EMTP
EUROPEAN EMTP USER CONFERENCE & WORKSHOP
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Electromagnetic Transients (EMT) Model Design based on Modular Multilevel Converter Mockup

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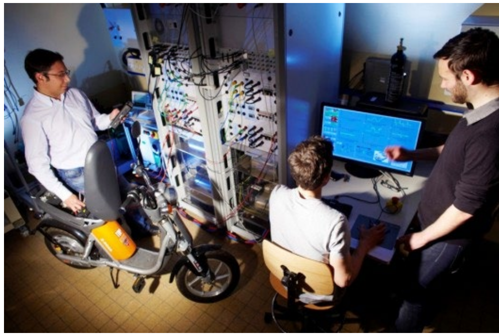
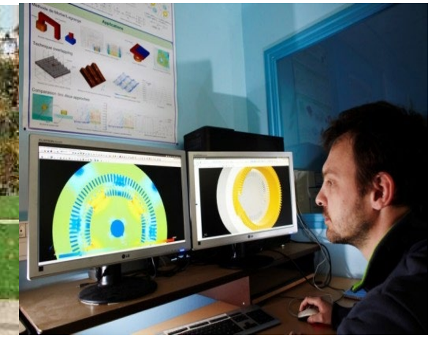
Introduction: Who we are ?

L2EP 's Presentation

http://l2ep.univ-lille.fr/





Research Teams

Control Team
A. Bouscayrol
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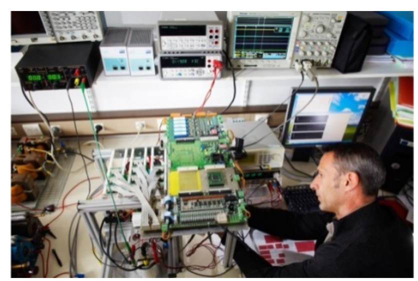
(3 EC-Lille, 1 A&M, 6 Lille1)



Introduction

Use of EMTP-RV in our Research Works

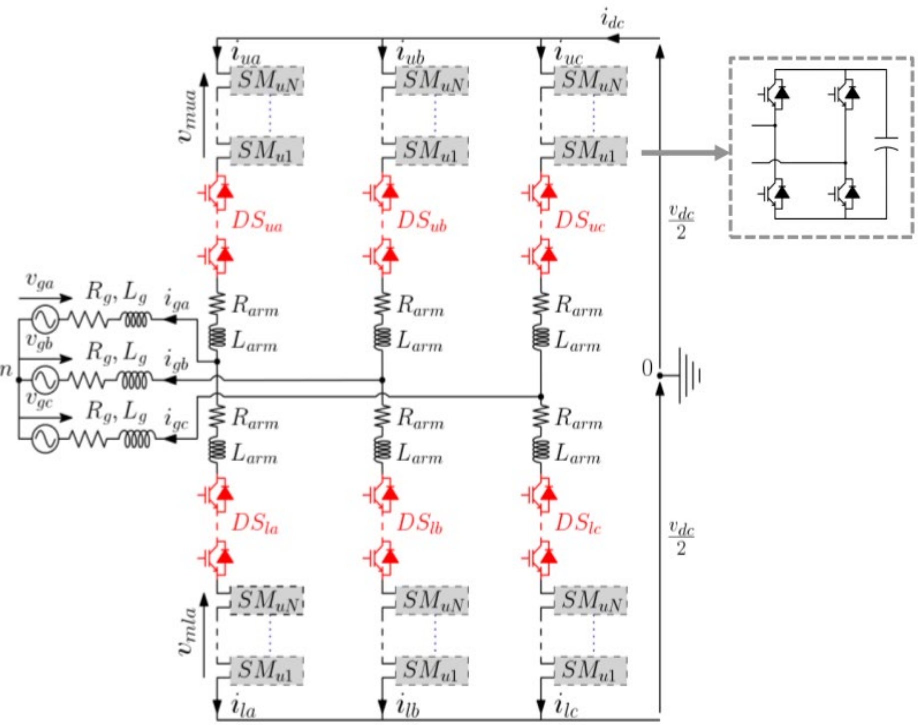
❑ EMT Modeling based on High Voltage Applications

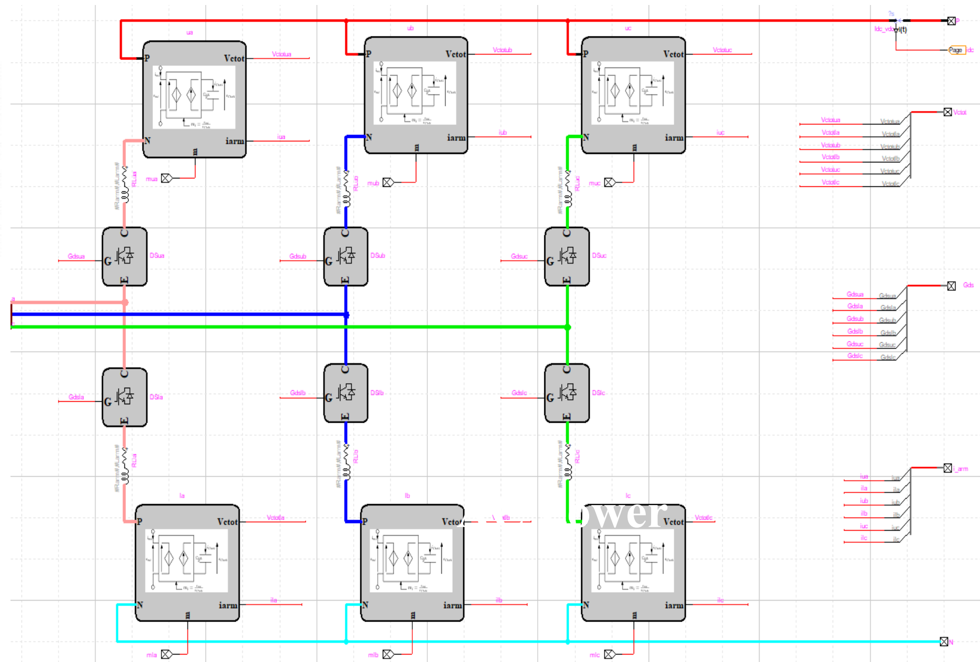
- VSC-HVDC system connected to ac grid;
- MMC-HVDC system connected to ac grid ;
- VSC/MMC based MTDC grid ;
- Alternate Arm Converter (AAC) Model;
- Modeling under normal and abnormal (fault) operating conditions

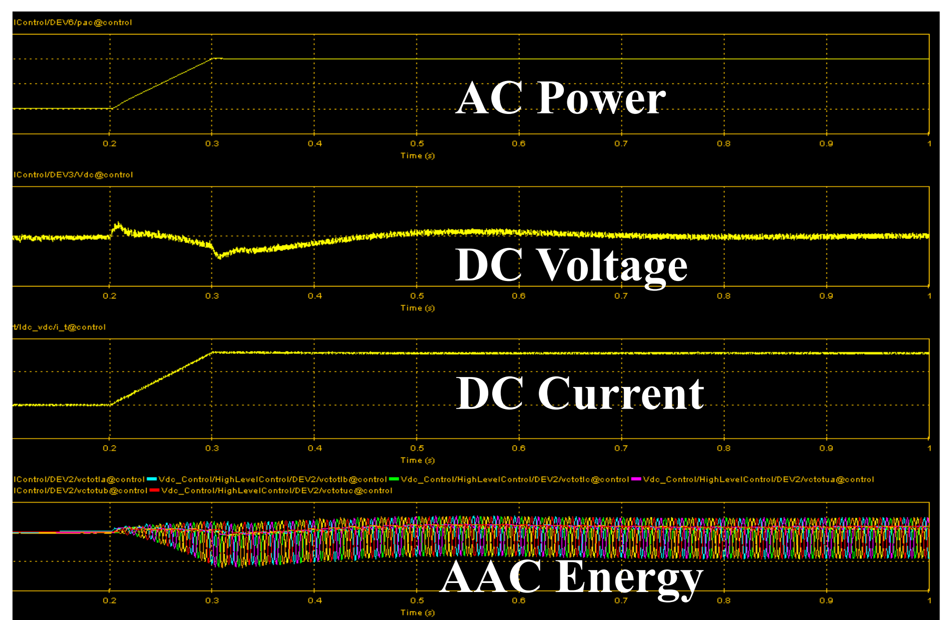
❑ EMT Modeling based on scale down power system applications

- Five Terminal VSC-MTDC grid;
- MMC-HVDC system ;
- …

Example : Modeling of AAC using EMTP-RV







The AAC : Hybrid MMC/2-Level VSC

- **High power capability (1 GW)**
- **Modular**
- **DC/AC Fault tolerant**
- **Compact**

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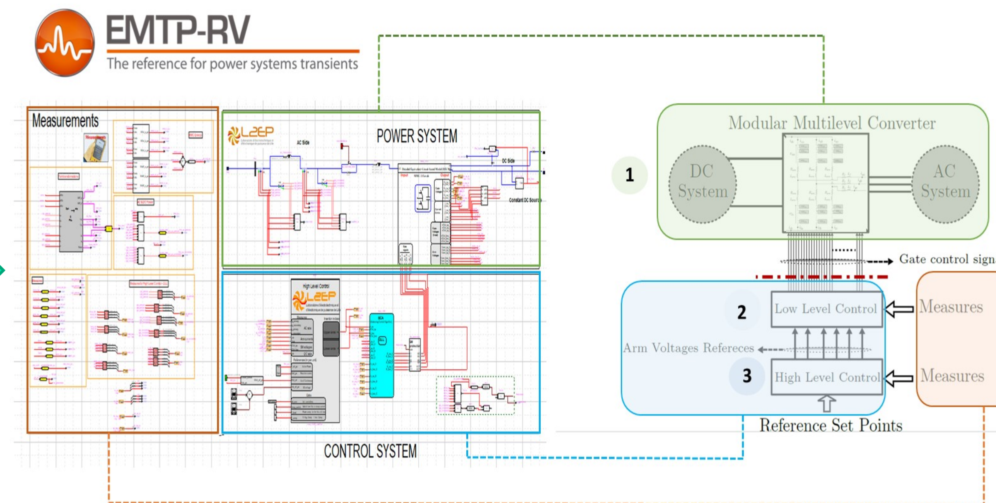
EDF

Introduction

The aim of this study is the conception and the development of a detailed EMT Model for MMC (Modular Multilevel Converter) based on experimental results obtained from a mock-up.

scaled down MMC prototype



How to exploit the performances of EMTP-RV simulation tools to develop a detailed model that represents accurately the behavior of a physical MMC.

