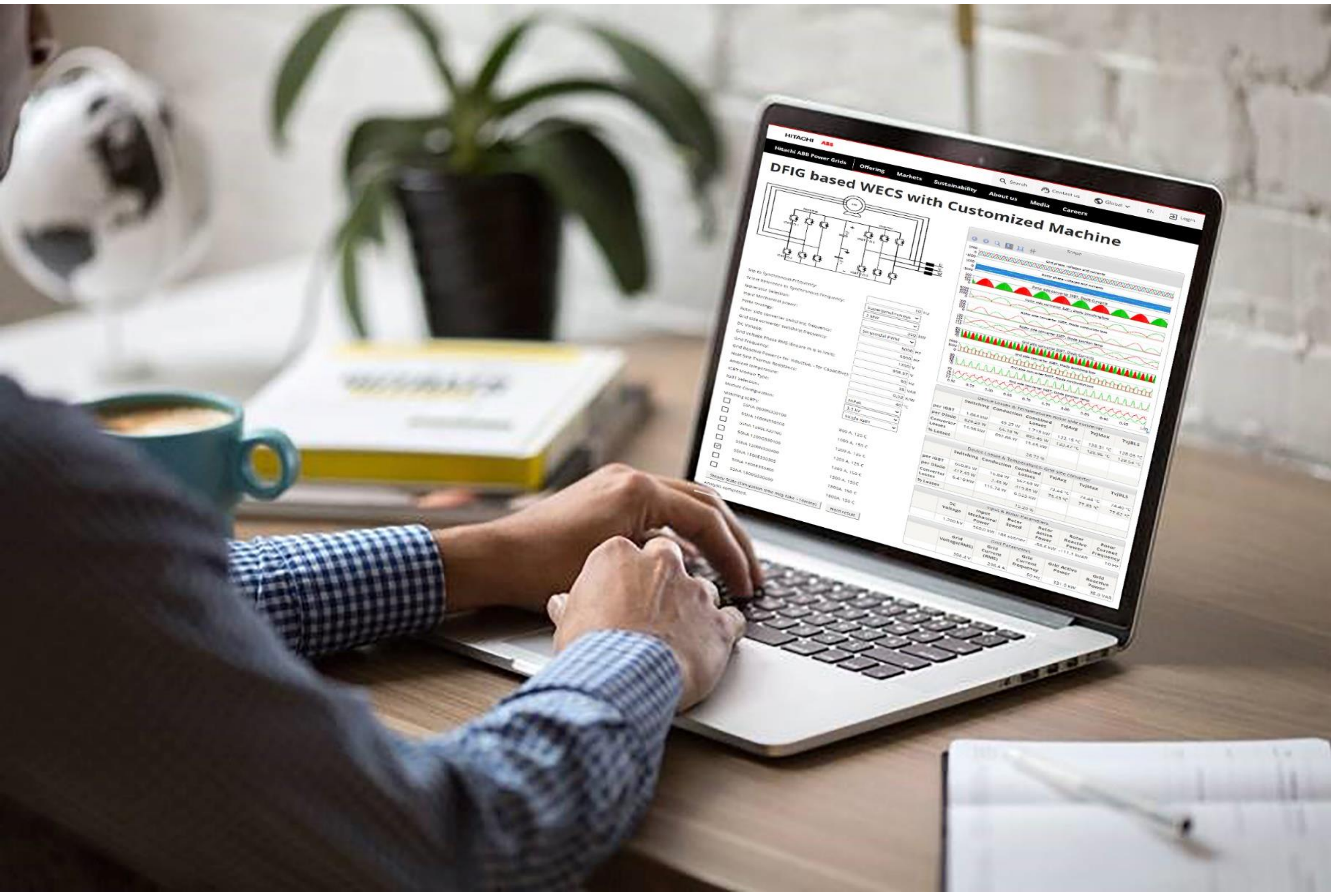
HITACHI ABB

SEMIS Simulation Tool
2 Level Doubly Fed Induction Generator with IGBT
User Manual



HITACHI ABB POWER GRIDS

Contents

List of figures

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 optimal selection of semiconductors for further investigations.

The SEMIS simulation tool is a user-friendly online application found on Hitachi ABB Power Grids' semiconductors website www.hitachiabb-powergrids.com/offering/product-and system/semiconductors/semis.

