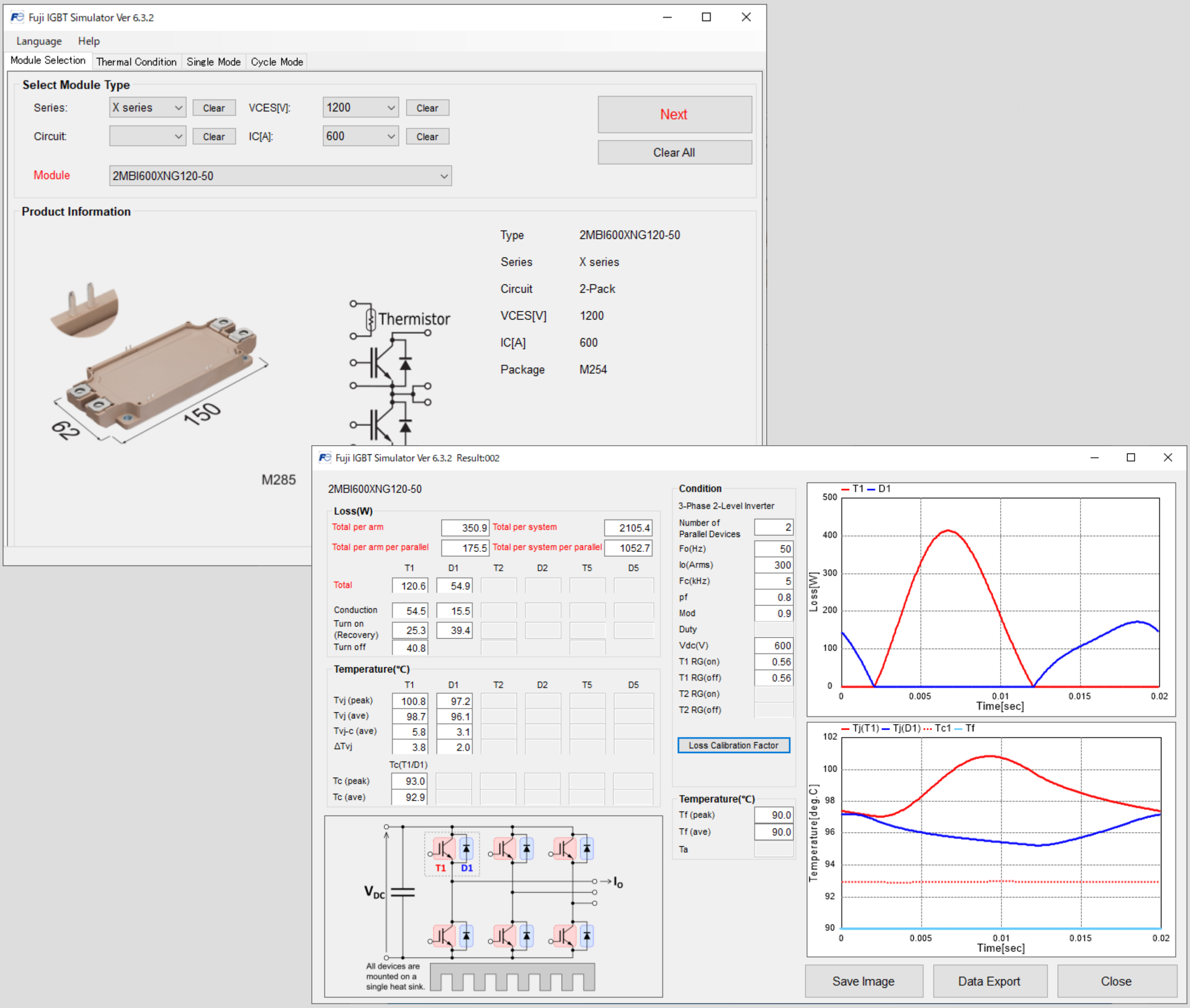
Fuji Electric
Innovating Energy Technology



Fuji IGBT Simulator Ver.6.3

User Manual

January 2022

Fuji Electric Co., Ltd.

MT5F31341 c

(Caution)

Before downloading and using the software, please read the following “End-user Software Agreement”. By downloading the software, you agree to be bound by the terms of the following agreement. If you don’t agree the agreement, remove the software and erase all copies of the software and the related documents.

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   Fuji pays close attention to the quality of the contents on this simulator. However, such continents are provided “as is “ without guarantees of any kinds.

   This software may not be able to accurately simulate temperature ripple due to changes in PWM operating conditions or operating modes. Please contact to Fuji if you need a help to discuss ΔTj-P/C capability.
5. (Program update) The program specification of this software is subject to change without any notice.

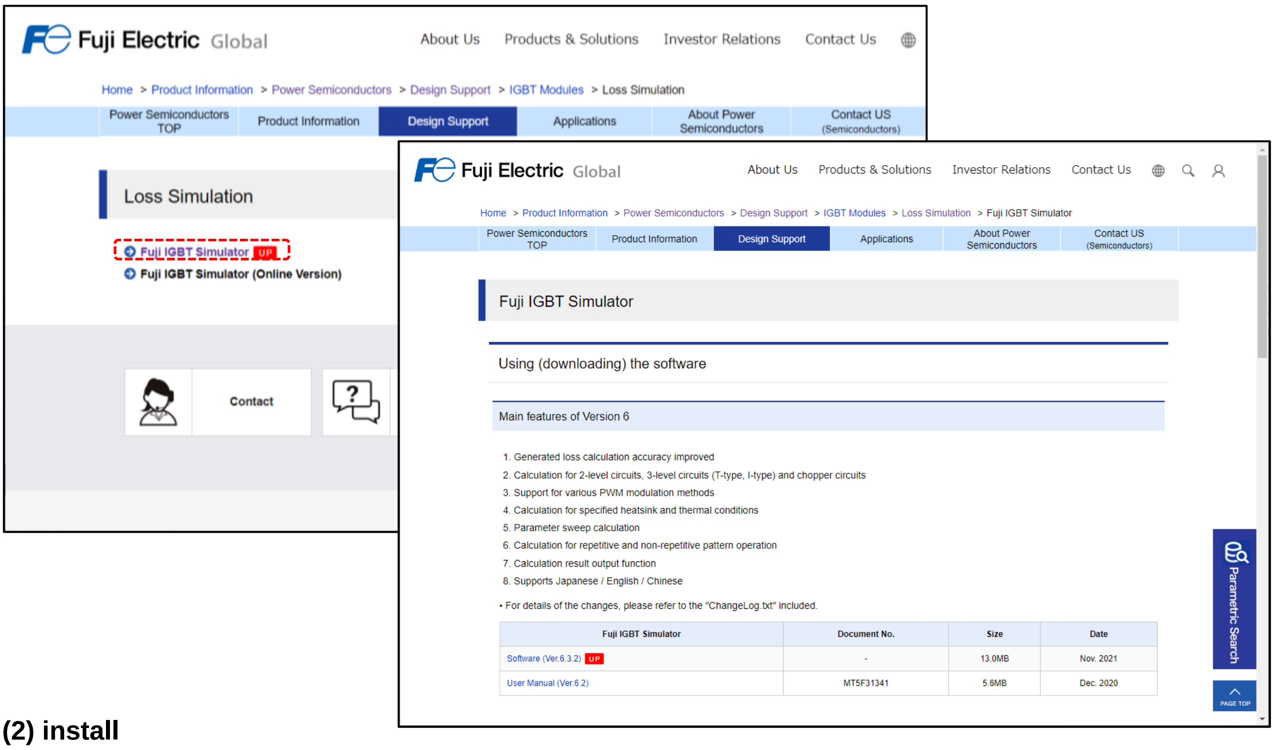
CONTENTS

1. Software Setup

This software is suitable for Microsoft® Windows® Windows7, Windows & Windows10.
In order to operate, Microsoft .NET Framework 3.5 or later is required .

(1) Download site

https://www.fujielectric.com/products/semiconductor/model/igbt/simulation/list.html



(2) install

Unzip the downloaded file and copy to a custom folder.
Please double-click the file “IGBTSim.exe” to start the simulator.

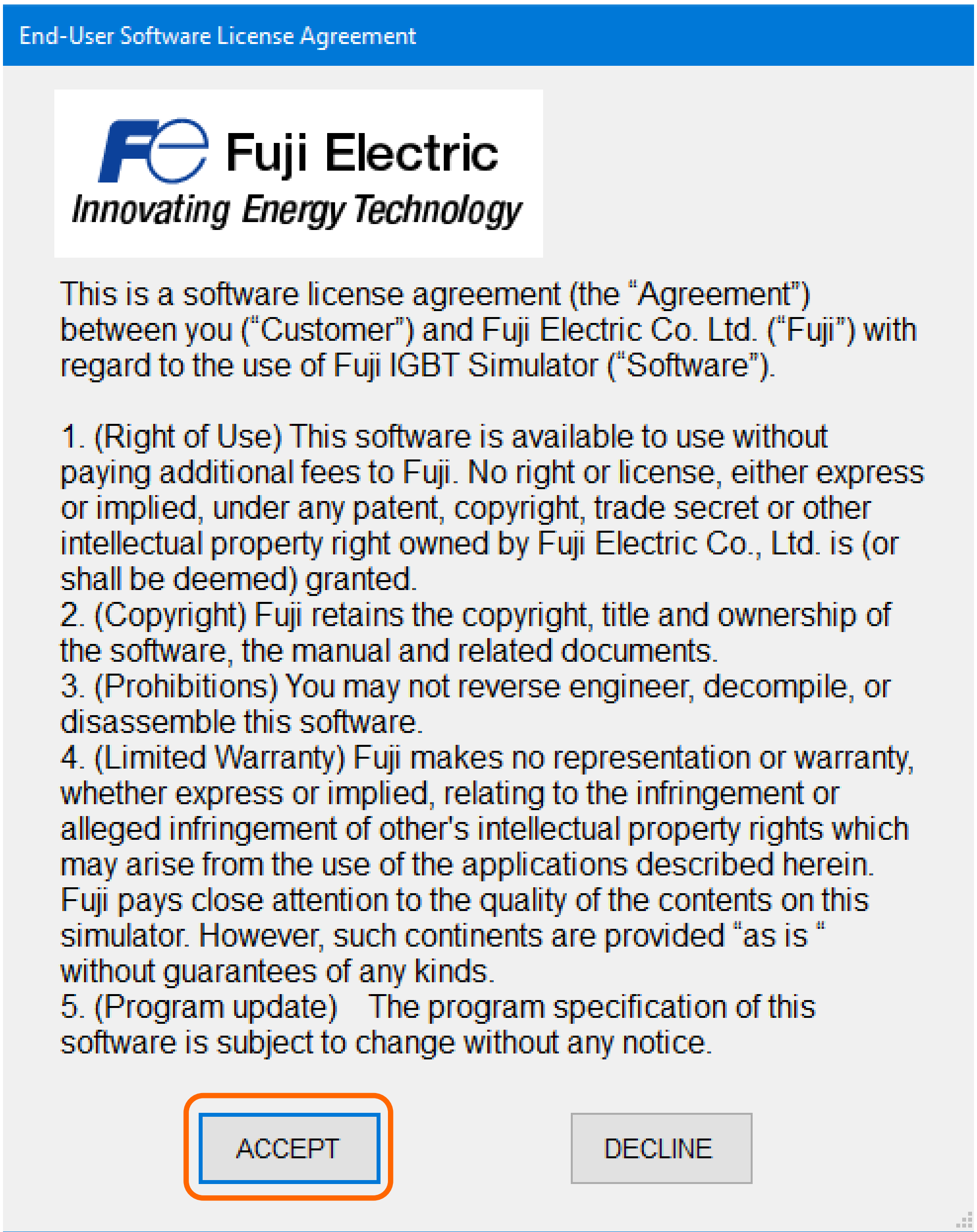
Windows is a registered trademark of Microsoft Corporation in the United States and other countries.

2. Startup screen

(1) End-User Software License Agreement

The software license agreement is displayed at startup.

Please confirm the contents and click the "ACCEPT" button.