Outline

I – MMC MOCKUP DESCRIPTION

II – STEP BY STEP EMTP-RV MODEL DEVELOPMENT OF MMC MOCKUP

III – COMPARATIVE STUDY BETWEEN EXPERIMENTAL AND SIMULATION RESULTS

IV – CONCLUSIONS AND SOME RECOMMANDATIONS

I. MMC MOCKUP DESCRIPTION

General Description of MMC Prototype and its environnement

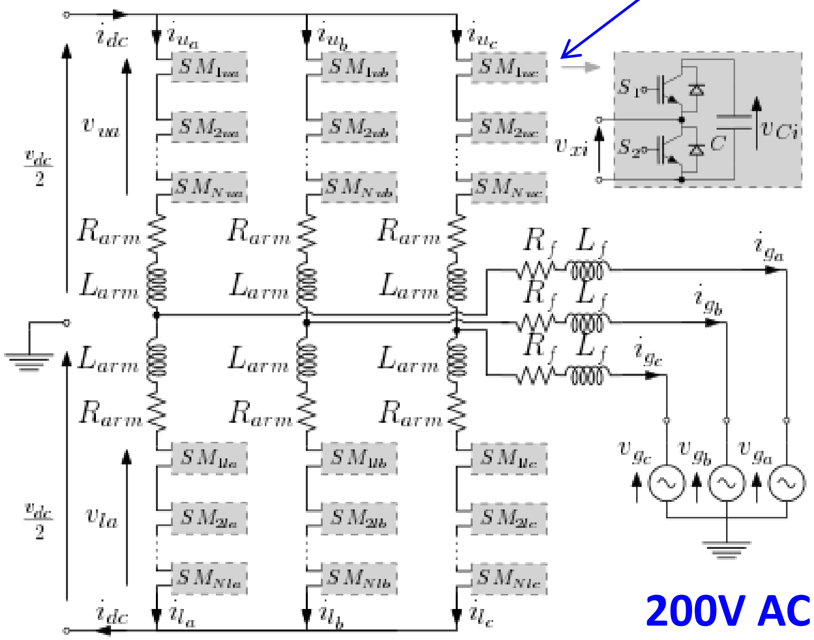
MMC Mockup
(Pn= 5kW – Qn= 1.5 kVAR)

20 Sub-modules/arms
V_{cn} ≈ 20V

DC Grid Side

DC Bus

400V



AC Grid Side

Three Phase Transformer
Δ/Y

AC Cable

AC Amplifier

200V AC
50Hz

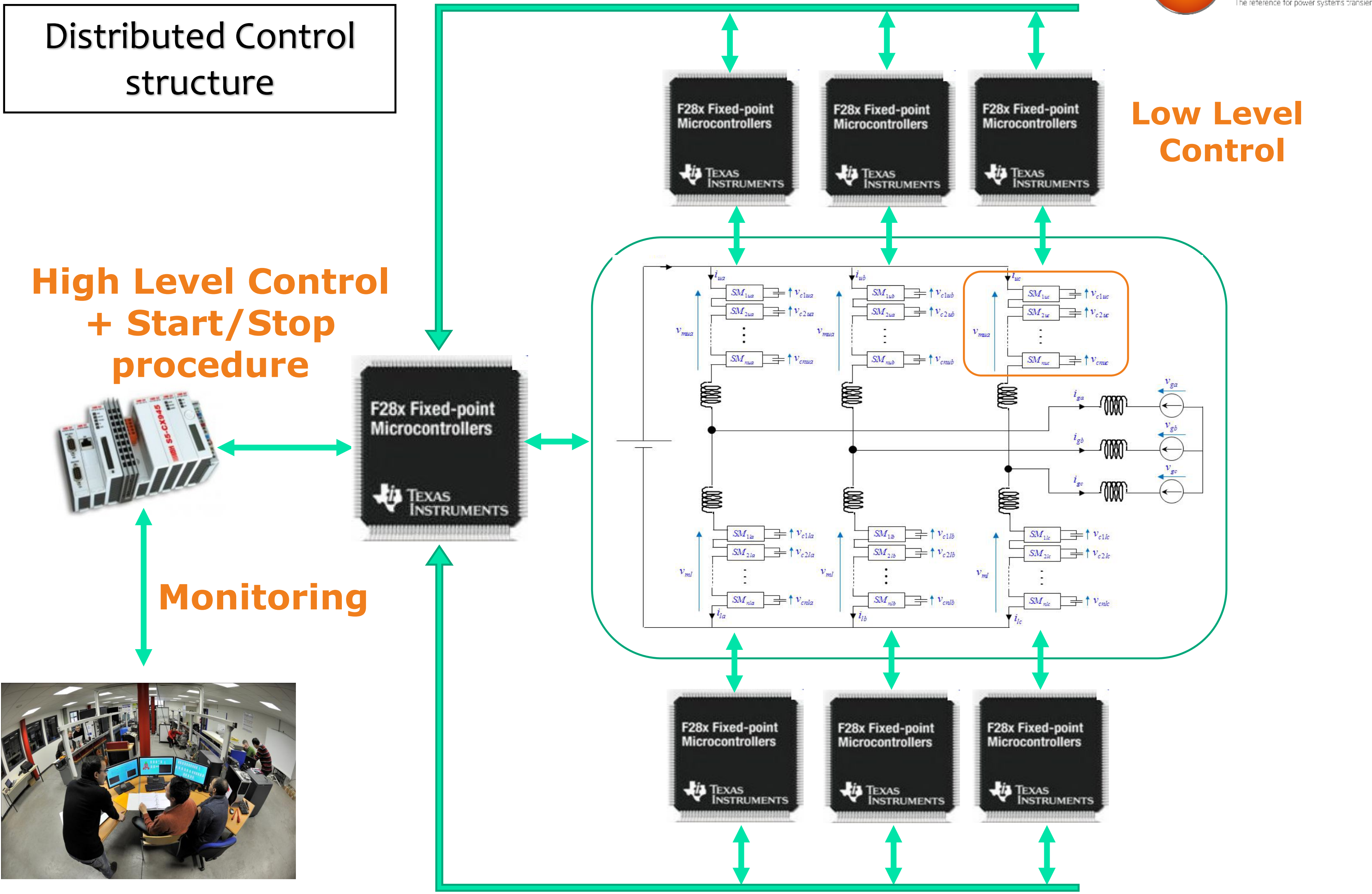
MMC Control Systems :
High and Low Levels Controllers

dSPACE

120 Sub-modules to drive 240 transistors to control

Complex topology = Complex control architecture

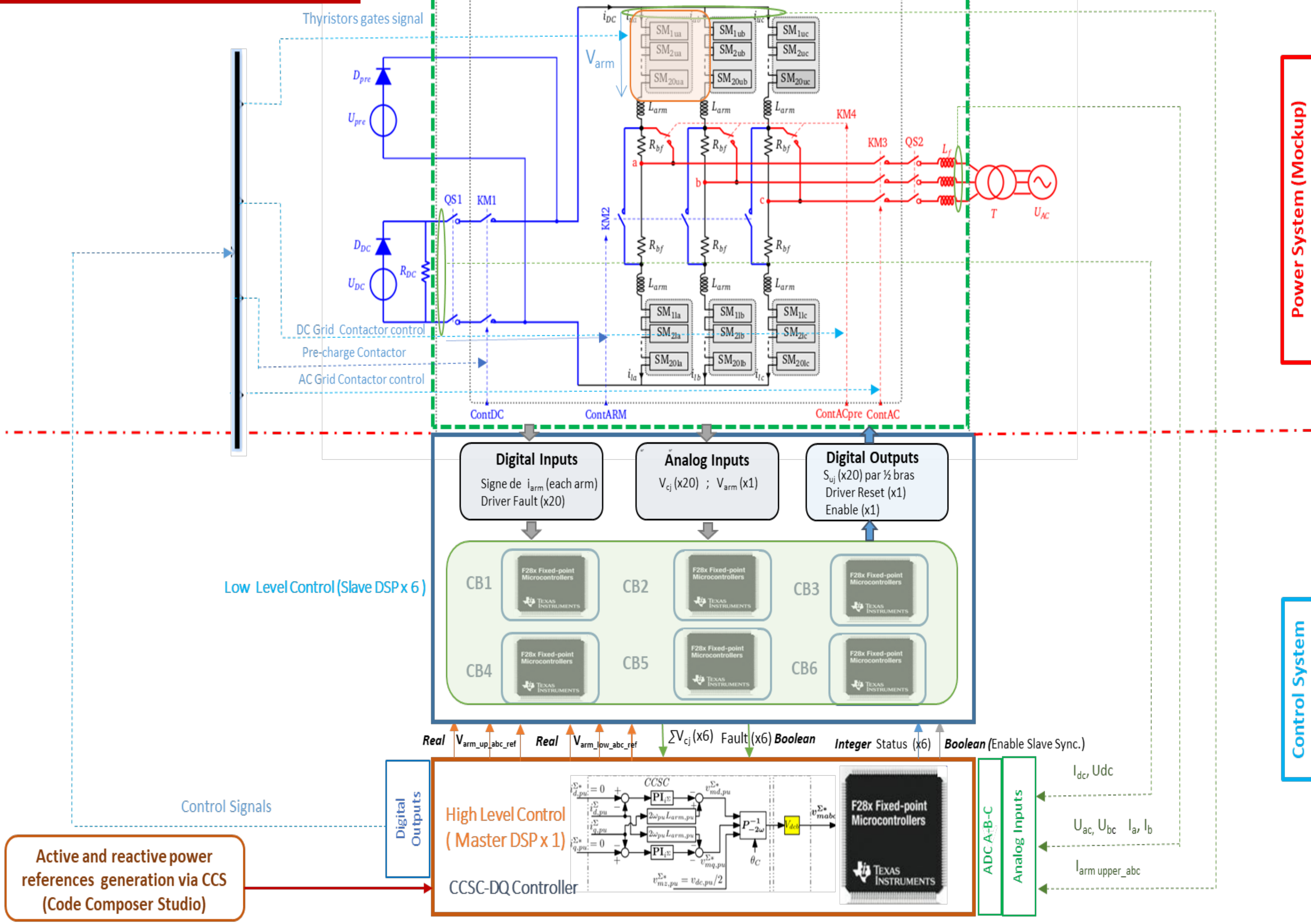
I. MMC MOCKUP DESCRIPTION



TMS320F2837xD Dual-Core Delfino Microcontrollers

I. MMC MOCKUP DESCRIPTION

Material Description of MMC Prototype



II. STEP BY STEP EMTP-RV MODEL DEVELOPMENT OF MMC MOCKUP

- The fundamental purpose of this work is to develop an accurate **EMT model**, which will be able to describe accurately the behaviour of the mock-up.

- The design of the **EMTP-RV simulation model** is based mainly on four steps:

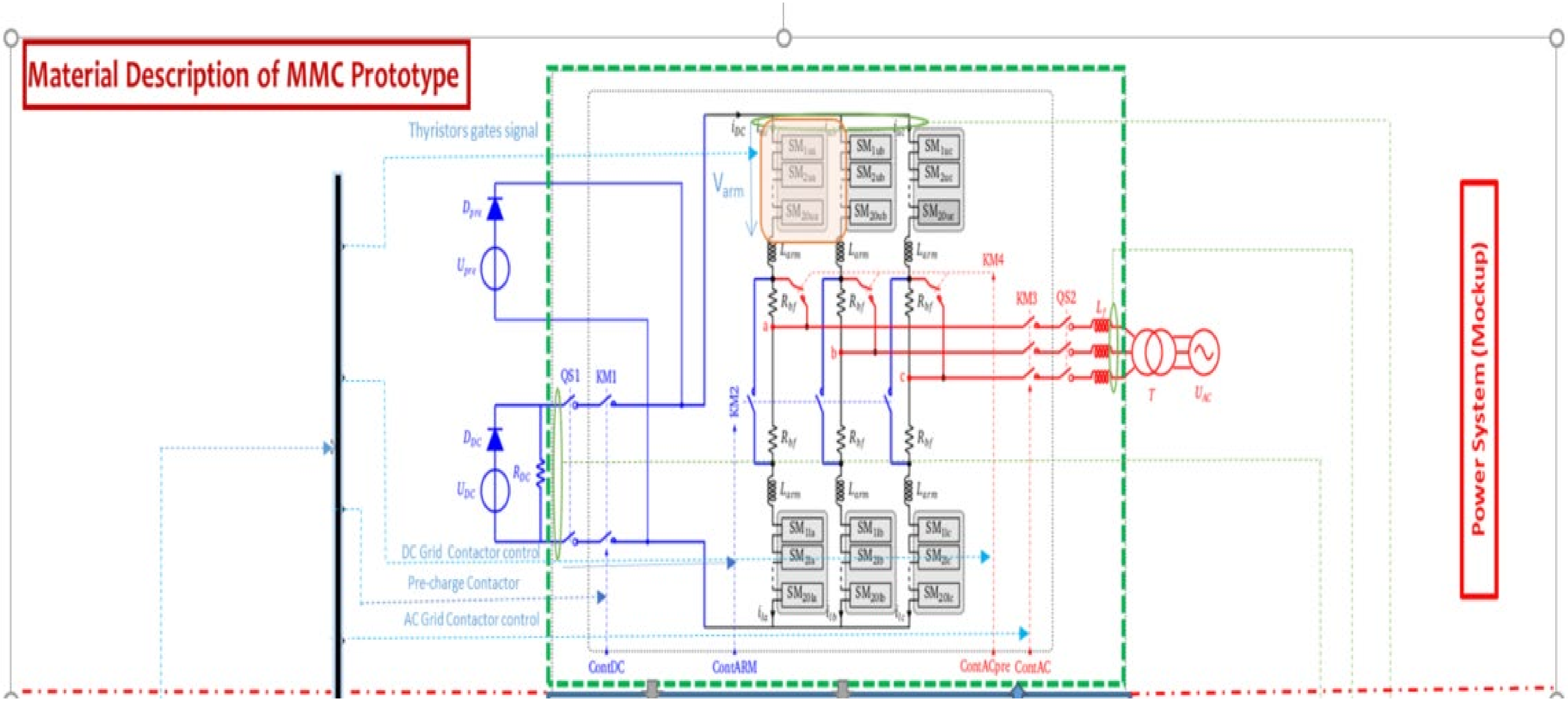
  - Modeling of the power part of the converter ;

  - Modeling of the high-level control given by CCSC-DQ ;

  - Modeling of the low-level controller given by Capacitors Balancing Algorithm and Nearest Level Control (NLC) ;

  - Modeling of measurement process, ADC (Analog Digital Converter), quantization, sensors dynamics, sensors offsets and the communication delays.

