WEBINAR AND DEMO:
The New Universal Converter Model — A Revolution in Real-Time Power Electronics Simulation

RTDS Technologies

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AGENDA

No general technology intro today

- History of power electronics modelling with the RTDS Simulator
- UCM overview
- UCM details: theory, performance, and demonstration in RSCAD
- Q&A

HISTORY OF THE RTDS SIMULATOR & POWER ELECTRONICS SIMULATION

- **1986**

  RTDS development project begins

- **1989**

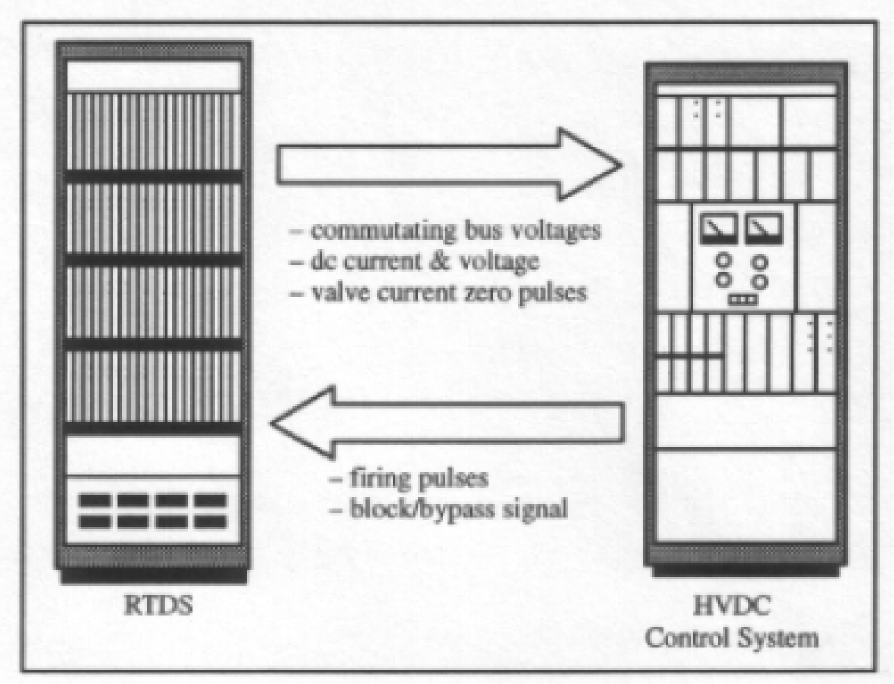
  World's 1st real-time digital HVDC simulation

- **1993**

  1st commercial installation

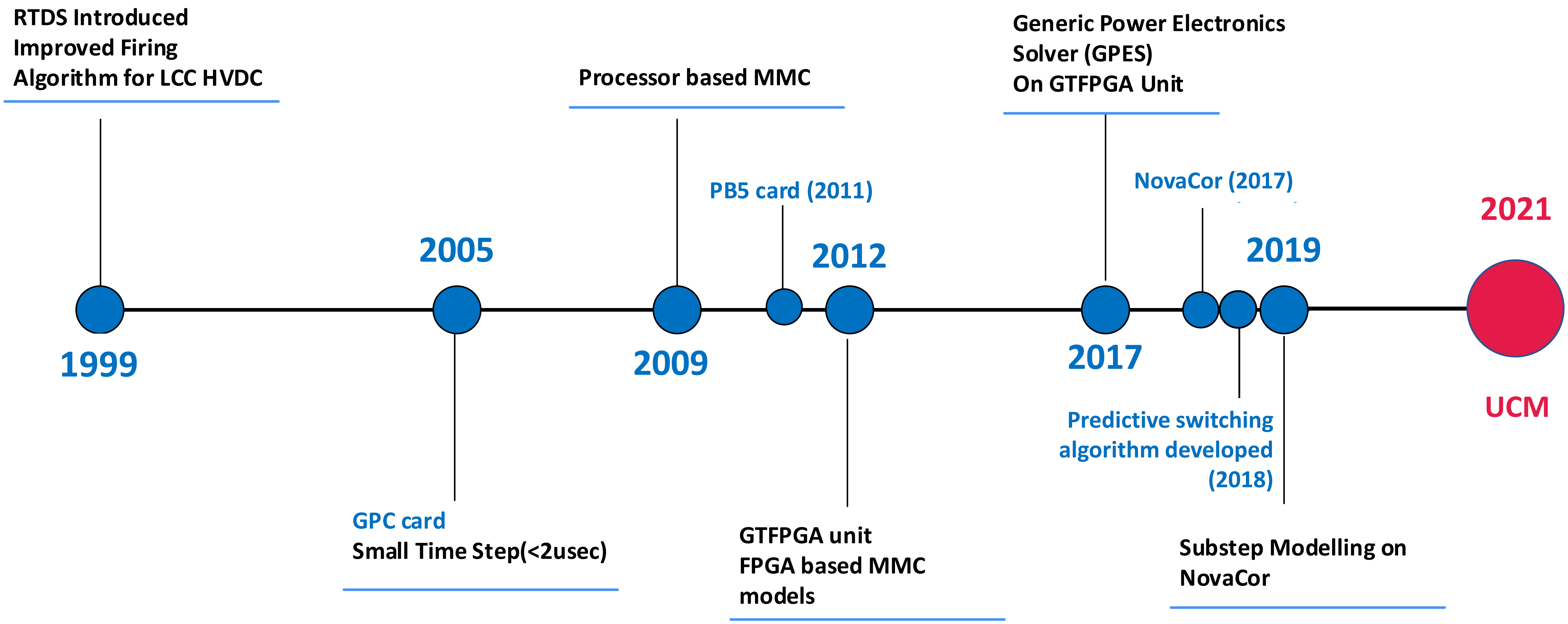
- **1994**

  RTDS Technologies Inc. created



- Line-commutated converter simulation was an essential part of the original RTDS Simulator offering

POWER ELECTRONICS MODELLING TIMELINE



1999

RTDS Introduced
Improved Firing
Algorithm for LCC HVDC

2005

GPC card
Small Time Step(<2usec)

2009

Processor based MMC

PB5 card (2011)

2012

GTFPGA unit
FPGA based MMC
models

2017

Generic Power Electronics
Solver (GPES)
On GTFPGA Unit

NovaCor (2017)

Predictive switching
algorithm developed
(2018)

2019

Substep Modelling on
NovaCor

2021

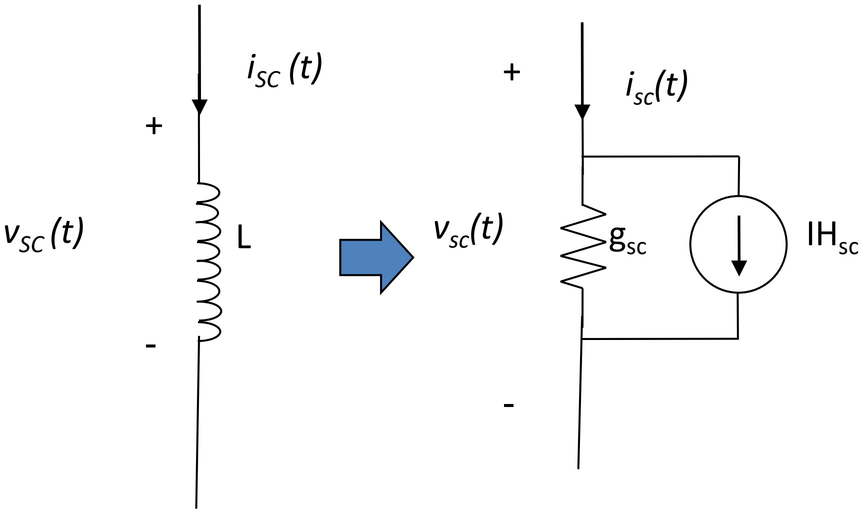
UCM

SMALL TIMESTEP ENVIRONMENT FOR VSC MODELLING

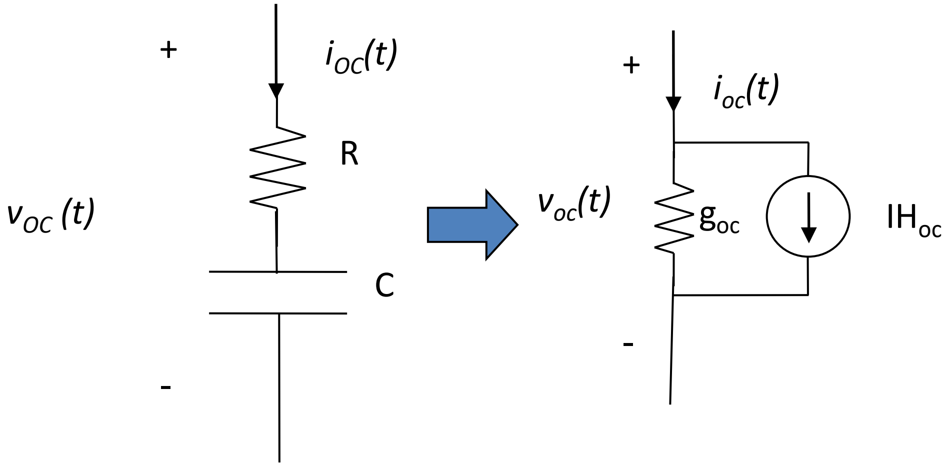
LC Switching Representation

- Matrix inversion/decomposition not practical to perform at 1-3 µsec timestep for GPC/PB5 hardware
- If $g_{oc}=g_{sc}$, admittance matrix is constant
- Difference in ON/OFF impedance is presented from the history current source

Short Circuit:



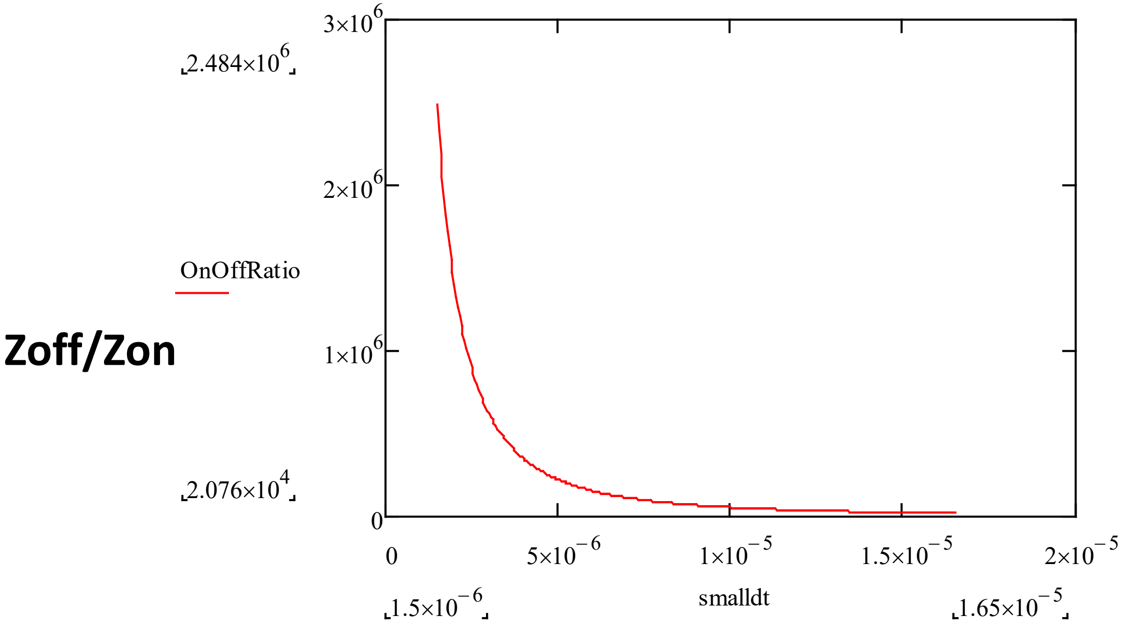
Open Circuit:



SMALL TIMESTEP ENVIRONMENT FOR VSC MODELLING

LC Switching Representation

Side effect: Operational bandwidth



Time step cannot be too high → Δt <3.75 usec

Side effect: switching losses

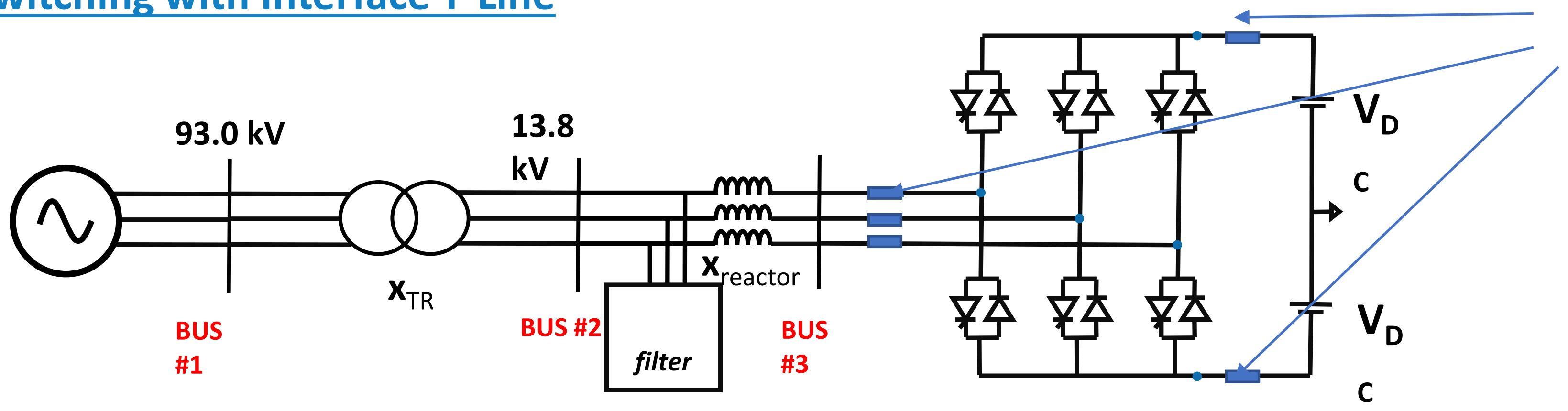
$$Energy\ stored\ in\ inductor = \frac{1}{2} L\, i^2$$

$$Energy\ stored\ in\ capacitor = \frac{1}{2} C\, v^2$$

- **Artificial switching losses are higher as the switching frequency increases**
- **Limit switching frequency with LC model < 2-3 kHz**

SMALL TIMESTEP ENVIRONMENT FOR VSC MODELLING

Resistive Switching with Interface T-Line



1 small Δt travel time t-lines

Generally

$$G = \begin{bmatrix} Y_{1,1} & Y_{1,2} & Y_{1,3} & \cdots & Y_{1,100} \\ Y_{2,1} & & & & \vdots \\ \vdots & & & & \vdots \\ \vdots & & & & \vdots \\ Y_{100,1} & \cdots & \cdots & \cdots & Y_{100,100} \end{bmatrix}$$

100 x 100 matrix

After adding T-lines....