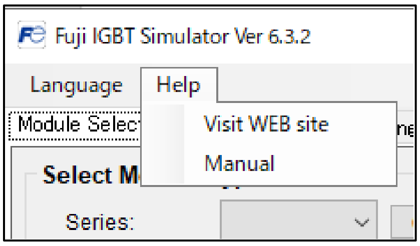


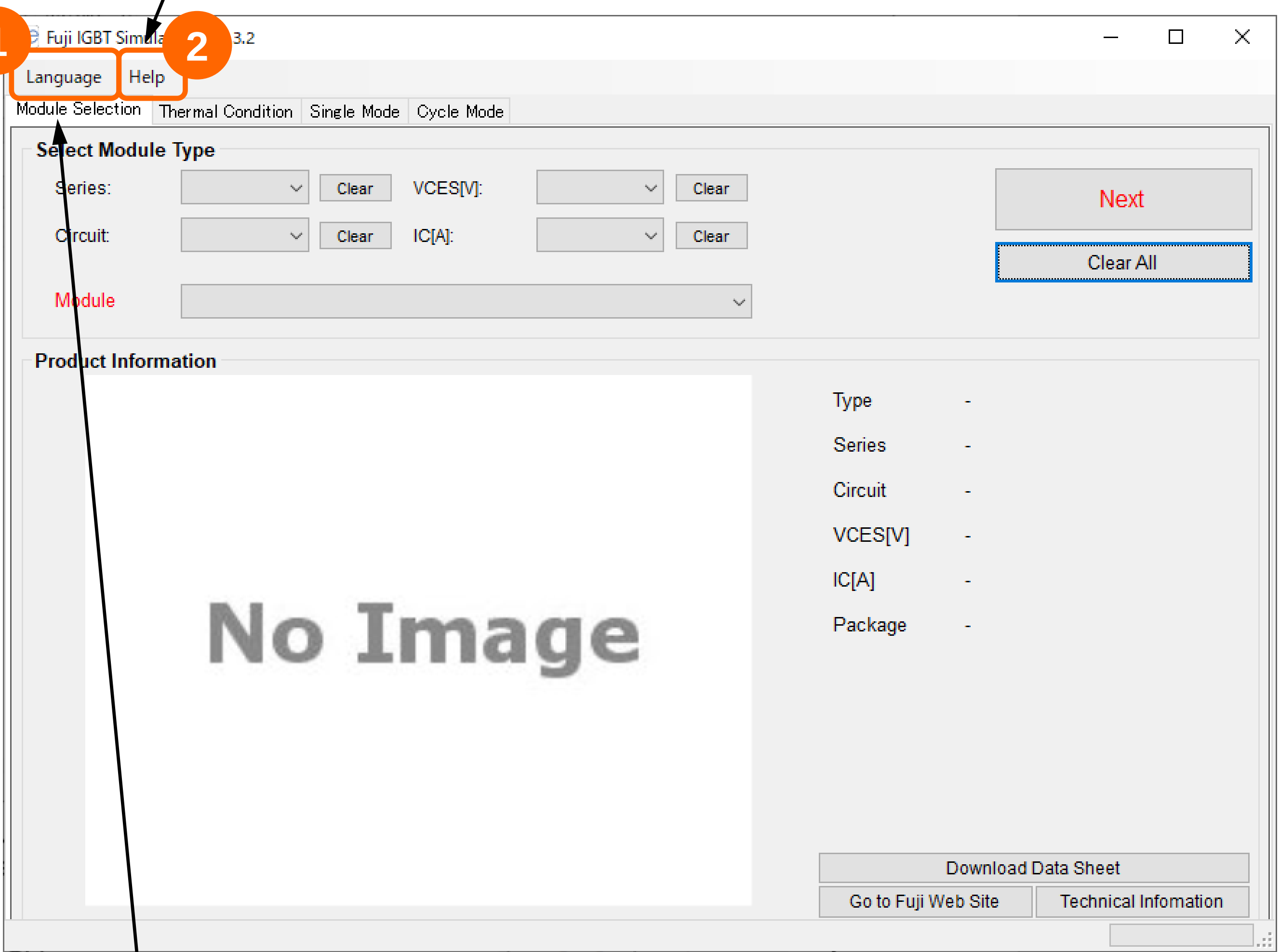
(2) IGBT simulator menu

You can select the language from the menu. Help is available.

2 Help menu

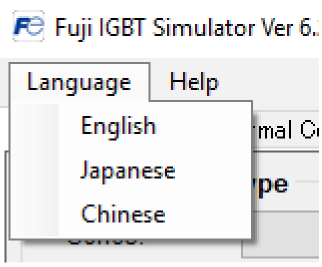
The latest version of this software can be downloaded from web site by clicking "Visit WEB site".





1 Select language

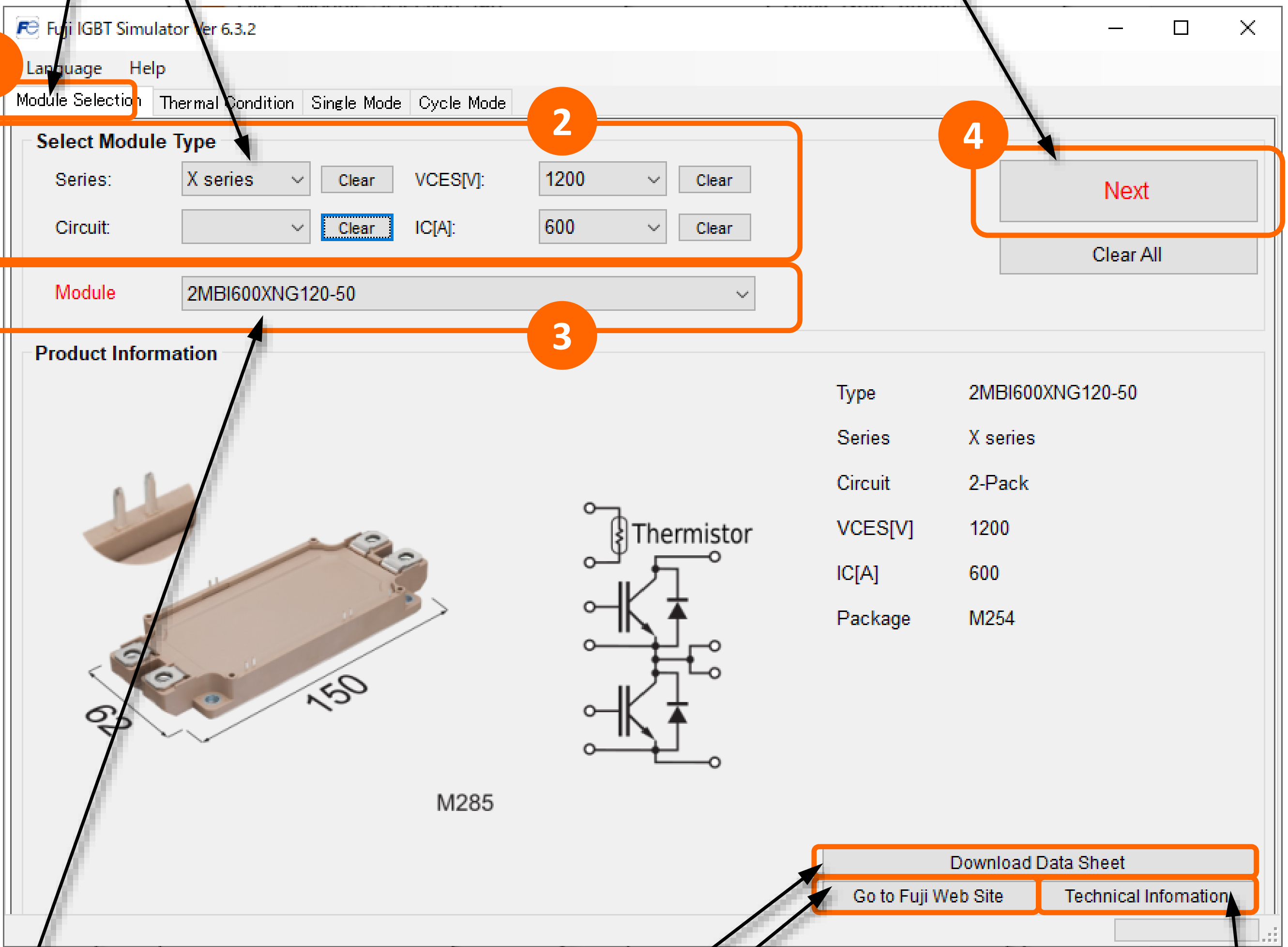
You can select the language by clicking "Language"
- English
- Japanese
- Chinese



3. Module Selection

Select the IGBT to simulation.

1. Click “Module Selection” tab.
2. Select “Series, Circuit, VCES, IC” from each dropdown list.
3. Select module from the dropdown list.
4. Click “Next” button.



Download product datasheet.

Visit Fuji Semiconductor web site.

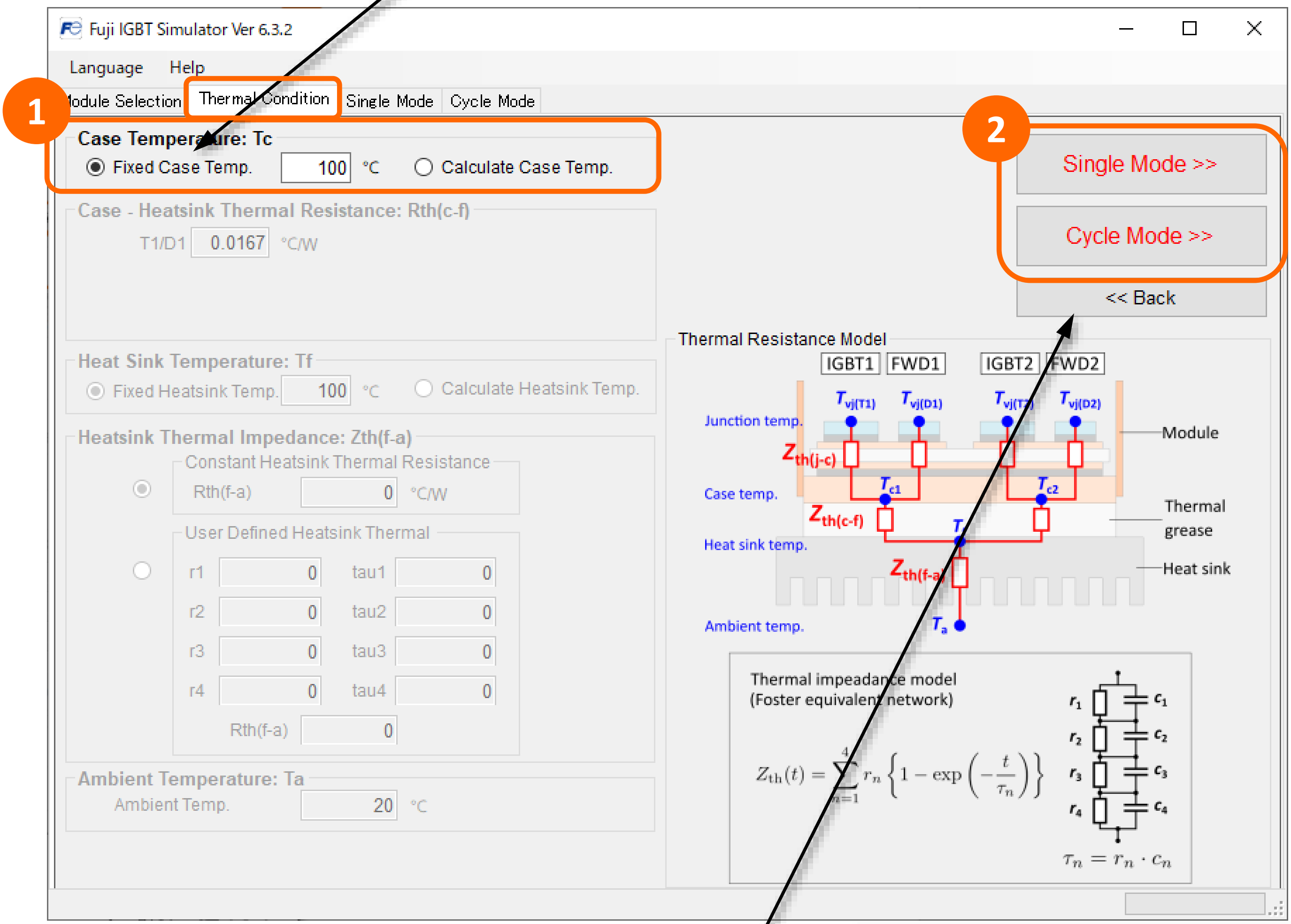
Visit technical information page.