II.1. MODELING OF THE POWER PART OF THE CONVERTER



- **Step 1:** Direct Identification of system parameters on the prototype and its environment ;
- **Step 2:** Detailed Modeling of the SubModule ;
- **Step 3:** Modeling in measurement and instrumentation.

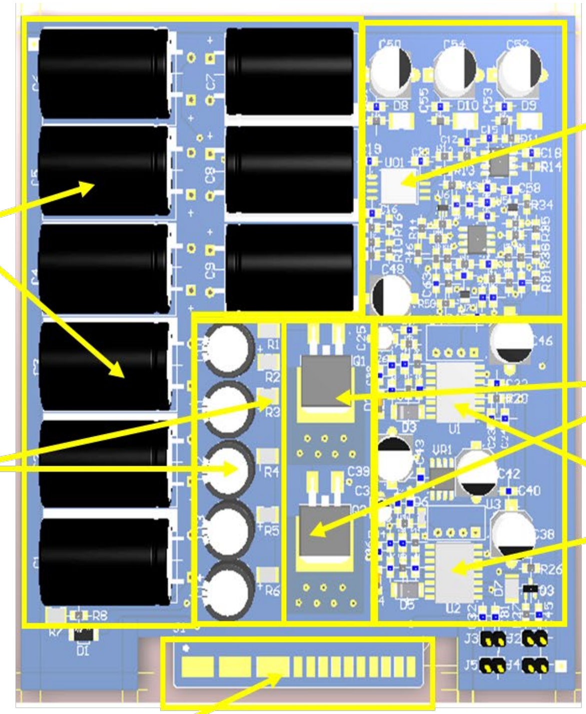
Detailed Modeling of the SubModule

Submodule (SM) Circuit

Power adaptation card

SM Capacitances (8mF – 63V)

Capacitances (1.5mF – 63V) and resistances for unbalancing



Voltage sensors (ACPL-C87B)

MOSFET (120A – 100V) PSMN3R8-100BS

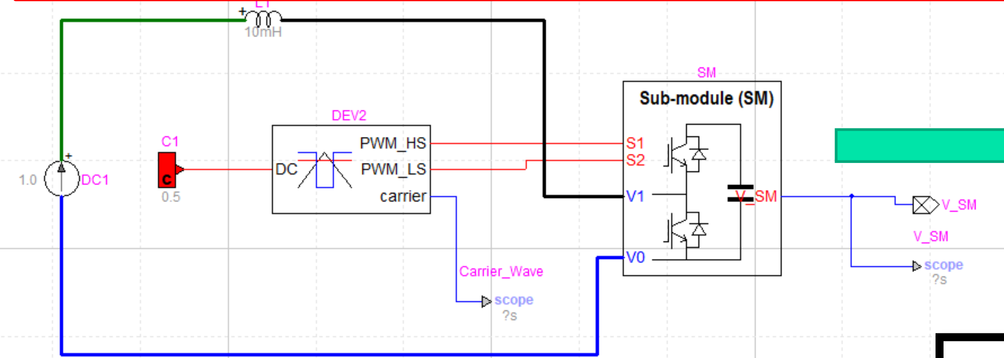
Driver (ACPL_332J)

Power and signal connectors

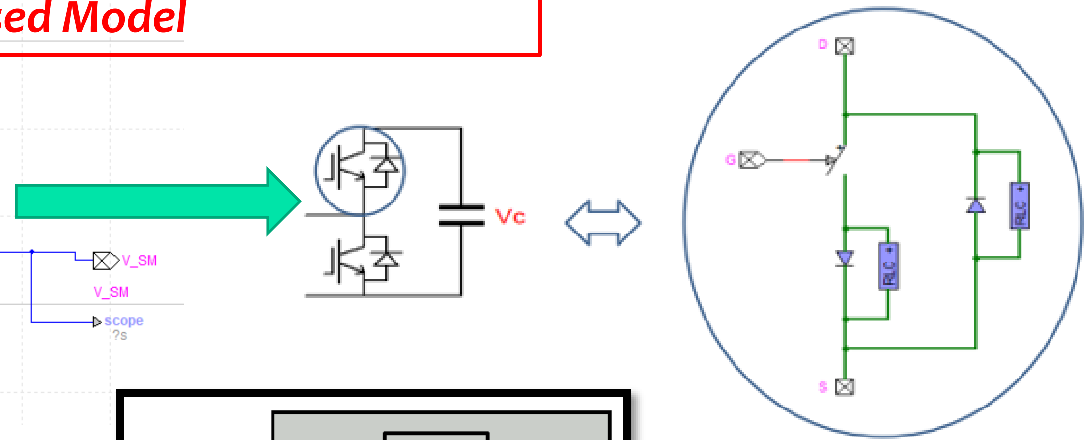
Several experimental tests have been performed in order to identify the SM parameters :

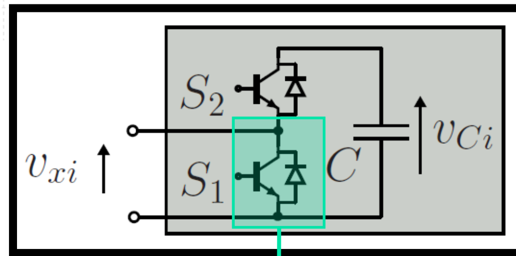
- MOSFET parameters : Ron and Roff of controlled switch as well as the dead time of PWM;
- Identification of I-V characteristics of nonlinear diode behavior ;
- Identification of SM capacitance and voltage sensor delay ;
- Maximum propagation delay of driver.

