SEMIS Simulation Tool
FACTS Full Bridge MMC with IGCT
User manual

INTRODUCTION

SEMIS is a web-based semiconductor simulation tool providing a thermal calculation of the semiconductor losses for common converter circuits. The simulation simplifies significantly the selection of the switching device and enables the optimal selection of semiconductors for further investigations.

The SEMIS Simulation Tool is a user-friendly online application found on ABB Semiconductors website www.abb.com/semiconductors/semis

SEMIS users select from a substantial selection of topologies. By assigning the circuit parameters and selecting the desired switching device, multiple ABB products can be simulated at the same time. Once a simulation is run, SEMIS returns comprehensive results on semiconductor losses as well as on the electrical parameters in the input and output of the circuit. The results are shown in both graphical (waveforms) and numerical (tables) way.

The SEMIS tool is based on the PLECS simulation software. PLECS users can download our product models in the XML file format from the ABB Semiconductors website and use them for their own simulations. For more specific topologies ABB offers customized converter simulations for non-standard topologies with PLECS simulation software on a project basis.

COPYRIGHTS

Release: April 2020

Document number: 5SYA 2128

TABLE OF CONTENTS

LIST OF FIGURES

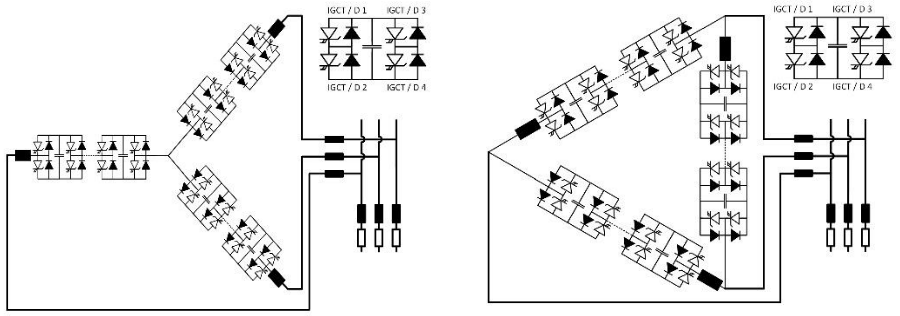
1. FACTS FULL BRIDGE MMC WITH IGCT

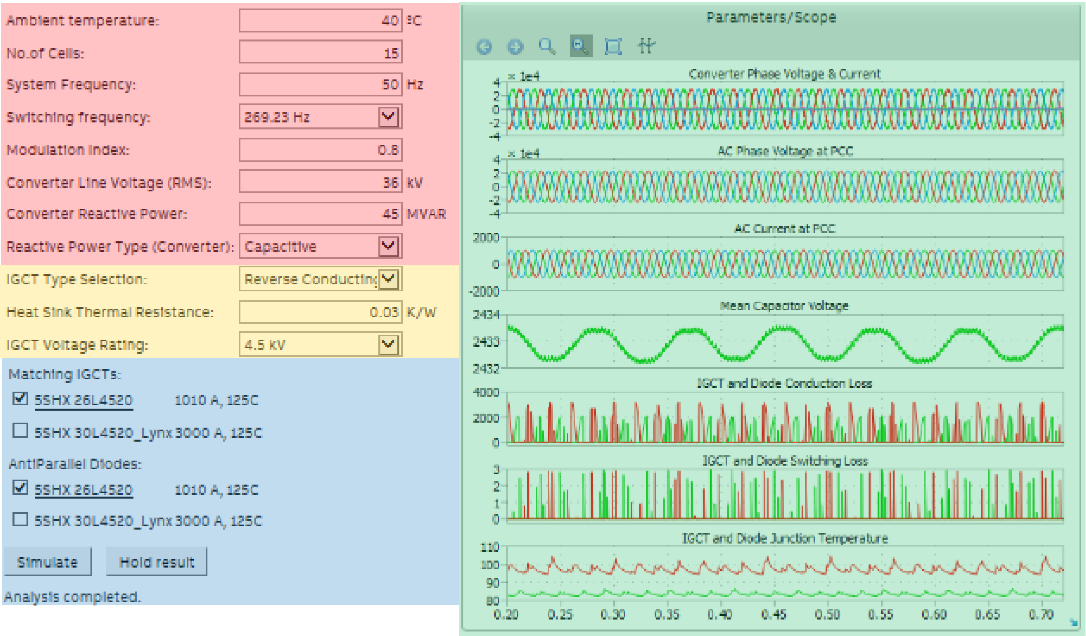
The use of powerful modular multilevel converters (MMC) for FACTS applications has resulted in the development of new STATCOM products, due to its superior characteristics and competitive costs. The converter module comprises of 3 phases with each phase having a several IGCT based full bridge cells are connected in series to build up the requisite voltage. Each arm contains the phase reactor. The MMC simplifies equipment design, improves response time and reduces losses.