4. Set temperature condition

Set the temperature conditions for the simulation.

(1) When calculating with fixed Case Temperature

1 Select fixed Case Temperature. Calculate *Tc* as constant.



2 Click "Single Mode" or "Cycle Mode" to proceed to the next step.

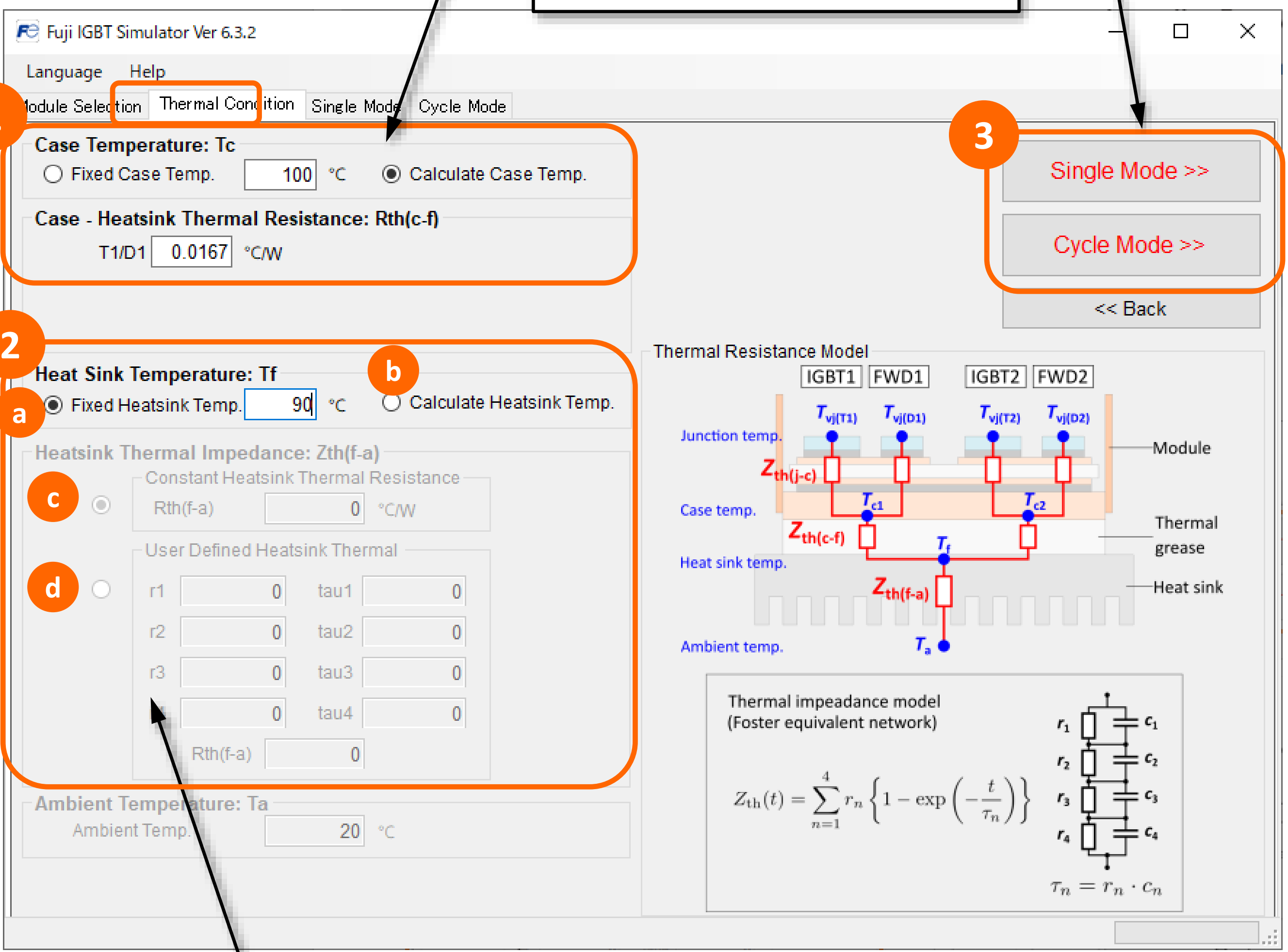
For details of the thermal circuit model, refer to pages 9 to 10.

(2) When calculating without fixed Case Temperature

When calculating the case temperature, you can choose between fixed heatsink and heatsink temperature calculation.

1 **Select Calculate Case Temperature.**
Calculate *Tc* using thermal resistance $R_{th(c-f)}$ case to heat sink.

3 Click "Single Mode" or "Cycle Mode" to proceed to the next step.



2 Input heat sink condition

a **Fixed heat sink condition**
Calculate with constant T_f

b **Calculate heat sink temperature**
T_f is calculated using thermal impedance $Z_{th(f-a)}$ between heat sink and ambient temperature

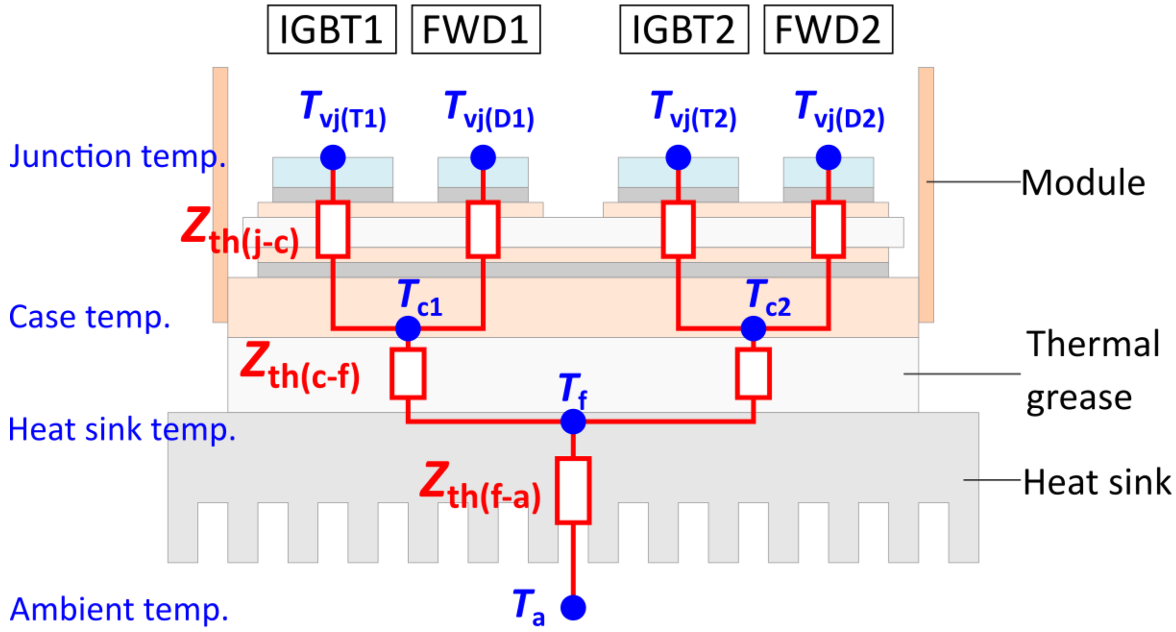
c Input $Z_{th(f-a)}$ as constant without any time constants.

d If $Z_{th(f-a)}$ is represented by a 4th order Foster network model, input r_1 to r_4 and τ_1 to τ_4.

5. Thermal Circuit Model

(1) Thermal Circuit Model

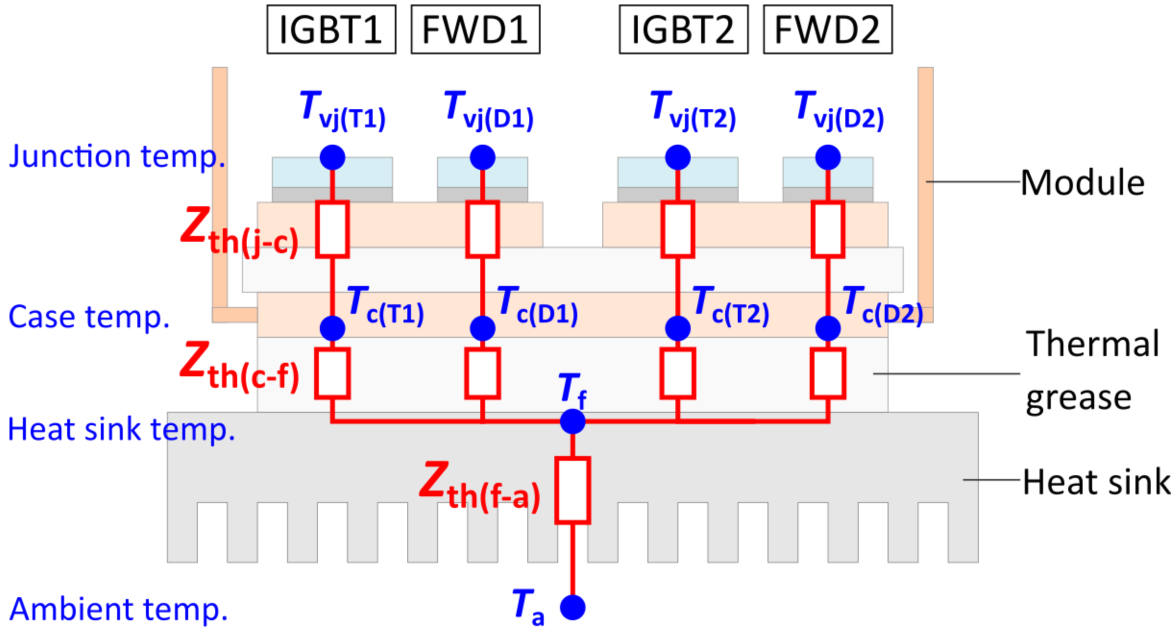
In the simulator, calculations are performed based on the following thermal circuit model.



The heat sink temperature T_f is calculated based on the assumption that the surface temperature distribution of the heat sink‘s area, which is in contact with the module, is uniform. If there is a deviation in the real temperature distribution, the calculated value might be different to the real one.

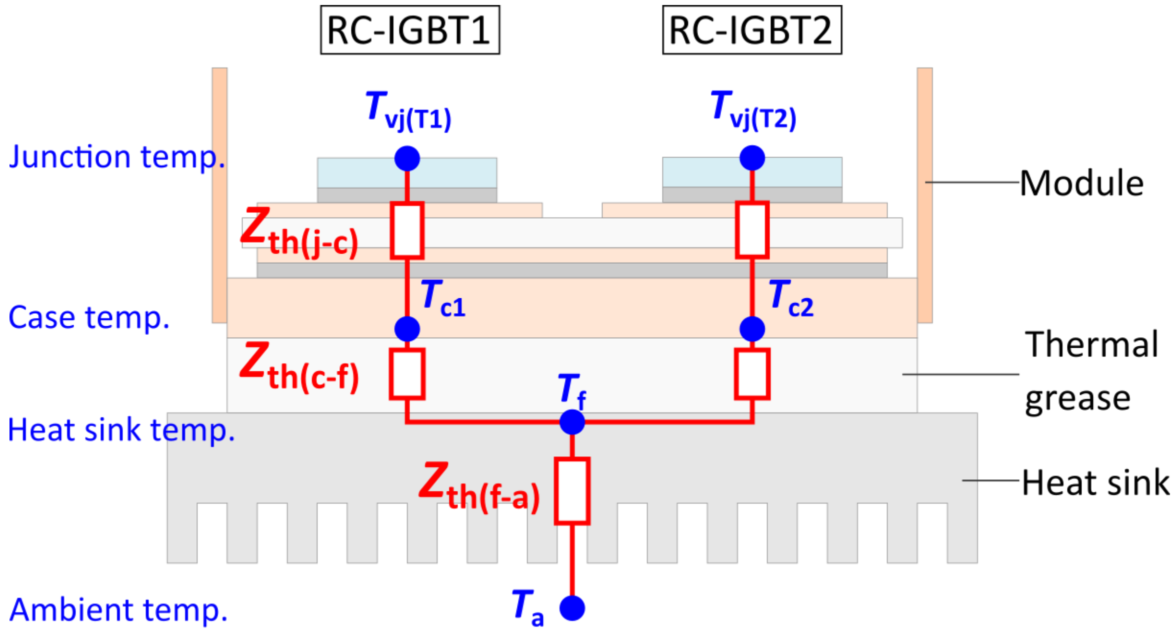
(2) Thermal Circuit Model - without copper baseplate **-**

The following thermal circuit model is applied for modules without copper baseplate.