EMT Model – Type 1 : *Detailed IGBT-Based Model*

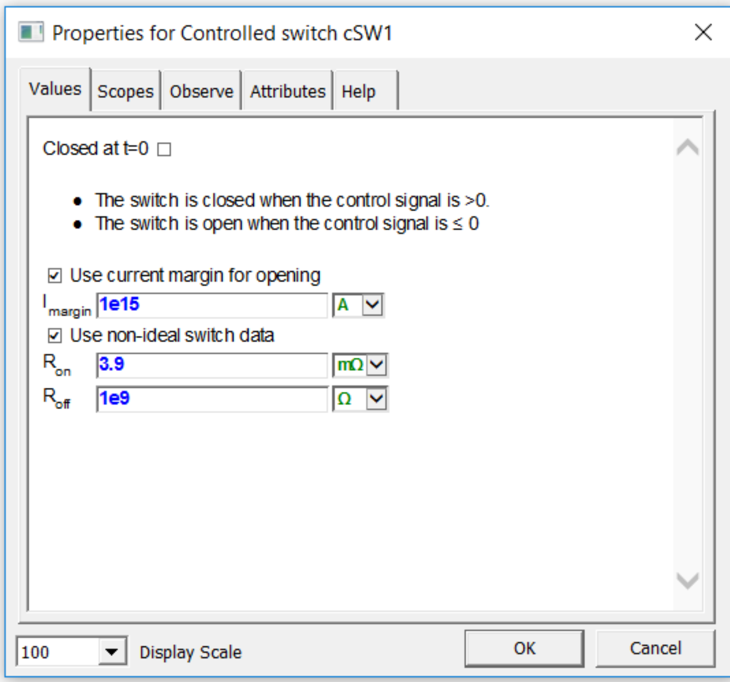


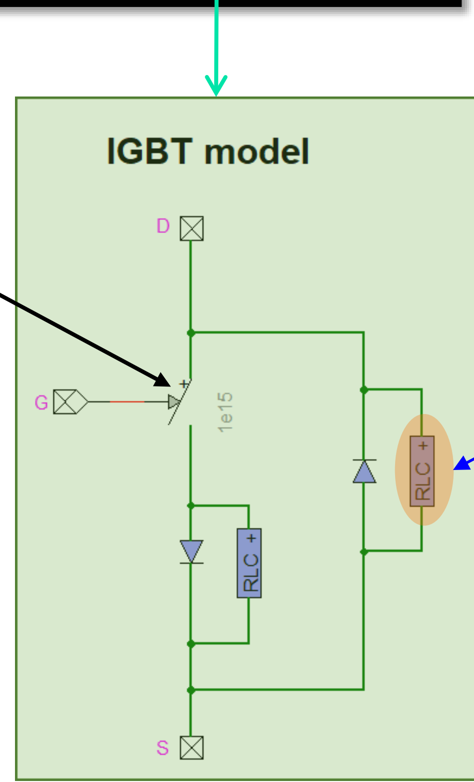
IGBT model





Half–Bridge Sub-Modules

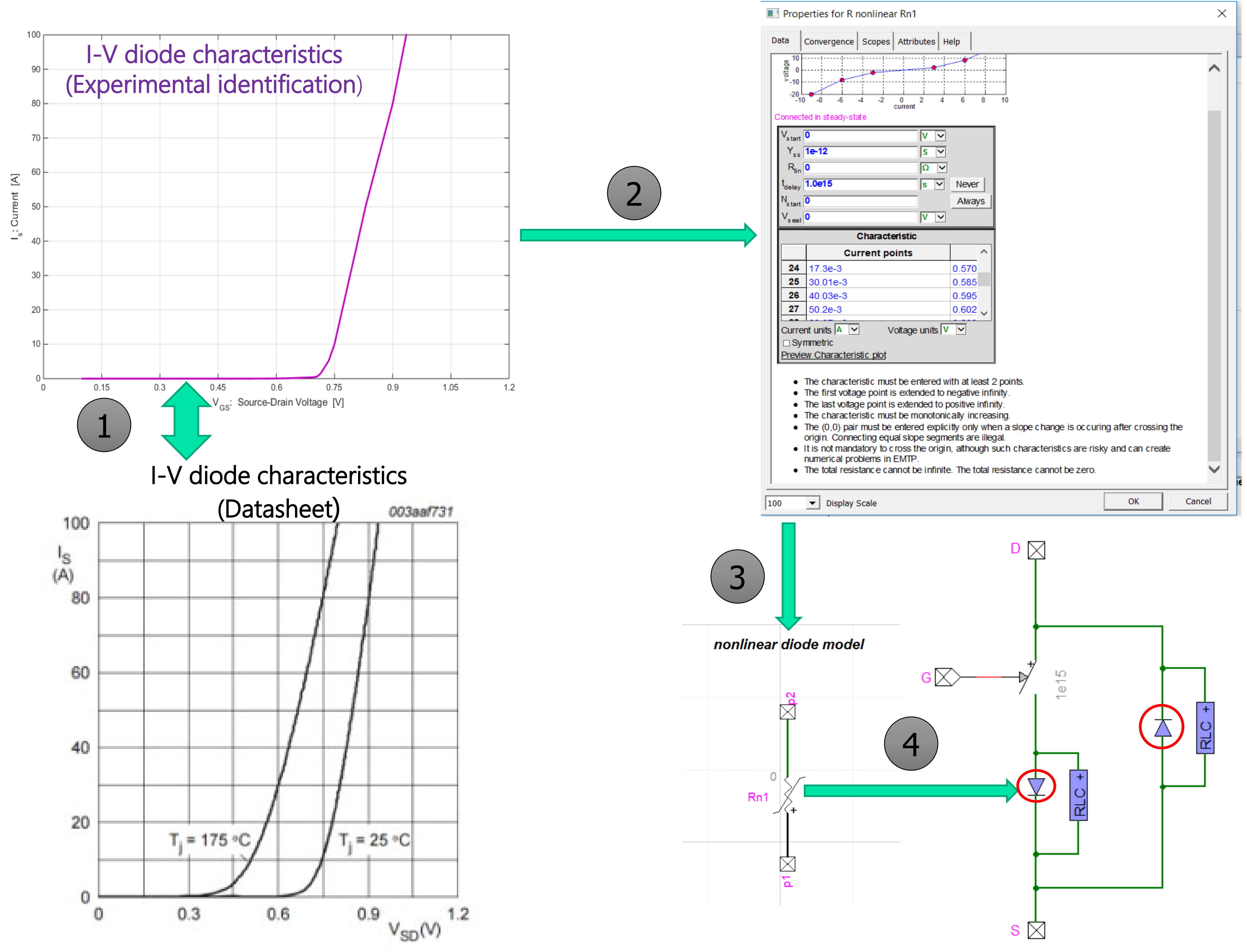




IGBT Snubber:
Rn = 3000 Ω ; Cn=10μF

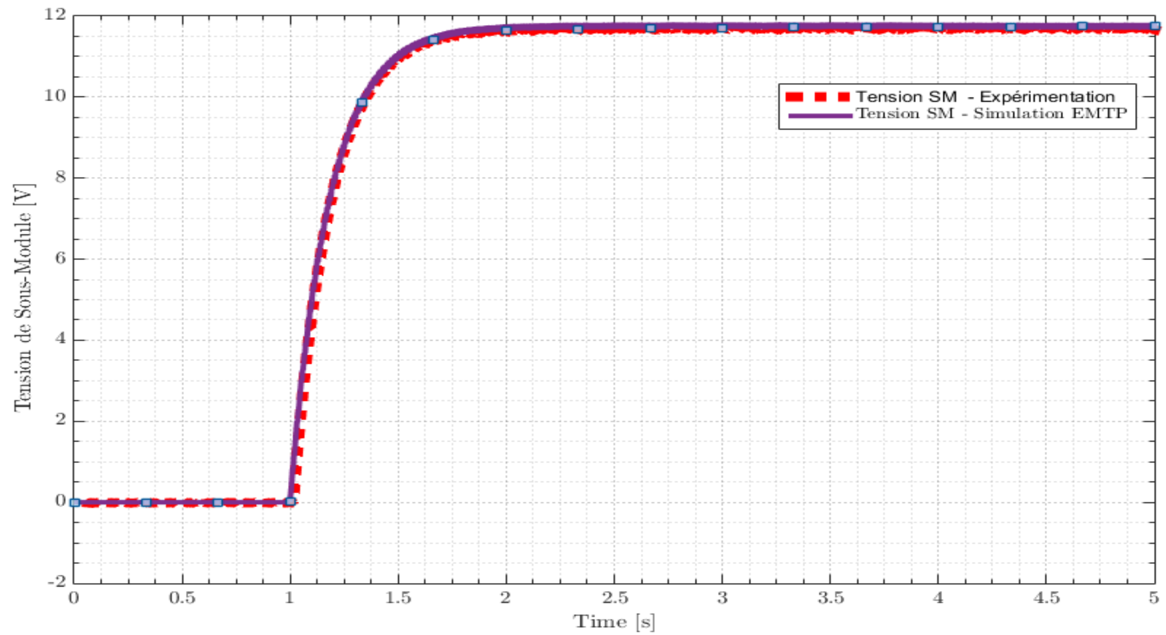
Mimic the reverse recovery condition

Ron	*Roff*	Dead-Time
3.9 mΩ	1e9 Ω	$1\ \mu s \leq \Delta t \leq 2\ \mu s$

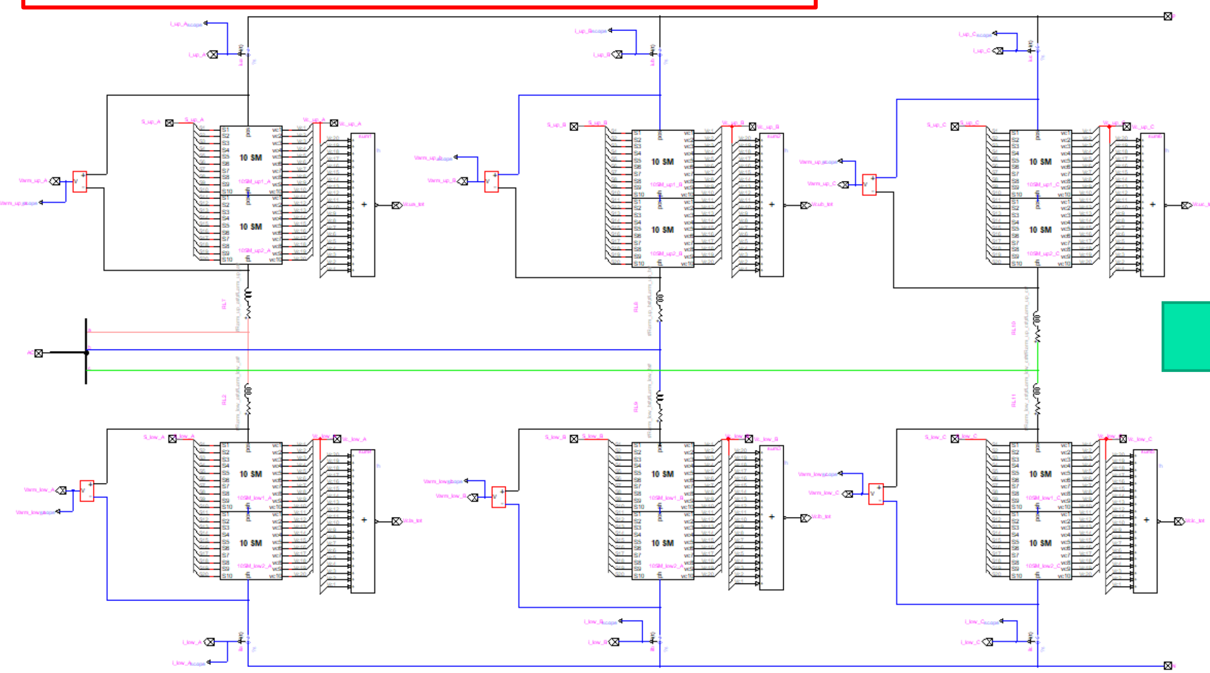

I-V diode characteristics
(Experimental identification)
I_s: Current [A]
V_{GS}: Source-Drain Voltage [V]
1
2
I-V diode characteristics
(Datasheet)
003aaf731
I_S (A)
T_j = 175 °C
T_j = 25 °C
V_{SD}(V)
Properties for R nonlinear Rn1
Data
Convergence
Scopes
Attributes
Help
voltage
current
Connected in steady-state
V_{start} 0 V
Y_{ss} 1e-12 S
R_{lin} 0 Ω
t_{delay} 1.0e15 s
Never
N_{start} 0
Always
V_{seal} 0 V
Characteristic
Current points
24 17.3e-3 0.570
25 30.01e-3 0.585
26 40.03e-3 0.595
27 50.2e-3 0.602
Current units A
Voltage units V
Symmetric
Preview Characteristic plot
The characteristic must be entered with at least 2 points.
The first voltage point is extended to negative infinity.
The last voltage point is extended to positive infinity.
The characteristic must be monotonically increasing.
The (0,0) pair must be entered explicitly only when a slope change is occuring after crossing the origin. Connecting equal slope segments are illegal.
It is not mandatory to cross the origin, although such characteristics are risky and can create numerical problems in EMTP.
The total resistance cannot be infinite. The total resistance cannot be zero.
100
Display Scale
OK
Cancel
3
nonlinear diode model
p2
0
Rn1
p1
4
D
G
1e15
RLC
S

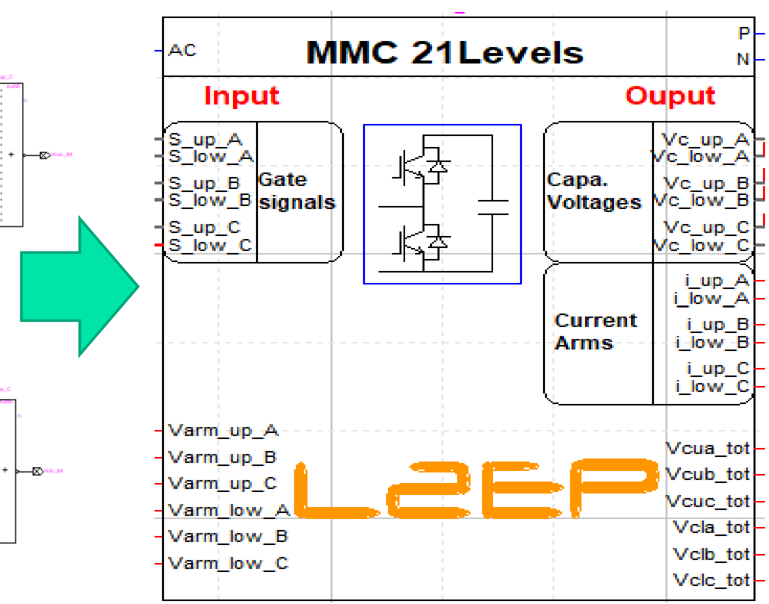
Validation of SubModule

The method has been extende
to 20-SM MMC by validating tł
precharge cycle

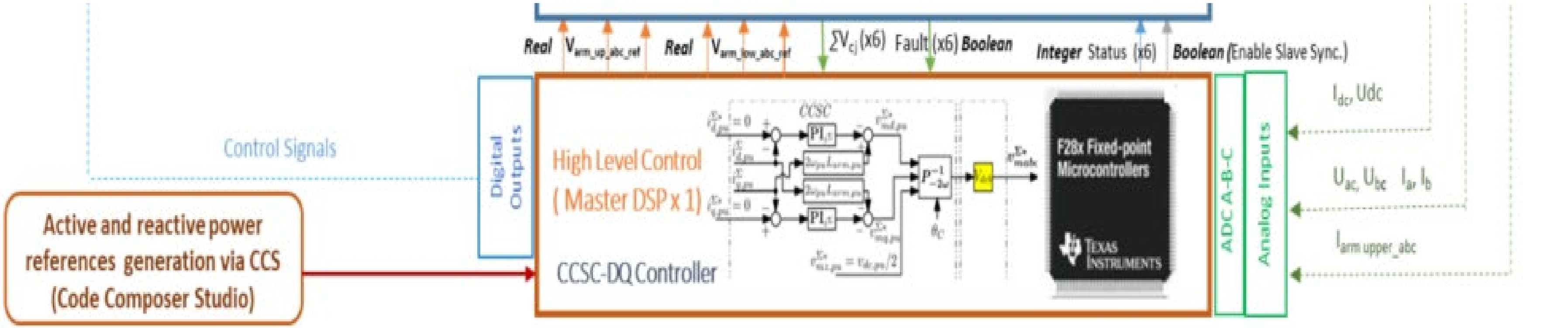


EMTP-RV Model of 21-Level MMC

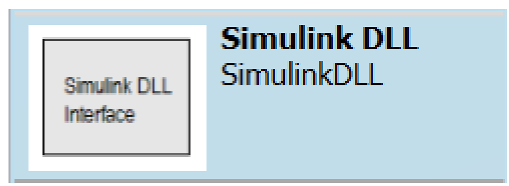




II.2. Modeling of the high-level control given by CCSC-DQ + PLL (Phase Locked Loop)