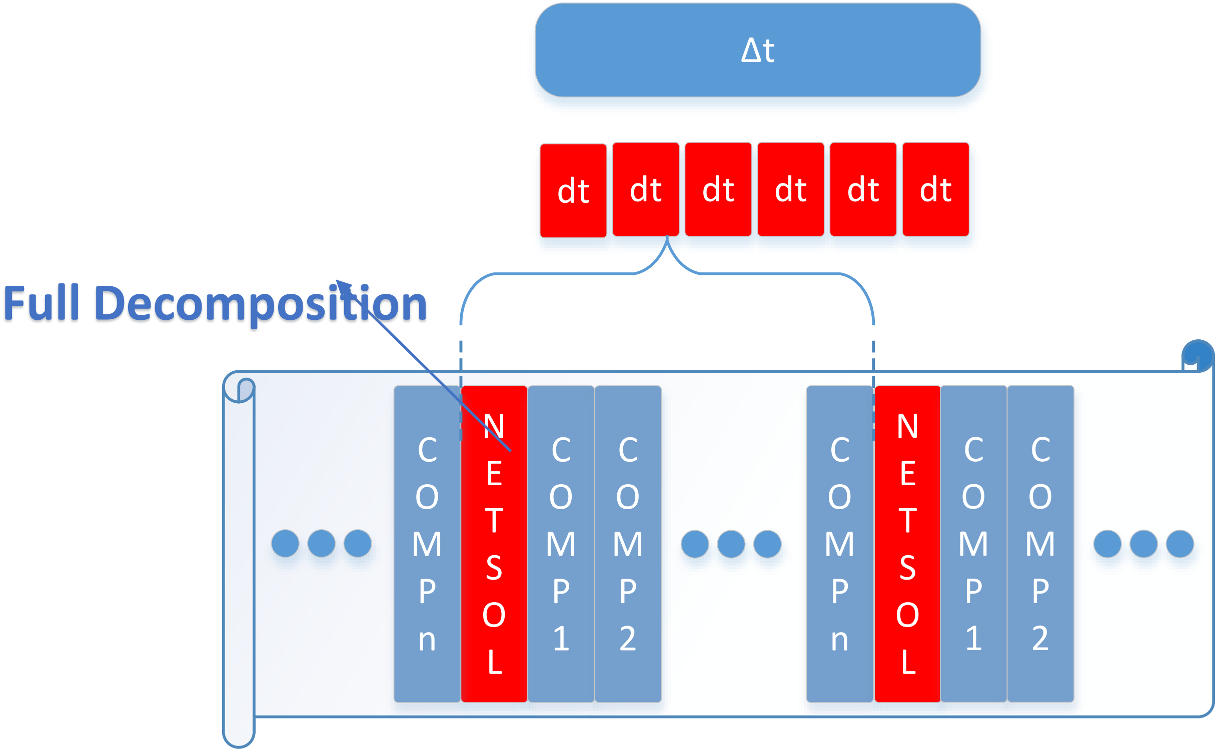
$$G = \begin{bmatrix} \begin{bmatrix} Y_{1,1} & \cdots & \cdots & \cdots & Y_{1,95} \\ \vdots & & & & \vdots \\ \vdots & & & & \vdots \\ \vdots & & & & \vdots \\ Y_{95,1} & \cdots & \cdots & \cdots & Y_{95,95} \end{bmatrix} & 0 \\ 0 & \begin{bmatrix} Y_{96,96} & \cdots & Y_{96,100} \\ \vdots & & \vdots \\ Y_{100,96} & \cdots & Y_{100,100} \end{bmatrix} \end{bmatrix}$$

1 Large Matrix, 1 Small Matrix

- The valves are decoupled from the small time-step network solution for any given time-step and can solved separately.
- The valves can be modeled as resistances with pre-calculated matrices.
- limit on the maximum valve switching rate no longer applies.

SUBSTEP ENVIRONMENT

- Enabled by increased processing power of NovaCor hardware
- Innovative, proprietary switching algorithm

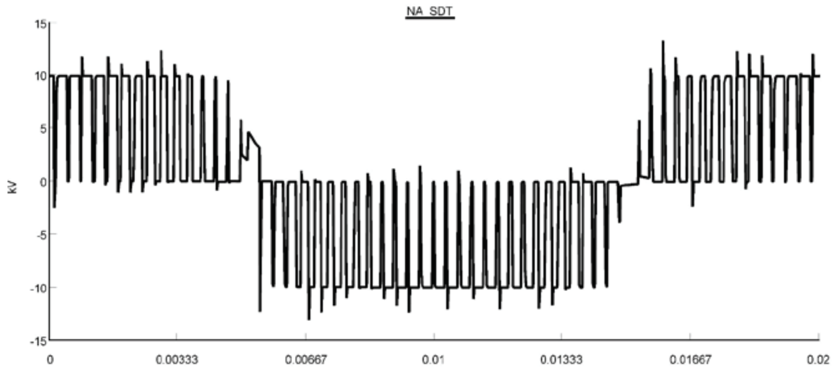


- Each Substep network requires a full core – can run multiple Substep networks
- Substep library has models optimized for a smaller time step – however, Mainstep components are also supported
- No limit on the number of resistive switching elements
- Accurate representation of non linear elements
- No interface lines required for use of resistive switching
- IO cards supported (excluding GTNET)

SUBSTEP ENVIRONMENT

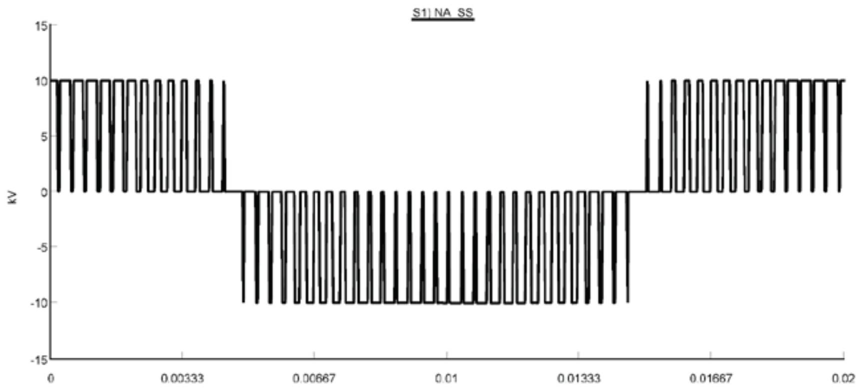
Switching with L/C discrete circuits

Switching Frequency (Hz)	**Losses (%)**
500	0.785
1000	2.944
2000	3.969
3000	5.556
4000	4.751
5000	6.22



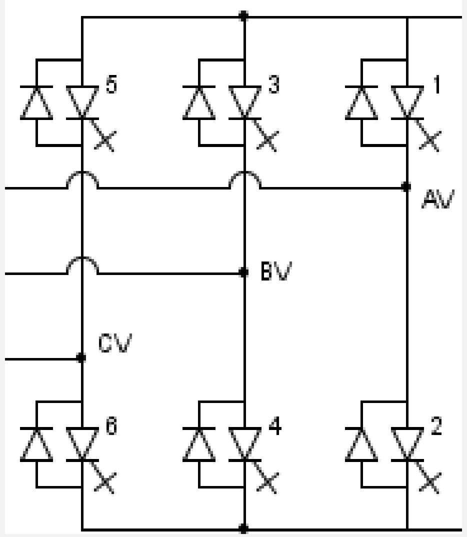
Resistive switching with Substep

Switching Frequency (Hz)	**Losses (%)**
500	0.17677
1000	0.23942
2000	0.29634
3000	0.35097
4000	0.40486
5000	0.48544
7500	0.64673
10000	0.78104
12500	0.91324
15000	1.04670
20000	1.25735
25000	1.44307

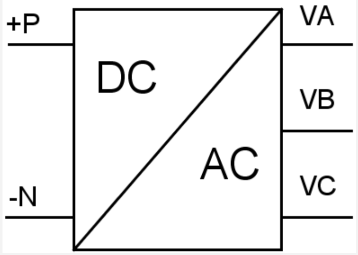


AVERAGE VS. FULLY-SWITCHED MODELS: CONSIDERATIONS

Fully-switched models



- Consider the switching topology, switching characteristics of the converter, characteristic harmonics
- Allows for low level control testing (firing pulses)
- **May be modelled with resistive switching or L/C switching**
- **May or may not be decoupled/interfaced**
- **Higher computational burden**



Average value models

- Replaces detailed models with controlled voltage and current sources
- Modulation waveforms from the same current controller can be used to strategically control the sources such as to reproduce an averaged version of the high frequency switching transients
- **May or may not be decoupled/interfaced**
- **Lower computational burden**

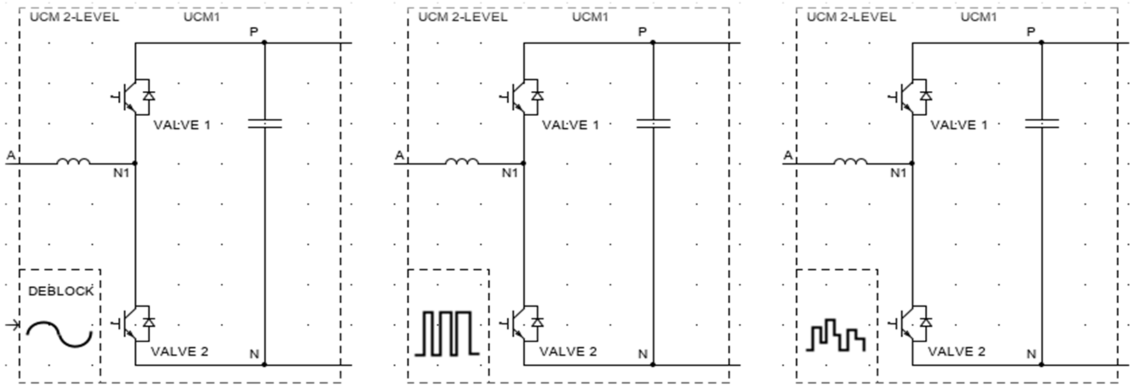
INTRODUCING THE UCM

Motivation

- Demand for converter modelling and simulation with higher switching frequency (>30 kHz)
- Research found that average modelling may be used to achieve high resolution of firing
- Other average model implementation is decoupled on the DC bus – can cause instability

Solution: Universal Converter Model

- Available for 2-level, NPC (ANPC), T-type, boost and buck
- Multiple input (control) types
- Can be used in Mainstep OR Substep
- Improving performance and reducing computational burden
- **No decoupling / interface lines**



2-level UCM

UCM

Input Types

- Modulation Waveform
- Full Firing Pulse (reads firing pulse once per simulation timestep)
- **Improved Firing (with Mean Value High Precision)**
    - Captures firing pulses within a timestep at high resolution to calculate how much of the timestep the switch should be “on” (producing an effective duty cycle)
    - Multiple turn-on/turn-off transitions per timestep are allowed

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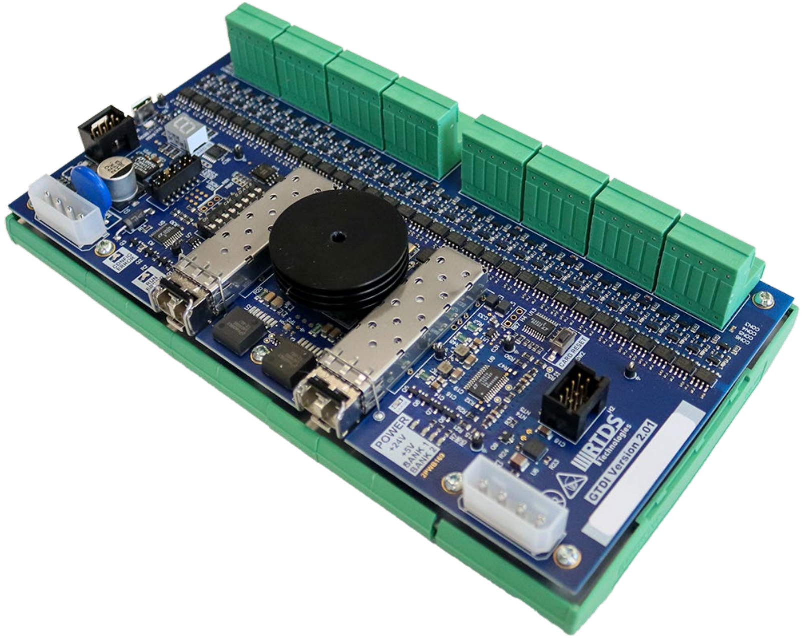
HIL testing with the UCM – Digital input card

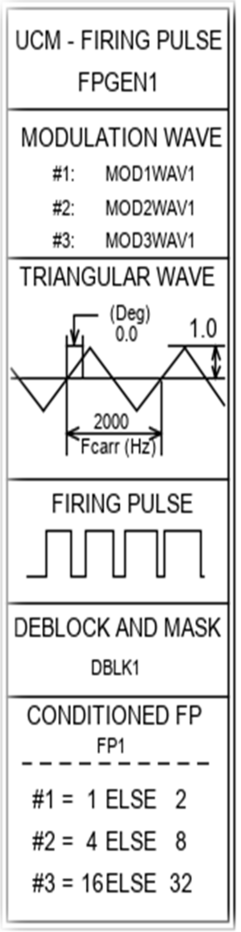
- New GTDI v2 required for Improved Firing feature
- Samples firing pulses every 10 ns