(3) Thermal Circuit Model -RC-IGBT-

The following thermal circuit model is applied for RC-IGBT modules.



The heat sink temperature T_f is calculated based on the assumption that the surface temperature distribution of the heat sink‘s area, which is in contact with the module, is uniform. If there is a deviation in the real temperature distribution, the calculated value might be different to the real one.

Single Mode Calculation

6. Single Mode Calculation

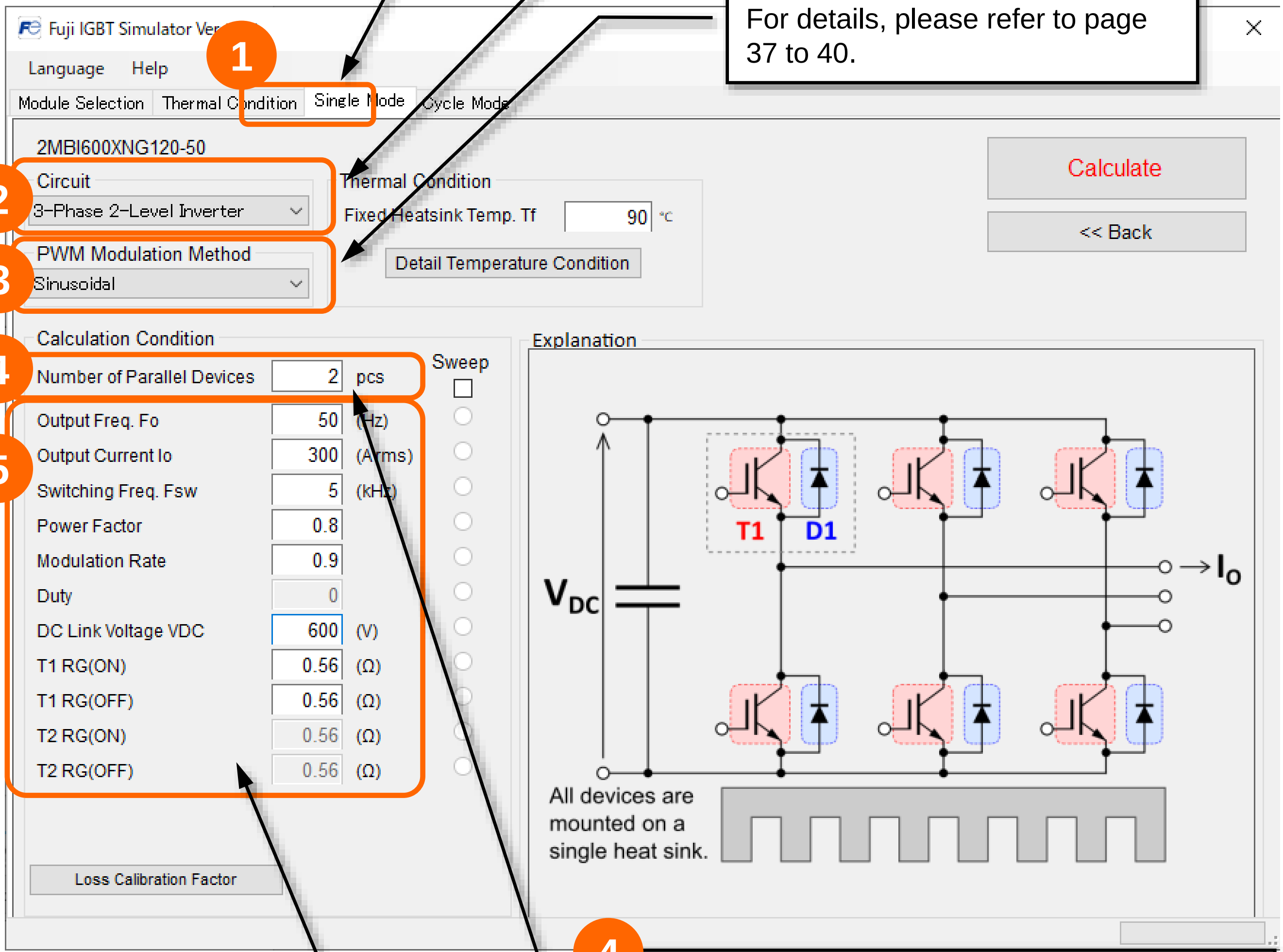
(1) Input simulation condition

Single mode calculation allows simulation for one cycle.

1 Click “Single Mode“ Tab.

2 Select circuit topology.
For details, please refer to page 34 to 36.

3 Select PWM modulation method.
For details, please refer to page 37 to 40.

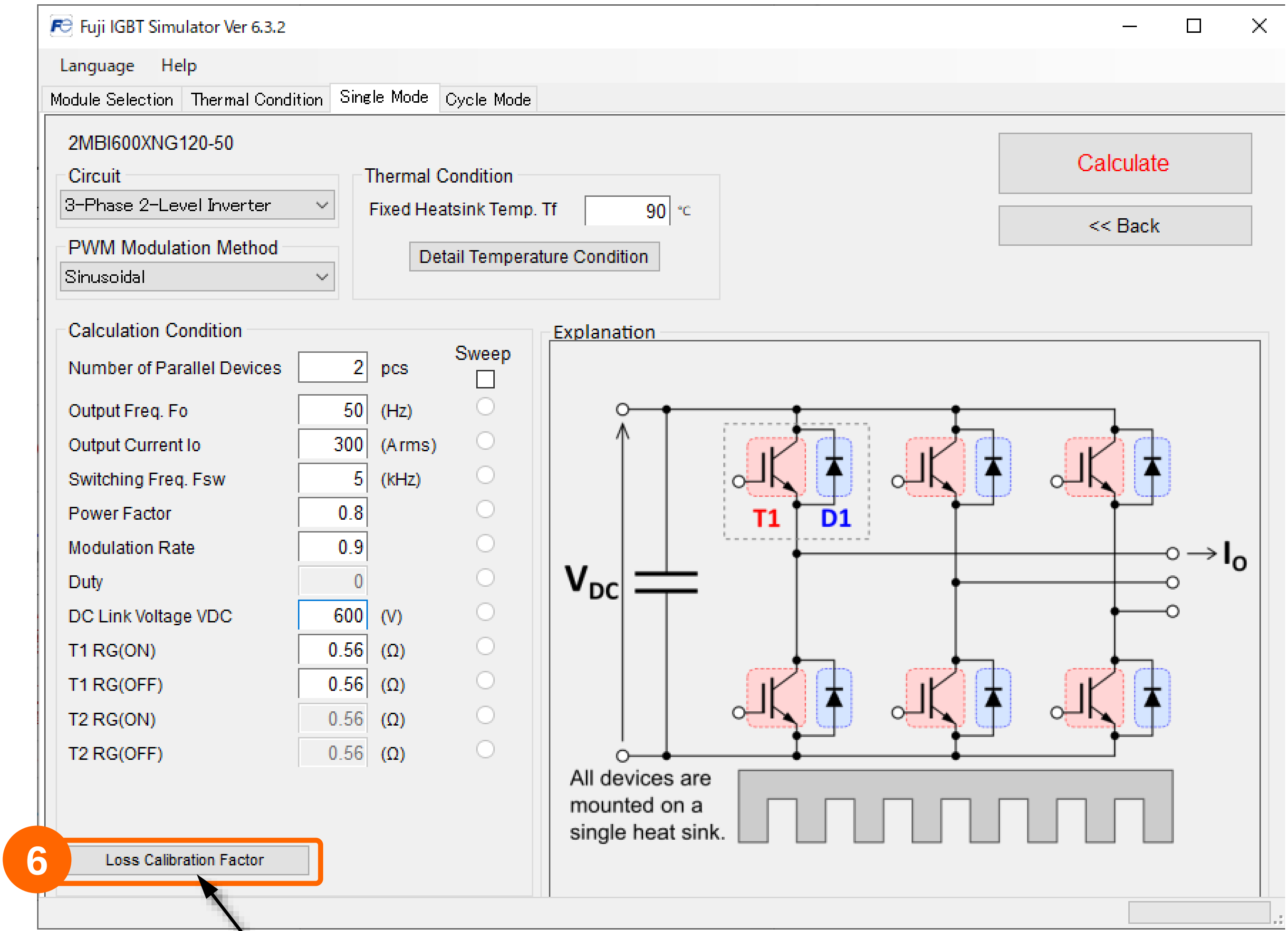


4 Input the number of parallel connected modules.
The calculation is based on the assumption that all modules are mounted on the same heat sink.

5 Input operation condition.
For paralleled modules, the current through the individual module is obtained by dividing given I_O by number of parallel modules.

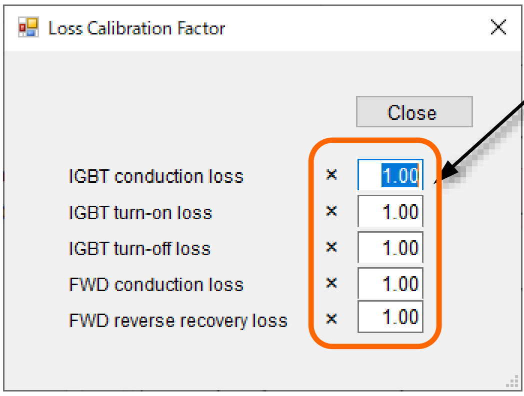
(2) Loss Calibration Factor

The calibration factor of each parameter can be set from "Loss calibration Factor".



6

Click “Loss Calibration Factor“ tab.
The dialog box to input coefficients for calibrating the loss calculation value will open.

