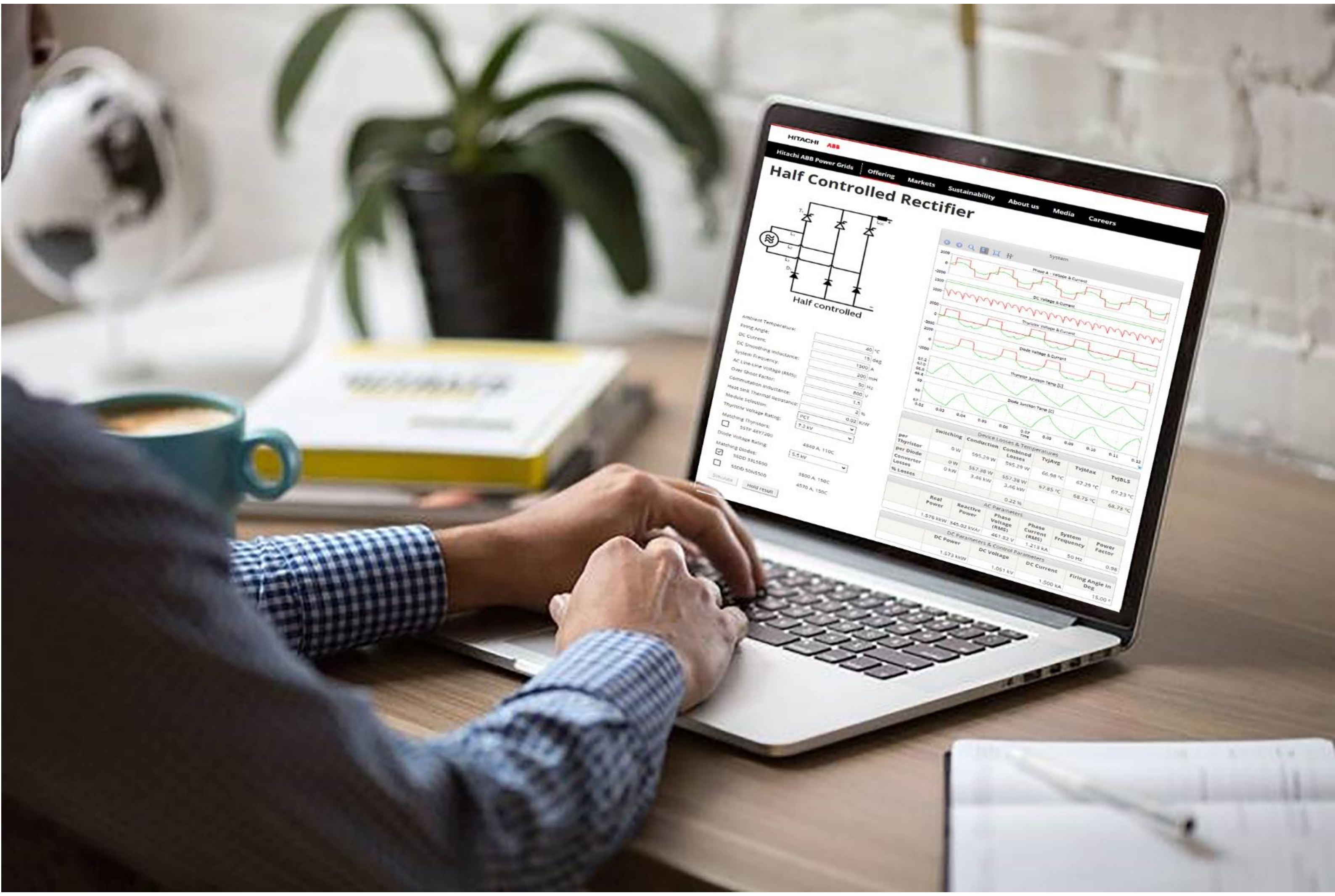
HITACHI ABB

SEMIS Simulation Tool
3 Phase Half Controlled Rectifier
User Manual



HITACHI ABB POWER GRIDS

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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.