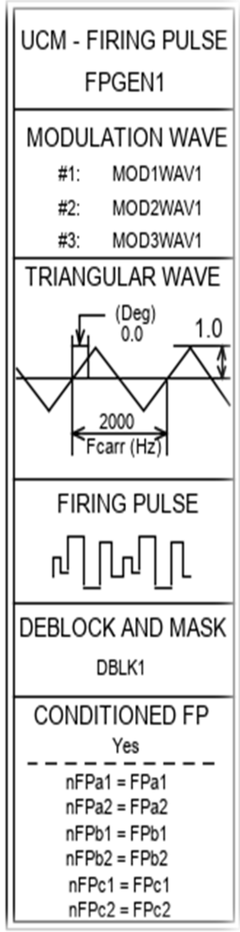


UCM

Internal Firing Pulse Generator

- Full simulation without GTDI/controller
- Can generate regular firing pulses
    - Same as previous model
- Can generate Improved Firing (Mean Value High Precision) input for UCM
    - Uses interpolation to find the precise crossing point(s) of the modulation and triangle waveform within each timestep





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Substep Environment (<10 us)

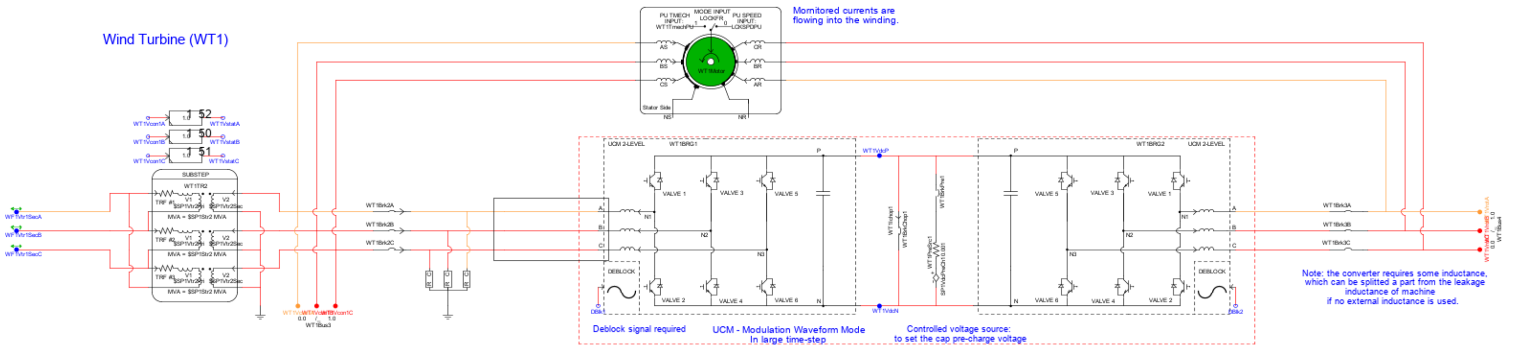
- Full Firing Pulse Input
    - Similar to existing resistive-switching Substep models
- Modulation Wave Input
    - Similar to average model, but with improved performance
    - Proper transition between blocked and de-blocked states
- Improved Firing Input
    - Accurately represents converter performance with PWM firing **>100 kHz**

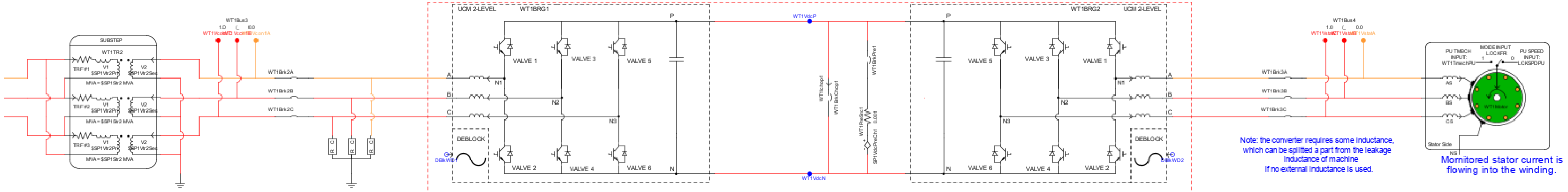
Mainstep Environment (30-50 us)

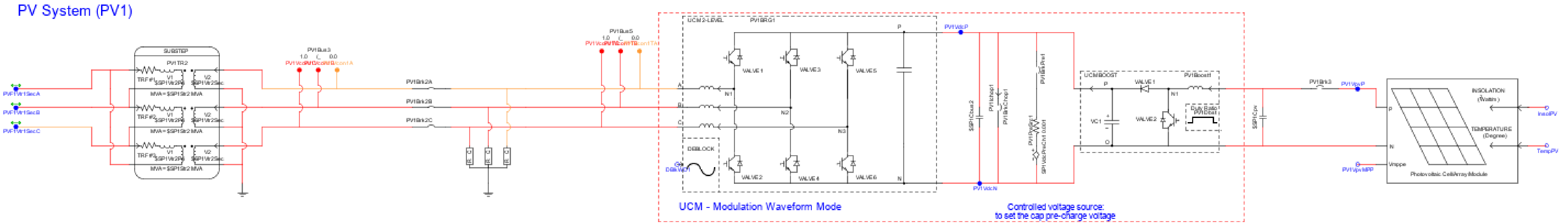
- Modulation Wave Input
- Improved Firing Input
    - Accurately represents converter performance in the **3 kHz range**
    - 10 load units per converter

UCM

No decoupling or Interface lines







UCM

Benefits

- Good results even with a 30-50 us timestep – no need to maintain very small timesteps like other simulators which use decoupled models – fit many detailed converter models on a significantly reduced quantity of hardware
- Proper transitioning from blocked to deblocked states – UCM incorporates proprietary predictive switching technique from Substep models
- Improved Firing represents the characteristic harmonics very well and introduces minimal non-characteristic harmonics
- Improved firing has good comparisons with PSCAD
- **UCM sample cases are now available in RSCAD 5.014 and RSCAD-FX 1.0**

Thank you!

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Universal Converter Model (UCM)

--Principle, Implementation, and Applications

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Content

1 Definition of UCM

2 Converter Modelling

4 Improved Firing Pulse Modelling

5 Demo and Discussion

1 Definition of Universal Converter Model (UCM)

Key Feature of UCM: *Universal*

- Support PB5-based and NovaCor-based Hardware
- Support SubStep, MainStep, and Distribution Mode Simulations
- Support Software-in-the-loop and Hardware-in-the-loop Testing
- Support Different Inputs
  - Modulation Waveform
  - Firing Pulse
  - Improved Firing Pulse with Mean Value High Precision

2 Converter Modelling

Key Techniques of Converter Modelling

- ☐ Switching Function
  - ❖ Flexible Inputs
- ☐ Descriptor State Space (DSS)
  - ❖ Eliminate the Controlled Source Delay
- ☐ Predictive Algorithm in Blocked Mode

2 Converter Modelling

2.1 Switching Function

❑ Algebraic Equations

$$\begin{cases} \mathbf{v}_{\mathbf{CS}} = \mathbf{m} \cdot v_P + (\mathbf{1} - \mathbf{m}) \cdot v_N \\ i_{CS\_P} = \mathbf{m}^{\mathbf{T}} \cdot \mathbf{i}_{\mathbf{ac}} \\ i_{CS\_N} = (\mathbf{1} - \mathbf{m})^{\mathbf{T}} \cdot \mathbf{i}_{\mathbf{ac}} \\ i_{ac\_a} + i_{ac\_b} + i_{ac\_c} + i_P + i_N + i_O = 0 \end{cases}$$

where,

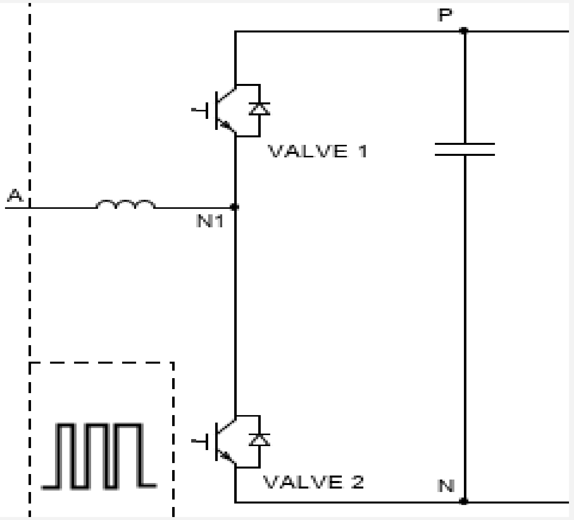
$\mathbf{v}_{\mathbf{CS}}$: voltage controlled source;

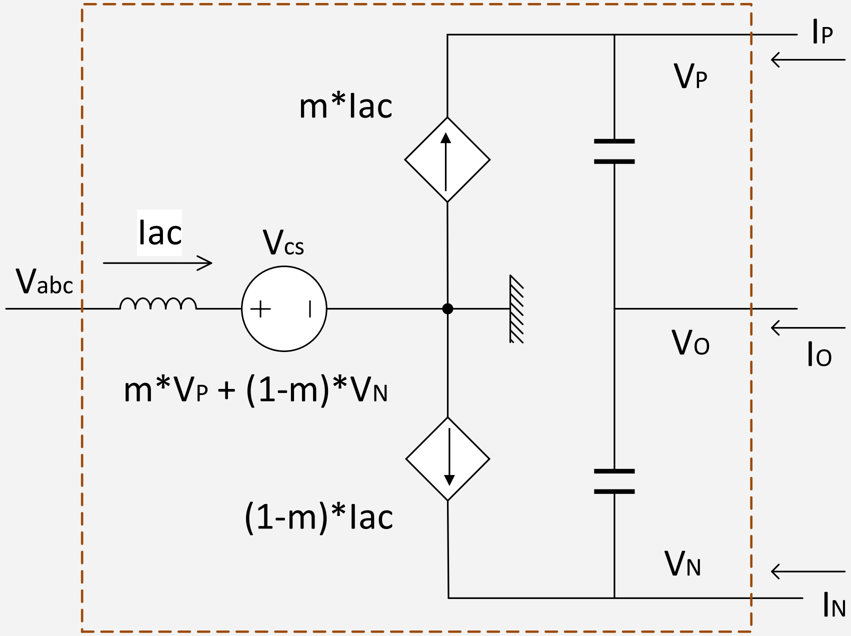
i_{CS_P}, i_{CS_N} : current controlled source;

$\mathbf{i}_{\mathbf{ac}}$: ac inductor currents;

v_P, v_N : dc node voltages;

$\mathbf{m}$: switching function of top switch.





2 Converter Modelling

2.2 Descriptor State Space (DSS)

❑ Differential Equations

$$\begin{cases} L\dfrac{\mathbf{di_{ac}}}{\mathbf{dt}} + \mathbf{Ri_{ac}} + \mathbf{v_{CS}} = \mathbf{v_{abc}} \\ i_{C\_P} = C\dfrac{d(v_P - v_O)}{dt} \\ i_{C\_N} = C\dfrac{d(v_N - v_O)}{dt} \end{cases}$$

where,

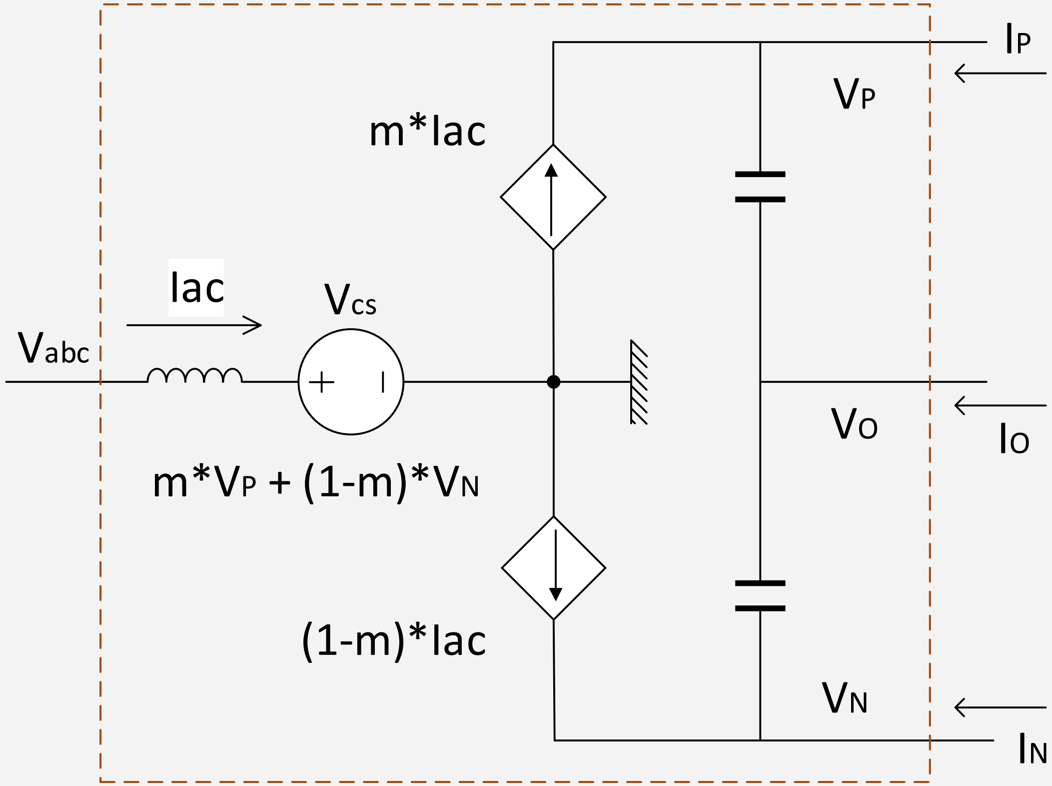
$\mathbf{v_{CS}}$: voltage controlled source;

i_{C_P}, i_{C_N} : capacitor current;

$\mathbf{i_{ac}}$: ac inductor currents;

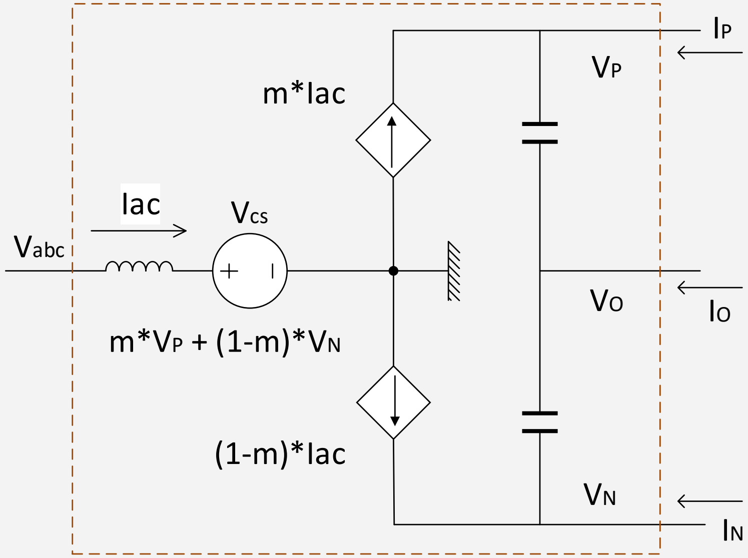
$\mathbf{v_{abc}}$: ac node voltages;

v_P, v_N, v_O : dc node voltages.