SEMIS users select from substantial selection of topologies. With assigning the circuit parameters and selecting the desired switching device, multiple Hitachi ABB Power Grids semiconductor 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 Hitachi ABB Power Grids' semiconductors website and use them for their own simulations. For more specific topologies Hitachi ABB Power Grids offers customized converter simulations for non-standard topologies with PLECS simulation software on a project basis.

Copyrights

Release: May 2021

Document number: 5SYA 2131

1. 2 LEVEL DFIG CONVERTERS

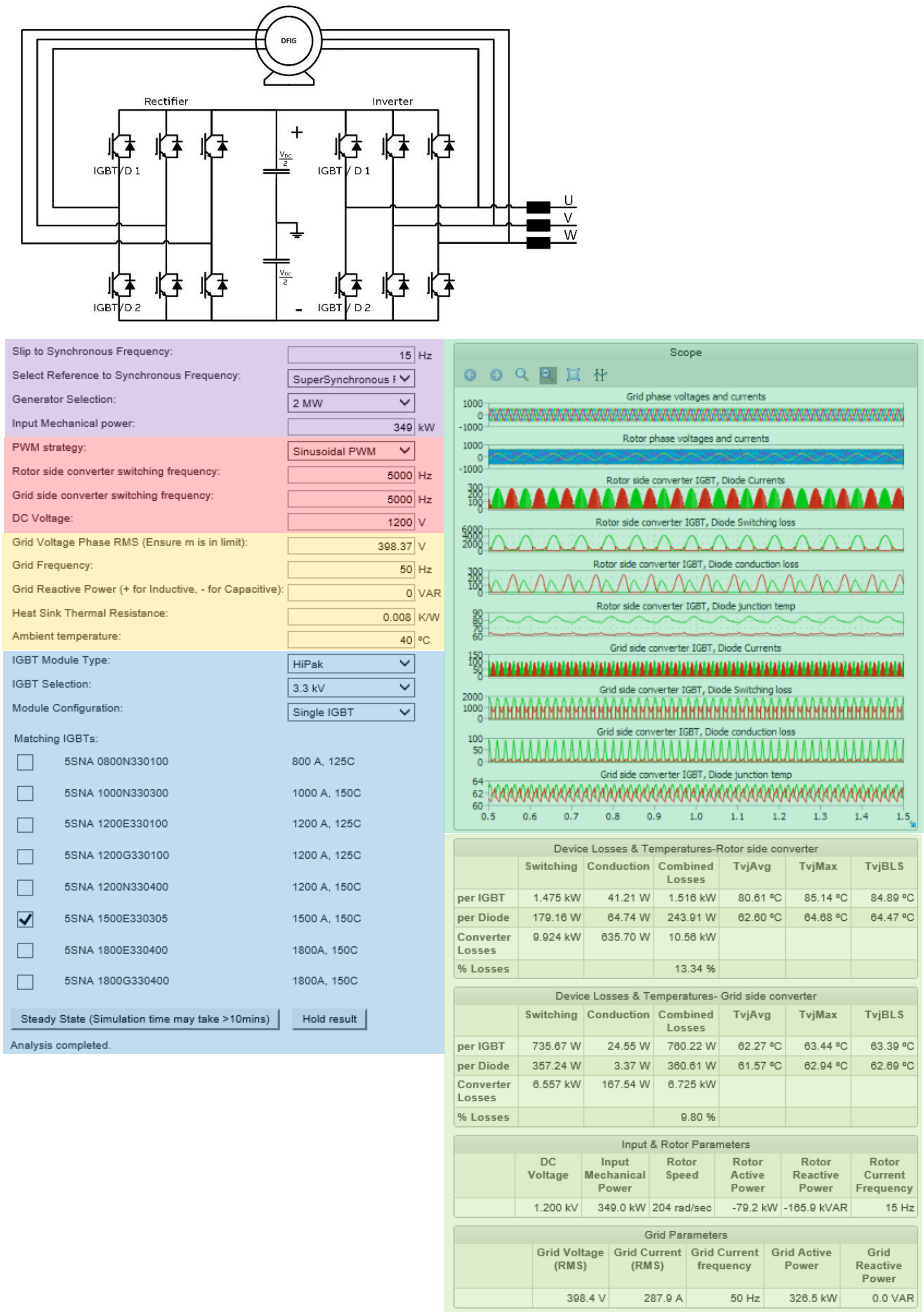
The use of powerful modular three-phase 2-level converters are very popular and have been used in various grid-tied applications for DC-AC (Three-phase Inverter) and AC-DC (Three-phase Rectifier) operation. Both Three-phase Rectifier and Inverter operations are very common, and this has resulted in the use of new 2 Level DFIG converters back-back in wind energy conversion system.