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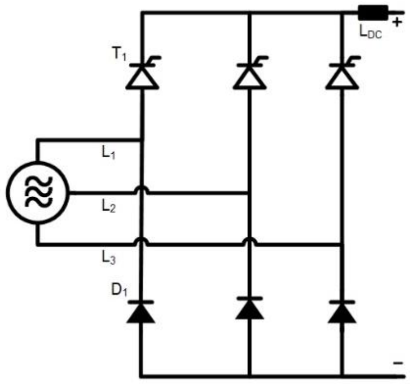
1. 3 PHASE HALF CONTROLLED RECTIFIER

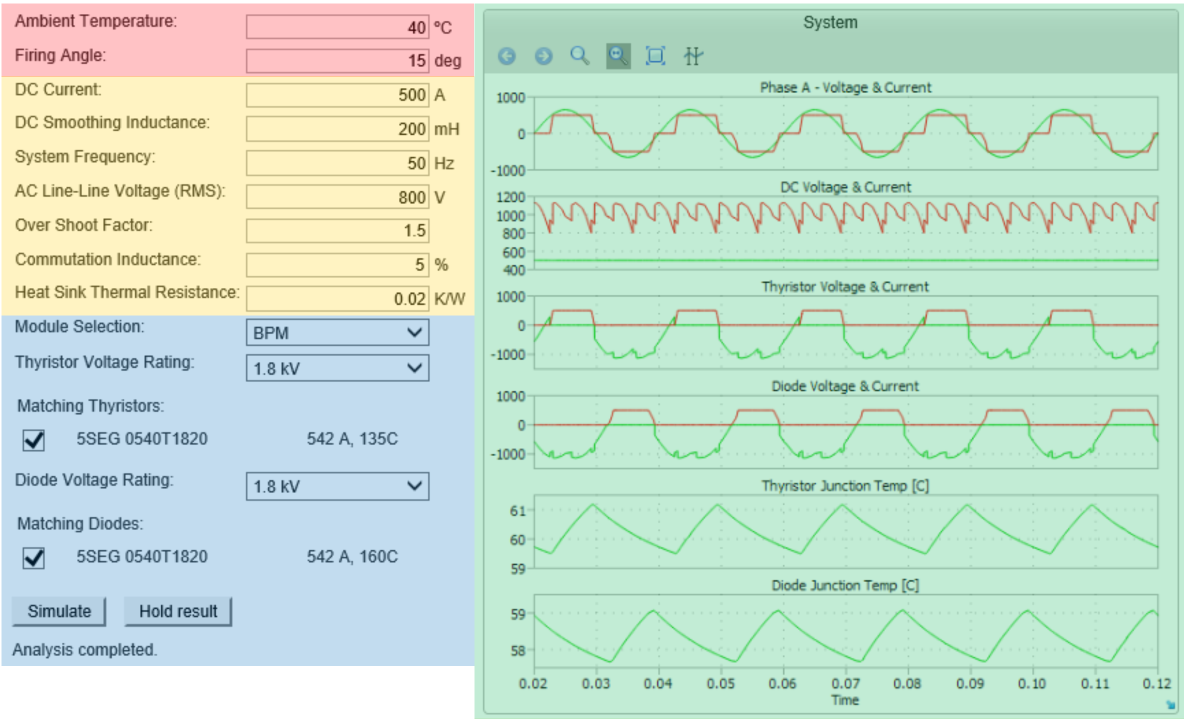
The main objective here is to develop a universal model for a 3-phase half-controlled rectifier. This model can be used by engineers for a quick check on the performance of the selected Hitachi ABB semiconductors best fitting their load demand and application. The estimated semiconductor conduction and switching losses, as well as the junction temperature will assist the user in selecting the optimum device that suits their converter operation and load requirements.