ABB offers the following Three-phase topologies for thermal analysis simulation with

- Three-Phase Two-level VSC with IGBT
- Three-Phase Three-level VSC with IGBT (NPC, TNPC, ANPC)
- Three-Phase Three-level VSC with IGCT (NPC, TNPC, ANPC)
- Three-Phase Three-level VSC with IGBT Half-Bridge MMC
- Three-Phase Three-level VSC with IGCT Half-Bridge MMC
- Three-Phase Three-level VSC with IGCT Full Bridge MMC
- Three-Phase Three-level VSC FACTS with IGBT Full Bridge Star Connected
- Three-Phase Three-level VSC FACTS with IGCT Full Bridge Star Connected
- Three-Phase Three-level VSC FACTS with IGBT Full Bridge Delta Connected
- Three-Phase Three-level VSC FACTS with IGCT Full Bridge Delta Connected

2. Overview





Device Losses & Temperatures

	Switching	Conduction	Combined Losses	TvjAvg	TvjMax	TvjBLS
IGCT 1	238.86 W	291.57 W	530.43 W	83.44 ºC	86.38 ºC	85.41 ºC
IGCT 2	238.87 W	291.45 W	530.31 W	83.44 ºC	85.87 ºC	84.67 ºC
Diode 1	179.41 W	440.67 W	620.08 W	97.11 ºC	104.56 ºC	102.09 ºC
Diode 2	179.78 W	440.66 W	620.44 W	97.13 ºC	104.21 ºC	101.40 ºC
IGCT 3	244.41 W	292.93 W	537.34 W	83.57 ºC	87.02 ºC	85.68 ºC
IGCT 4	233.31 W	292.46 W	525.77 W	83.34 ºC	85.98 ºC	84.73 ºC
Diode 3	174.54 W	439.35 W	613.90 W	96.91 ºC	104.30 ºC	101.72 ºC
Diode 4	185.79 W	438.35 W	624.14 W	97.24 ºC	104.64 ºC	101.94 ºC

Loss Summary

	Clamp	Semiconductor	Total
per Cell	734.64 W	4.602 kW	5.337 kW
per Converter	33.06 kW	207.1 kW	240.2 kW
% Losses	0.07 %	0.46 %	0.53 %

Converter AC Parameters

	Real Power	Reactive Power	Phase Voltage (RMS)	Phase Current (RMS)	Output Frequency
	-0.07 kW	45.05 MVAR	20.81 kV	722 A	50 Hz

Control Parameters

	Cell Voltage	Switching Frequency	Modulation Index	No. of Cells/phase
	2.433 kV	269 Hz	0.80	15.00