ABB offers the following DFIG topologies for thermal analysis simulation with

– 2 Level DFIG converters with IGBT

– 3 Level DFIG converters with IGBT (NPC, TNPC, ANPC)

2. OVERVIEW



Device Losses & Temperatures-Rotor side converter

	Switching	Conduction	Combined Losses	TvjAvg	TvjMax	TvjBLS
per IGBT	1.475 kW	41.21 W	1.516 kW	80.61 °C	85.14 °C	84.89 °C
per Diode	179.16 W	64.74 W	243.91 W	62.60 °C	64.68 °C	64.47 °C
Converter Losses	9.924 kW	635.70 W	10.56 kW			
% Losses			13.34 %			

Device Losses & Temperatures- Grid side converter

	Switching	Conduction	Combined Losses	TvjAvg	TvjMax	TvjBLS
per IGBT	735.67 W	24.55 W	760.22 W	62.27 °C	63.44 °C	63.39 °C
per Diode	357.24 W	3.37 W	360.61 W	61.57 °C	62.94 °C	62.69 °C
Converter Losses	6.557 kW	167.54 W	6.725 kW			
% Losses			9.80 %			

Input & Rotor Parameters

	DC Voltage	Input Mechanical Power	Rotor Speed	Rotor Active Power	Rotor Reactive Power	Rotor Current Frequency
	1.200 kV	349.0 kW	204 rad/sec	-79.2 kW	-165.9 kVAR	15 Hz

Grid Parameters

	Grid Voltage (RMS)	Grid Current (RMS)	Grid Current frequency	Grid Active Power	Grid Reactive Power
	398.4 V	287.9 A	50 Hz	326.5 kW	0.0 VAR

Figure 1: 2-Level DFIG converters circuit in ABB Powergrids Switzerland Ltd Semiconductors website.

Converter settings

Grid Definitions

IGBT selection

Results graphs

Results tables

Generator settings

3. SIMULATION SETTINGS

3.1 Circuit parameters

3.1.1 Generator Settings

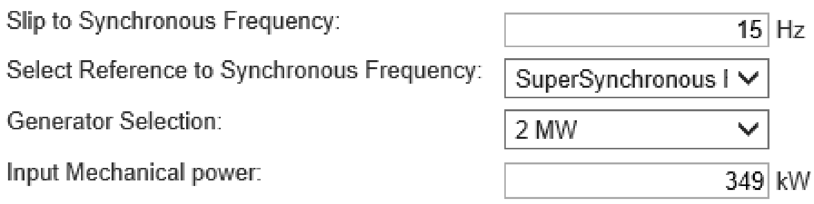


Figure 2 Generator related inputs

Slip to synchronous frequency	Rotor slip frequency	Range 0.01 to 15 Hz
Select reference to synchronous frequency		
	Above or Below synchronous frequency	Selection
Generator selection	Fixed or customizable generator	Selection
	Customizable generator requires rotor and stator parameters like leakage inductance, resistance, poles, turns ratio…	
Input mechanical power	Mechanical power input to DFIG	Range 100 to 2000 kW

3.1.2 Converter Settings

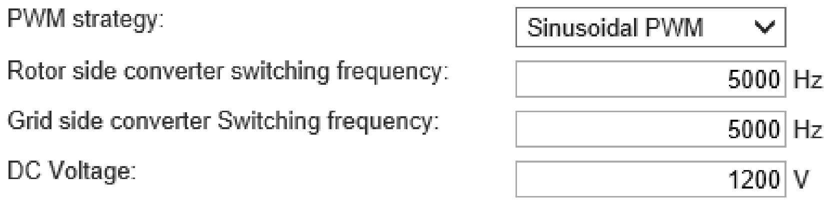


Figure 3 Converter Parameters

RSC switching Frequency	Definition of switching frequency applied for PWM control (Rotor Side Converter)	Range 1000 to 10000 Hz
GSC switching Frequency	Definition of switching frequency applied for PWM control (Grid Side Converter)	Range 5000 to 10000 Hz
PWM Strategy	Definition of PWM strategy	Selection
	Two different control methods are implemented, which are Sine PWM and Space vector PWM.	
DC Voltage	Converter DC Voltage	Range 200 to 4500 V