ABB offers the following thyristor topologies for thermal analysis simulation with

- Half controlled rectifier
- 6-Pulse controlled rectifier/inverter
- 12-Pulse series controlled rectifier/inverter
- 12-Pulse parallel controlled rectifier/inverter
- 2-Pulse controlled rectifier/inverter
- SVC Classic

2. OVERVIEW





Device Losses & Temperatures						
	Switching	Conduction	Combined Losses	TvjAvg	TvjMax	TvjBLS
per Thyristor	0 W	165.21 W	165.21 W	60.27 °C	61.17 °C	61.14 °C
per Diode	0 W	142.88 W	142.88 W	58.32 °C	59.07 °C	59.00 °C
Converter Losses	0 kW	0.92 kW	0.92 kW			
% Losses			0.18 %			

AC Parameters						
	Real Power	Reactive Power	Phase Voltage (RMS)	Phase Current (RMS)	System Frequency	Power Factor
	515.13 kW	146.94 kVAr	461.82 V	399.89 A	50 Hz	0.96

DC Parameters & Control Parameters				
	DC Power	DC Voltage	DC Current	Firing Angle in Deg
	514.21 kW	1.035 kV	500 A	15.00 °

Figure 1: 3 Phase Half Controlled Rectifier Circuit in ABB Powergrids Switzerland Ltd website.

Converter settings

Grid Definitions

Thyristor & Diode selection

Results graphs

Results tables

3. SIMULATION SETTINGS

3.1 Circuit parameters

3.1.1 Converter Settings

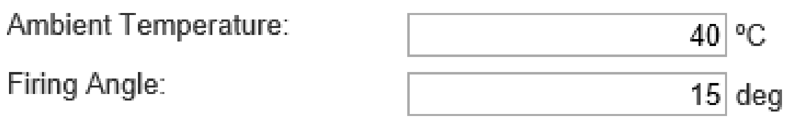


Figure 2 Converter Parameters

Ambient temperature	Definition of environmental temperature around the converter for temperature / cooling calculations	Range -25 to 90 °C
Firing Angle	Instant of thyristor turn on	Range 15 to 150 deg

3.1.2 Load Definitions

Figure 3 Load Definitions

DC Current	Load current on DC side	Range 1 to 7000 A
DC Smoothing Inductance	Inductance on the load side	Range 100 to 500 mH

3.1.3 Grid Definitions

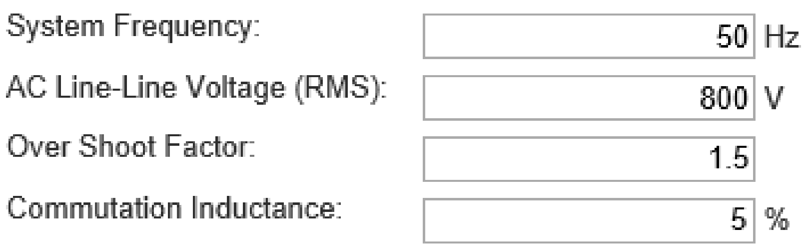


Figure 4 Grid Definitions

System Frequency	Converter output frequency	Range 10 to 100 Hz
AC Line-Line Voltage RMS	According Definition	Range 400 to 4000 V
Overshoot Factor	Defines maximum surge peak voltage	Range 1.5 to 3.5
Commutation Inductance	Percentage of Grid Inductance	Range 0 to 10%

3.2 Device settings

3.2.1 Heat Sink settings

Figure 5 Thermal settings

Heat Sink Thermal Resistance	Definition of thermal resistance of cooling system applied.	Range 0.0001 to 0.5 K/W
Remark:	The selected Rth is also accounted for the diode position for which same consideration applies for its electrical configuration.	

3.2.2 Switch settings

Figure 6 Thyristor selection

Module Selection	Select type of thyristor & diode module	Selection
Thyristor Voltage Rating	Select voltage class of Thyristor for filtering	Selection

Figure 7 Diode Selection

Diode Voltage Rating	Select voltage class of Diode for filtering	Selection

3.2.3 Matching Thyristors

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

Figure 8 Matching Thyristors for selection

User can select the desired Thyristor 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.