2 Converter Modelling

2.2 Descriptor State Space (DSS)



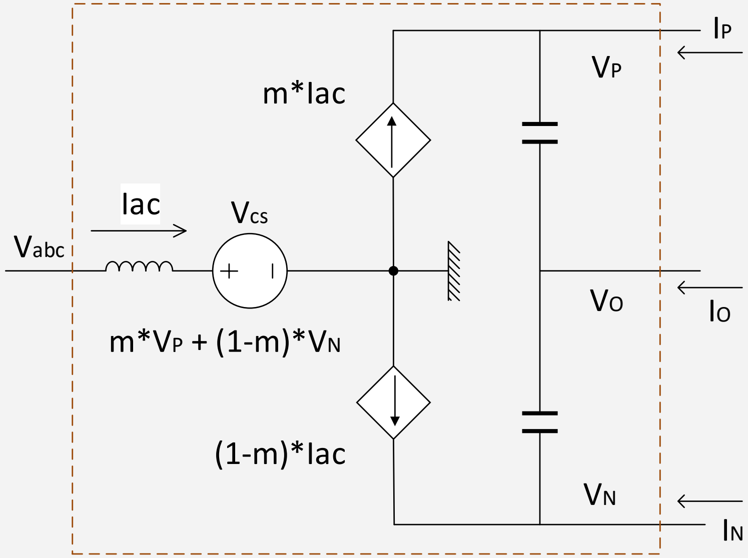
❑ Differential Algebraic Equations

$$\begin{cases} L\frac{\mathbf{di_{ac}}}{\mathbf{dt}} + \mathbf{Ri_{ac}} + \mathbf{v_{CS}} = \mathbf{v_{abc}} \\ i_{C\_P} = C\frac{d(v_P - v_O)}{dt} \\ i_{C\_N} = C\frac{d(v_N - v_O)}{dt} \end{cases}$$

$$\begin{cases} \mathbf{v_{CS}} = \mathbf{m}\cdot v_P + (\mathbf{1}-\mathbf{m})\cdot v_N \\ i_{CS\_P} = \mathbf{m}^{\mathbf{T}}\cdot \mathbf{i_{ac}} \\ i_{CS\_N} = (\mathbf{1}-\mathbf{m})^{\mathbf{T}}\cdot \mathbf{i_{ac}} \\ i_{ac\_a} + i_{ac\_b} + i_{ac\_c} + i_P + i_N + i_O = 0 \end{cases}$$

2 Converter Modelling

2.2 Descriptor State Space (DSS)



☐ Differential Algebraic Equations (Sequential Solution)

AC SIDE:

$$\begin{cases} \mathbf{v}_{\mathbf{CS}} = \mathbf{m}\cdot v_P + (\mathbf{1}-\mathbf{m})\cdot v_N \\ L\dfrac{\mathbf{di}_{\mathbf{ac}}}{\mathbf{dt}} + \mathbf{R}\mathbf{i}_{\mathbf{ac}} + \mathbf{v}_{\mathbf{CS}} = \mathbf{v}_{\mathbf{abc}} \end{cases}$$

DC SIDE:

$$\begin{cases} i_P + \mathbf{m}^{\mathbf{T}}\cdot \mathbf{i}_{\mathbf{ac}} = C\dfrac{d(v_P - v_O)}{dt} \\ i_N + (\mathbf{1}-\mathbf{m})^{\mathbf{T}}\cdot \mathbf{i}_{\mathbf{ac}} = C\dfrac{d(v_N - v_O)}{dt} \end{cases}$$

$$i_{ac\_a} + i_{ac\_b} + i_{ac\_c} + i_P + i_N + i_O \approx 0$$

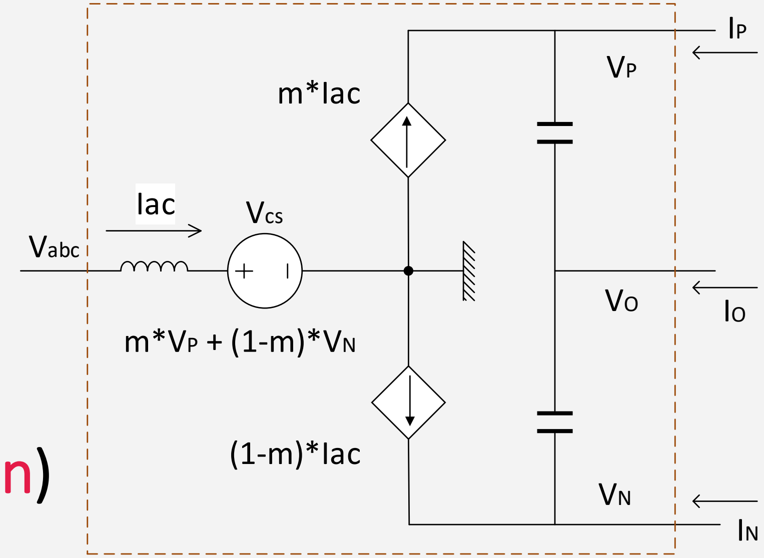
Issues:

1, Numerical instable;

1, Power imbalance between ac and dc side

2 Converter Modelling

2.2 Descriptor State Space (DSS)



- ☐ Differential Algebraic Equations (Simultaneous Solution)

$$\underbrace{\begin{bmatrix} \mathbf{L} & 0 & 0 & 0 \\ 0 & C & 0 & -C \\ 0 & 0 & C & -C \\ 0 & 0 & 0 & 0 \end{bmatrix}}_{\mathbf{M}} \frac{d}{dt} \underbrace{\begin{bmatrix} \mathbf{i}_{\mathbf{abc}} \\ v_P \\ v_N \\ v_O \end{bmatrix}}_{\mathbf{X}} = \underbrace{\begin{bmatrix} -\mathbf{R} & \mathbf{-m}_{\mathbf{abc}} & \mathbf{-\overline{m}}_{\mathbf{abc}} & 0 \\ \mathbf{m}_{\mathbf{abc}}^{\mathbf{T}} & 0 & 0 & 0 \\ \overline{\mathbf{m}}_{\mathbf{abc}}^{\mathbf{T}} & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}}_{\mathbf{A}} \begin{bmatrix} \mathbf{i}_{\mathbf{abc}} \\ v_P \\ v_N \\ v_O \end{bmatrix}$$

$$+ \underbrace{\begin{bmatrix} 0 & 0 & 0 & \mathbf{1}_{\mathbf{3x3}} \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 \end{bmatrix}}_{\mathbf{B}} \underbrace{\begin{bmatrix} i_P \\ i_N \\ i_O \\ \mathbf{i}_{\mathbf{abc}} \end{bmatrix}}_{\mathbf{U}}$$

2 Converter Modelling

2.2 Descriptor State Space (DSS)

$$\mathbf{M\dot{x}} = \mathbf{Ax} + \mathbf{Bu}$$

Discretize and Reorganize DSS Equations

$$\begin{bmatrix} \mathbf{O}_{\mathbf{ii}} & \mathbf{O}_{\mathbf{iv}} \\ \mathbf{O}_{\mathbf{vi}} & \mathbf{O}_{\mathbf{vv}} \end{bmatrix} \begin{bmatrix} \mathbf{x}_{\mathbf{i}} \\ \mathbf{x}_{\mathbf{v}} \end{bmatrix} + \begin{bmatrix} \mathbf{P}_{\mathbf{ii}} & \mathbf{P}_{\mathbf{iv}} \\ \mathbf{P}_{\mathbf{vi}} & \mathbf{P}_{\mathbf{vv}} \end{bmatrix} \begin{bmatrix} \mathbf{u}_{\mathbf{i}} \\ \mathbf{u}_{\mathbf{v}} \end{bmatrix} = \begin{bmatrix} \mathbf{Q}_{\mathbf{ii}} & \mathbf{Q}_{\mathbf{iv}} \\ \mathbf{Q}_{\mathbf{vi}} & \mathbf{Q}_{\mathbf{vv}} \end{bmatrix} \begin{bmatrix} \mathbf{x}_{\mathbf{i}} \\ \mathbf{x}_{\mathbf{v}} \end{bmatrix} \mathbf{z}^{-1} + \begin{bmatrix} \mathbf{R}_{\mathbf{ii}} & \mathbf{R}_{\mathbf{iv}} \\ \mathbf{R}_{\mathbf{vi}} & \mathbf{R}_{\mathbf{vv}} \end{bmatrix} \begin{bmatrix} \mathbf{u}_{\mathbf{i}} \\ \mathbf{u}_{\mathbf{v}} \end{bmatrix} \mathbf{z}^{-1}$$

$$\begin{bmatrix} \mathbf{O}_{\mathbf{ii}} & \mathbf{P}_{\mathbf{ii}} \\ \mathbf{O}_{\mathbf{vi}} & \mathbf{P}_{\mathbf{vi}} \end{bmatrix} \begin{bmatrix} \mathbf{x}_{\mathbf{i}} \\ \mathbf{u}_{\mathbf{i}} \end{bmatrix} + \begin{bmatrix} \mathbf{P}_{\mathbf{iv}} & \mathbf{O}_{\mathbf{iv}} \\ \mathbf{P}_{\mathbf{vv}} & \mathbf{O}_{\mathbf{vv}} \end{bmatrix} \begin{bmatrix} \mathbf{u}_{\mathbf{v}} \\ \mathbf{x}_{\mathbf{v}} \end{bmatrix} = \begin{bmatrix} \mathbf{Q}_{\mathbf{ii}} & \mathbf{R}_{\mathbf{ii}} \\ \mathbf{Q}_{\mathbf{vi}} & \mathbf{R}_{\mathbf{vi}} \end{bmatrix} \begin{bmatrix} \mathbf{x}_{\mathbf{i}} \\ \mathbf{u}_{\mathbf{i}} \end{bmatrix} \mathbf{z}^{-1} + \begin{bmatrix} \mathbf{R}_{\mathbf{iv}} & \mathbf{Q}_{\mathbf{iv}} \\ \mathbf{R}_{\mathbf{vv}} & \mathbf{Q}_{\mathbf{vv}} \end{bmatrix} \begin{bmatrix} \mathbf{u}_{\mathbf{v}} \\ \mathbf{x}_{\mathbf{v}} \end{bmatrix} \mathbf{z}^{-1}$$

$$\rightarrow \mathbf{S}_1\mathbf{i} + \mathbf{S}_2\mathbf{v} = \mathbf{S}_3\mathbf{iz}^{-1} + \mathbf{S}_4\mathbf{vz}^{-1}$$

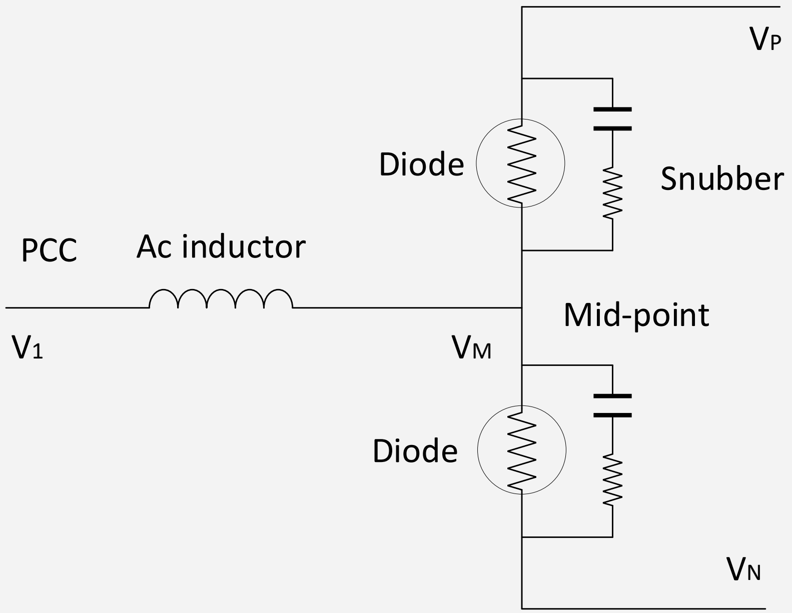
$$\rightarrow \mathbf{i} = -\mathbf{S}_1^{-1}\mathbf{S}_2\mathbf{v} + \mathbf{S}_1^{-1}\left(\mathbf{S}_3\mathbf{iz}^{-1} + \mathbf{S}_4\mathbf{vz}^{-1}\right) = -\mathbf{S}_1^{-1}\mathbf{S}_2\mathbf{v} + \mathbf{K}_{\mathbf{i}}\mathbf{iz}^{-1} + \mathbf{K}_{\mathbf{v}}\mathbf{vz}^{-1}$$

$$\rightarrow \mathbf{i} = \mathbf{Gv} + \mathbf{i}_{\mathbf{his}}$$

2 Converter Modelling

2.3 Blocked Mode (Predictive Algorithm)

Maguire, T., et al. (2018). Predicting Switch ON/OFF Statuses in Real Time Electromagnetic Transients Simulations with Voltage Source Converters. 2018 2nd IEEE Conference on Energy Internet and Energy System Integration (EI2).