3.1.3 Grid Definitions

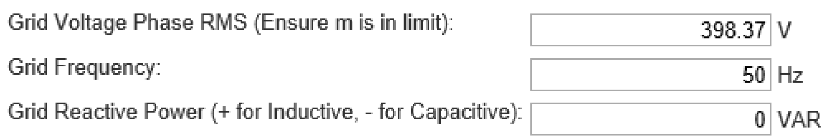


Figure 4 Grid Definitions

Grid Frequency	According Definition	Range 50 to 60 Hz
Grid Reactive Power	According Definition + values for Inductive reactive power - values for Capacitive reactive power	Range +/- 2019381 VAR
Grid voltage phase RMS	According Definition Ensure the value such that modulation index is under limit	Range 100 to 1850 V

3.2 Device settings

3.2.1 Ambient

Figure 5 Thermal settings

Ambient temperature	Definition of environmental temperature around the converter for temperature / cooling calculations	Range -25 to 90 °C
Heat Sink Thermal Resistance	Definition of thermal resistance of cooling system applied.	Range 0.0001 to 0.5 K/W

Remark:

The value entered is attributed to each individual switch shown in the electrical configuration schematic of the IGBT module data sheet.
Therefore, if user selects a dual switch module, the Rth should be multiplied with a factor of 2 to differentiate from the single switch case, if 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.

3.2.2 Switch settings

Figure 6 IGBT selection

IGBT module type	Select housing type of IGBT for filtering	Selection
IGBT selection	Select voltage class of IGBT for filtering	Selection
Module configuration	Select topology of IGBT module for filtering	Selection

3.2.3 Matching Devices

Once the IGBT voltage rating is selected, the matching IGBT option is populated with device. By clicking on the product code name, the user may access the data sheet from ABB website.

Figure 7 Matching IGBTs for selection

User can select the desired IGBT product names for simulation.

All the elements can be selected simultaneously and simulated. If one or more elements produce results exceeding the safe operating area (SOA) then they will return no results. 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 number of calculated Jacobian.
Abort	Stops the simulation; No results generated
Hold Result	To compare multiple simulations, results can be hold for later viewing. By selecting the button, result are hold after simulation has finalized for later comparison with succeeding simulations

Figure 8 Start of simulation

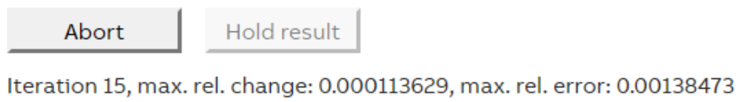


Figure 9 Simulation progress and termination

4. SIMULATION RESULTS

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

To hide curves of selected articles, unselect in the table “Results History”

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

4.1 Graphical Output – Waveforms

When the simulation finishes the semiconductor device waveforms are appearing as follows:

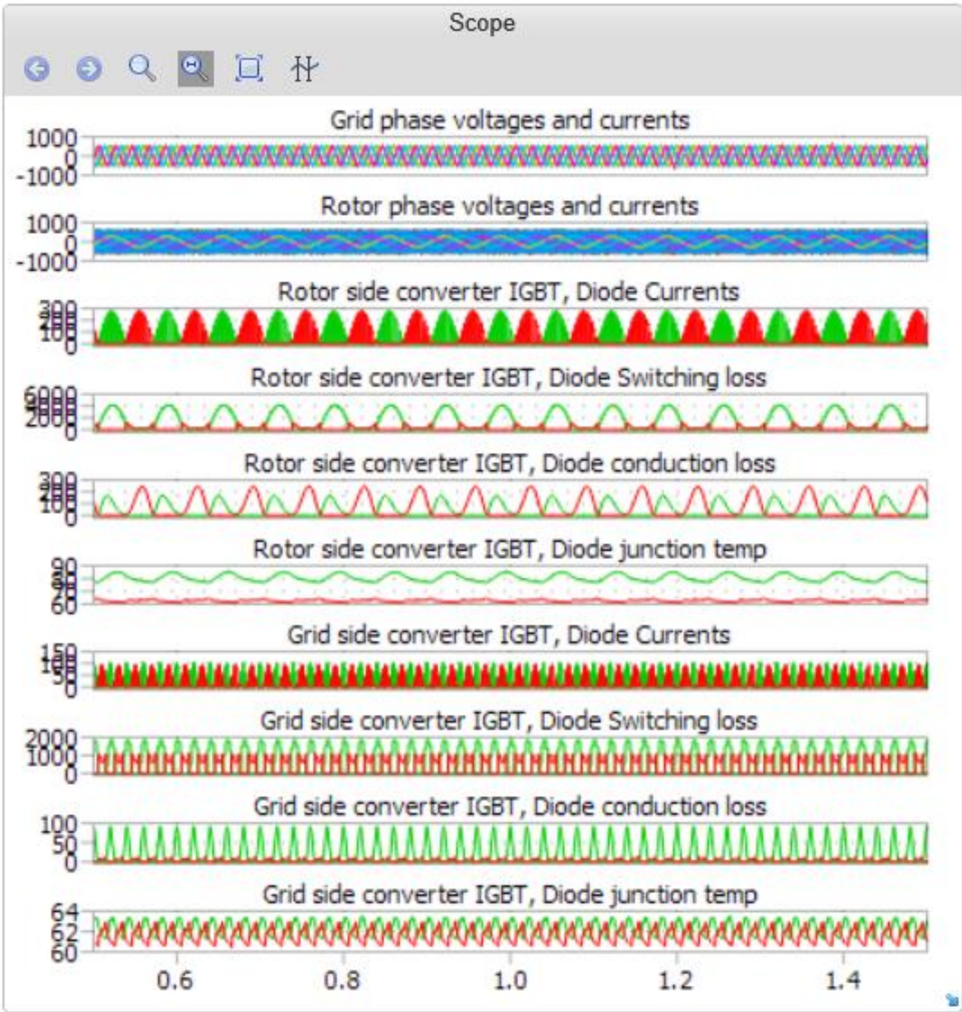
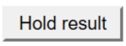


Figure 10 Graphical results of 2-Level DFIG converters

4.1.1 Control

For 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 cursor position


Zoom selectable rectangle


Zoom horizontal or vertical band

4.1.2 Parameters values indication

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

Name	Cursor 1	Cursor 2	Delta
Time	1.48	1.5	0.02
Grid phase voltages and currents			
Parameters:stator voltage:1	563.4	563.4	0.000
Parameters:stator voltage:2	-281.7	-281.7	1.046e-11
Parameters:stator voltage:3	-281.7	-281.7	-1.046e-11
Parameters:stator voltage:4	407.1	407.0	0.1034
Parameters:stator voltage:5	-204.1	-204.1	-0.04234
Parameters:stator voltage:6	-203.1	-203.0	-0.06108
Rotor phase voltages and currents			
Parameters:rotor voltage:1	-600.0	-600.0	0.0002106
Parameters:rotor voltage:2	-600.0	-600.0	0.0002106
Parameters:rotor voltage:3	-600.0	-600.0	0.0002106
Parameters:rotor voltage:4	-190.2	-125.7	-64.52
Parameters:rotor voltage:5	-72.90	271.4	-344.3
Parameters:rotor voltage:6	263.1	-145.7	408.8
Rotor side converter IGBT, Diode Currents			
Parameters:IGBT.diode current:1	0.000	0.000	0.000
Parameters:IGBT.diode current:2	0.000	0.000	0.000
Rotor side converter IGBT, Diode Switching loss			
Parameters:IGBT,diode sw.loss:1	0.000	0.000	0.000
Parameters:IGBT,diode sw.loss:2	176.2	445.7	-269.5
Rotor side converter IGBT, Diode conduction loss			
Parameters:IGBT,diode cond.loss:1	0.000	0.000	0.000
Parameters:IGBT,diode cond.loss:2	78.80	122.5	-43.73
Rotor side converter IGBT, Diode junction temp			
Parameters:IGBT,diode jn temp:1	79.80	77.32	2.480
Parameters:IGBT,diode jn temp:2	62.83	63.38	-0.5472
Grid side converter IGBT, Diode Currents			
Parameters:IGBT.diode current1:1	0.000	0.000	0.000
Parameters:IGBT.diode current1:2	0.000	0.000	0.000
Grid side converter IGBT, Diode Switching loss			
Parameters:IGBT,diode sw.loss1:1	1838	1838	0.005511
Parameters:IGBT,diode sw.loss1:2	0.000	0.000	0.000
Grid side converter IGBT, Diode conduction loss			
Parameters:IGBT,diode cond.loss1:1	91.63	91.40	0.2328
Parameters:IGBT,diode cond.loss1:2	0.000	0.000	0.000
Grid side converter IGBT, Diode junction temp			
Parameters:IGBT,diode jn temp1:1	63.02	63.02	0.00001156
Parameters:IGBT,diode jn temp1:2	61.05	61.05	-0.00001440