3.2.4 Matching Diodes

Once the Thyristor is selected then the user can select the matching Diode based on the voltage and current ratings. By clicking on the product code name, the user may access the data sheet from the ABB website.

Figure 9 Matching Diodes for selection

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 10 Start of simulation

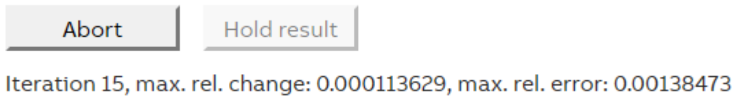


Figure 11 Simulation progress and termination

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:

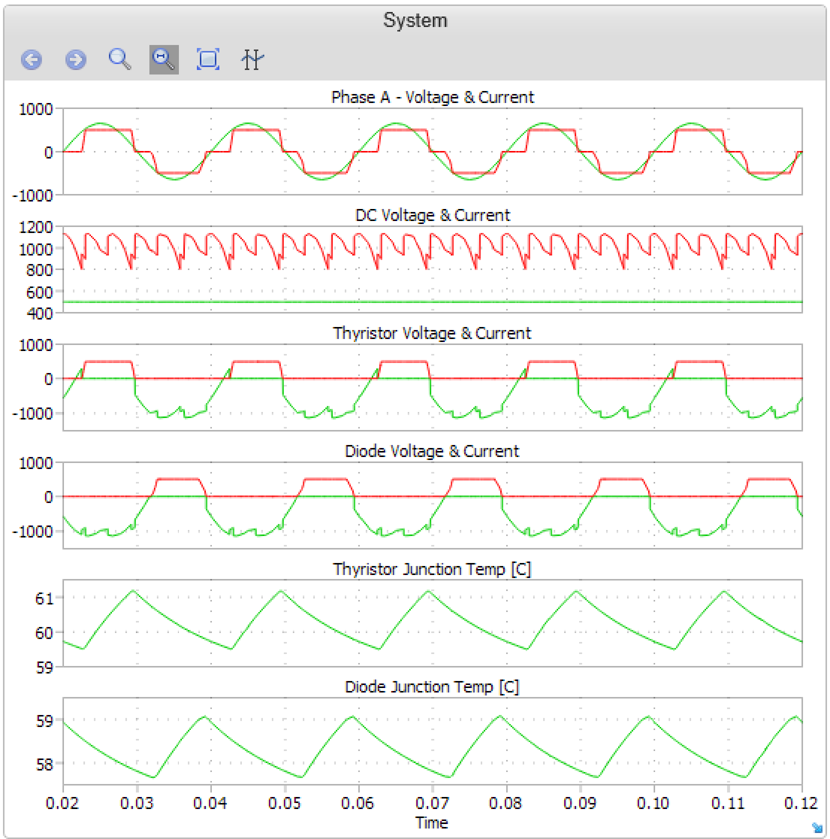
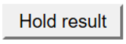


Figure 12 Graphical results of 3 Phase Half Controlled Rectifier

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	0.053333	0.086667	0.033333
Phase A - Voltage & Current			
Phase Voltage-A	-563.0	559.5	-1122
Phase Current-A	-499.9	499.9	-999.8
DC Voltage & Current			
idc:Measured current	499.9	499.9	-0.00001062
v_DC:Measured voltage	1126	1119	7.507
Thyristor Voltage & Current			
converter:Thyristor Voltages:1	-1126	0.000	-1126
converter:Thyristor Currents:1	0.000	499.9	-499.9
Diode Voltage & Current			
converter:Diode Voltages:1	0.000	-1119	1119
converter:Diode Currents:1	499.9	0.000	499.9
Thyristor Junction Temp [C]			
converter:Thyristor Junction Temperature:1	60.50	60.59	-0.08626
Diode Junction Temp [C]			
converter:Diode Junction Temperature:1	57.91	58.10	-0.1865

Figure 13 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 Thyristor 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 Thyristor or Diode.