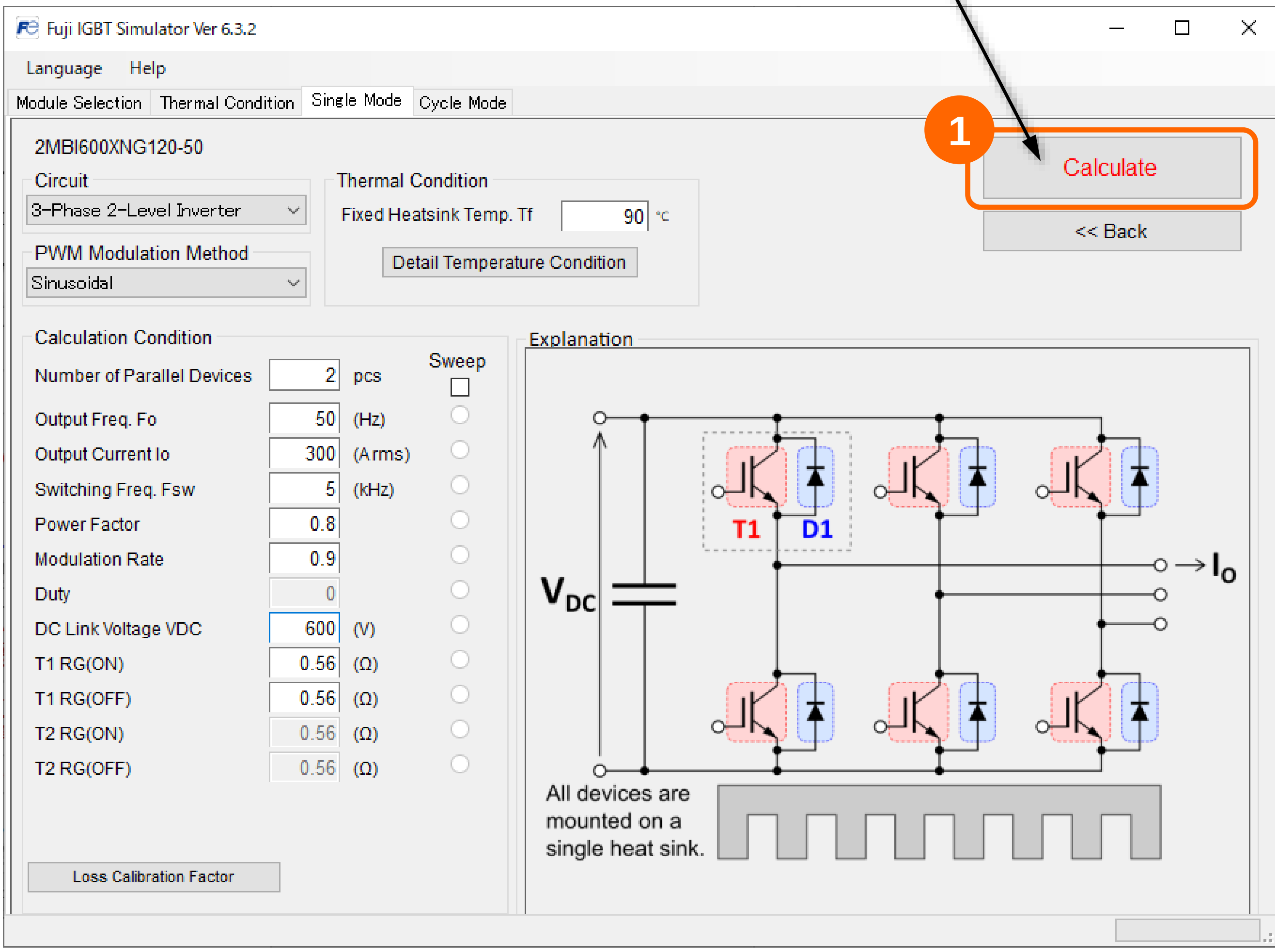


Every generated loss by IGBT / FWD is multiplied with the provided calibration factor.

(3) Run Calculation

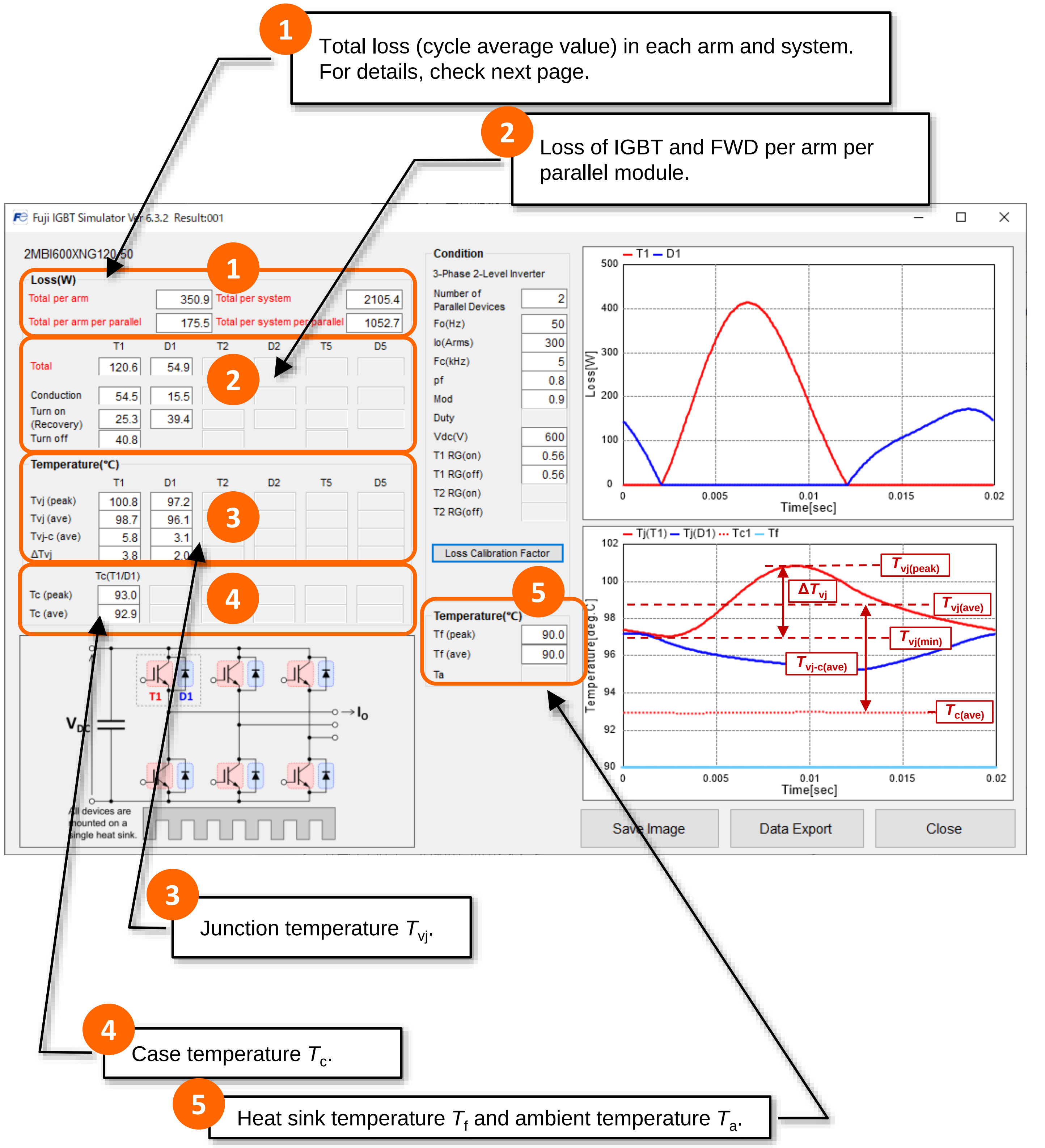
Entering “Calculation Condition” will allow you to perform the calculation.

Calculation will start when you click the “Calculation” Button.



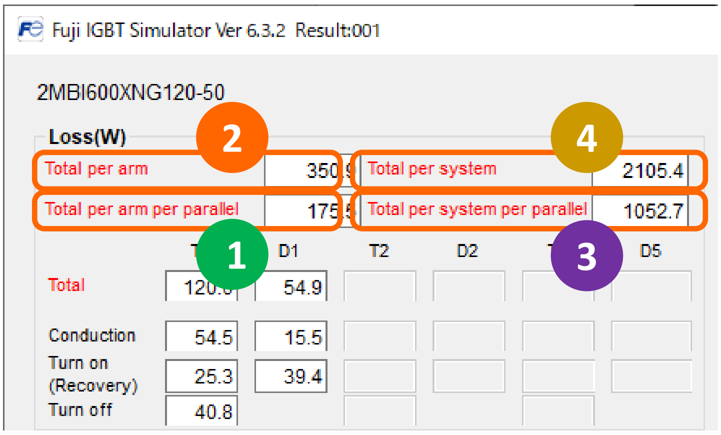
(4) Simulation Results

When the calculation is executed, the calculation result will be output in a separate window.



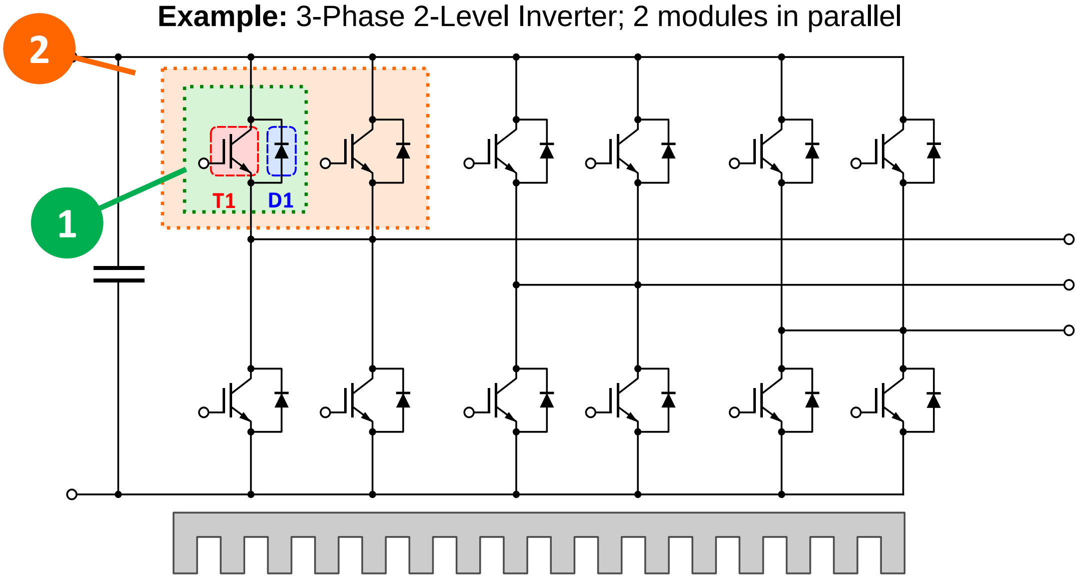
(4)-1 Simulation Results (Total Loss)

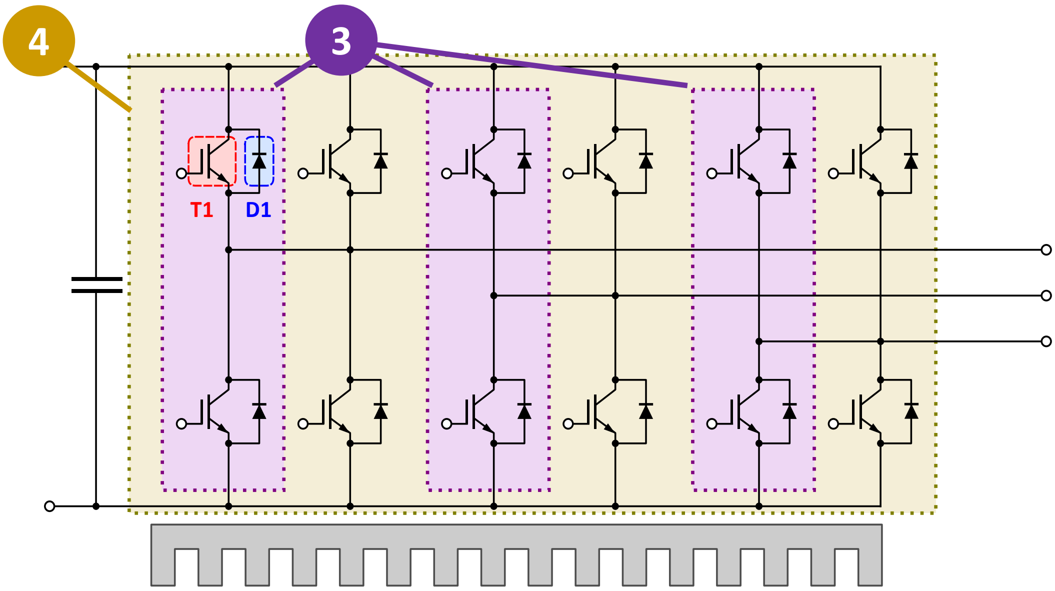
The detail of total loss (cycle average) for each arm and each system is shown below.