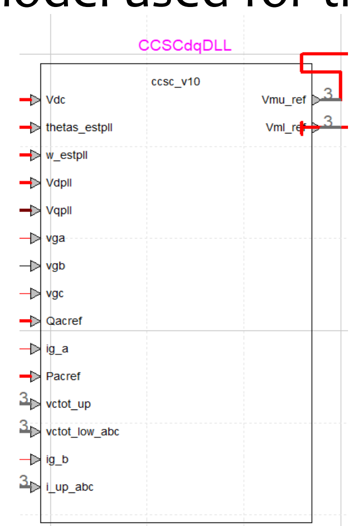


The main idea is to import the control Simulink Model into EMTP model using **SimulinkDLL** component :



DLL: Dynamic Link Library

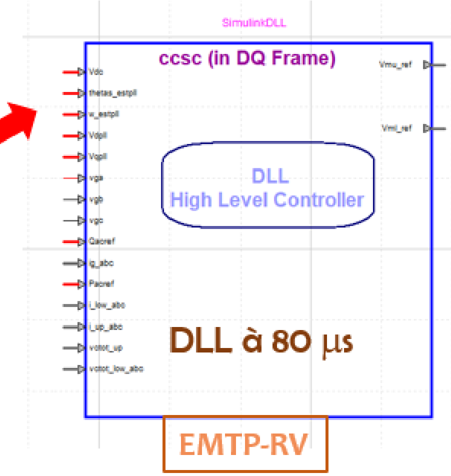
Based on the Simulink control model used for the code generation :



DLL of high level control integrated in EMTP-RV running at 80 µs

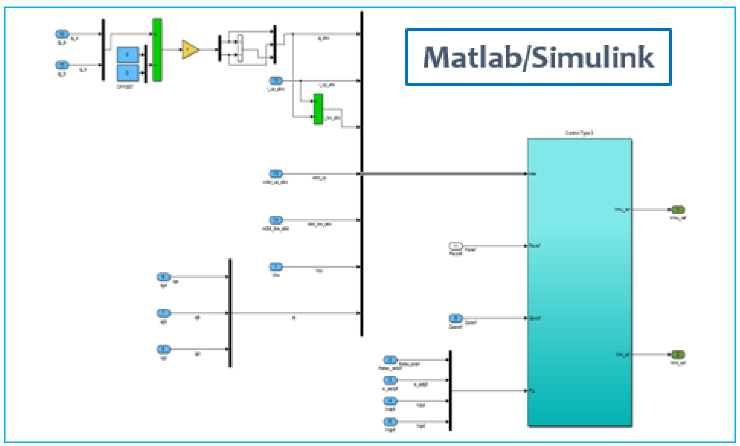
II.2. Modeling of the high-level control given by CCSC-DQ + PLL (Phase Locked Loop)

DLL Running at 80 µs



Toolbox SimulinkDLL from EMTP-RV Library
EMTP.tlc

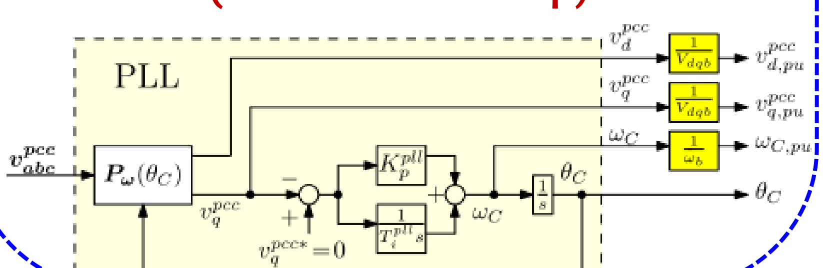
CCSC-DQ Controller



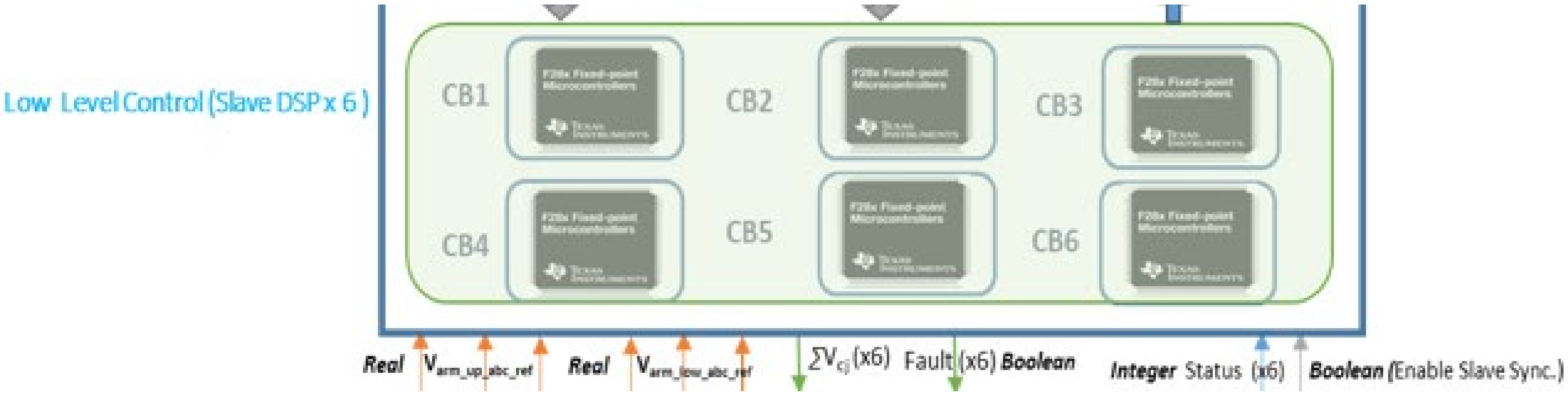
Embedded Coder under Matlab/Simulink
Embedded Code Generation

Dual Core DSP
TMS320F28377D

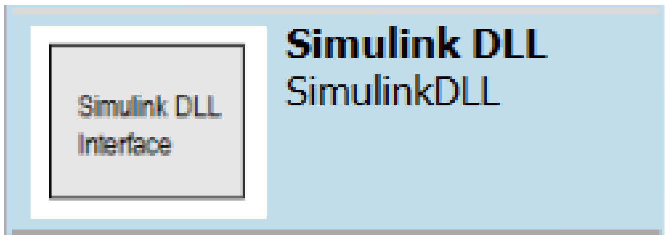
PLL (Phase Locked Loop)



II.3. Modeling of the Low-level control (CBA: Capacitors Balancing Algorithm + NLC : Nearest Level Control)

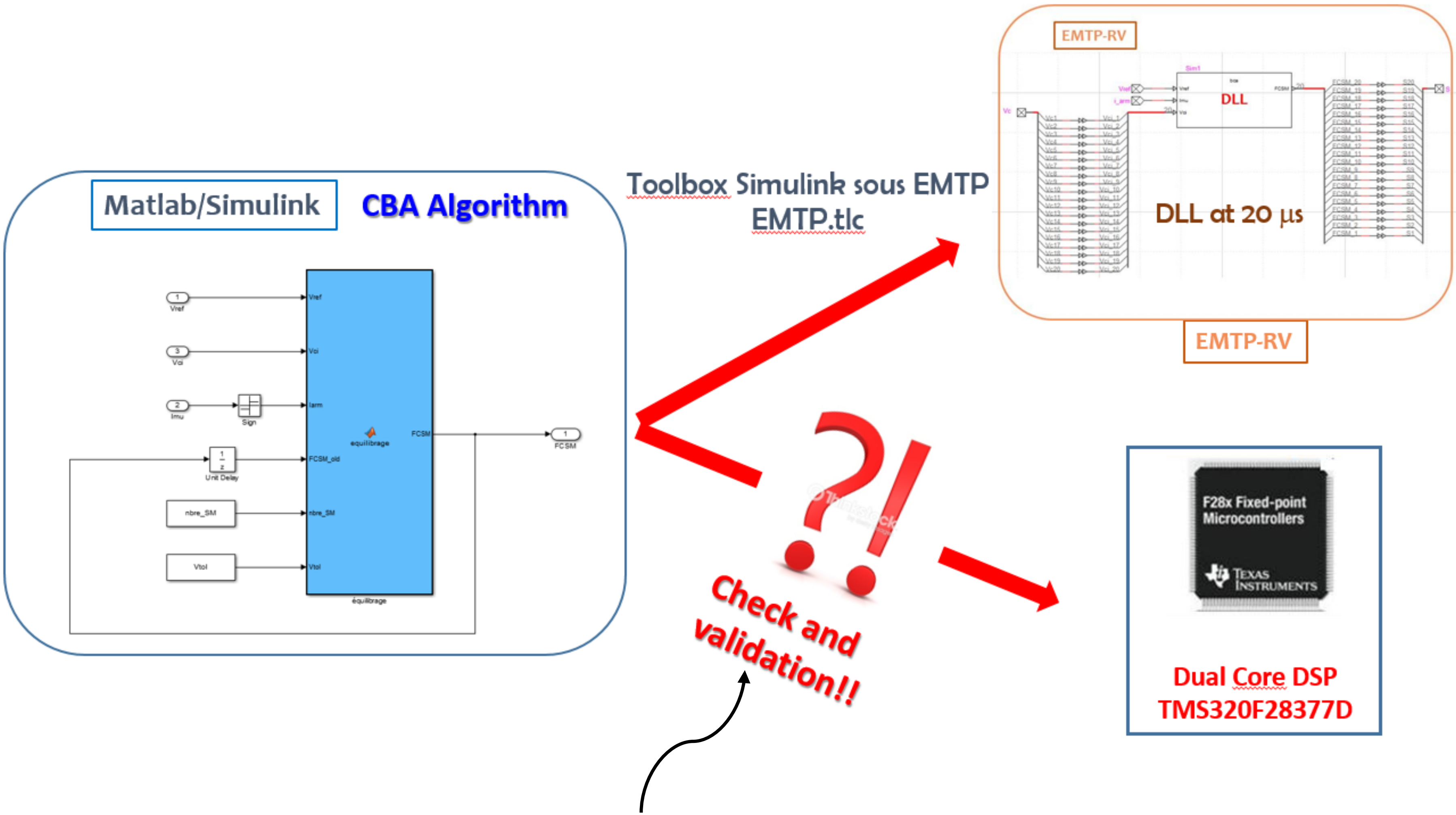


The same strategy as the high level control has been adopted using **SimulinkDLL** component:



Since it is not possible to use the same DLL in simulation and experimentation for the CBA because the assembly code in DSP is optimized to minimize the computing time on CPU.

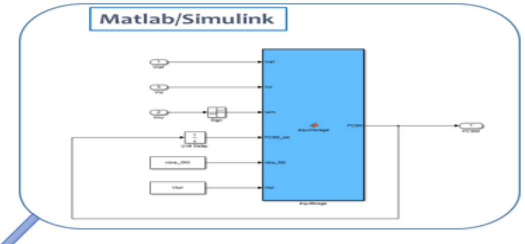
II.3. Modeling of the Low-level control (CBA: Capacitors Balancing Algorithm + NLC : Nearest Level Control)



A validation method based on real-time simulation and HIL(Hardware In the Loop) has been performed.