Device Losses & Temperatures						
	Switching	Conduction	Combined Losses	TvjAvg	TvjMax	TvjBLS
per Thyristor	0 W	165.21 W	165.21 W	60.27 °C	61.17 °C	61.14 °C
per Diode	0 W	142.88 W	142.88 W	58.32 °C	59.07 °C	59.00 °C
Converter Losses	0 kW	0.92 kW	0.92 kW			
% Losses			0.18 %			

Figure 14 Device Losses & Temperatures

Switching loss	Single Thyristor or Diode Loss during turn on an d turn off events (dynamic)
Conduction loss	Single Thyristor or Diode Loss during on state (static)
Combined losses	Sum of single Thyristor or Diode switching and conduction loss.
Converter losses	Sum of all the Thyristor 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.

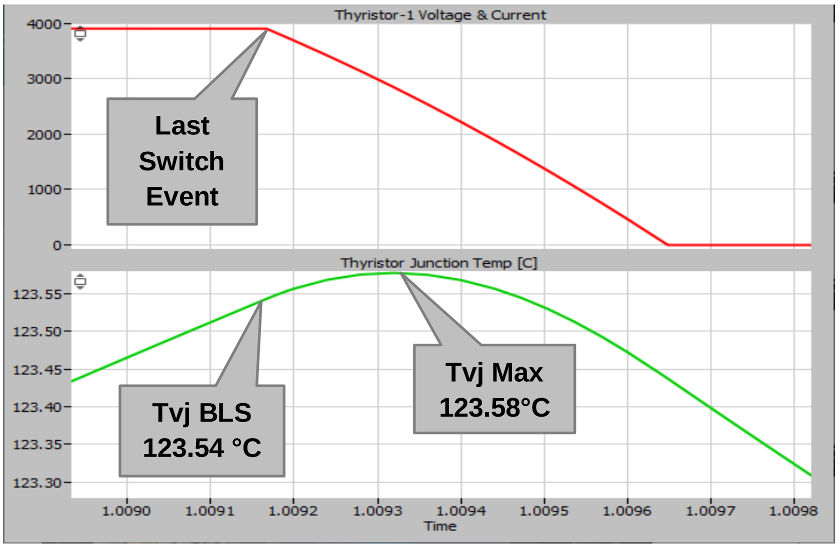


Figure 15 Definition of Tvj before last switch

Converter AC parameters

AC Parameters						
	Real Power	Reactive Power	Phase Voltage (RMS)	Phase Current (RMS)	System Frequency	Power Factor
	515.13 kW	146.94 kVAr	461.82 V	399.89 A	50 Hz	0.96

Figure 16 AC Parameters

Real Power P	Active power / real power output of the converter
Reactive Power Q	Q as supplied to the grid as effective power (reactive) on converter AC side. Calculation see in section 6.5
Phase Voltage RMS	According AC phase value 1st order harmonics of AC frequency
Phase Current RMS	According AC phase value total order harmonics of AC frequency
System Frequency	According Definition
Power Factor	According Definition

DC & Control parameters

DC Parameters & Control Parameters				
	DC Power	DC Voltage	DC Current	Firing Angle in Deg
	514.21 kW	1.035 kV	500 A	15.00 °

Figure 17 DC & Control Parameters

DC Power	According AC power definition - Losses
DC Voltage	According definition
DC Current	According definition
Firing Angle in Degrees	According definition

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

5.2 Maximum Surge Peak Voltage

Parameter	AC Line-Line Peak voltage
Verification	If the maximum surge peak voltage is greater than the safe operating voltage rating of thyristor, an alert message is displayed
Warning message	For the device voltage of 1.8kV, V_DSM should be less than 1800V

6. APPLIED CALCULATIONS

6.1 Input Parameter Definitions

Idc	Mean value of DC current waveform
VLL_RMS	Line-Line voltage RMS
alpha	Firing angle of the thyristor
Ls	Commutation inductance in H
Lpu	Percentage commutation inductance

6.2 Phase Current

$$I_s = \sqrt{\frac{2}{3}} I_{DC}$$ for alpha <= 60 deg

$$I_s = \sqrt{\frac{pi-alpha}{pi}} I_{DC}$$ for alpha > 60 deg

The above equations are for ideal phase rms current i.e with zero grid inductance. But these equations are still used in practical case for easier calculation of actual grid inductance value from percentage/p.u value.