Traditional Way (Open loop):

1, Using previous node voltages to determine the status of each diode;
2, Solve the circuit using the status of diodes from Step 1;

Issues:

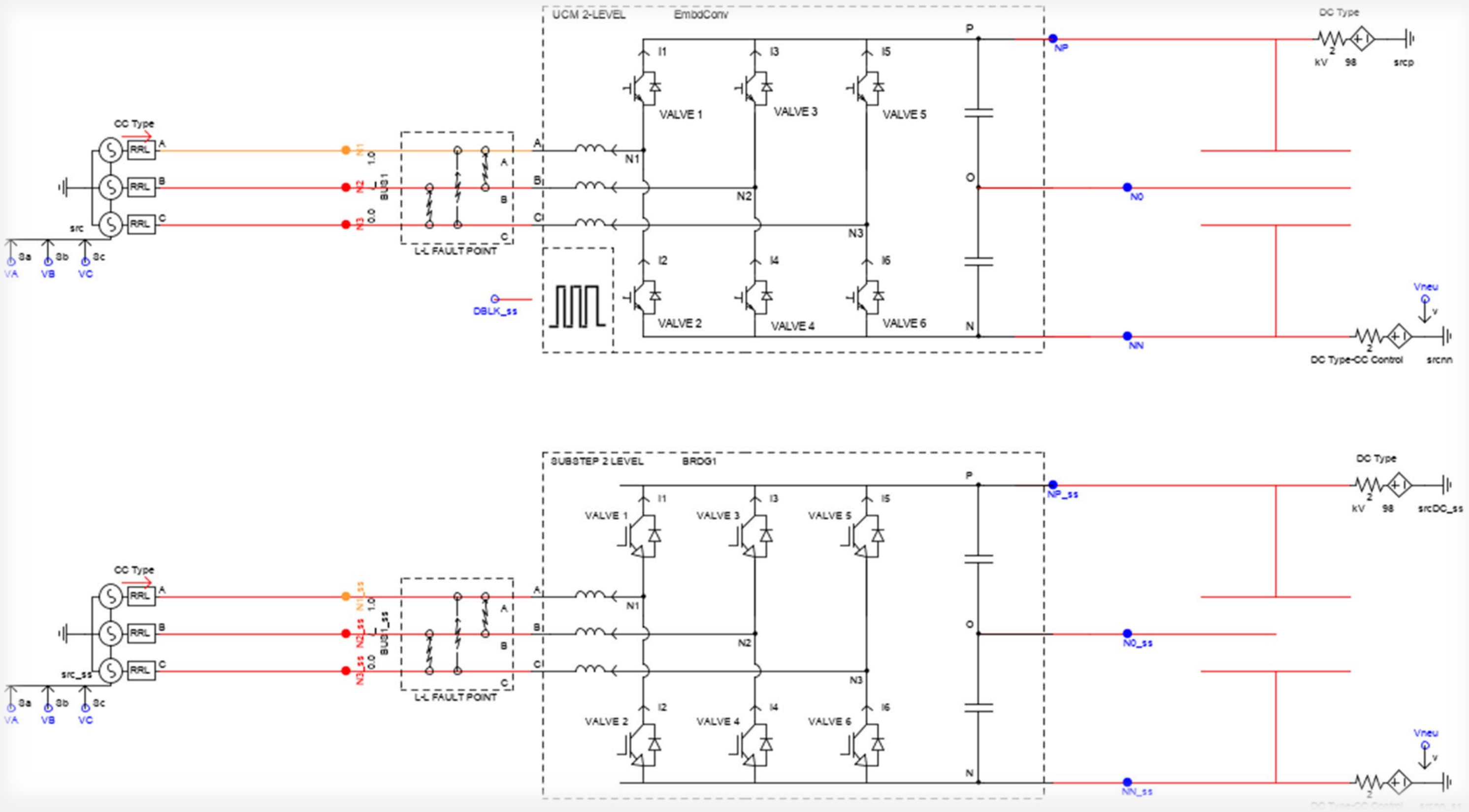
Possible diodes status jump between ON and OFF

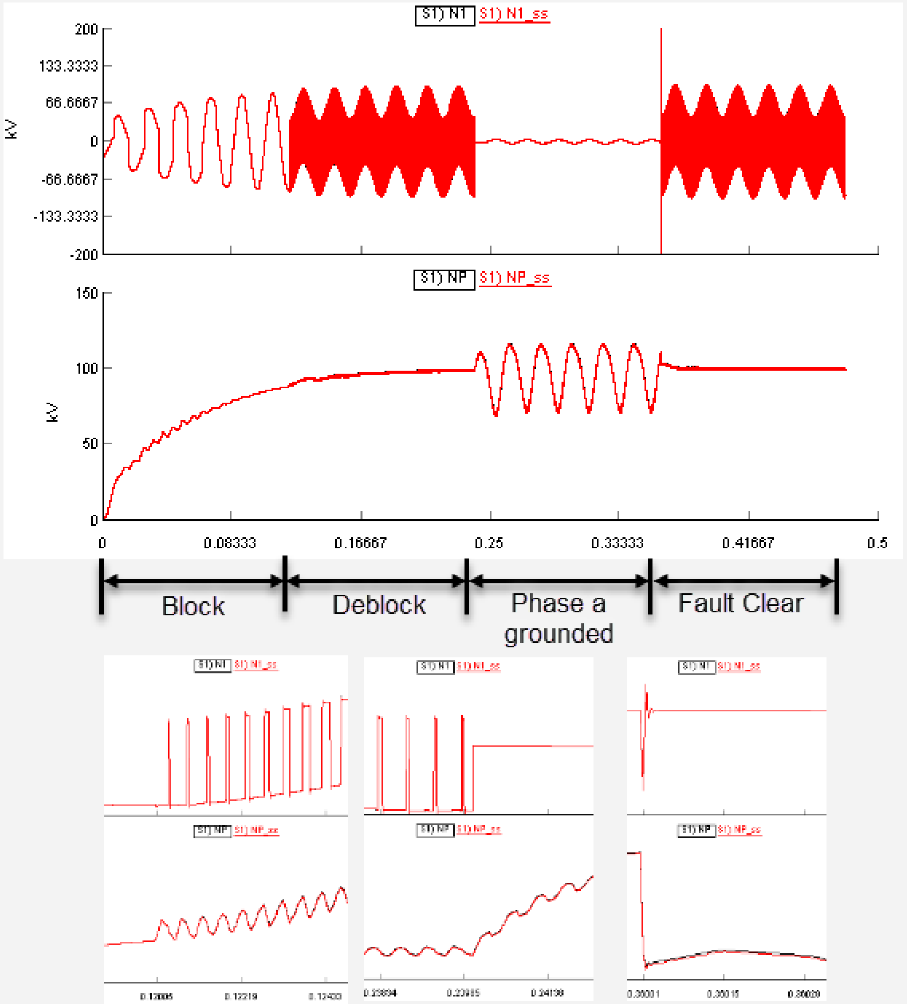
Blocked Mode in UCM ("Predict and Check"):

1, Choose one combination of all the diodes status (00, 01, 10, 11);
2, Predict the node voltage Vm with the previous step external node voltages;
3, check the status of the diodes:
  match with the chosen combination: predict successfully;
  does not match with the chosen combination: choose a new combination and go back to Step 2 and 3.

2 Converter Modelling

2.3 Blocked Mode (Validation)

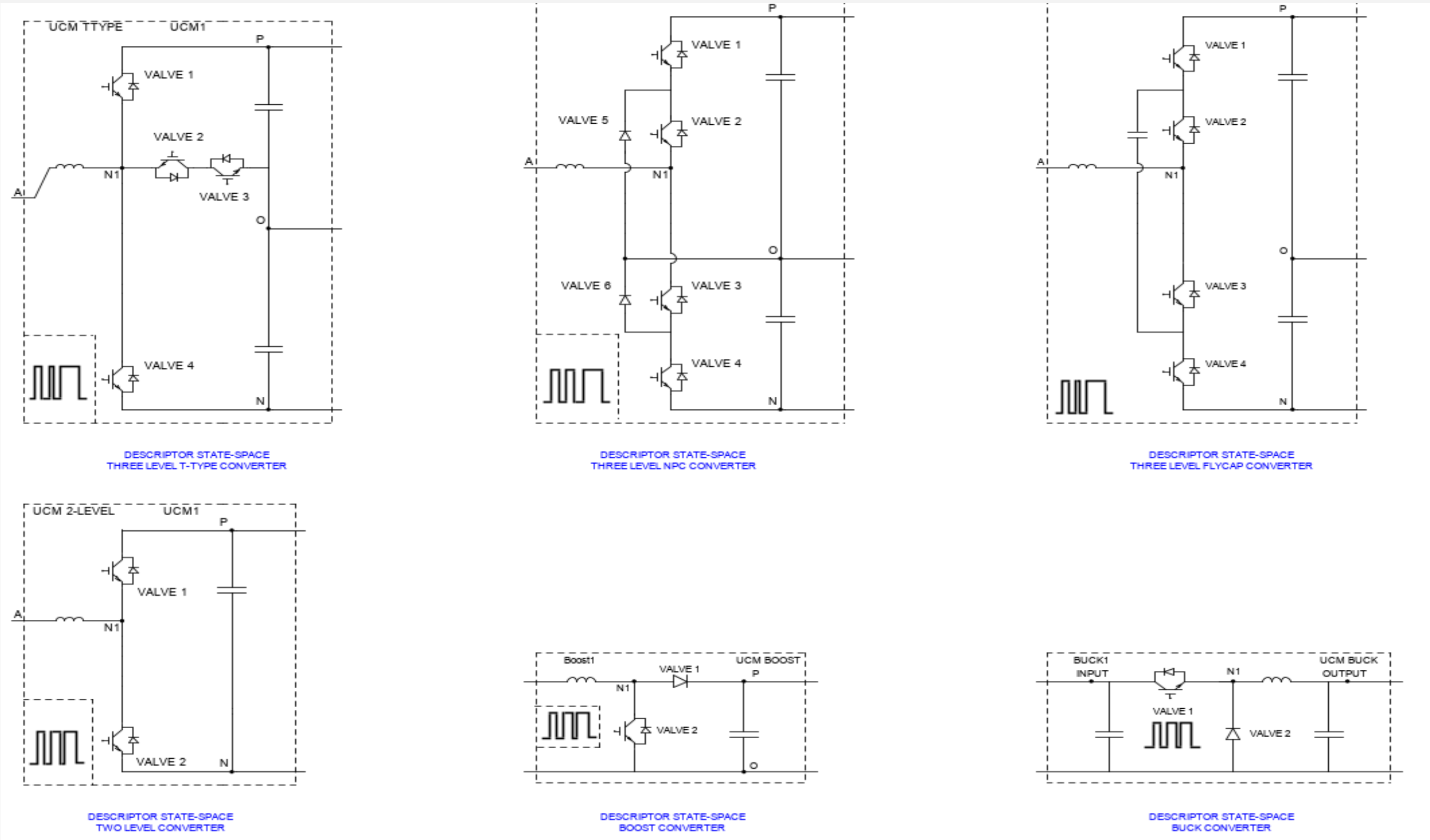




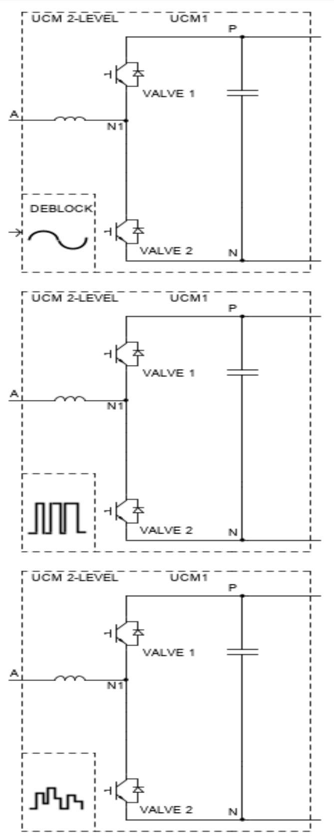
Solution Step: 5.0us; Carrier Frequency: 2.0k Hz; Open-loop Testing

2 Converter Modelling

Models Supported in the Library



Converters and FP Generator Models



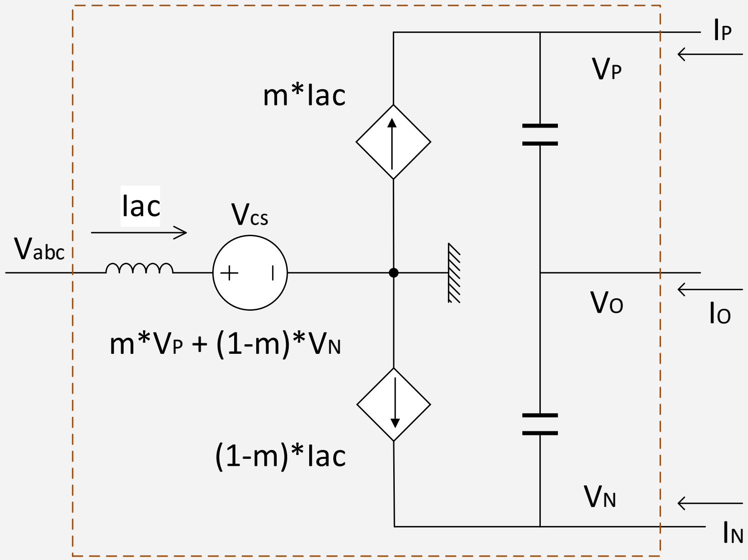
Converter Types

3 Improved Firing Pulse Modelling

3.1 Question: How to Improve the Overall Performance of Converter Simulation?

Main Components in the UCMs:

- ❖ Dynamic Elements: inductors and Capacitors;
- ❖ Controlled Source: Controlled Voltages and Current Sources;
- ❖ Switching Function (Inputs).