1. Total loss per arm per parallel module (= T1 + D1 + T2 + D2 + D5)
2. Total loss per arm (= 1 × number of parallel modules)
3. Total loss of system per parallel module (3-Phase 2-Level Inverter: 1 × 6)
4. Total loss of the sytem (= 3 ×number of parallel modules)

Example: 3-Phase 2-Level Inverter; 2 modules in parallel

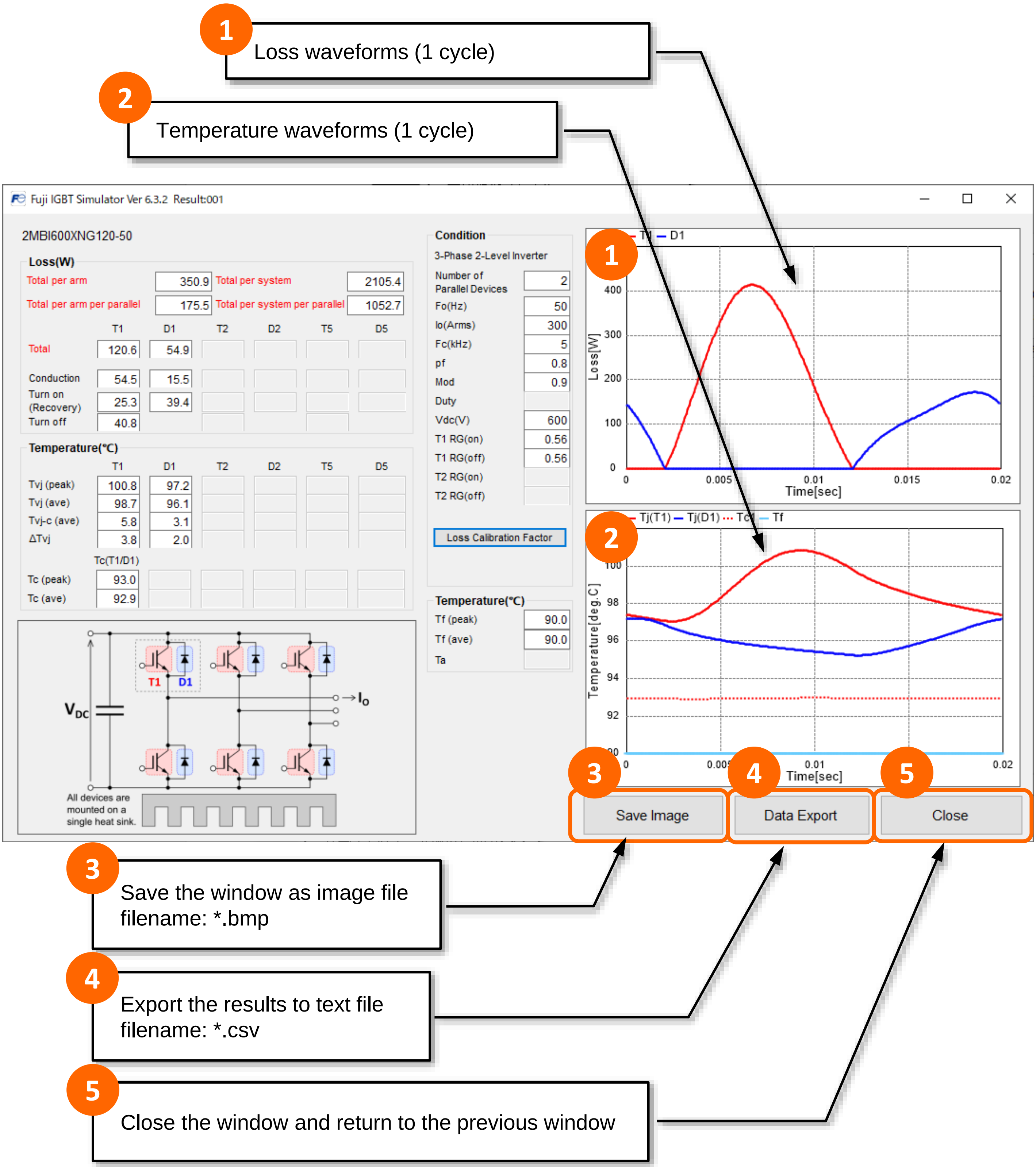




(4)-2 Simulation Results (Graph / Data output)

The loss transition and temperature transition waveforms of the simulation results for one cycle are displayed.

The data can be saved in image data and csv format.



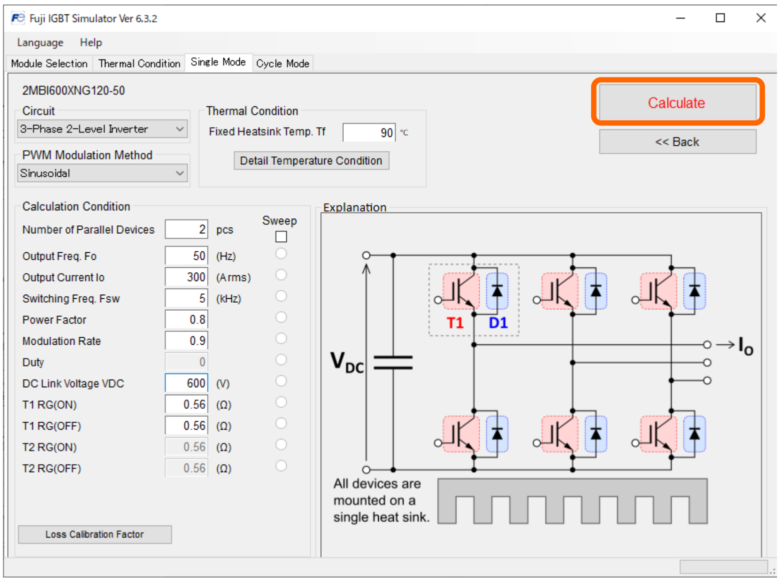
(5) Display Multiple Results

Multiple windows of calculation result can be displayed at the same time (max. 40).

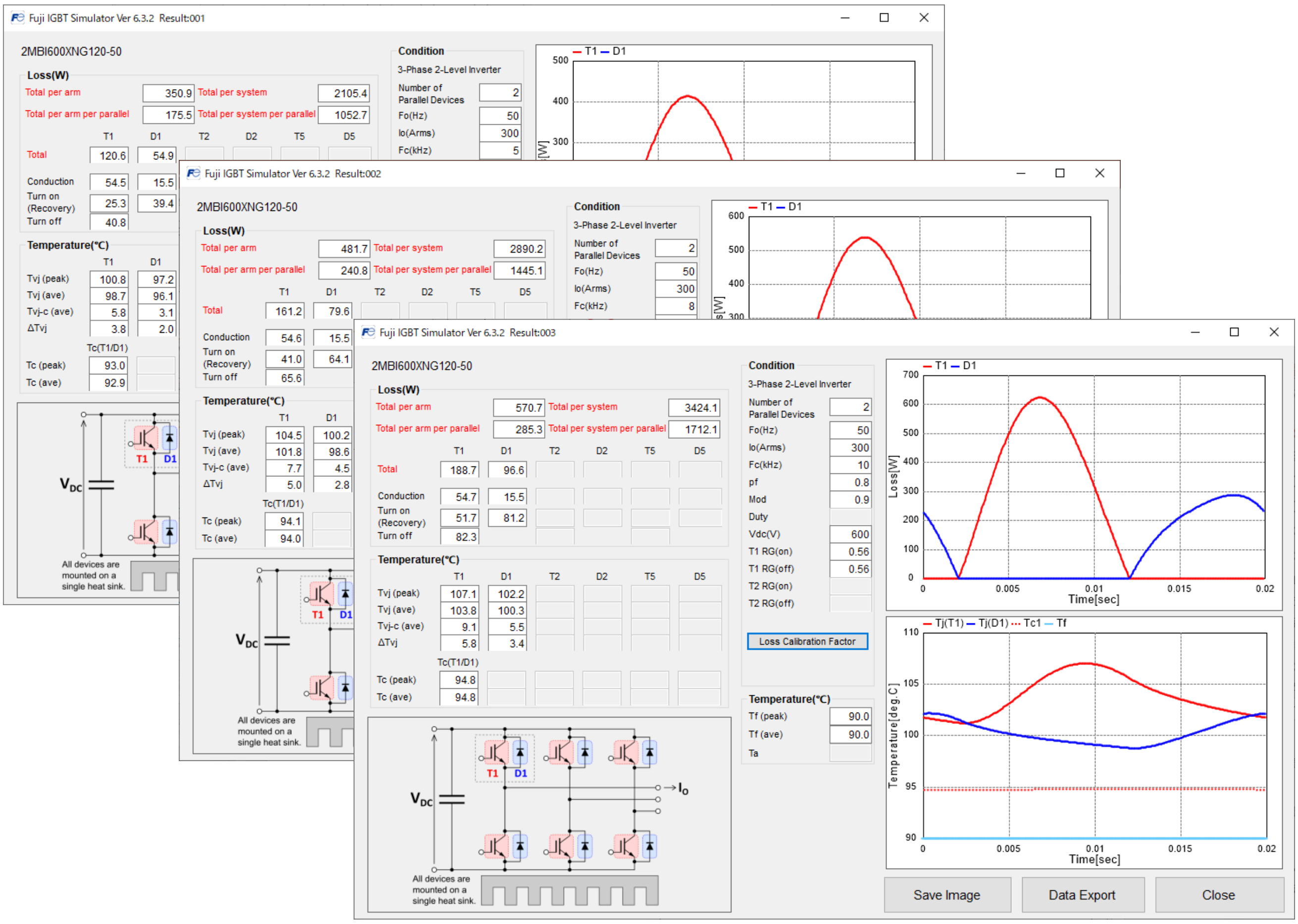
Each time you press the Execute Calculation button, a new Calculation Results window will be displayed.

The windows will be displayed in the order of Result001, Result002, … continuous numbering.

Please use this function for comparison when changing the calculation conditions.



