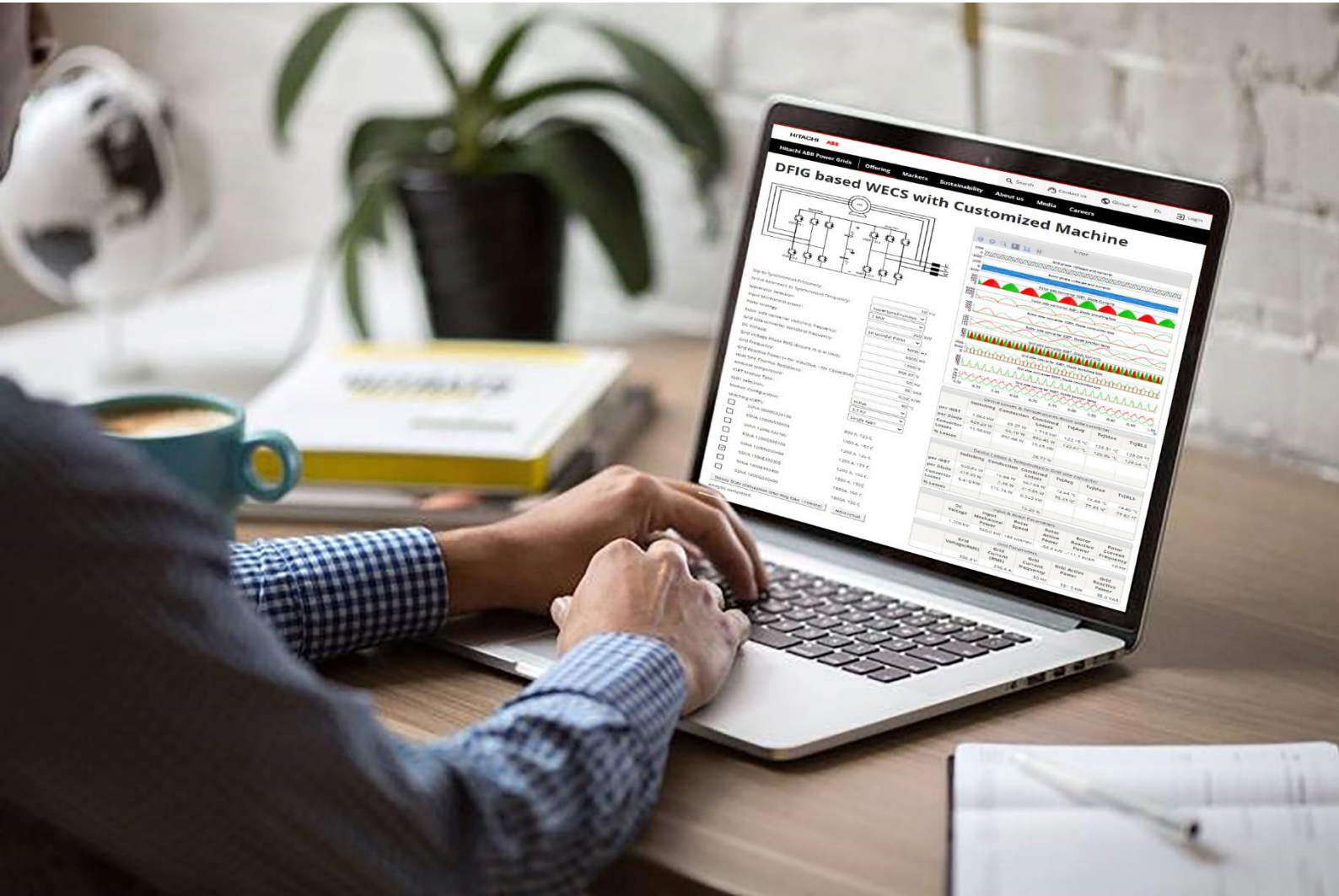


SEMIS Simulation Tool

2 Level Doubly Fed Induction Generator with IGBT

User Manual



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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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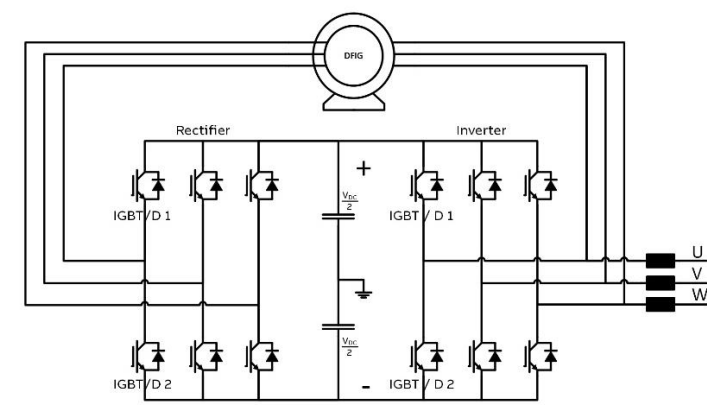
1. 2 LEVEL DFIG CONVERTERS

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.

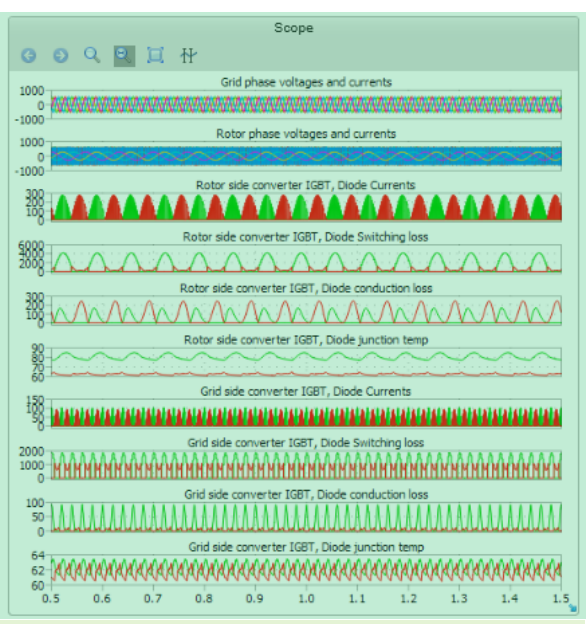
ABB offers the following DFIG topologies for thermal analysis simulation with

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

2. OVERVIEW



Slip to Synchronous Frequency: 15 Hz
 Select Reference to Synchronous Frequency: SuperSynchronous f
 Generator Selection: 2 MW
 Input Mechanical power: 349 kW
 PWM strategy: Sinusoidal PWM
 Rotor side converter switching frequency: 5000 Hz
 Grid side converter switching frequency: 5000 Hz
 DC Voltage: 1200 V
 Grid Voltage Phase RMS (Ensure m is in limit): 398.37 V
 Grid Frequency: 50 Hz
 Grid Reactive Power (+ for Inductive, - for Capacitive): 0 VAR
 Heat Sink Thermal Resistance: 0.008 K/W
 Ambient temperature: 40 °C
 IGBT Module Type: HiPak
 IGBT Selection: 3.3 kV
 Module Configuration: Single IGBT
 Matching IGBTs:
 5SNA 0800N330100 800 A, 125C
 5SNA 1000N330300 1000 A, 150C
 5SNA 1200E330100 1200 A, 125C
 5SNA 1200G330100 1200 A, 125C
 5SNA 1200N330400 1200 A, 150C
 5SNA 1500E330305 1500 A, 150C
 5SNA 1800E330400 1800A, 150C
 5SNA 1800G330400 1800A, 150C
 Steady State (Simulation time may take >10mins) Hold result
 Analysis completed.



| 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 | 735.87 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 | 328.5 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

| | |
|--|---|
| Slip to Synchronous Frequency: | <input type="text" value="15"/> Hz |
| Select Reference to Synchronous Frequency: | <input type="text" value="SuperSynchronous I"/> ▾ |
| Generator Selection: | <input type="text" value="2 MW"/> ▾ |
| Input Mechanical power: | <input type="text" value="349"/> kW |