Assumption:

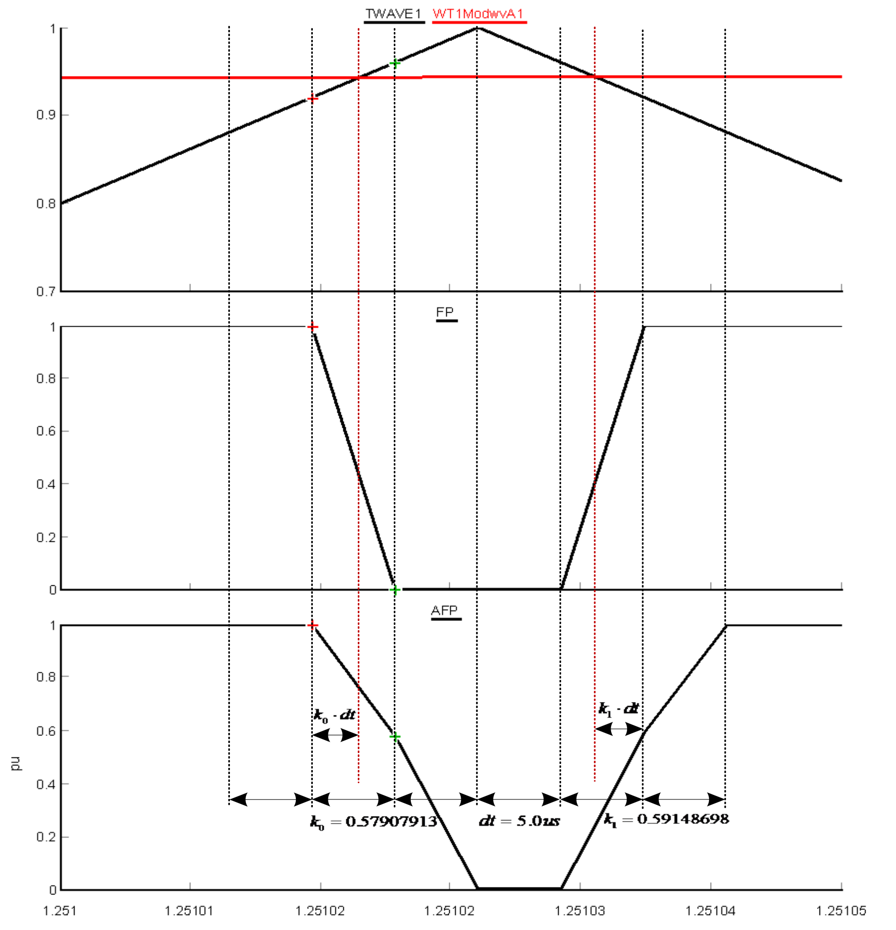
Dynamic Elements and Controlled Source could use larger time step size to obtain accurate results.

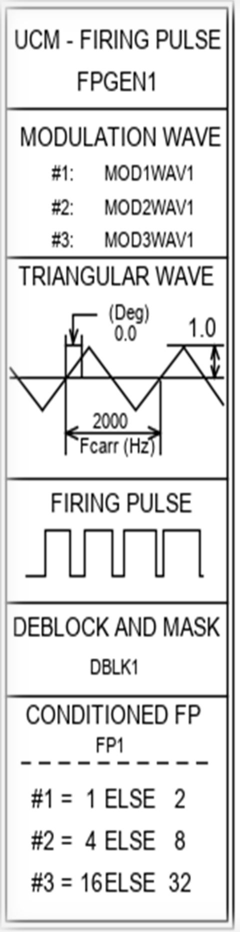
Bottleneck:

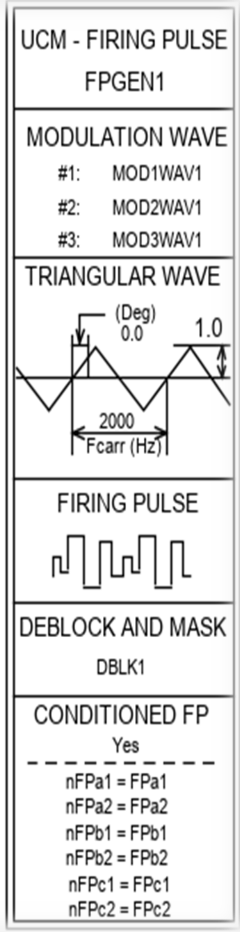
Accuracy of the Switching Function (i.e., Firing Pulse Inputs)

3 Improved Firing Pulse Modelling

3.1 UCM Firing Pulse Generator (Improved FP Generator: Interpolation)

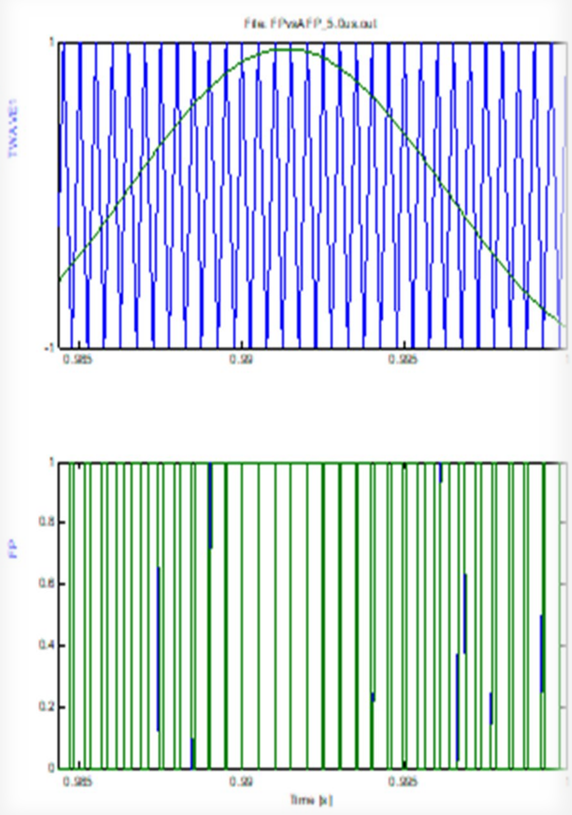




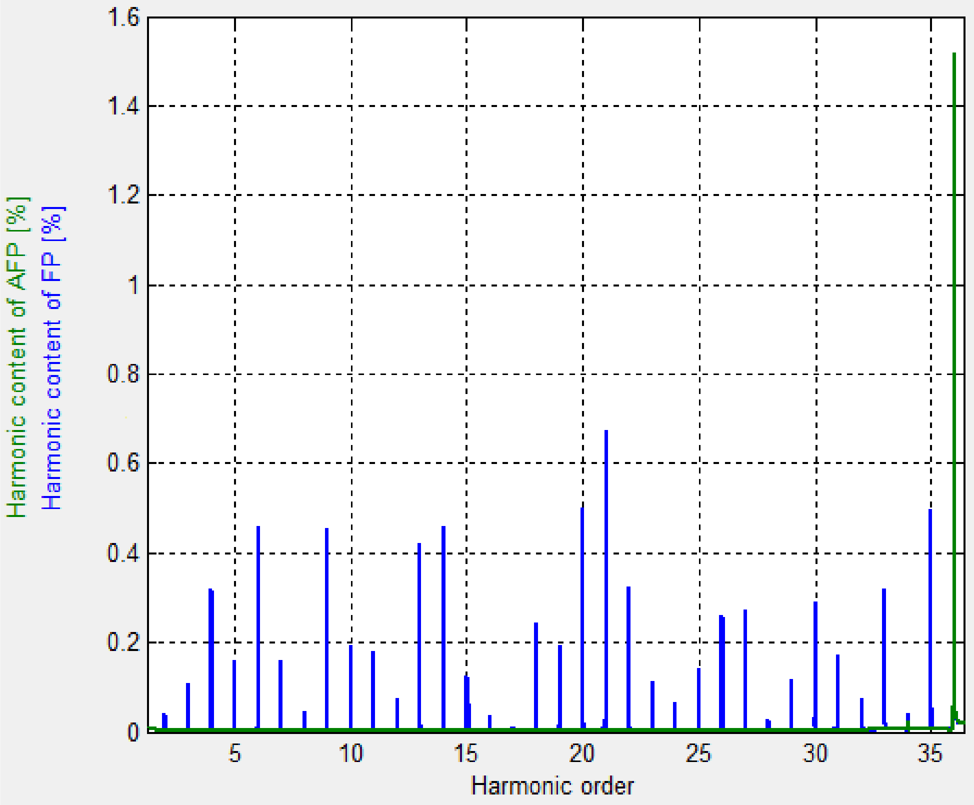


3 Improved Firing Pulse Modelling

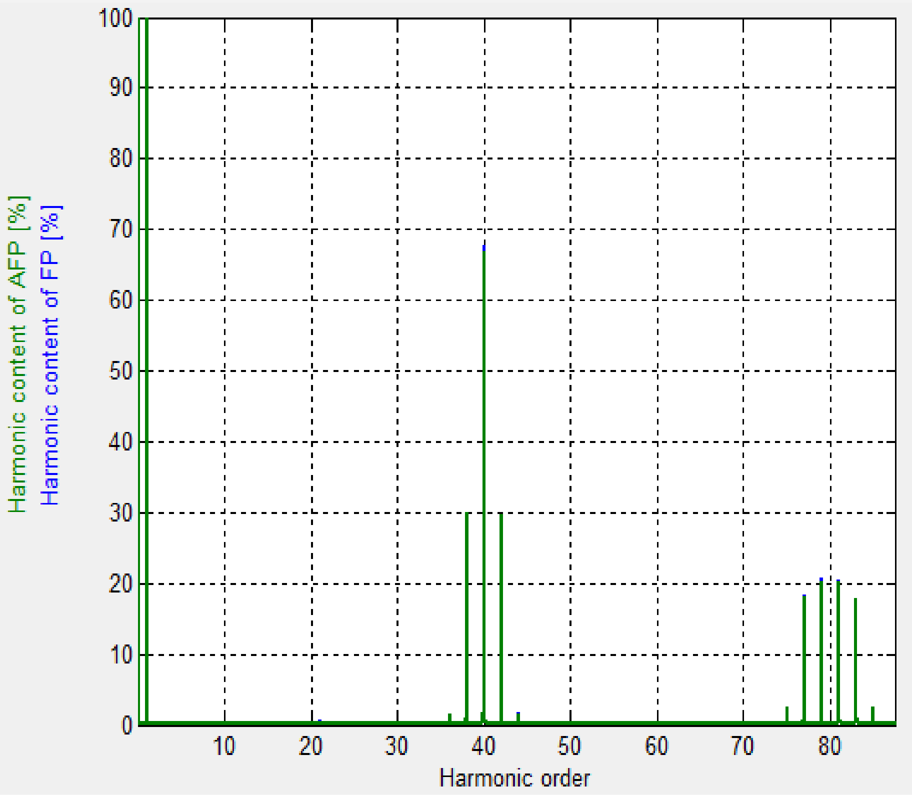
3.1 UCM Firing Pulse Generator: PWM Spectrum (fs=2.0k Hz, dt=5.0us, m=0.95)