Figure 11 Tabular indication of cursor position graph values

Remark:

The numerical values of Voltage/Current at the position of respective cursors are shown in the Table. The numerical values of IGBT or Diode current/Voltage along with their junction temperatures at the position of respective cursors are shown in the Table.

4.2 Numerical / Tabular results

The following parameters are given in a tabular format in multiple sections. All calculations and simulation results are based on datasheet typical values.

All types of semiconductor losses are calculated according to PLEXIM PLECS software principle through reference of look up table and linear interpolation of the actual device current, voltage and junction temperature.

As converter losses the aggregated losses in all devices are accounted. The losses per device are tabulated, the combined loss is calculated by adding the losses of each IGBT or Diode.

Device Losses & Temperatures-Rotor side converter						
	Switching	Conduction	Combined Losses	TvjAvg	TvjMax	TvjBLS
per IGBT	1.475 kW	41.21 W	1.516 kW	80.61 ºC	85.14 ºC	84.89 ºC
per Diode	179.16 W	64.74 W	243.91 W	62.60 ºC	64.68 ºC	64.47 ºC
Converter Losses	9.924 kW	635.70 W	10.56 kW			
% Losses			13.34 %			

Device Losses & Temperatures- Grid side converter						
	Switching	Conduction	Combined Losses	TvjAvg	TvjMax	TvjBLS
per IGBT	735.67 W	24.55 W	760.22 W	62.27 ºC	63.44 ºC	63.39 ºC
per Diode	357.24 W	3.37 W	360.61 W	61.57 ºC	62.94 ºC	62.69 ºC
Converter Losses	6.557 kW	167.54 W	6.725 kW			
% Losses			9.80 %			

Figure 12 Device Losses & Temperatures

Switching Loss	Single IGBT or Diode Loss during turn on and turn off events (dynamic)
Conduction loss	Single IGBT or Diode Loss during on state (static)
Combined losses	Sum of single IGBT or Diode switching and conduction loss.
Converter losses	Sum of all the IGBT and Diode losses
% Losses	Defined as the (%) ratio of calculated combined converter losses with respect to the total output power and losses i.e., total apparent power flow.
Junction Temperature Avg	Junction temperature average during the simulation period
Junction Temperature Max	Maximum junction temperature during simulation period
Junction Temperature BLS	Junction temperature at timepoint just before the switching,after which the maximum junction temperature is achieved.