Figure 1 FACTS Full Bridge MMC with IGCT circuit in website

Grid definitions	Results graphs
Converter settings	Results tables
IGCT selection	

2.1 FACTS Full Bridge MMC with IGCT power circuit schematic

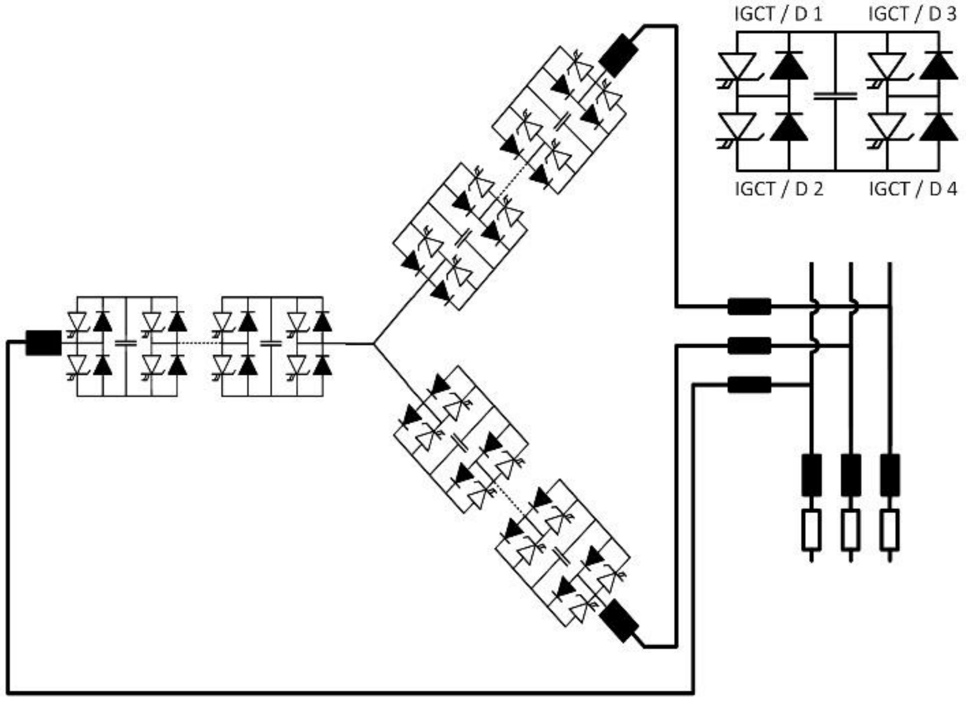


Figure 2 FACTS Full Bridge MMC Star Connected with IGCT schematic layout

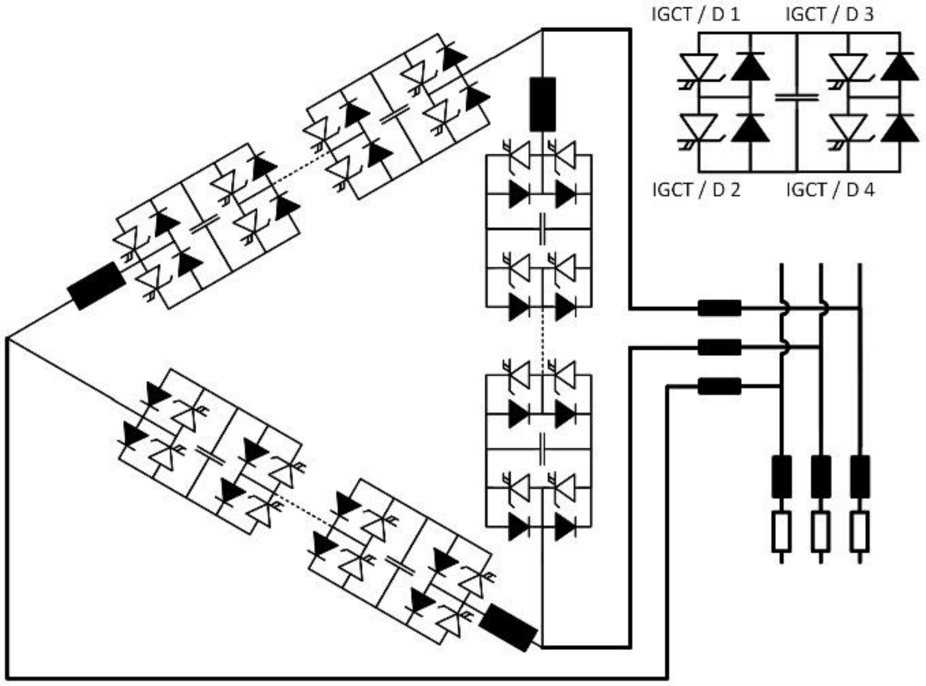


Figure 3 FACTS Full Bridge MMC Delta Connected with IGCT schematic layout

3. SIMULATION SETTINGS

3.1 Circuit parameters

3.1.1 Ambient temperature

Ambient temperature	Definition of environmental temperature around the converter for temperature / cooling calculations	Range -25 .. 90 °C

Figure 4 Ambient temperature input block

3.1.2 Controller

The user can define the following parameters as seen in figure 5. The controller generates the switching pulses for the upper and lower IGCTs of the cell in the converter.