Calculation result window

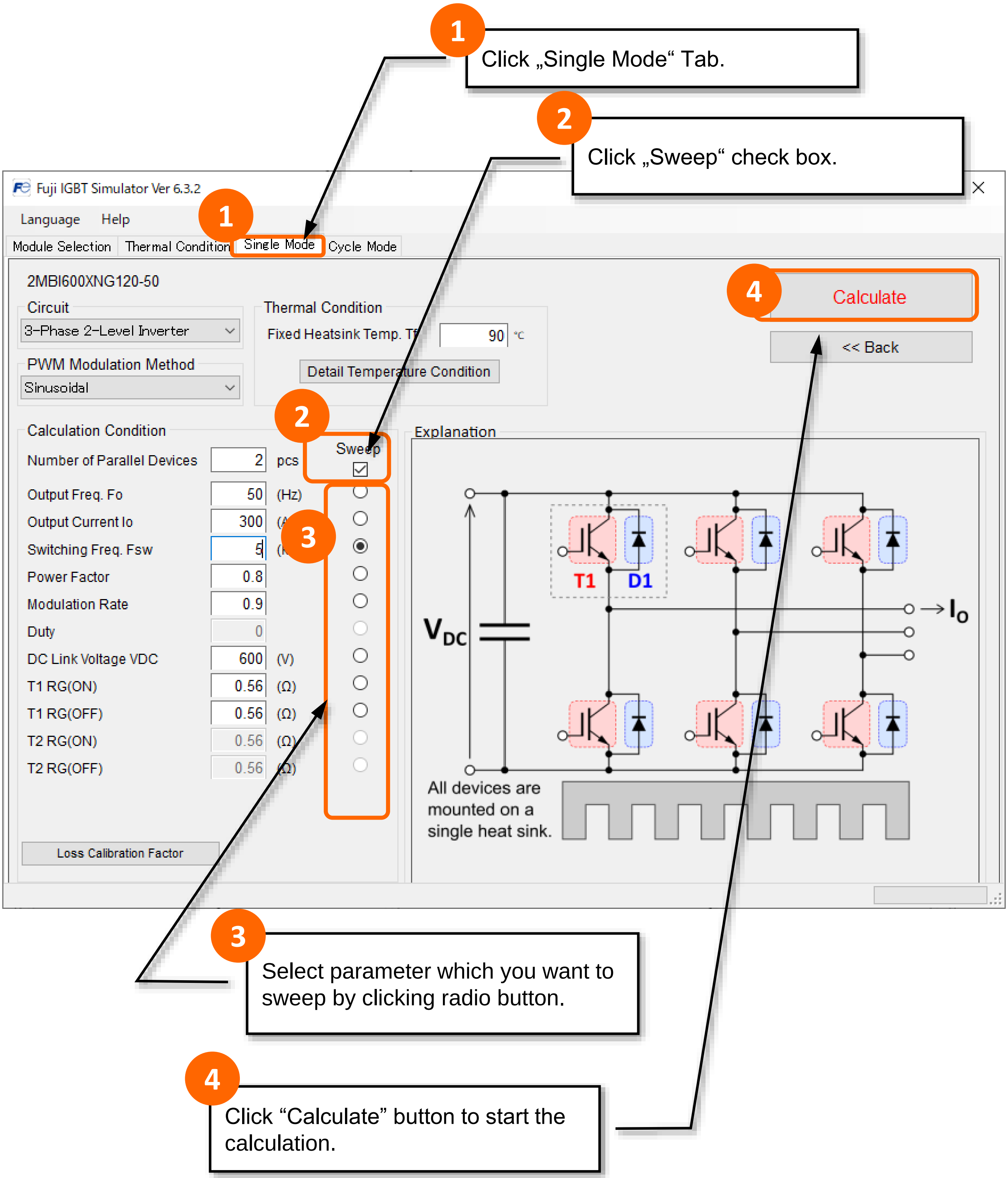


Parameter Sweep Calculation

6. Parameter Sweep Calculation

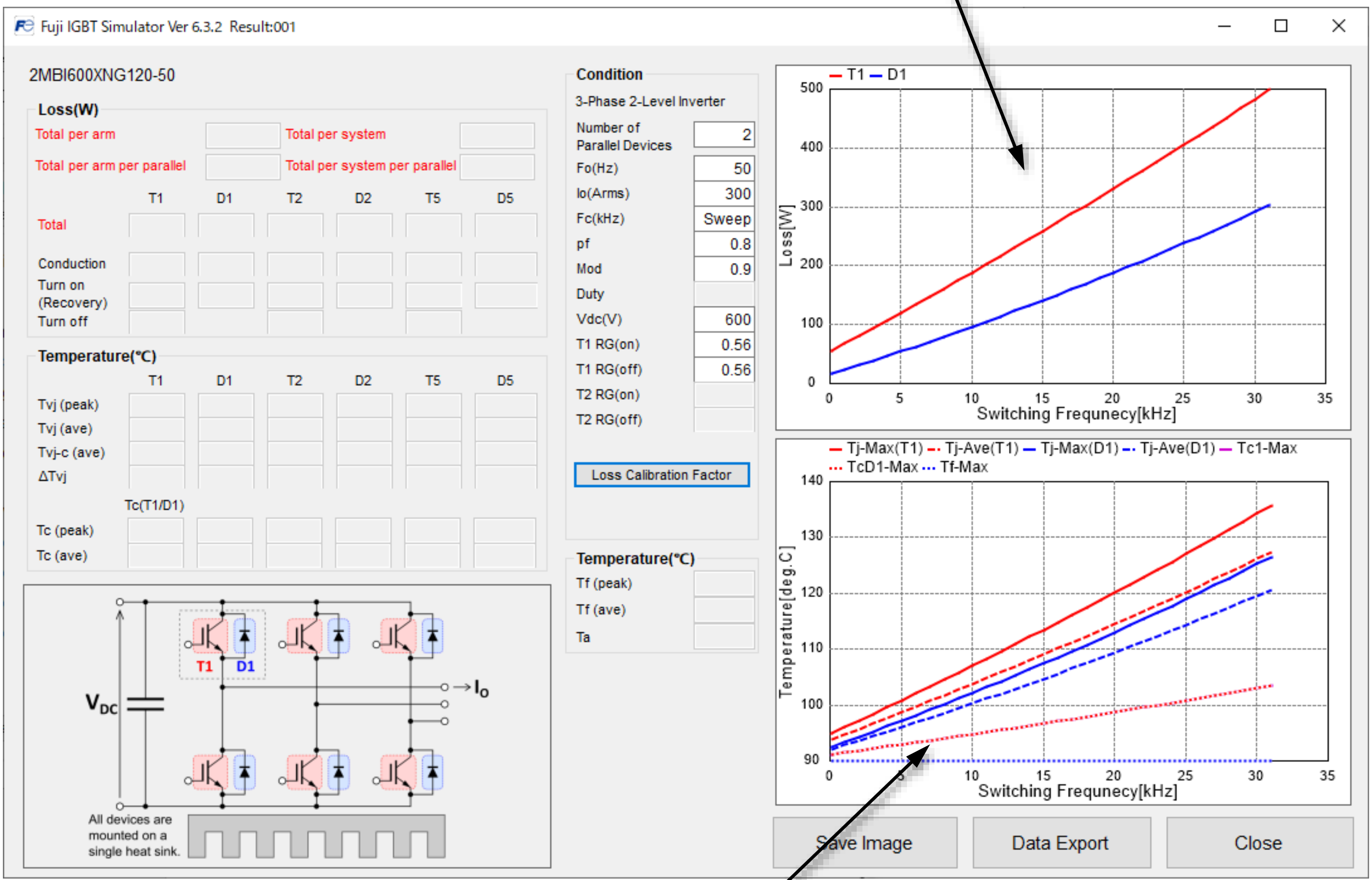
(1) Input simulation condition(Parameter Sweep Calculation)

In the parameter sweep calculation, it is possible to calculate the losses and temperature for a change in that parameter by setting one of the parameter in the calculation conditions as a sweep.



(2) Parameter Sweep Calculation Result

Calculated losses with variable parameter on horizontal axis.



Calculated temperature with variable parameter on horizontal axis.

Cycle Mode Calculation

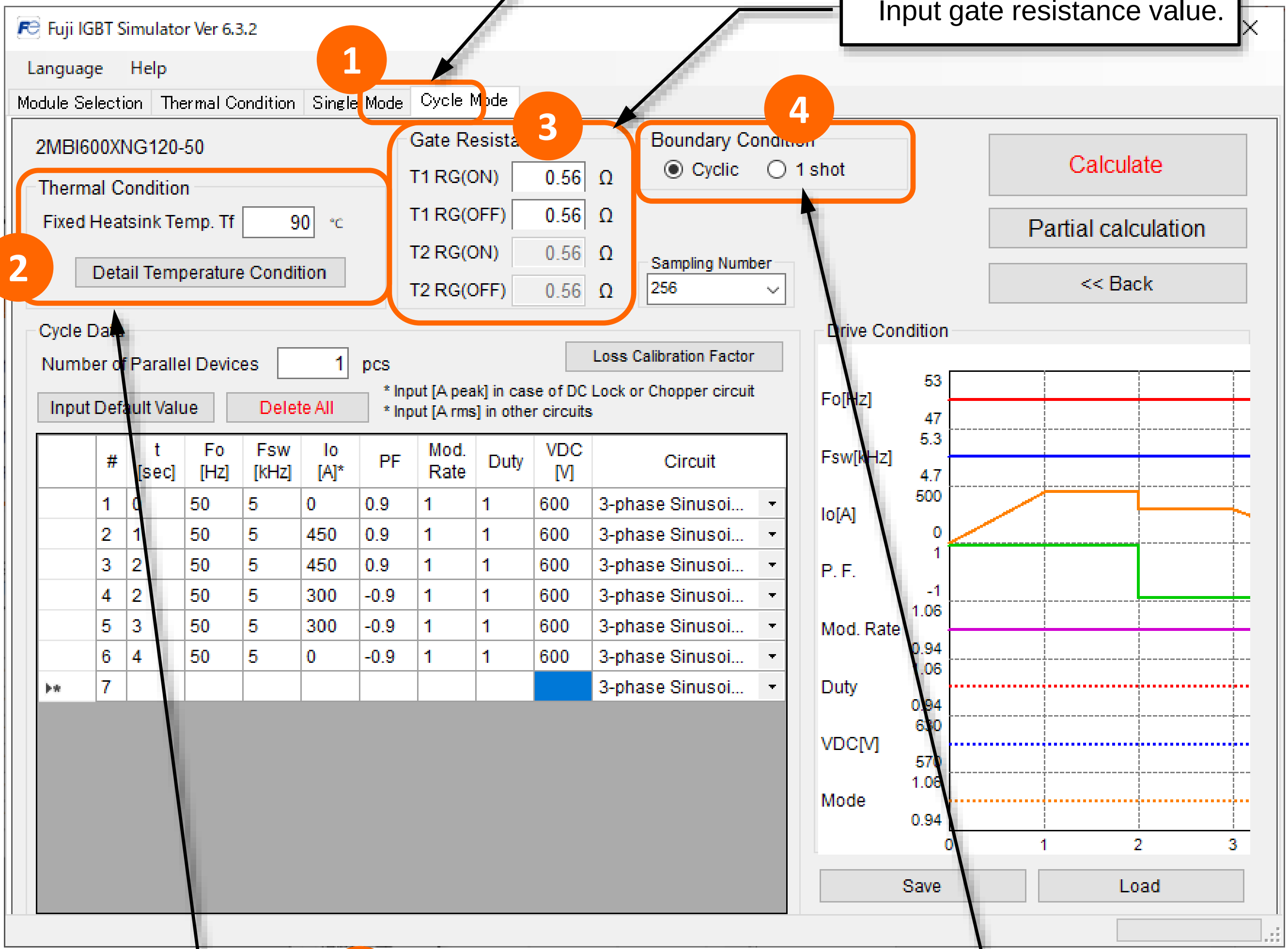
7. Cycle Mode Calculation

(1) Input simulation condition(Cycle Mode Calculation)

Cycle mode calculation enables simulation under intended operating conditions.

1 Click the „Cycle Mode“ tab.

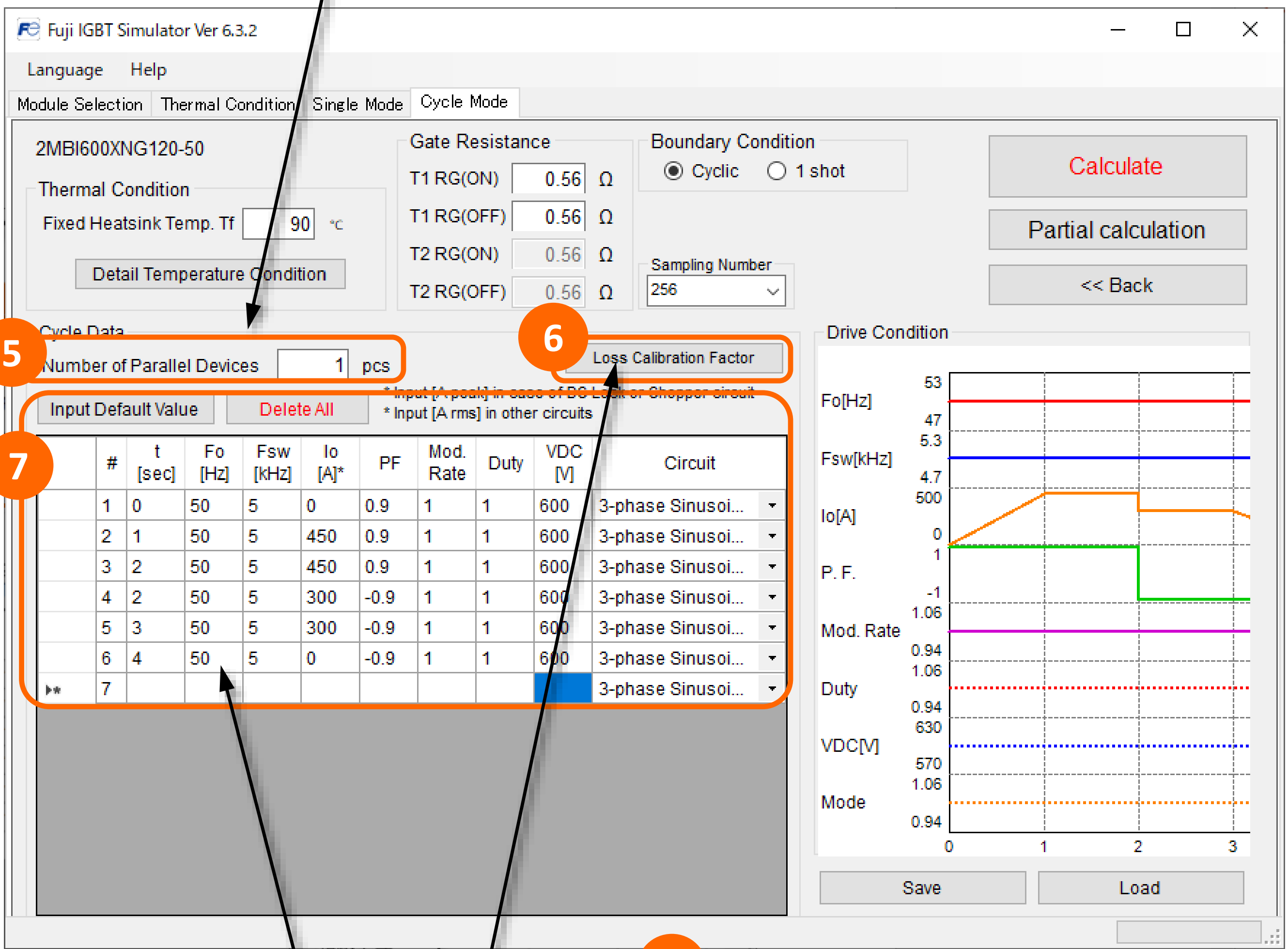
3 Input gate resistance value.