6.3 DC Voltage Definition

$$L_s = L_{PU} * V_{LL_{RMS}} \ / \ (100 \ * I_s * 2 * pi * F_{Hz} * 1.732)$$

$$V_{dc} = 1.35 * V_{LL_{RMS}} * (1 + cos(alpha)) - (6 * F_{Hz} * L_s * I_{dc})$$

6.4 Real Power

P_{DC} P_{AC}	DC power / real power absorbed from DC side calculated according 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
I_{DC}	DC current in Load
R_{DC}	Load resistance
L_{DC}	Load inductance

$$R_{DC} = \frac{V_{DC}}{I_{DC}}$$

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

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

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:

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

6.5 Reactive Power

Q	Effective reactive power on converter AC side [VAr]

$$Q = 3 * V_{Ph\_RMS} * I_{Ph\_RMS} * sin(\varphi_1)$$

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

7. VALIDATION OF PLECS RESULTS

To ensure supplied simulation results are reliable, 3 phase half controlled rectifier model is validated with another simulation platform or compared to real measurement data.

The circuit topology is reconstructed in PSCAD to validate the results obtained from the SEMIS web simulation tool. The objective of the work is to develop a 3 phase half controlled rectifier with loss and temperature estimation in PSCAD and to validate the steady-state results obtained through web simulation model.

The XML data of the thyristor and diode which were created from the device datasheets for SEMIS simulations are modified to individual .txt files to capture the on-state voltage drop of the thyristor (VT at different temperatures, to make the data readable in PSCAD.

The PSCAD and SEMIS circuit models are made as identical as possible to prevent any errors in validation due to the dissimilarities. Junction to Case and Case to Heat sink thermal resistances for the Thyristor have been captured from the device datasheet.

Five cases each have been simulated in PSCAD and SEMIS by varying different parameters like input line-line voltage, Firing angle, Load current, etc.

Results analysis according settings

Topology	**SEMIS 35 Half Controlled rectifier**
Tester:	**Harshavardhan Marabathina**
Date	**May 21, 2021**
Device used (.xml)	**5SEG 0540T1820**
Limit acceptance level Green / Orange / Red	**0%** / 2% / 5%
Instructions	1. Enter all values according the final results table in the column SEMIS 2. Enter all values according the final results from the PSCAD in the column PSCad 3. Verify the relative difference; Results must not vary more than 2 %