Figure 5 Controller input block

NO. OF CELLS	No. of cells in a phase leg	Range 2 to 20
SYSTEM FREQUENCY	Converter AC output frequency	Range 10 to 100 Hz
SWITCHING FREQUENCY	Definition of switching frequency applied for PWM control (Phase-shifted PWM)	Range 86 to 500 Hz
MODULATION INDEX	Definition of modulation index	Range 0 .. 1

3.1.3 Load parameters

The user can define the following parameters as seen in figure 6.

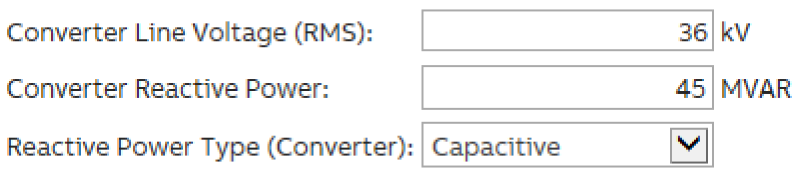


Figure 6 Grid/Load parameter input blocks

Simulation settings

CONVERTER LINE VOLTAGE (RMS)		
	AC Line voltage of converter	Range 1 .. 1000 kV
CONVERTER REACTIVE POWER		
	Reactive Power supplied by the converter.	Range 1 .. 1000 MVAr
REACTIVE POWER TYPE	The reactive power type can be selected as Inductive or Capacitive based on load requirement	Selection

3.2 Switch settings

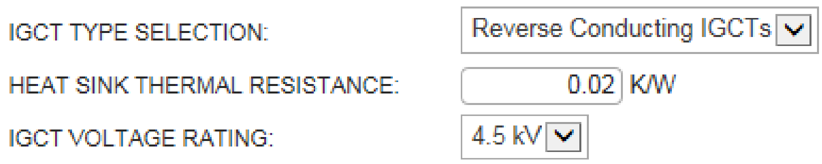


Figure 7 Thermal settings and IGCT selection

Heat Sink Thermal Resistance		Range 0.0001 .. 0.5 K/W
	Definition of thermal resistance of the cooling system applied.	
Remark:	Include the thermal resistance of case to heatsink to ensure correct simulation results. The value entered is attributed to each individual switch shown in the electrical configuration schematic of the IGCT module data sheet. Therefore, if a user selects a dual switch module, the Rth should be multiplied with a factor of 2 to differentiate from the single switch case, if the same heatsink would be used in both cases. Same applies for the case of full bridge modules. The selected Rth is also accounted for the antiparallel diode position for which same consideration applies for its electrical configuration.	
IGCT Type Selection	Select the type of IGCT for filtering	Selection
IGCT Voltage Rating	Select voltage class of IGCT for filtering	Selection

3.2.1 Matching IGCTs and Antiparallel Diodes

Once the previous IGCT properties are selected, the matching IGCT and Antiparallel Diodes options appear. By clicking on the product code name the user may access the data sheet from the ABB website.

Figure 8 Matching IGCTs and Antiparallel Diodes for selection

Up to 2 elements can be selected simultaneously and simulated. If one or more elements produce results exceeding the safe operating area (SOA), no results are returned. In this case, the user should run the simulation again with changed parameters and/or product selection to enable results within SOA operating conditions.