Regular FP vs. Improved FP



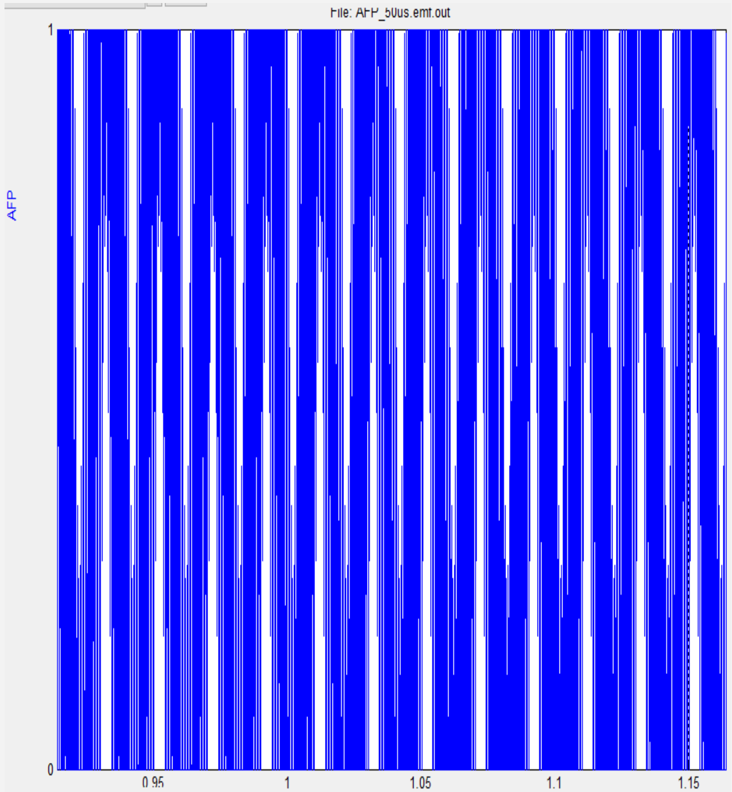
Non-characteristic Harmonics



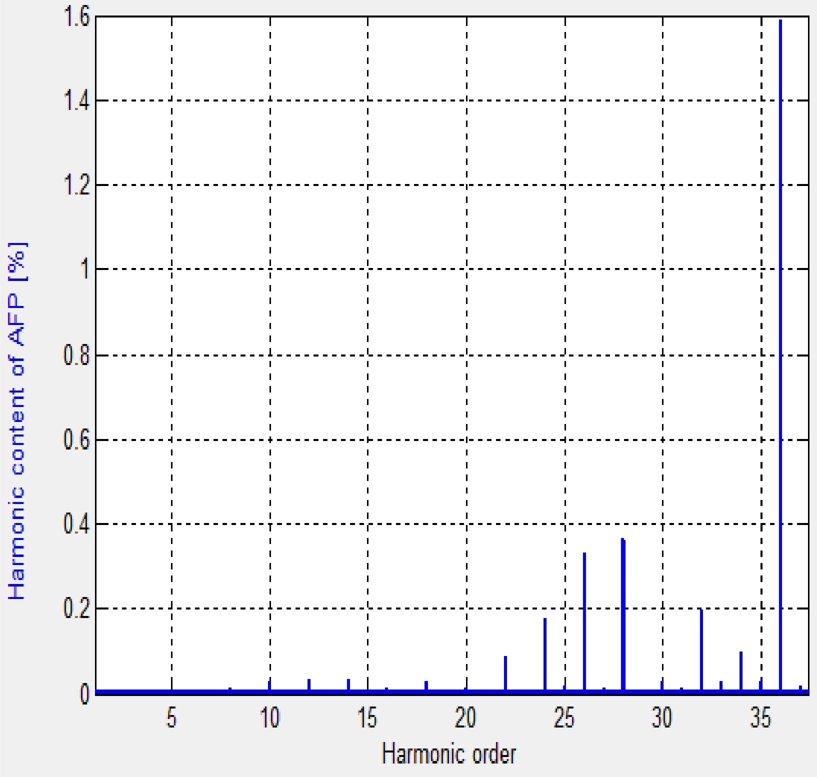
Characteristic Harmonics

3 Improved Firing Pulse Modelling

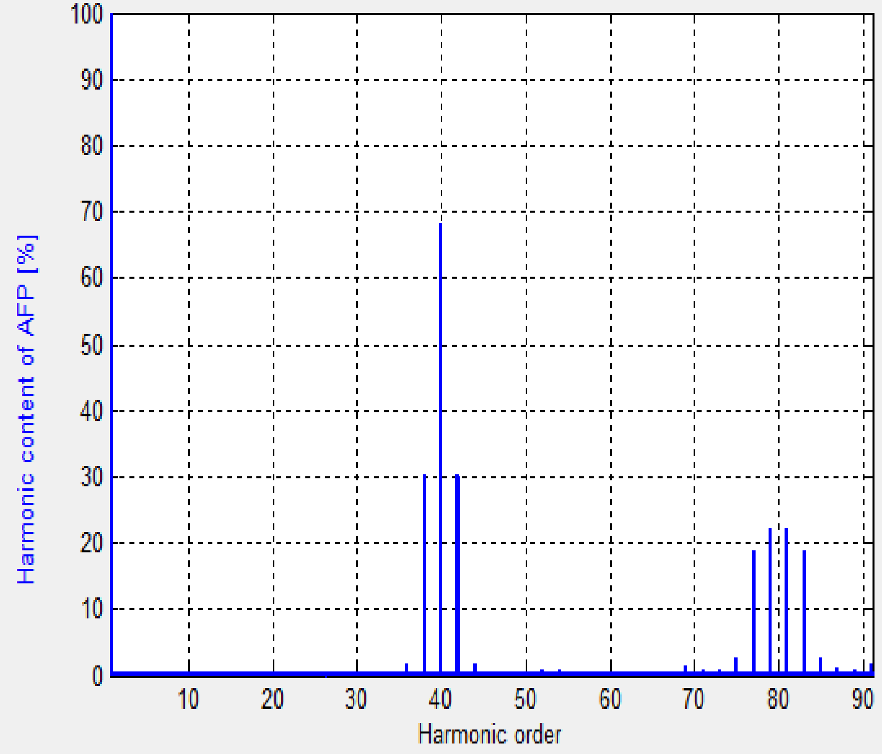
3.1 UCM Firing Pulse Generator: PWM Spectrum (fs=2.0k Hz, *dt=50.0us,* m=0.95)



Improved firing pulse



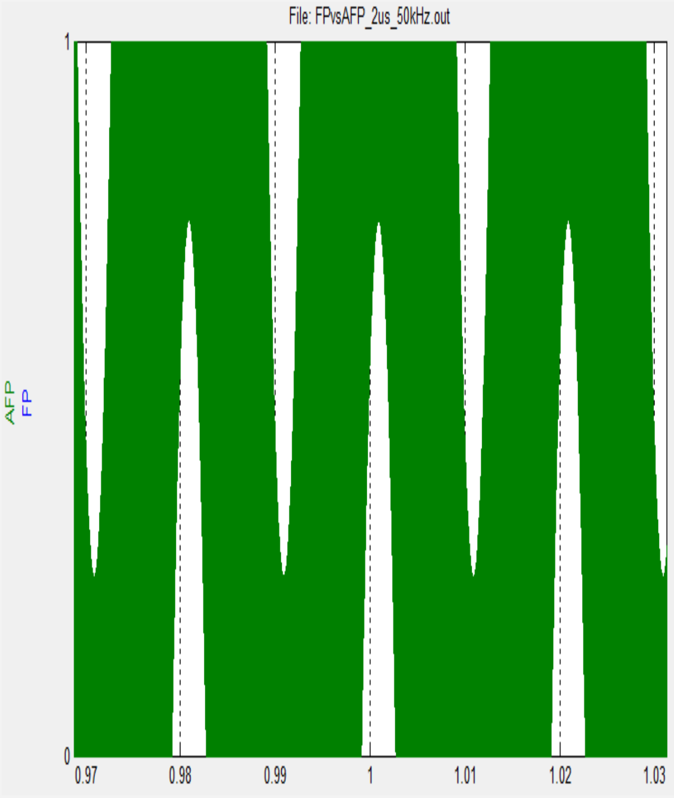
Non-characteristic Harmonics



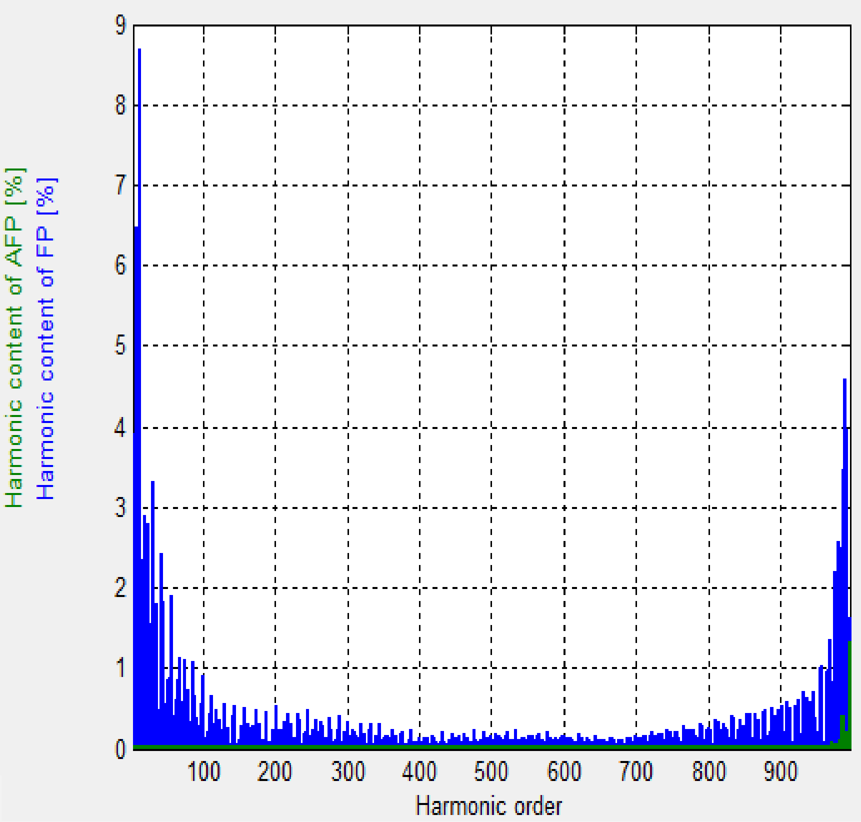
Characteristic Harmonics

3 Improved Firing Pulse Modelling

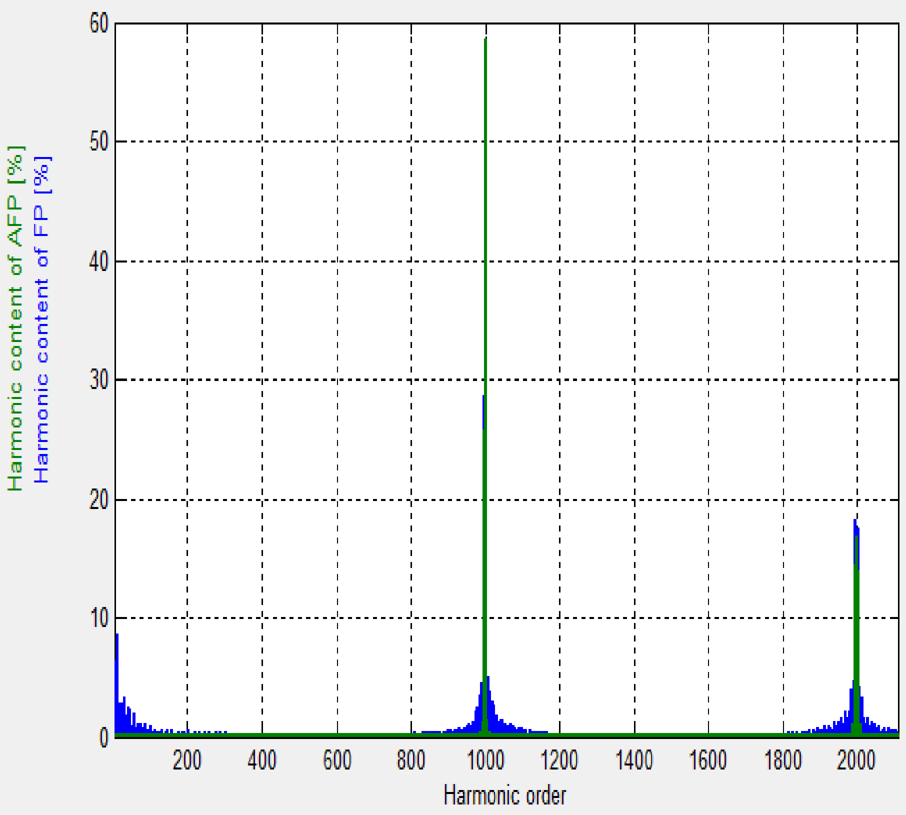
3.1 UCM Firing Pulse Generator: PWM Spectrum (fs=50.0k Hz, dt=2.0us, m=0.95)



Improved FP



Non-characteristic Harmonics



Characteristic Harmonics

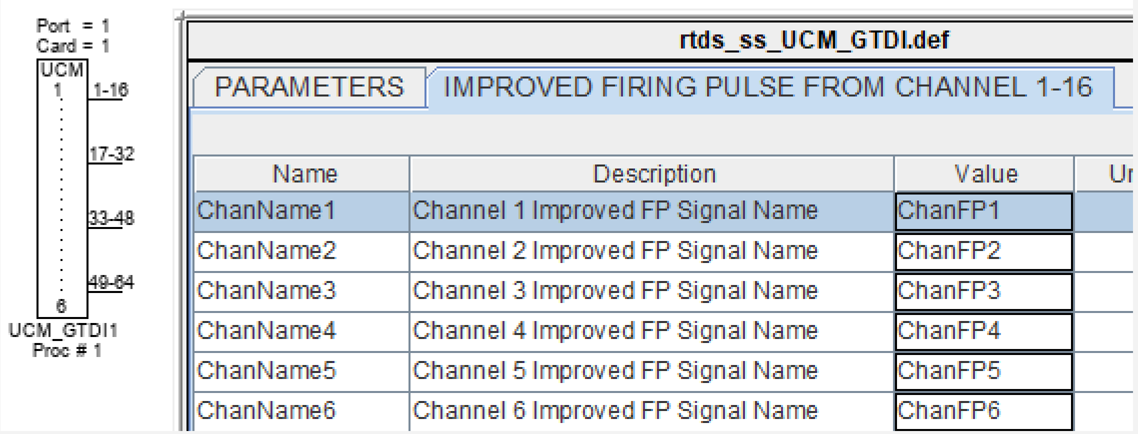
3 Improved Firing Pulse Modelling

3.2 UCM GTDI

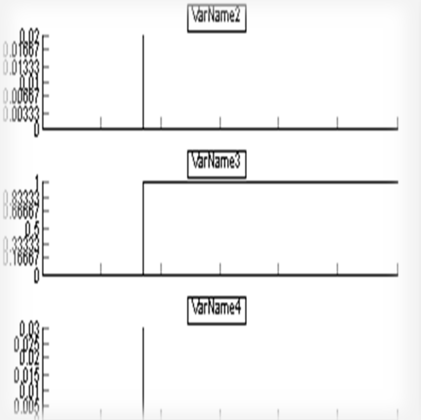
❑ GTDI in MainStep and SubStep

- ❖ Improved FP
- ❖ 10.0ns Resolution

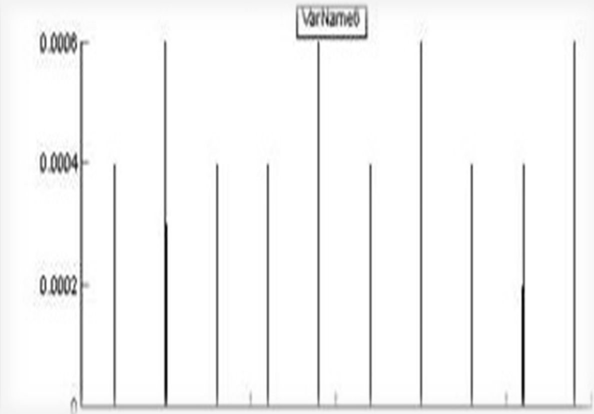
Individually shielded twisted pairs are recommended for the cable harness.



