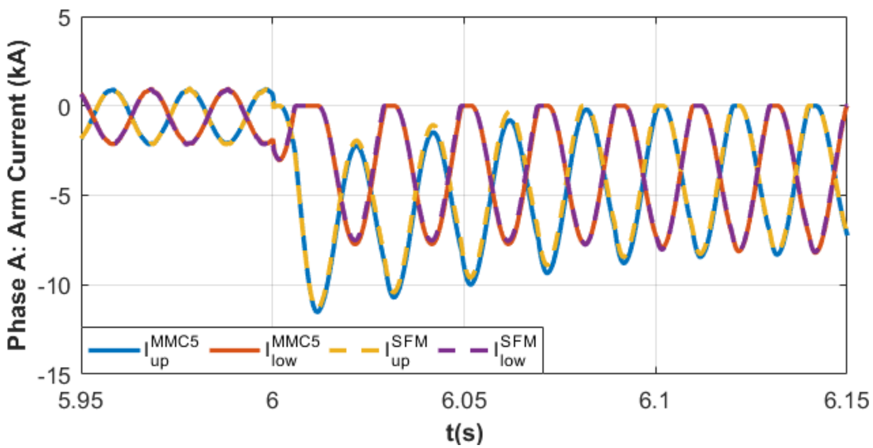


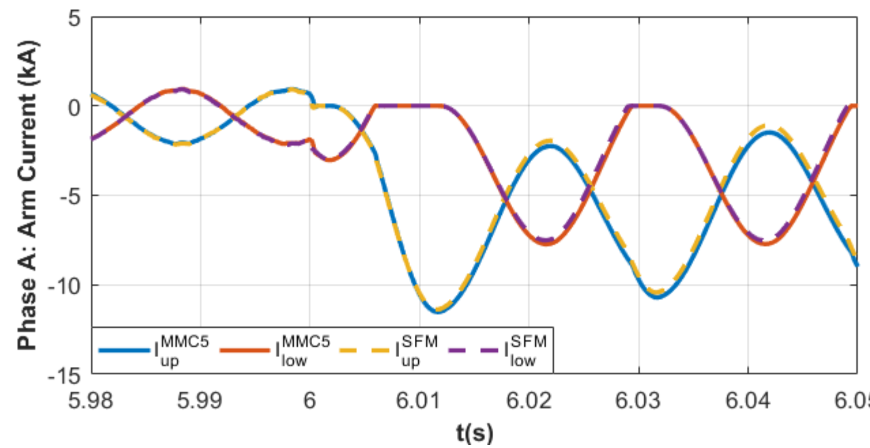
- Observe that both pole-to-pole DC voltages and DC currents are well agreed during steady-state and transition to new steady-sate in post-fault.

2. Pole-to-pole DC Fault

- Sum of capacitor voltages and arm currents are well agreed







Limitations of this model

- The user-defined model converted from Matlab/Simulink is a processor-based model.
- The total number of SMs per arm is limited by capability of single processor (assigned one processor for capacitor voltage balancing and capacitor voltage calculation of each arm).
- Because of switching function modelling method, this model is not able to be used for simulation of internal faults.

Conclusion

- Matlab/Simulink could be used to speed up the develop of efficient and high fidelity user-defined components for RTDS platform such as HVDC converter models and control systems.
- An illustrative example that implements a user-defined half-bridge MMC model is presented.
- Its results are validated against that of the benchmark model MMC5 from RTDS library.
- Detailed one-to-one comparison of the simulation waveforms show that the user-defined and MMC5 models simulation waveforms are in full agreement to the microscopic level.

Thank you for your attention!

Question?