3.3 Selection of Articles / Start simulation

To simulate one or more articles, select from the list by activating the checkbox

Simulate	Starts the simulation The progress of the simulation is shown with a number of calculated Jacobian.
Abort	Stops the simulation; No results generated
Hold results	To compare multiple simulations, results can be held for later viewing By selecting the button, result are hold after the simulation has finalized for later comparison with succeeding simulations

Figure 9 Start of simulation

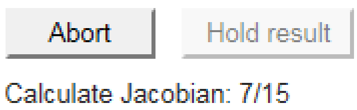


Figure 10 Simulation progress and termination

4. SIMULATION RESULTS

The simulation results are displayed in two different ways for all selected articles simulated.

Graphical results	Visual analysis of waveforms for fast and efficient detection of most significant sources
Numerical results	Numeric indication of all simulations values for direct comparison

Remark: To hide curves of selected articles, unselect in the table "Results History"

4.1 Graphical Output – Waveforms

When the simulation finishes the semiconductor and AC side waveforms are shown as follows:

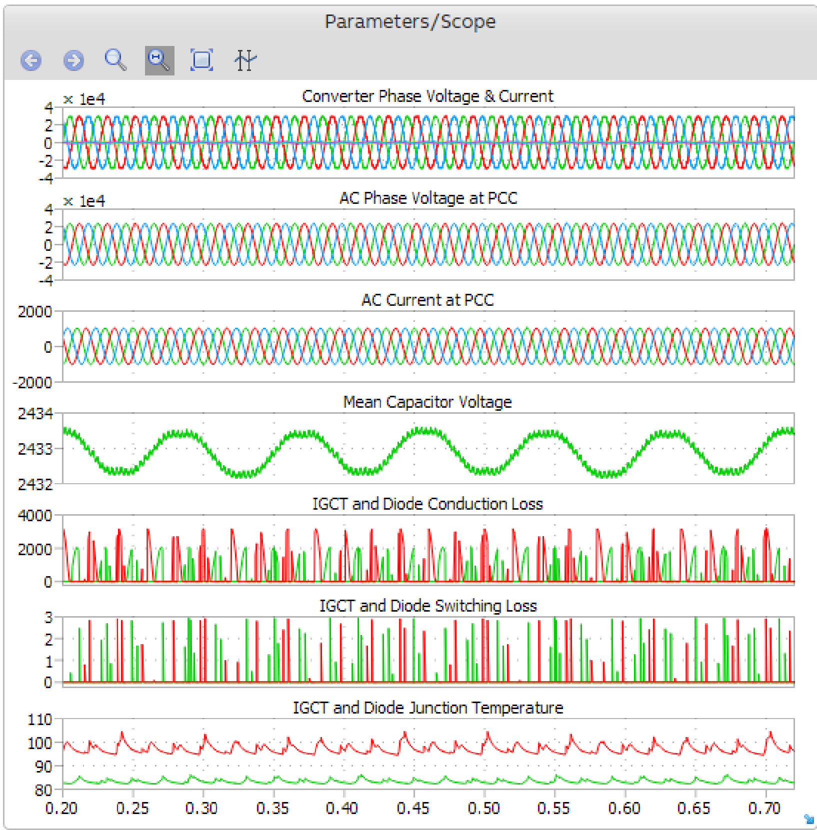
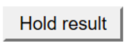


Figure 11 Graphical results of FACTS Full Bridge MMC with IGCT

4.1.1 Control

For an indication of values within the graph, a cursor can be activated to show curve values in a table.

Sections of graphs can be zoomed in by click, move and release mouse button for more details



Hide selectively waveforms of products

Rest zoom to full view

Activate cursors and to show parameter values table according to the cursor position

Zoom selectable rectangle

Zoom horizontal or vertical band

4.1.2 Parameters values indication

Tabular indication of graphical wave forms values according to the cursor position selected. Values are indicated for each parameter Color of the wave form is indicated. The third column shows the difference between the two cursors per parameter.