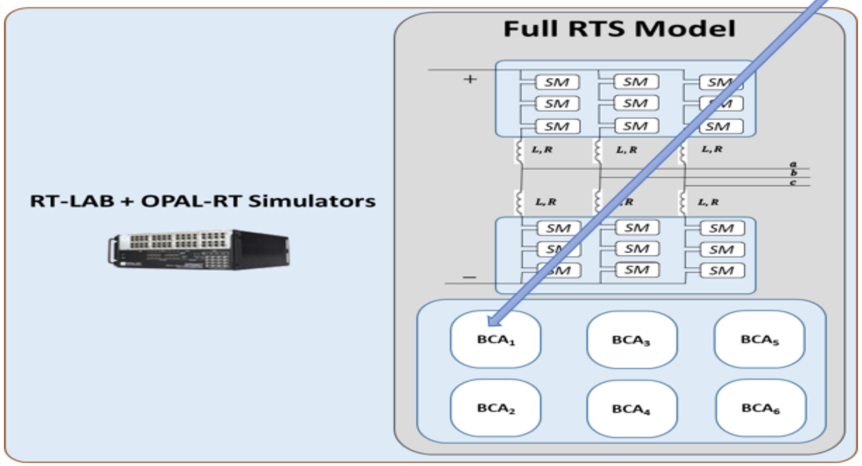
II.3. Modeling of the Low-level control (CBA: Capacitors Balancing Algorithm + NLC : Nearest Level Control)

A dynamic comparative study has been performed for a given operating point.



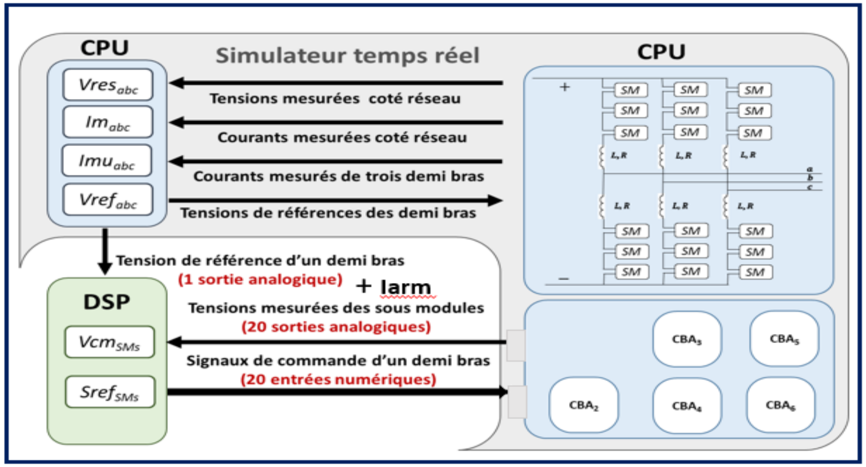
CBA 1

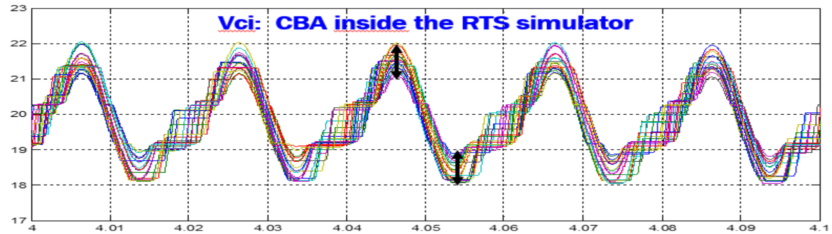
Full RTS Method

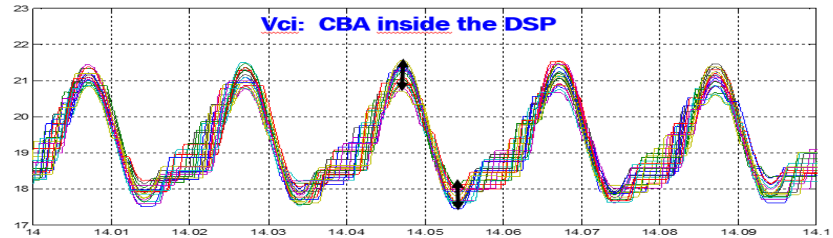


V.S

HIL Strategy



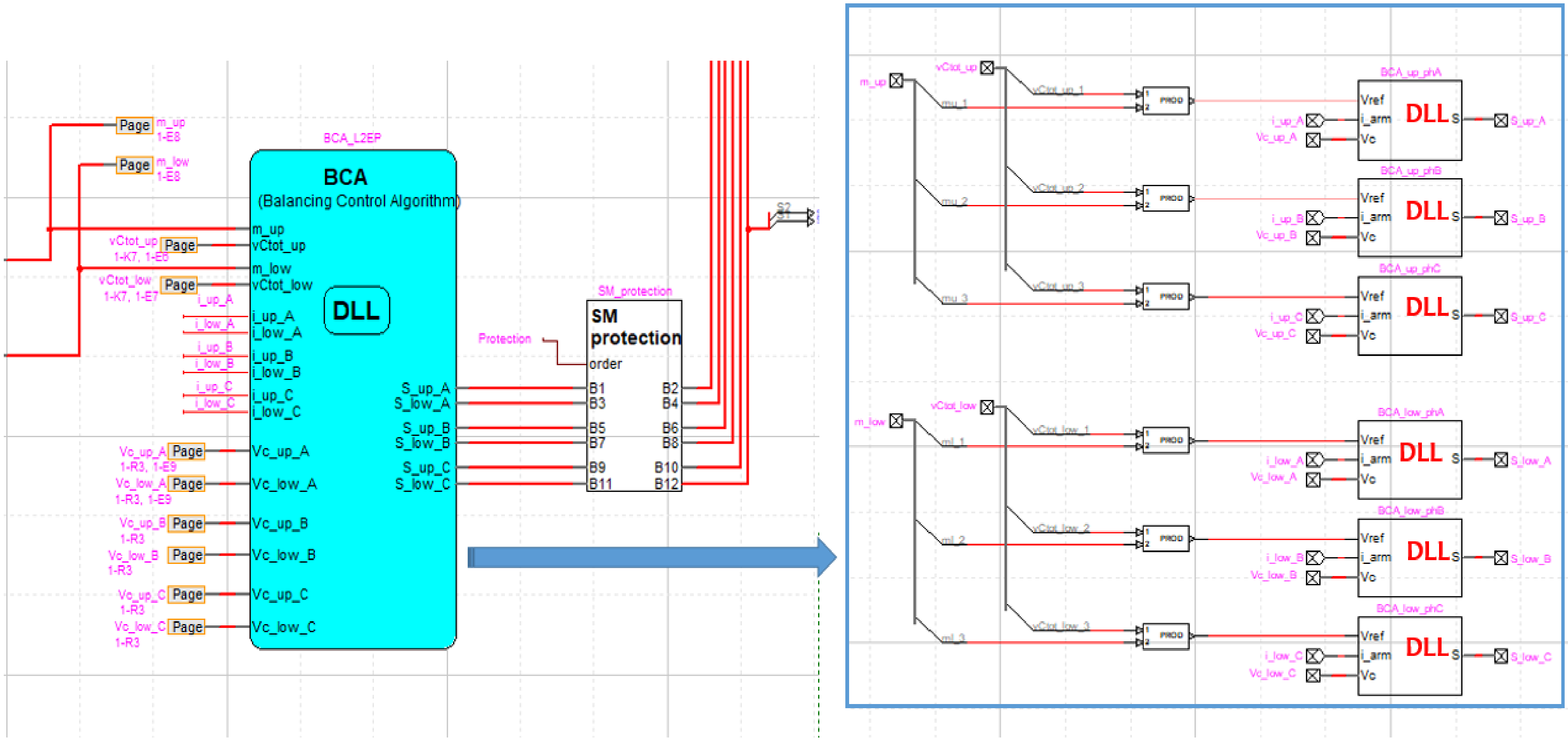




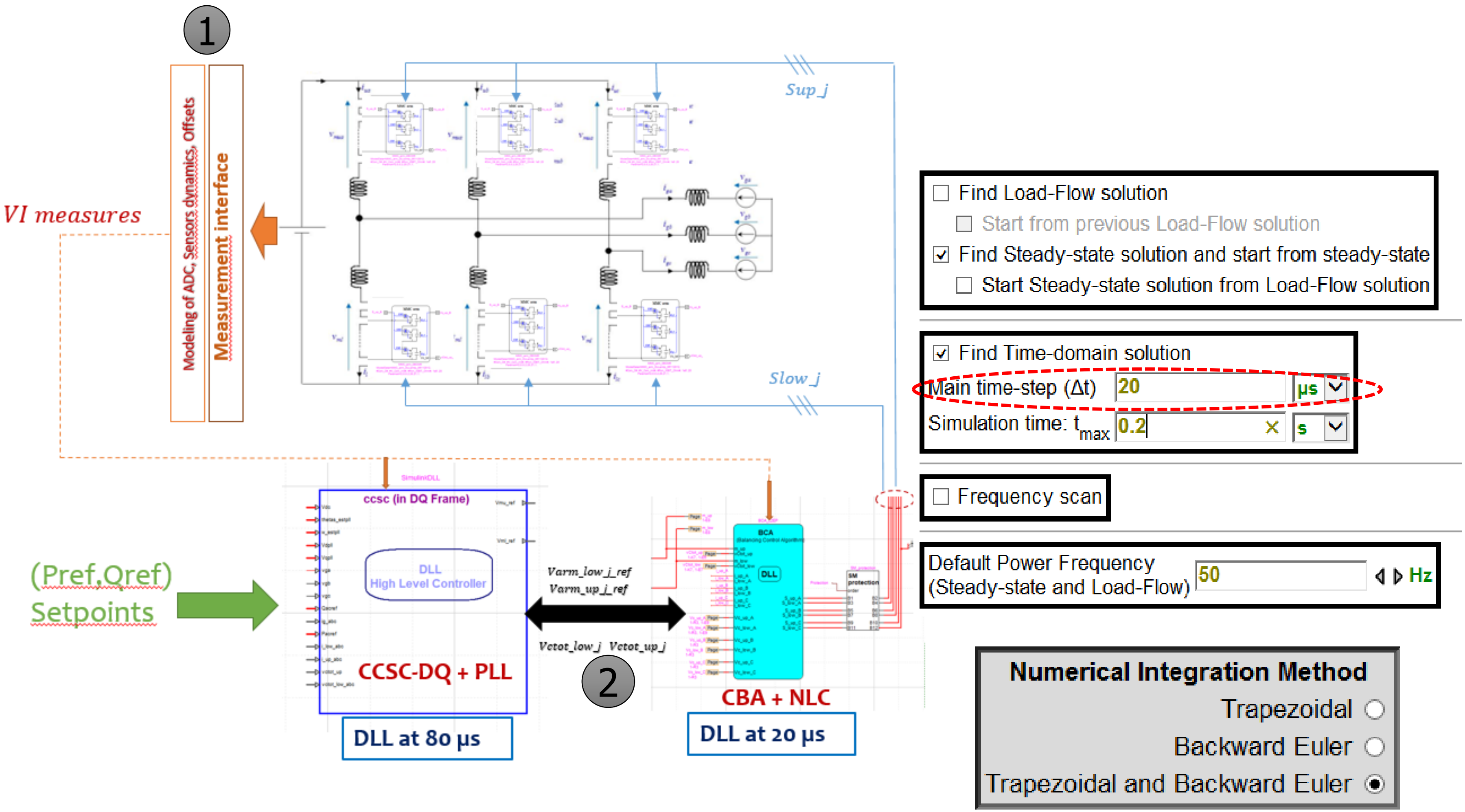
Similar results for the same input = Validation

II.3. Modeling of the Low-level control (CBA: Capacitors Balancing Algorithm + NLC : Nearest Level Control)

DLL Running at 20 μs



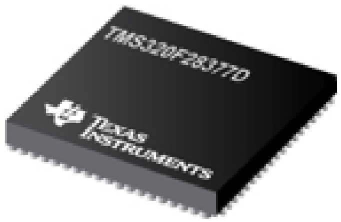
II.4. Modeling of ADC, Sensors dynamics, Offsets and Communication Delays