Description of Settings Set

Parameter	**Set 1 SEMIS**	**Set 1 PSCad**	**Set 1 Difference**	**Set 2 SEMIS**	**Set 2 PSCad**	**Set 2 Difference**	**Set 3 SEMIS**	**Set 3 PSCad**	**Set 3 Difference**	**Set 4 SEMIS**	**Set 4 PSCad**	**Set 4 Difference**	**Set 5 SEMIS**	**Set 5 PSCad**	**Set 5 Difference**
Absolute average difference [%]			0.29%			0.18%			0.25%			0.26%			0.49%
Max difference [%]			0.67%			0.81%			0.50%			0.92%			1.49%
Device Losses & Temperatures															
Conduction Loss per Thyristor (W)	165.21	166.23	- 0.62%	410.36	411.9	- 0.38%	411.39	412.4	- 0.25%	276.95	279.5	- 0.92%	107.22	107.36	- 0.13%
Switching Loss per Thyristor (W)															
Combined Loss per Thyristor (W)	165.21	166.23	- 0.62%	410.36	411.9	- 0.38%	411.39	412.4	- 0.25%	276.95	279.5	- 0.92%	107.22	107.36	- 0.13%
Conduction Loss per Diode (W)	142.88	143.19	- 0.22%	325.94	326.26	- 0.10%	326.91	327.98	- 0.33%	229.97	229.38	+ 0.26%	95.65	96.3	- 0.68%
Switching Loss per Diode (W)															
Combined Losses per Diode (W)	142.88	143.19	- 0.22%	325.94	326.26	- 0.10%	326.91	327.98	- 0.33%	229.97	229.38	+ 0.26%	95.65	96.3	- 0.68%
Junction Temperature Avg Thyristor (°C)	60.27	60.31	- 0.07%	89.6	89.71	- 0.12%	74.73	74.6	+ 0.17%	52.79	52.83	- 0.08%	53.18	53.19	- 0.02%
Junction Temperature Avg Diode (°C)	58.32	58.36	- 0.07%	82.41	82.48	- 0.08%	67.54	67.68	- 0.21%	48.54	48.56	- 0.04%	52.24	52.26	- 0.04%
Converter Losses (W)	922.08	928.26	- 0.67%	2210	2215	- 0.23%	2210	2221.14	- 0.50%	1530	1526.6	+ 0.22%	608.6	610.98	- 0.39%
Losses Efficiency	0.18	0.18	+ 0.56%	0.25	0.25	+ 0.81%	0.37	0.37	+ 0.27%	0.40	0.40	+ 0.25%	0.18	0.18	+ 1.12%
AC Parameters															
Real Power (kW)	515	517.8	- 0.54%	895	897.3	- 0.26%	599	601.79	- 0.47%	382	382.1	- 0.03%	339	343.8	- 1.42%
Reactive Power (kVAR)	147	146.7	+ 0.20%	508	507.69	+ 0.06%	408	408.6	- 0.15%	496	495.5	+ 0.10%	141	141.4	- 0.28%
Phase Voltage RMS (V)	461.82	461.89	- 0.02%	461.82	461.89	- 0.02%	346.37	346.4	- 0.01%	461.82	461.89	- 0.02%	461.82	461.89	- 0.02%
Phase Current RMS (A)	399.89	401.6	- 0.43%	805.84	807.2	- 0.17%	810.65	813.1	- 0.30%	552.91	548.2	+ 0.85%	277.58	281.4	- 1.38%
Output Frequency (Hz)	50	50	+ 0.00%	50	50	+ 0.00%	50	50	+ 0.00%	50	50	+ 0.00%	50	50	+ 0.00%
Power Factor	0.96	0.962	- 0.21%	0.87	0.8703	- 0.03%	0.83	0.827	+ 0.36%	0.61	0.61	+ 0.00%	0.92	0.924	- 0.43%
DC Parameters & Control Parameters															
DC Power (kW)	514.21	516.87	- 0.52%	892.72	895	- 0.26%	597.05	599.56	- 0.42%	380.09	380.57	- 0.13%	338.15	343.19	- 1.49%
DC Voltage (V)	1035	1034.8	+ 0.02%	895	895.2	- 0.02%	599	599.51	- 0.09%	509	510	- 0.20%	981	980.9	+ 0.01%
DC Current (A)	500	500.1	- 0.02%	1000	1001.3	- 0.13%	1000	1002.3	- 0.23%	750	748.5	+ 0.20%	350	350.2	- 0.06%

Figure 18 Validation results comparison for 3 Phase Half controlled rectifier

8. USER MANUAL REVISION HISTORY

Rev.	Page	Change Description	Date / Initial
1.0	all	Initial version	2021-05-27 PGGI/HM

9. SIMULATION SOFTWARE RELEASE HISTORY

Rev.	New topic	Fixed defects	Tvj influence	Date
1.0	Initial version	-	-	2021-05-27 PGGI/HM

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