Name	Cursor 1	Cursor 2	Delta
Time	0.37333	0.54667	0.17333
Converter Phase Voltage & Current			
Measured voltage:1	-2.685e+4	2.442e+4	-5.126e+4
Measured voltage:2	2.434e+4	0.000	2.434e+4
Measured voltage:3	0.000	-2.686e+4	2.686e+4
Measured current:1	513.0	509.8	3.175
Measured current:2	509.7	-1023	1532
Measured current:3	-1023	512.8	-1535
AC Phase Voltage at PCC			
Measured voltage:1	-2.036e+4	2.036e+4	-4.073e+4
Measured voltage:2	2.036e+4	0.00008379	2.036e+4
Measured voltage:3	0.00002118	-2.036e+4	2.036e+4
AC Current at PCC			
Measured current:1	513.0	509.8	3.175
Measured current:2	509.7	-1023	1532
Measured current:3	-1023	512.8	-1535
Mean Capacitor Voltage			
Gain2	2433	2433	-0.01447
IGCT and Diode Conduction Loss			
IGCT conduction loss	0.000	830.3	-830.3
Diode conduction loss	0.000	0.000	0.000
IGCT and Diode Switching Loss			
IGCT switching loss	0.000	0.000	0.000
Diode switching loss	0.000	0.000	0.000
IGCT and Diode Junction Temperature			
IGCT junction temp	84.15	82.65	1.502
Diode junction temp	95.23	96.91	-1.684

Figure 12 Tabular indication of cursor position graph values

Remark:
The numerical values of each indicated parameter are shown according to the position of the respective cursor in the graph. Drag cursor to investigate about full details.

4.2 Numerical / Tabular results

The following parameters are given in a tabular format in multiple sections.

The indicated elements in the table IGCT1 etc. correspond to the different semiconductor positions in a full bridge cell as shown in Figure 2Figure 2 FACTS Full Bridge MMC Star Connected with IGCT schematic layout.

As converter losses, the aggregated losses in all 3 phase legs are accounted for.

In addition to the semiconductor losses, there are also losses occurring in the passive components (e.g. Resistances, grid-impedances, etc.). These Losses are not taken into consideration for this simulation. For the simplicity of the simulation, it is assumed that all semiconductors in one phase leg are loaded symmetrically and no voltage asymmetries do exist.

Simulation Results

Device losses and temperatures

Device Losses & Temperatures						
	Switching	Conduction	Combined Losses	TvjAvg	TvjMax	TvjBLS
IGCT 1	238.86 W	291.57 W	530.43 W	83.44 ºC	86.38 ºC	85.41 ºC
IGCT 2	238.87 W	291.45 W	530.31 W	83.44 ºC	85.87 ºC	84.67 ºC
Diode 1	179.41 W	440.67 W	620.08 W	97.11 ºC	104.56 ºC	102.09 ºC
Diode 2	179.78 W	440.66 W	620.44 W	97.13 ºC	104.21 ºC	101.40 ºC
IGCT 3	244.41 W	292.93 W	537.34 W	83.57 ºC	87.02 ºC	85.68 ºC
IGCT 4	233.31 W	292.46 W	525.77 W	83.34 ºC	85.98 ºC	84.73 ºC
Diode 3	174.54 W	439.35 W	613.90 W	96.91 ºC	104.30 ºC	101.72 ºC
Diode 4	185.79 W	438.35 W	624.14 W	97.24 ºC	104.64 ºC	101.94 ºC

Loss Summary			
	Clamp	Semiconductor	Total
per Cell	734.64 W	4.602 kW	5.337 kW
per Converter	33.06 kW	207.1 kW	240.2 kW
% Losses	0.07 %	0.46 %	0.53 %

Figure 13 Device Losses & Temperatures

Switching Loss	Single IGCT or Diode Losses during turn on and turn off events (dynamic)
Conduction loss	Single IGCT or Diode Losses during on state (static)
Combined losses	Sum of single IGCT or Diode switching and conduction loss.
Cell losses	Sum of IGCT and Diode losses in a full bridge cell
Converter losses	Sum of all IGCT and Diode losses
Clamp loss	Losses in the Clamp circuit
% Losses	Defined as the (%) ratio of calculated combined converter losses with respect to the converter MVA rating i.e., total apparent power flow. Since the converter is meant for a THREE-PHASE application, the kVA rating would correspond to total three-phase AC Power delivered by the converter.
Junction Temperature Avg	Junction temperature average during the simulation period
Junction Temperature Max	Maximum junction temperature during the simulation period
Junction Temperature BLS	Junction temperature at timepoint just before the last switching, after which the maximum junction temperature is achieved