Name	Description	Value	Ur
ChanName1	Channel 1 Improved FP Signal Name	ChanFP1	
ChanName2	Channel 2 Improved FP Signal Name	ChanFP2	
ChanName3	Channel 3 Improved FP Signal Name	ChanFP3	
ChanName4	Channel 4 Improved FP Signal Name	ChanFP4	
ChanName5	Channel 5 Improved FP Signal Name	ChanFP5	
ChanName6	Channel 6 Improved FP Signal Name	ChanFP6	



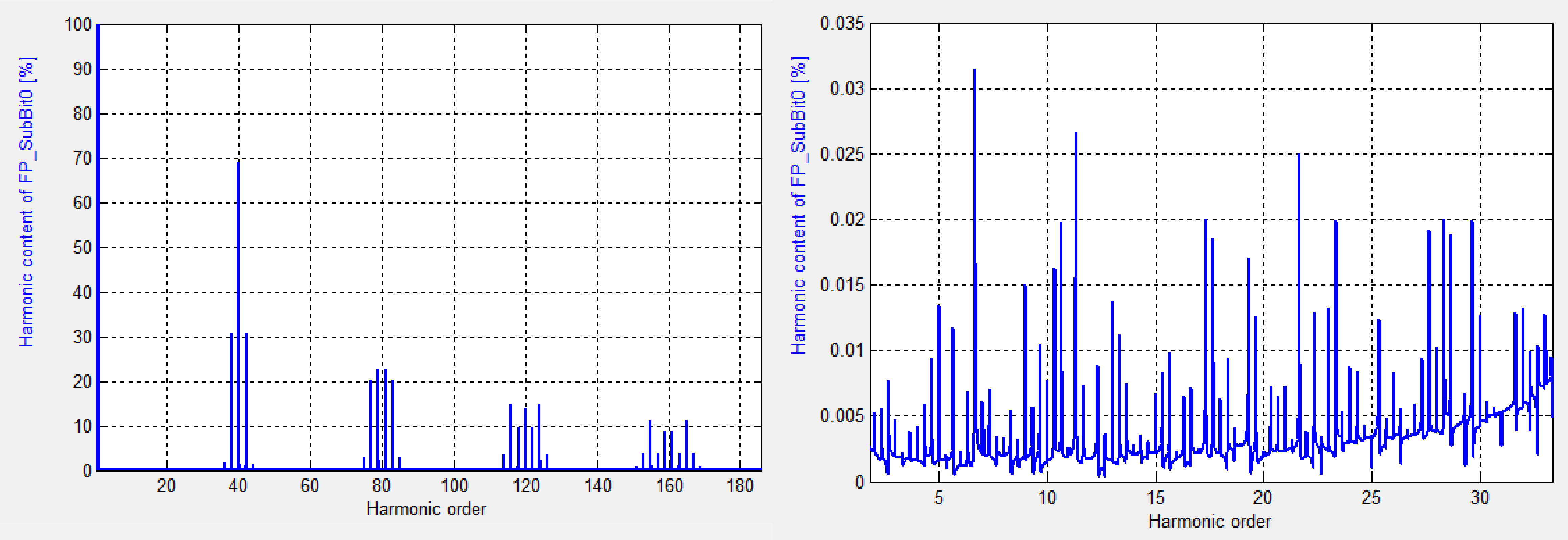
SubStep (1.0us)



MainStep (50.0us)

3 Improved Firing Pulse Modelling

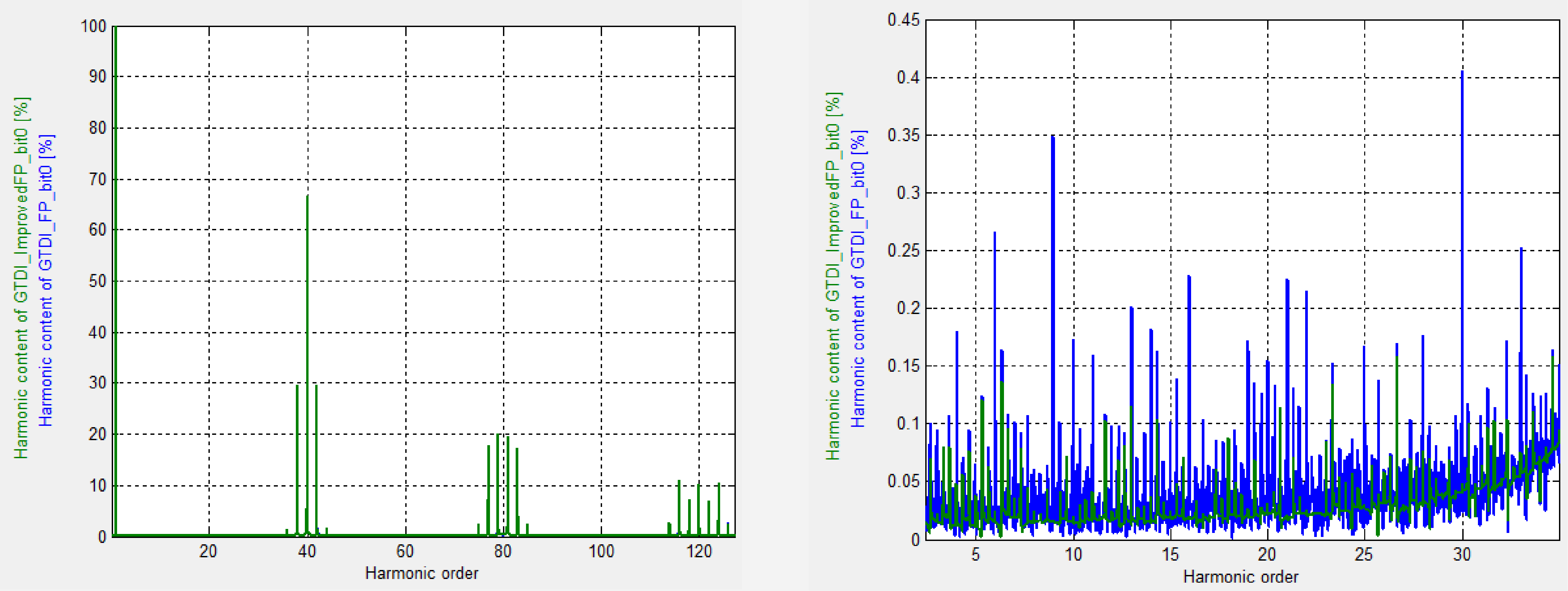
3.2 GTDO Firing Pulse Generator: PWM Spectrum (fs=2.0k Hz, dt=0.375us, **m=0.95)**



FP Input with 375ns Time-step

3 Improved Firing Pulse Modelling

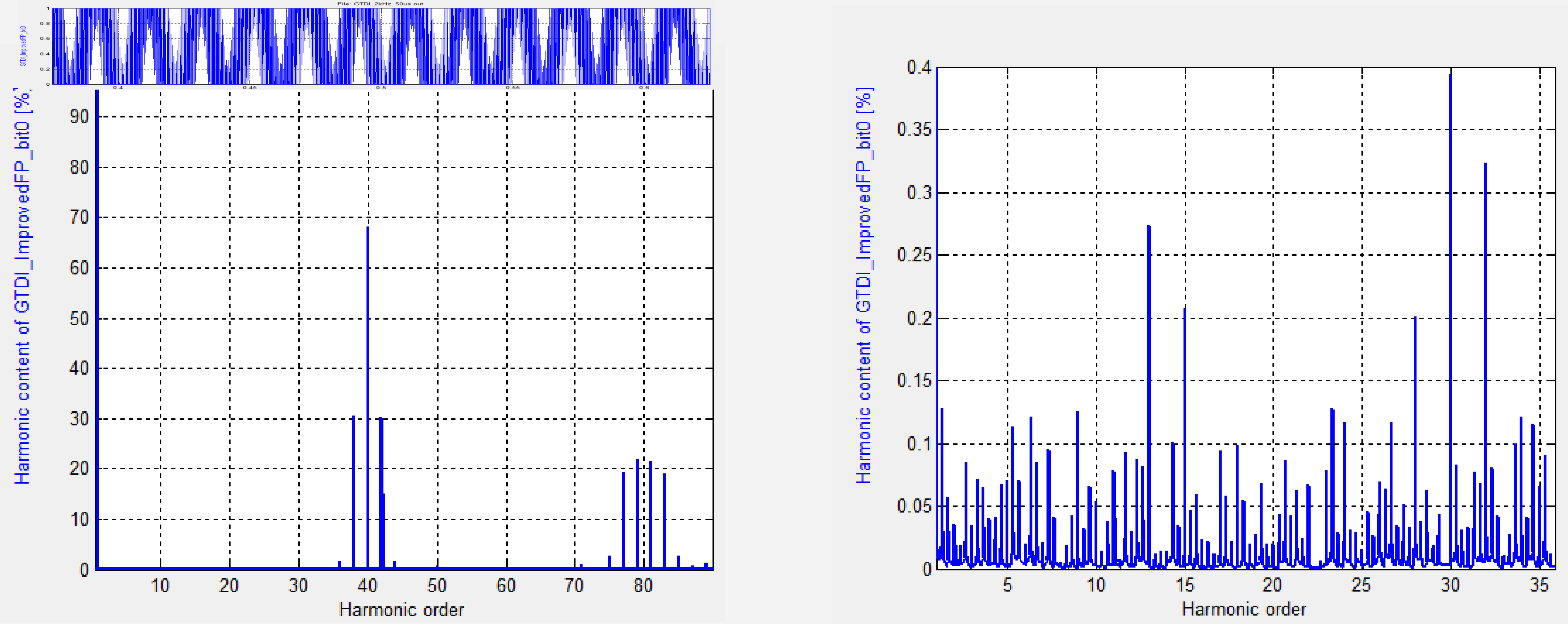
3.2 UCM GTDI **PWM Spectrum (fs=2.0k Hz, dt=5.0us, m=0.95)**



Spectrum (Regular PWM Vs Improved PWM)

3 Improved Firing Pulse Modelling

3.2 UCM GTDI **PWM Spectrum (GTDO: fs=2.0k Hz, dt=50.0us, m=0.95)**



Spectrum (Improved PWM)

3 Improved Firing Pulse Modelling

3.3 UCM FP Generator and UCM_GTDI Accuracy

❑ Improved FP in MainStep and SubStep

- ❖ Improved FP is accurate at fundamental frequency
- ❖ Improved FP introduces much less non-characteristic harmonics
- ❖ Improved FP is accurate at characteristic harmonics

With improved FP, the accuracy of FP will not be a bottleneck for converter modelling in real time simulation.

3 Improved Firing Pulse Modelling

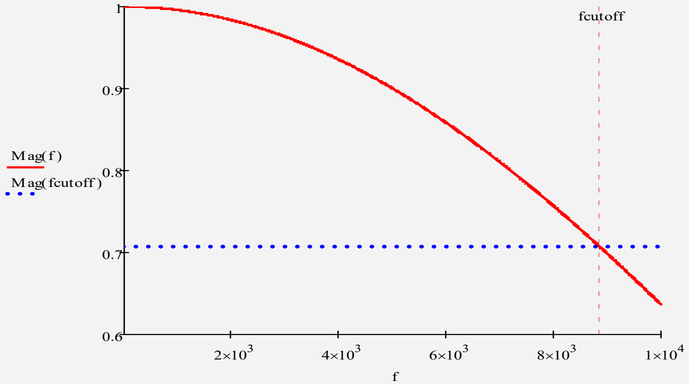
3.3 UCM Firing Pulse Generator: Cut-off Frequency

☐ Mean Value in one Simulation Step [2]

$$x(t) = A\cos(\omega t + \phi)$$

$$y(t) = \frac{1}{dt}\int_{t-dt}^{t} A\cos(\omega\tau + \phi)d\tau = \frac{2}{\omega dt}\sin(\frac{\omega dt}{2})A\cos(\omega\left[t + \frac{dt}{2}\right] + \phi)$$

☐ Cut-off Frequency Definition



$$f_{cutoff} = \frac{1}{dt \cdot 2.2576}$$

$$= \begin{cases} 8.86 \quad kHz, \text{ if } dt = 50.0us \\ 221.5\ kHz, \text{ if } dt = 2.0 \quad us \end{cases}$$

[2] K. L. Lian and P. W. Lehn, "Real-time simulation of voltage source converters based on time average method," *IEEE Transactions on Power Systems,* vol. 20, no. 1, pp. 110-118, 2005.

Summary

- ❑ UCM Models are developed to enhance the capability of Power Electronics Modelling on RTDS Simulator;
- ❑ The simulation accuracy of Power electronic converters is determined by the converter model and its inputs. Using the “Improved Firing Pulse with Mean Value High Precision”, the performance of a converter modelling can be greatly improved.
- ❑ UCMs can cover a wide-band frequency range, i.e., from dc to hundreds kilo-hertz. Within this frequency range and proper time step, UCMs can guarantee the accuracy of fundamental frequency and characteristic harmonics, and will not introduce non-characteristic harmonics.

4 Demo and Discussion

Demo Cases:

☐ DAB DC/DC converter

- ❖ Regular FP and Improved FP in SubStep (fs = 20.0k Hz; dt = 2.5us)

☐ UCM in STATCOM

- ❖ Regular FP and Improved FP in SubStep (fs = 2.0k Hz; dt = 5.0us)
- ❖ Improved FP in MainStep (fs = 2.0k Hz; DT = 50.0us)
- ❖ Improved FP in SubStep and AVM in MainStep (fs = 2.0k Hz; dt = 5.0us, DT = 50.0us)
- ❖ Improved FP in SubStep and AVM in MainStep (fs = 50.0k Hz; dt = 5.0us,DT = 50.0us)

☐ UCM in Renewables

- ❖ Type-4 Windfarm with Improved FP in SubStep (fs = 2.0k Hz; dt = 5.0us);
- ❖ Type-4 Windfarm with Improved FP in MainStep (fs = 2.0k Hz; DT = 50.0us);
- ❖ Type-4 Windfarm with AVM in MainStep (DT = 50.0us);

THANK YOU!
QUESTIONS?

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