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

| | |
|---|---|
| PWM strategy: | <input type="text" value="Sinusoidal PWM"/> ▾ |
| Rotor side converter switching frequency: | <input type="text" value="5000"/> Hz |
| Grid side converter Switching frequency: | <input type="text" value="5000"/> Hz |
| DC Voltage: | <input type="text" value="1200"/> V |

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

| | |
|--|---------------------------------------|
| Grid Voltage Phase RMS (Ensure m is in limit): | <input type="text" value="398.37"/> V |
| Grid Frequency: | <input type="text" value="50"/> Hz |
| Grid Reactive Power (+ for Inductive, - for Capacitive): | <input type="text" value="0"/> VAR |

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

Heat Sink Thermal Resistance: K/W

Ambient temperature: °C

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: 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 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

IGBT Module Type: ▼

IGBT Selection: ▼

Module Configuration: ▼

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.

| Matching IGBTs: | | |
|-------------------------------------|------------------|--------------|
| <input type="checkbox"/> | 5SNA 0800N330100 | 800 A, 125C |
| <input type="checkbox"/> | 5SNA 1000N330300 | 1000 A, 150C |
| <input type="checkbox"/> | 5SNA 1200E330100 | 1200 A, 125C |
| <input type="checkbox"/> | 5SNA 1200G330100 | 1200 A, 125C |
| <input type="checkbox"/> | 5SNA 1200N330400 | 1200 A, 150C |
| <input checked="" type="checkbox"/> | 5SNA 1500E330305 | 1500 A, 150C |
| <input type="checkbox"/> | 5SNA 1800E330400 | 1800A, 150C |
| <input type="checkbox"/> | 5SNA 1800G330400 | 1800A, 150C |

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 |

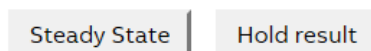


Figure 8 Start of simulation



Iteration 15, max. rel. change: 0.000113629, max. rel. error: 0.00138473

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:

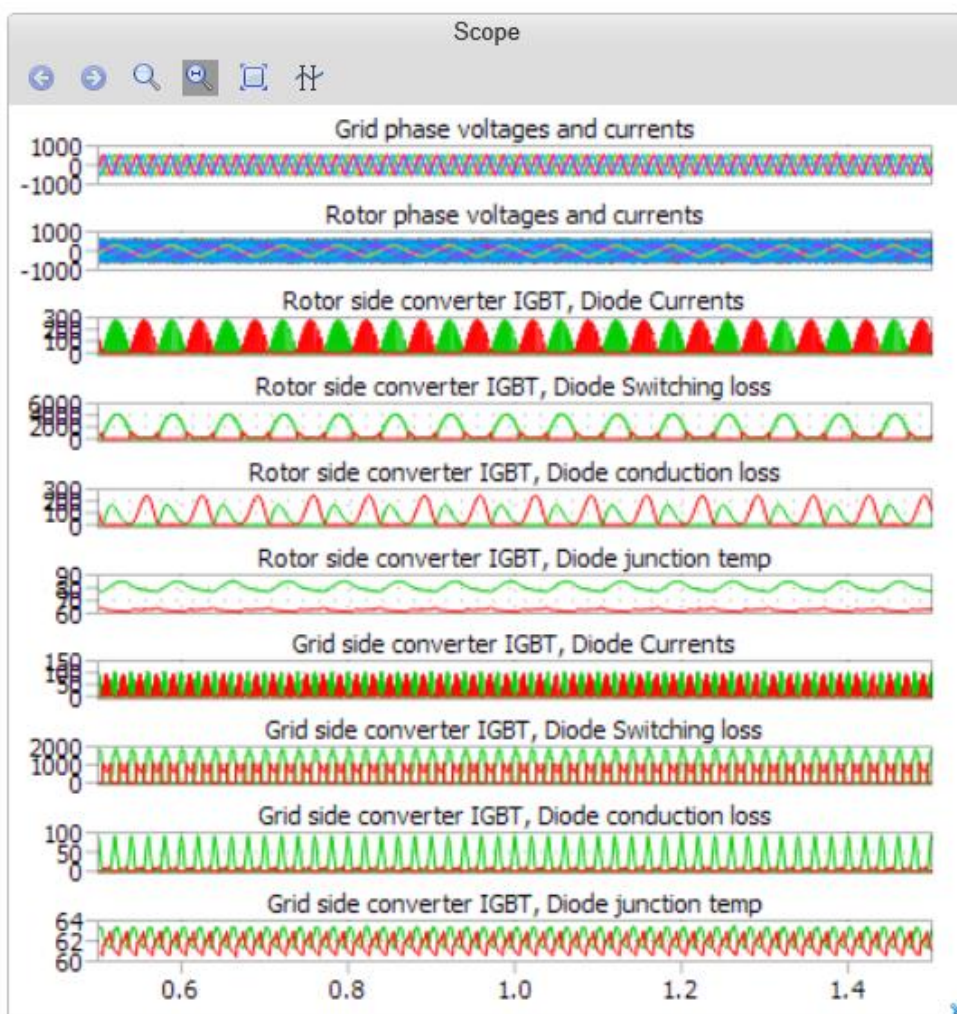


Figure 10 Graphical results of 2-Level DFIG converters

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

Hold result

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 °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 % | | | |

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. |

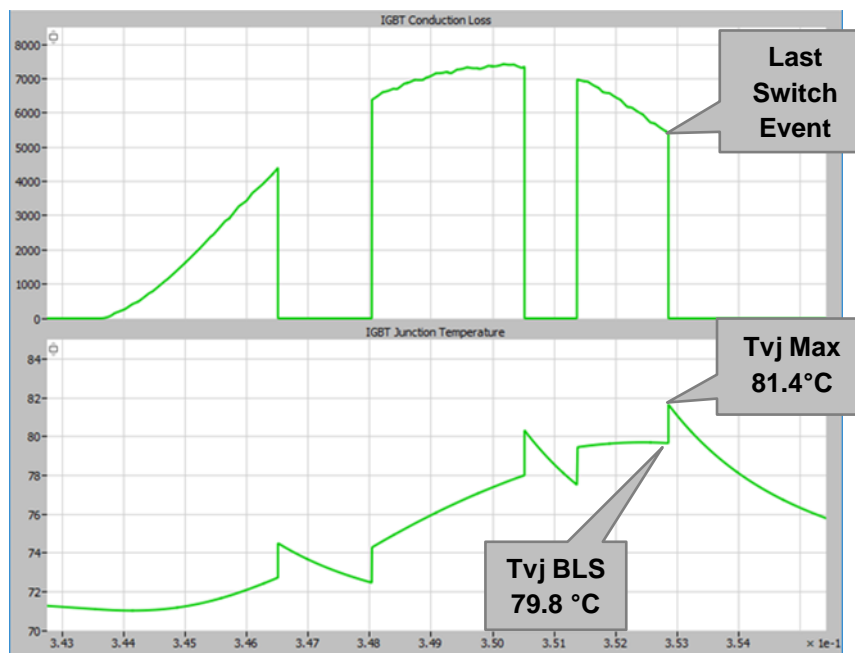


Figure 13 Definition of Tvj before last switch

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, $V_{dcmin} = 200V$ & $V_{dcmax} = 1100V$ |

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 |

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

$$V_{trueRMS} = \sqrt{\frac{1}{n} \sum_{v=1}^n \widehat{u}_v^2}$$

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

$$I_{trueRMS} = \sqrt{\frac{1}{n} \sum_{v=1}^n \widehat{i}_v^2}$$

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

According to:

$$P_{AC} = \frac{3}{n} \sum_{v=1}^n \widehat{u}_v \cdot \widehat{i}_v \cdot \cos \varphi_v = 3 \cdot V_{trueRMS} \cdot I_{trueRMS} \cdot PF$$

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]

$$Q = 3 * V_{Ph_{RMS}} * I_{Ph_{RMS}} * \sin(\varphi_1)$$

$V_{Ph_{RMS}}$ Phase voltage (RMS)

$I_{Ph_{RMS}}$ Phase current (RMS)

ρ_1 Fundamental power factor angle

7. VALIDATION OF PLECS RESULTS

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 |

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