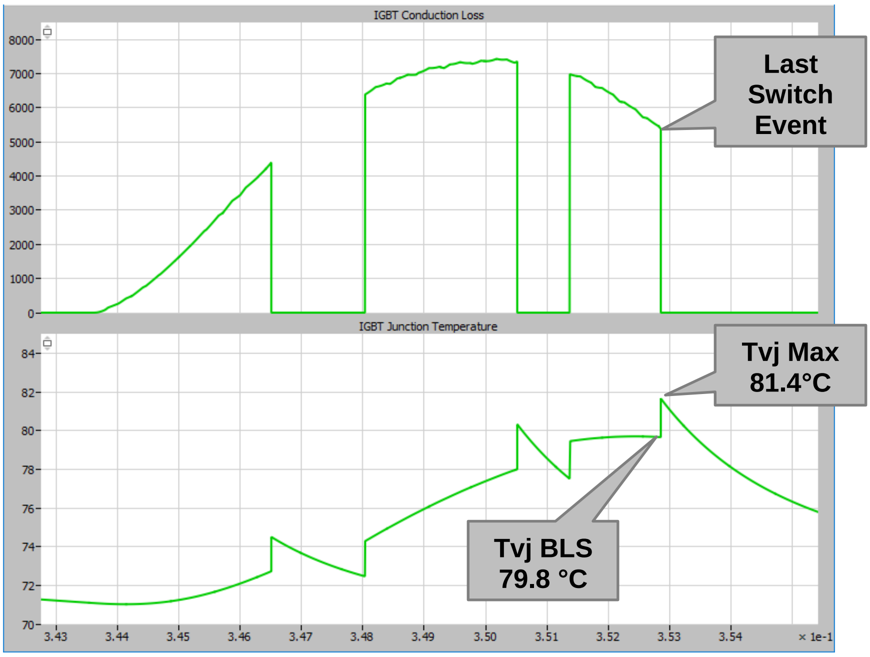


Figure 14 Definition of Tvj before the last switch

Converter AC parameters

Converter AC Parameters					
	Real Power	Reactive Power	Phase Voltage (RMS)	Phase Current (RMS)	Output Frequency
	-0.07 kW	45.05 MVAR	20.81 kV	722 A	50 Hz

Figure 15 Converter AC Parameters

Real power P — Active power / real power output of the converter

Reactive power Q — Q as supplied to load as effective power (reactive) on converter AC side Calculation see in section 6.4.

Phase voltage RMS — According AC phase value according 1st order harmonic of AC frequency

Phase current RMS — According AC phase value according 1st order harmonic of AC frequency

Output frequency — According to the definition

Control Parameters

Control Parameters				
	Cell Voltage	Switching Frequency	Modulation Index	No. of Cells/phase
	2.433 kV	269 Hz	0.80	15.00

Figure 16 Control Parameters

Cell Voltage — Average capacitor voltage of a cell in a phase leg

Switching Freq. — According to the definition

Modulation Ind. — According to calculations defined in chapter 6.2

No. of Cells — Number of cells per phase leg

5. ALERTS & FEATURES

The system verifies results and generated warning messages in case of limits are violated.

5.1 Junction Temperature

Parameter	Junction temperature
Verification	If the junction temperature BLS of IGCT and/or diode is above its maximum junction temperature limit, the alert message is displayed
Warning message	IGCT temperature out of the safe operating area

5.2 Cell Voltage

Parameter	Cell Voltage
Verification	If the Cell voltage is greater than the safe operating voltage rating of IGCT and/or diode, the alert message is displayed
Warning message	For the voltage rating 4.5kV, Vcellmin = 200V & Vcellmax = 3400V

6. APPLIED CALCULATIONS

6.1 Input Parameter Definitions

V_{cell}	Cell Voltage
n_{cell}	No. of cells in a phase leg
$V_{LL\_AC\_RMS}$	Line voltage RMS