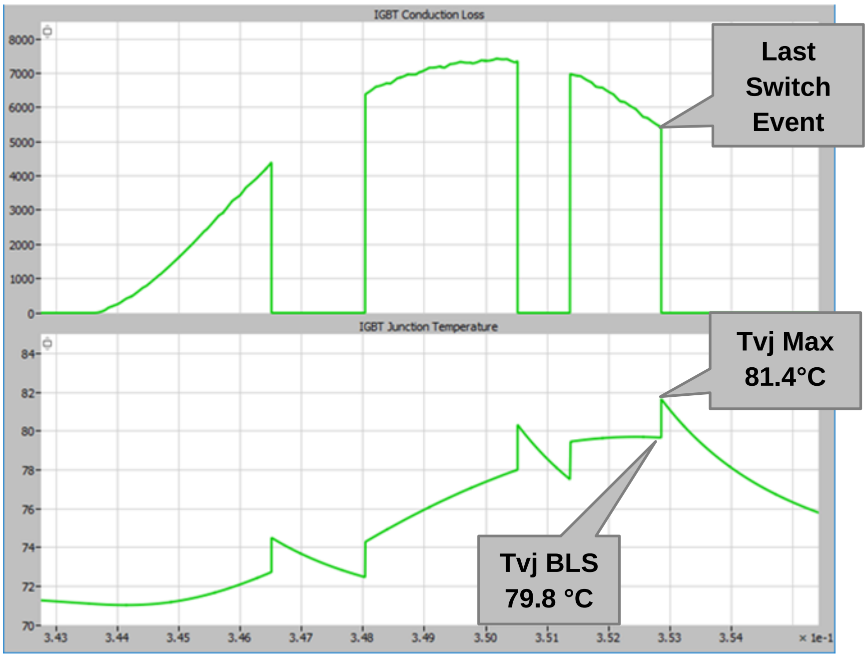


Figure 13 Definition of Tvj before last switch

Input & Rotor parameters

Input & Rotor Parameters						
	DC Voltage	Input Mechanical Power	Rotor Speed	Rotor Active Power	Rotor Reactive Power	Rotor Current Frequency
	1.200 kV	349.0 kW	204 rad/sec	-79.2 kW	-165.9 kVAR	15 Hz

Figure 14 Input & Rotor Parameters

DC Voltage	DC voltage across the capacitors
Rotor Speed	Rotor speed in rad/sec
Rotor Active/Reactive power	Real/Reactive power at rotor side
Rotor current frequency	Frequency at rotor side current/voltage

Grid parameters

Grid Parameters					
	Grid Voltage (RMS)	Grid Current (RMS)	Grid Current frequency	Grid Active Power	Grid Reactive Power
	398.4 V	287.9 A	50 Hz	326.5 kW	0.0 VAR

Figure 15 Grid Parameters

Grid Voltage/Current	Grid phase current/voltage
Grid current frequency	Frequency at grid side current/voltage
Grid Active Power	Real power at grid including the effect of converter losses
Grid Reactive Power	Reactive power at grid

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 IGBT and/or Diode is above its maximum junction temperature limit, alert message is displayed
Warning message	IGBT and/or Diode temperature out of safe operating area

5.2 DC Voltage

Parameter	DC Voltage
Verification	If the DC voltage is greater than safe operating voltage rating of IGBT, alert message is displayed
Warning message	For the voltage rating 1.7kV, Vdcmin = 200V & Vdcmax = 1100V

6. APPLIED CALCULATIONS

6.1 Input Parameter Definitions

VDC	Selected DC link voltage
VPh_AC_RMS	Phase voltage RMS
IPh_AC_RMS	Phase current RMS

6.2 Real Power

P_{DC}	DC power absorbed from DC side of VSC
P_{AC}	Real / Active power transferred to converter output
$V_{TrueRMS}$	True phase voltage RMS AC line to neutral
$I_{TrueRMS}$	True phase current RMS AC
η	Power conversion efficiency

$$P_{DC} = V_{DC} * I_{DC}$$

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

It includes all harmonic components NOT ONLY 1st order of output frequency.

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

It includes all harmonic components NOT ONLY 1st order of output frequency.

According to:

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

For Inverter or Rectifier mode, the DC power definition P_{DC} can be computed as

$$P_{DC} = P_{AC} + P_{LossConverter}$$

Defined as the Loss (%) η is the ratio of calculated combined converter losses with respect to the converter input power. For Inverter mode, the P_{DC} is the main input power definition. Loss (%) η is given by:

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

For Rectifier mode, the P_{AC} is the main input power definition. Loss (%) η is given by:

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

6.3 Reactive Power

Q	Effective reactive power on grid side [VAr]

$$\mathrm{Q} = 3 * \mathrm{V}_{\mathrm{Ph}_{\mathrm{RMS}}} * \mathrm{I}_{\mathrm{Ph}_{\mathrm{RMS}}} * \sin(\varphi_1)$$

V_{PH_RMS}	Phase voltage (RMS)
I_{PH_RMS}	Phase current (RMS)
ρ_1	Fundamental power factor angle

7. VALIDATION OF PLECS RESULTS

Due to the high complexity a market comparison analysis is done. Results are being implemented with user manual upon availability

8. USER MANUAL REVISION HISTORY

Rev.	Page	Change Description	Date / Initial
1.0	all		2021-05-28 PGGI/HM

9. SIMULATION SOFTWARE RELEASE HISTORY

Rev.	New topic	Fixed defects	Tvj influence	Date
1.0	Initial version	-	-	2021-05-28 PGGI/HM

ABB Power Grids Switzerland Ltd
Semiconductors
A Hitachi ABB Joint Venture
Fabrikstrasse 3
5600 Lenzburg, Switzerland
Phone: +41 58 586 1419
Fax: +41 58 586 1306
E-Mail: abbsem@hitachi-powergrids.com
www.hitachiabb-powergrids.com/semiconductors