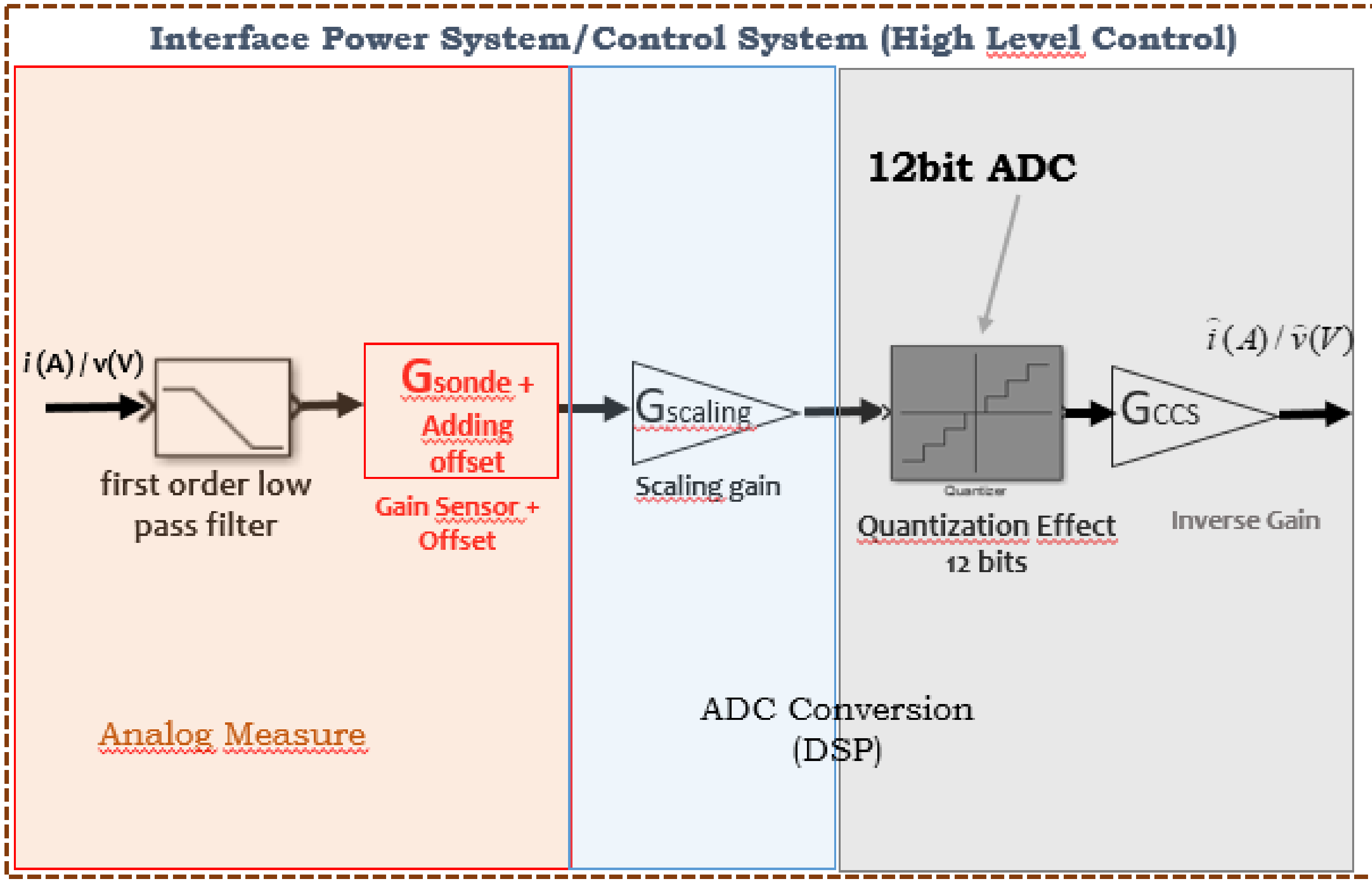
1. Modeling of the ADC, delays and Quantization effect ;
2. Modeling of the communication between DSP Master (HLC) and DSP Slave (LLC).

II.4. Modeling of ADC, Sensors dynamics, Offsets and Communication Delays

Modeling of the Measurements interface under Simulink/Matlab and its integration in the EMTP model as a DLL.

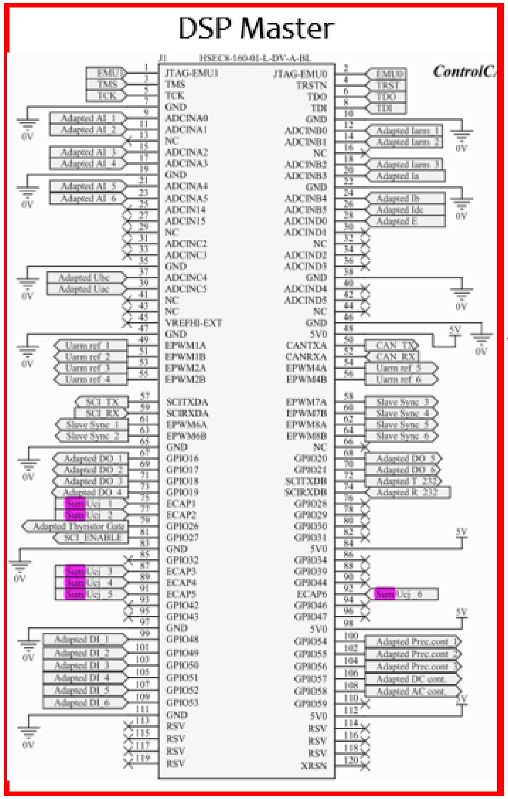


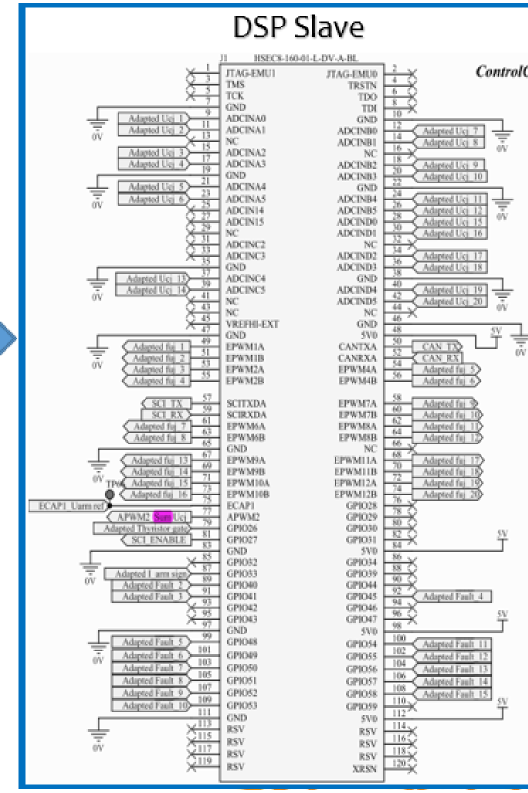
Master Controller



The addition of offsets for current measurements (mainly arm currents) impacts steady state behavior.

II.4. Modeling of ADC, Sensors dynamics, Offsets and Communication Delays



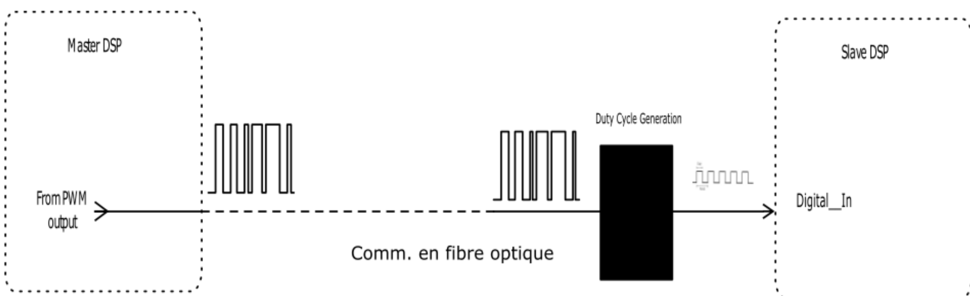


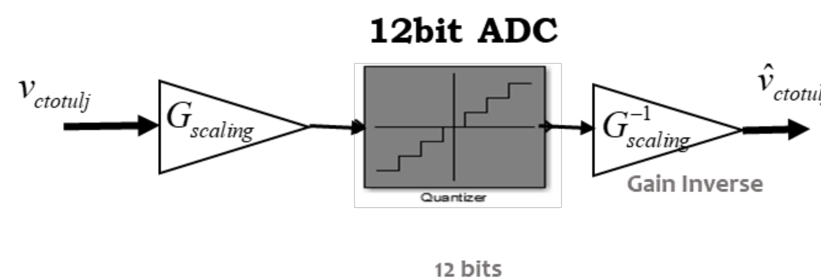
Communication on PWM and duty cycle

Optical Fibre communication

Master →Slave: ECAP_Uarm_ref ; Slave_Sync.