6.2 Line-Line RMS Voltage of Grid/Load Definition

$$V_{LL\_AC\_RMS} = \frac{\sqrt{3} * m * n_{cell} * V_{cell}}{\sqrt{2}}$$ *for Star connected*

$$V_{LL\_AC\_RMS} = \frac{m * n_{cell} * V_{cell}}{\sqrt{2}}$$ for Delta connected

6.3 Real Power

P_{DC}	DC power / real power absorbed from DC side of VSC calculated according
P_{AC}	real / active power transferred to converter output calculated as:
$V_{TrueRMS}$	True phase voltage RMS AC line to neutral
$I_{TrueRMS}$	True phase current RMS AC
η	Power conversion efficiency

$$V_{trueRMS} = \sqrt{\frac{1}{n} \sum_{\nu=1}^{n} \widehat{u_\nu^2}}$$

It includes all harmonic components <u>NOT ONLY</u> 1st order of output frequency.

$$I_{trueRMS} = \sqrt{\frac{1}{n} \sum_{\nu=1}^{n} \widehat{\imath_\nu^2}}$$

It includes all harmonic components <u>NOT ONLY</u> 1st order of output frequency.

According to:

$$P_{AC} = \frac{3}{n} \sum_{\nu=1}^{n} \widehat{u_\nu} . \widehat{\imath_\nu} . \cos \varphi_\nu = 3 . V_{trueRMS} . I_{trueRMS} . PF$$

In the FACTS application, real power is equal to zero ideally.

6.4 Reactive Power

Q	Effective reactive power on the converter AC side [VAr]

$$Q = 3 * V_{Ph\_RMS} * I_{Ph\_RMS}$$

V_{PH_RMS}	Phase voltage (RMS)
I_{PH_RMS}	Phase current (RMS)

Defined as the Loss (%) η is the ratio of calculated combined converter losses with respect to the converter input power.

The Q is the main input power definition. Loss (%) η is given by:

$$\eta = \frac{P_{LossConverter}}{Q} * 100\%$$

7. VALIDATION OF SEMIS RESULTS

To ensure supplied simulation results are reliable, each SEMIS topology is validated with another simulation system or compared to real measurement data.

In this case, FACTS Full Bridge MMC Star connected and Delta connected IGCT models are validated with FACTS Full Bridge MMC Star connected and Delta connected IGBT models respectively. The IGCT device XML is replaced by IGBT device XML and the results are compared with FACTS Full Bridge MMC Star connected and Delta connected IGBT models. The results are exactly matching with zero deviation. The clamp losses are additive to the losses as indicated with the FACTS Full Bridge MMC with IGBT Star connected and Delta connected respectively.

For the validation details of FACTS Full Bridge MMC Star connected and Delta connected with IGBT models, please refer to Section 7 in the user manual of SEMIS-15 FACTS Full Bridge MMC with IGBT.

8. USER MANUAL REVISION HISTORY

Rev.	Page	Change Description	Date / Initial
1.3	all	Inclusion of Validation results & Reactive Power Definition	2020-27-04 PGGI/HM
1.2	all	Inclusion of delta connected model	2019-23-12 PGGI/HM
1.1	all	Initial version new design	2019-23-09 PGGI/HM

9. SIMULATION SOFTWARE RELEASE HISTORY

Rev.	New topic	Fixed defects	Tvj influence	Date
1.1	Reactive Power Definition	-	-	2020-28-04 PGGI/HM
1.0	Initial version	-	-	2019-23-09 PGGI/HM

Contact

ABB Power Grids Switzerland Ltd.
Semiconductors
Fabrikstrasse 3
5600 Lenzburg, Switzerland
Phone: +41 58 586 1419
Fax: +41 58 586 1306
E-Mail: abbsem@ch.abb.com

abb.com/semiconductors

Note
We reserve the right to make technical changes or modify the contents of this document without prior notice. With regard to purchase orders, the agreed particulars shall prevail. ABB does not accept any responsibility whatsoever for potential errors or possible lack of information in this document.

Document no. 5SYA 2128