Slave → Master : PWM_Sum_Ucj ; Fault_signal

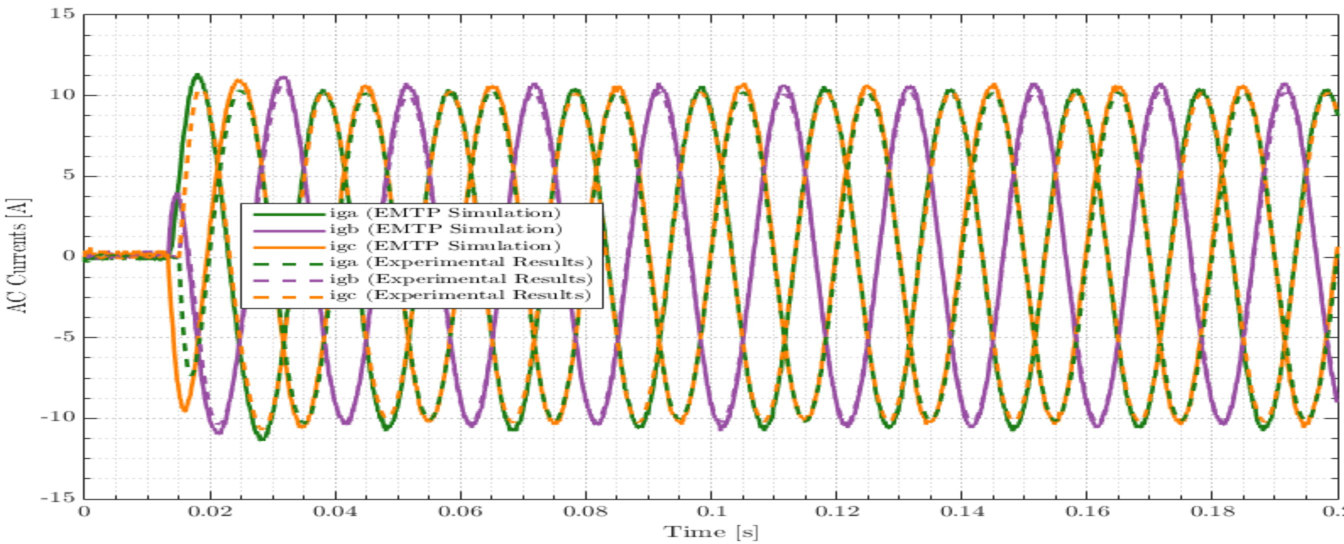


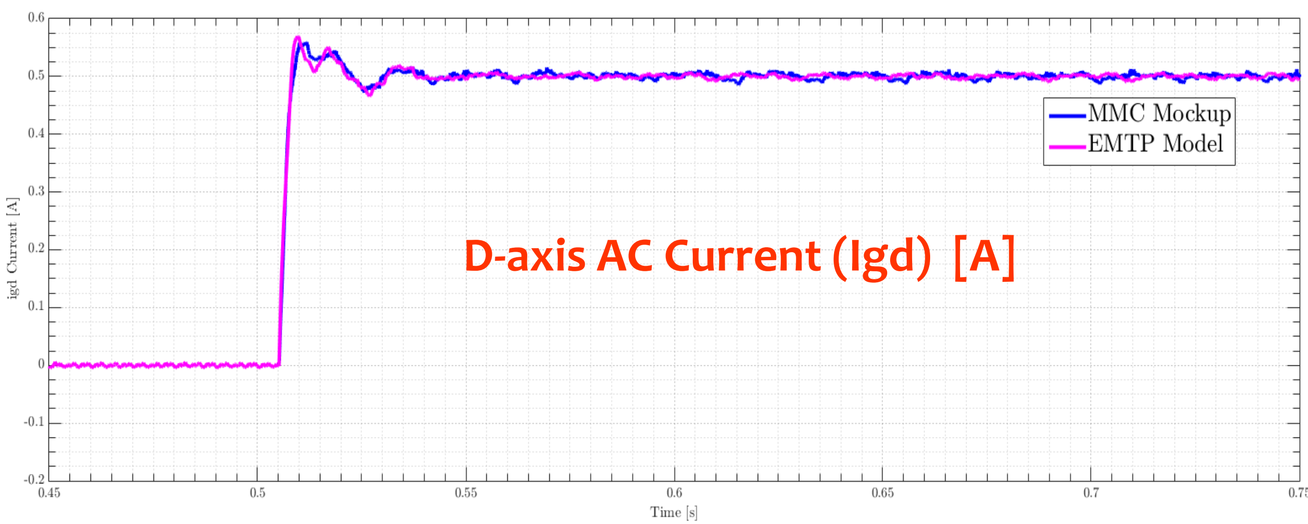


III. COMPARATIVE STUDY BETWEEN EXPERIMENTAL AND SIMULATION RESULTS

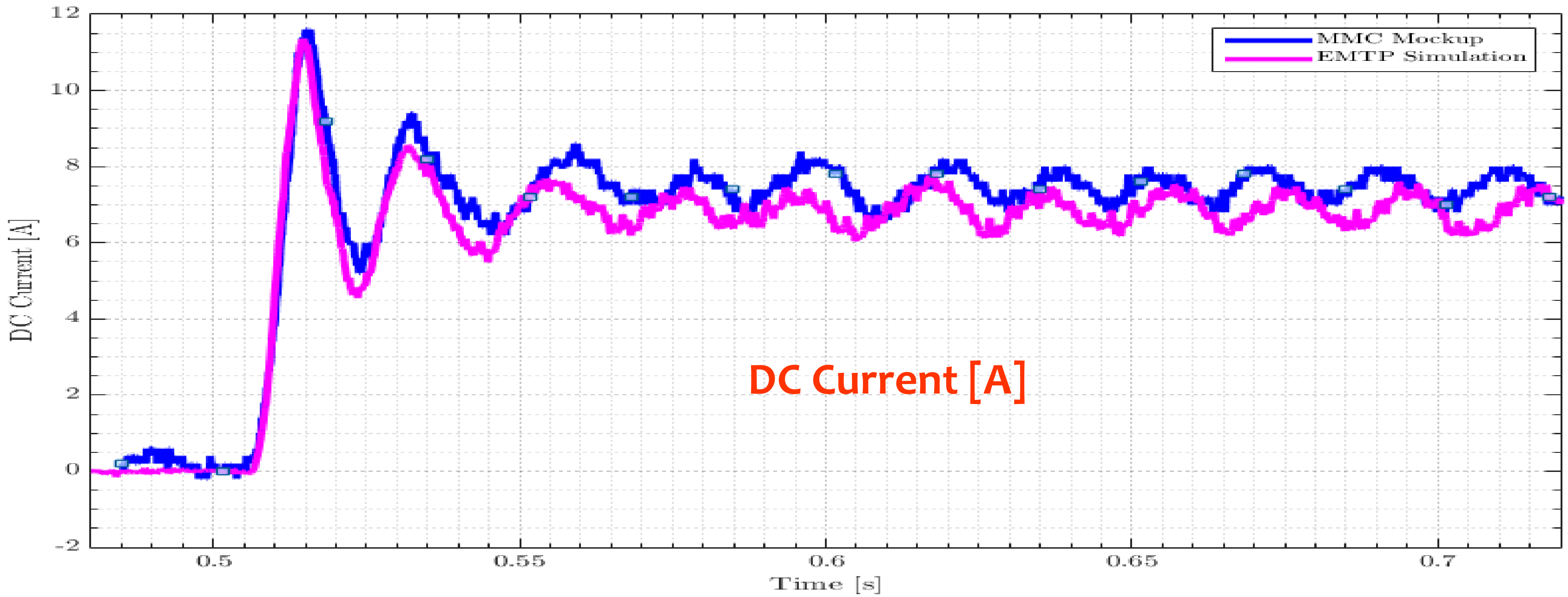
The comparative study is performed for 2500 W (0.5 pu) as active power step change and 0.0 W as reactive power:

AC Current in abc frame [A]

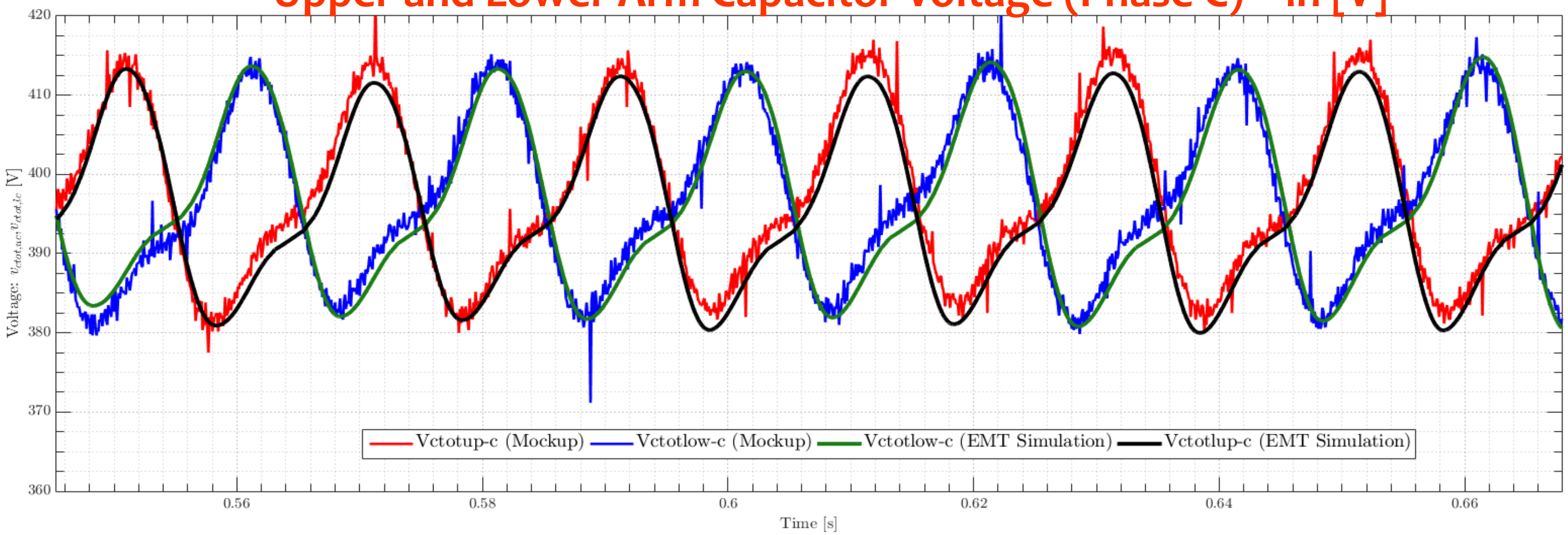




III. COMPARATIVE STUDY BETWEEN EXPERIMENTAL AND SIMULATION RESULTS



Upper and Lower Arm Capacitor Voltage (Phase C) - in [V]



IV.1. CONCLUSIONS

- The conception and development of a detailed simulation model under EMTP to faithfully produce the behavior of a small-scale 21-level MMC converter have been presented.

- A detailed EMT simulation model is designed and developed starting from the power part, then the high-level controller and finally the low-level controller.

- Thanks to the modeling of the measurement interface, quantization effect delays and the measurement offsets, the accuracy of the EMTP-RV model has been improved .

- The comparative study between experimental and simulation results leads to a quite similar behavior on the AC and DC sides.

IV.2. RECOMMANDATIONS (Share of our experience)

	Influential points in modeling	Non-Influential points in modeling
Power System	• Detailed identification of SM : SM capacitance, dead-time, Ron resistance of IGBT, time delay of voltage sensor… • Use of detailed model Type 1 of MMC Submodule. • Parametric identification of Prototype and its environment : Integration of these parameters in EMT Model.	• The Snubber parameters (R_n, C_n) • The time delay of the sensors less than $\Delta t \leq 1\ \mu s$ • Use of the same point-on-wave between the simulation model and the mockup.
Control System	• Use the **SimulinkDLL** library to implement the high and low level controllers as well as PLL. • Modeling of control sensor delay, Offsets. • Modeling of the ADC and quantization effect. • Modeling of the communication between Master-Slave controllers.	• Dynamics of voltage and current sensors of global controller which are very fast. • Any measurement delays that are below the microseconds.

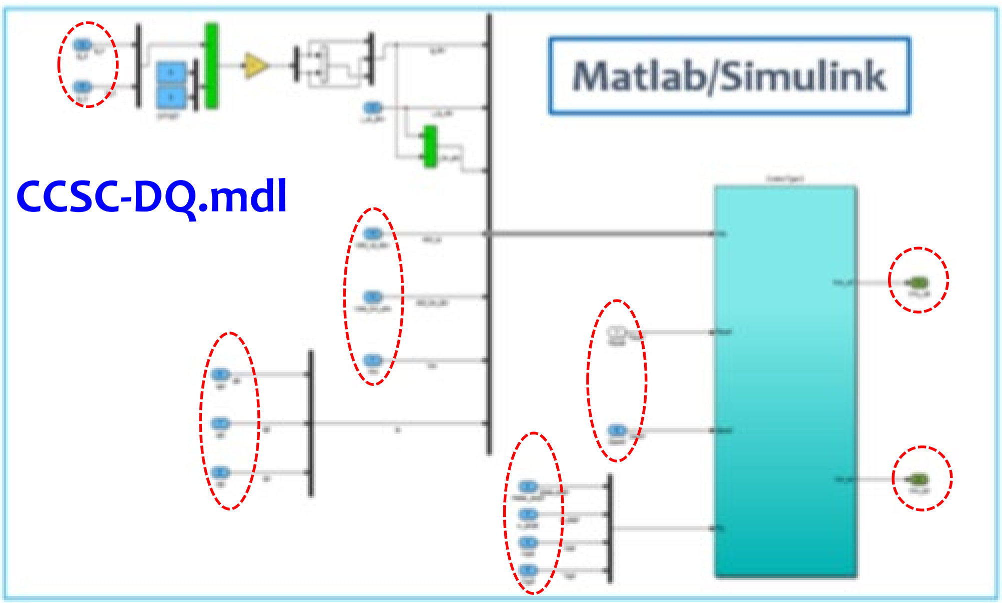
Electromagnetic Transients (EMT) Model Design based on Modular Multilevel Converter Mockup

THANK YOU!

Integration of Simulink Control Model in EMTP-RV Simulation

STEP 1: *Integration of SimulinkDLL toolbox in EMTP-RV and configuration of Visual C++ compiler in Matlab .*

STEP 2: *Generation of a compatible DLL with EMTP-RV from Simulink model: **Simulink Model Configuration***



→ Setting of each bloc;

→ Setting of In/out port dimensions and signal types;

→ Adjustment of sample time for In/out ports and Discrete-time integrators;

→ …

STEP 3: *Simulink configuration and code generation*

→ Simulation/Configuration Parameters >> Code Generation>> Browse>> select EMTP.tlc

→ Check the fundamental sample time in Solver/Fixed-step size

→ Select the tunable parameters without regenerate the code

Integration of Simulink Control Model in EMTP-RV Simulation

STEP 4: *Building the DLL*

Successful completion of build procedure for CCSC-DQ.mdl model → New folders : slprj and CCSC-DQ_EMTP_rtw + CCSC-DQ.dll

STEP 5: *Simulink model imported into EMTP-RV*