4 Select boundary conditions
For details, please refer to page 28.

2 Heat sink temperature T_f: if T_f is fixed, enter value.
For changing detailed temperature condition, please click this button and back to thermal condition tab.

5 Number of parallel connected modules.
Note: All modules are considered to be mounted on the same heat sink.

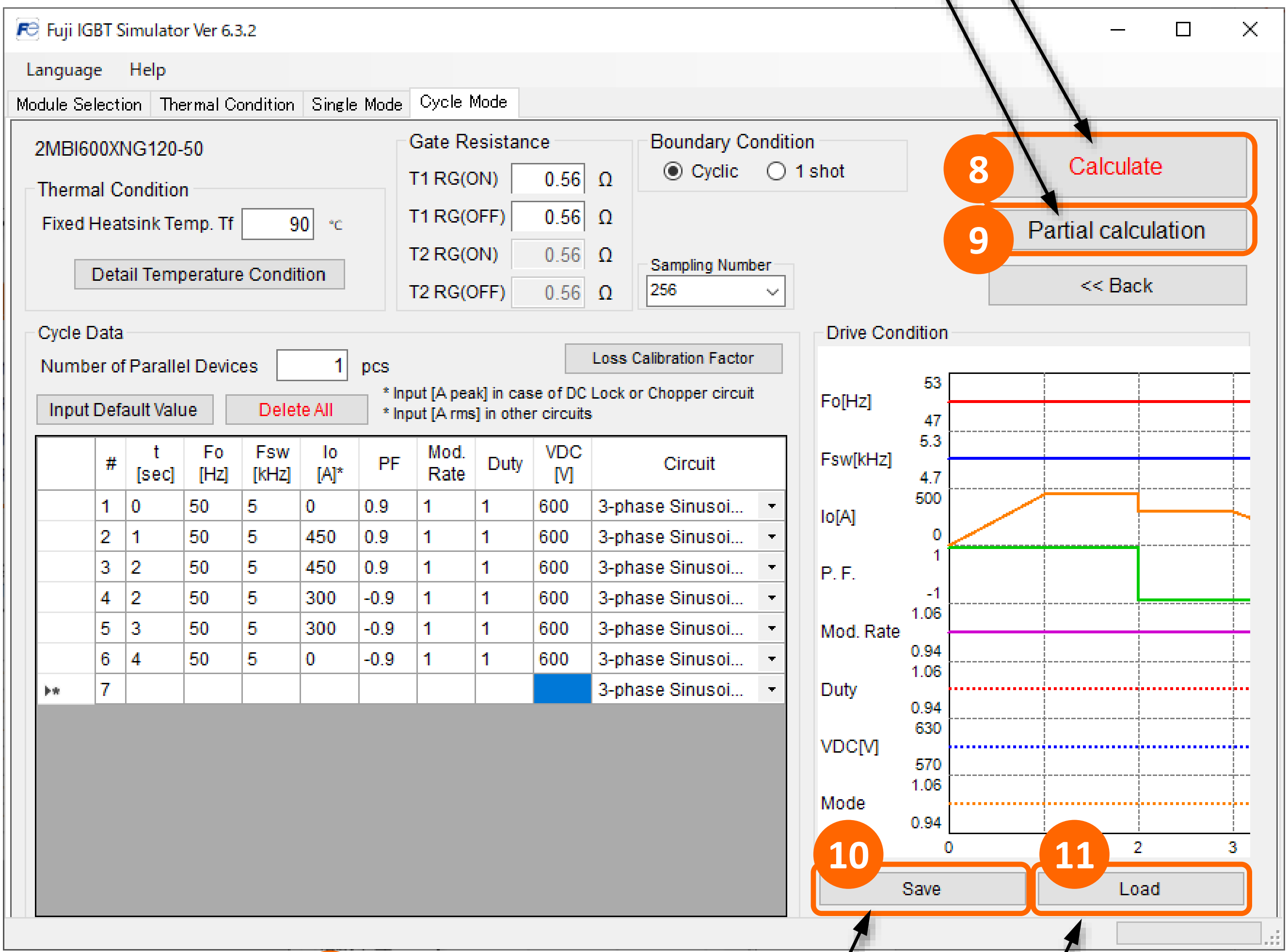


6 Click „Loss Calibration Coefficient“ button to enter calibration coefficients for each loss calculation.

7 Input operation pattern.
For details, please refer to page 29 et seq.

8 Click “Calculate” button to start the calculation.

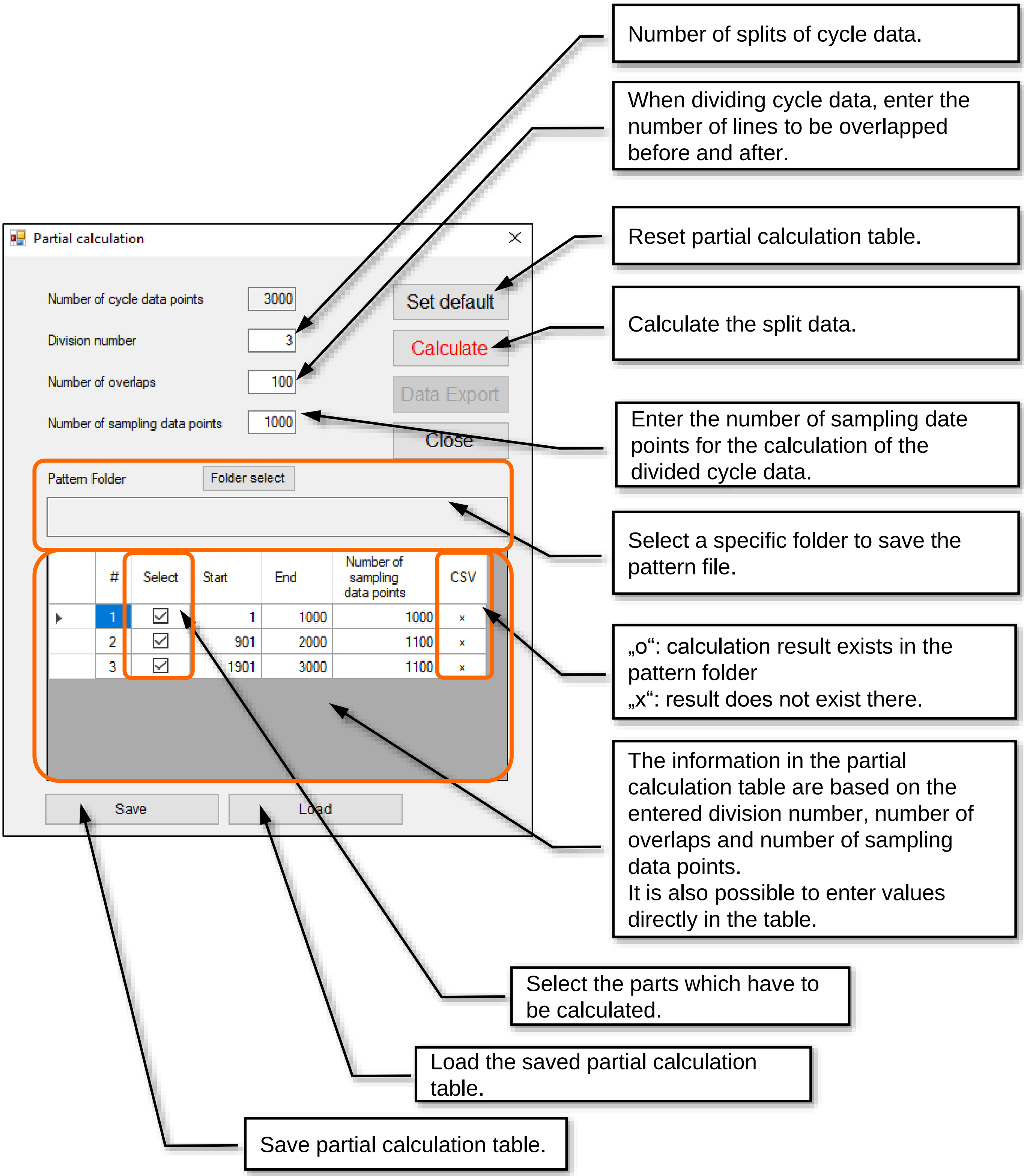
9 If the cycle data have more than 2048 lines, it is possible to divide the pattern and calculate them separately.



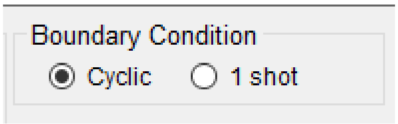
10 Save operation pattern
Filename: *.xml

11 Load operation pattern
Filename: *.xml

(2) Partial Calculation

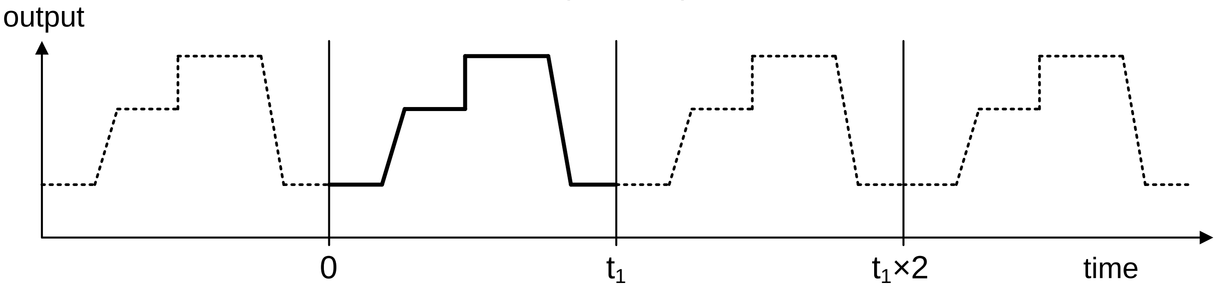


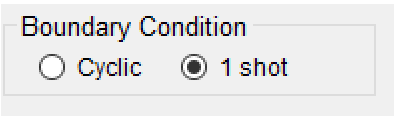
(3) Cycle Mode Calculation : Boundary Condition



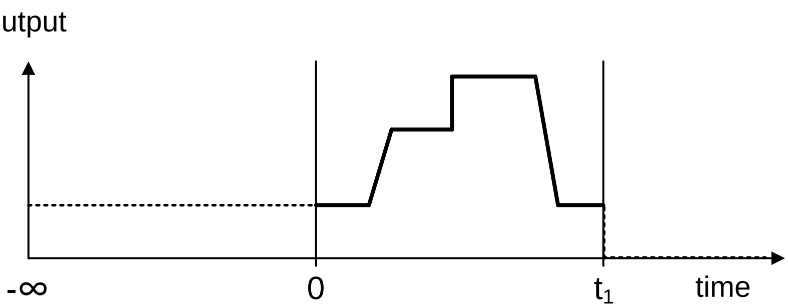
Cyclic mode: The load cycle pattern is repeated continuously.

Operation pattern





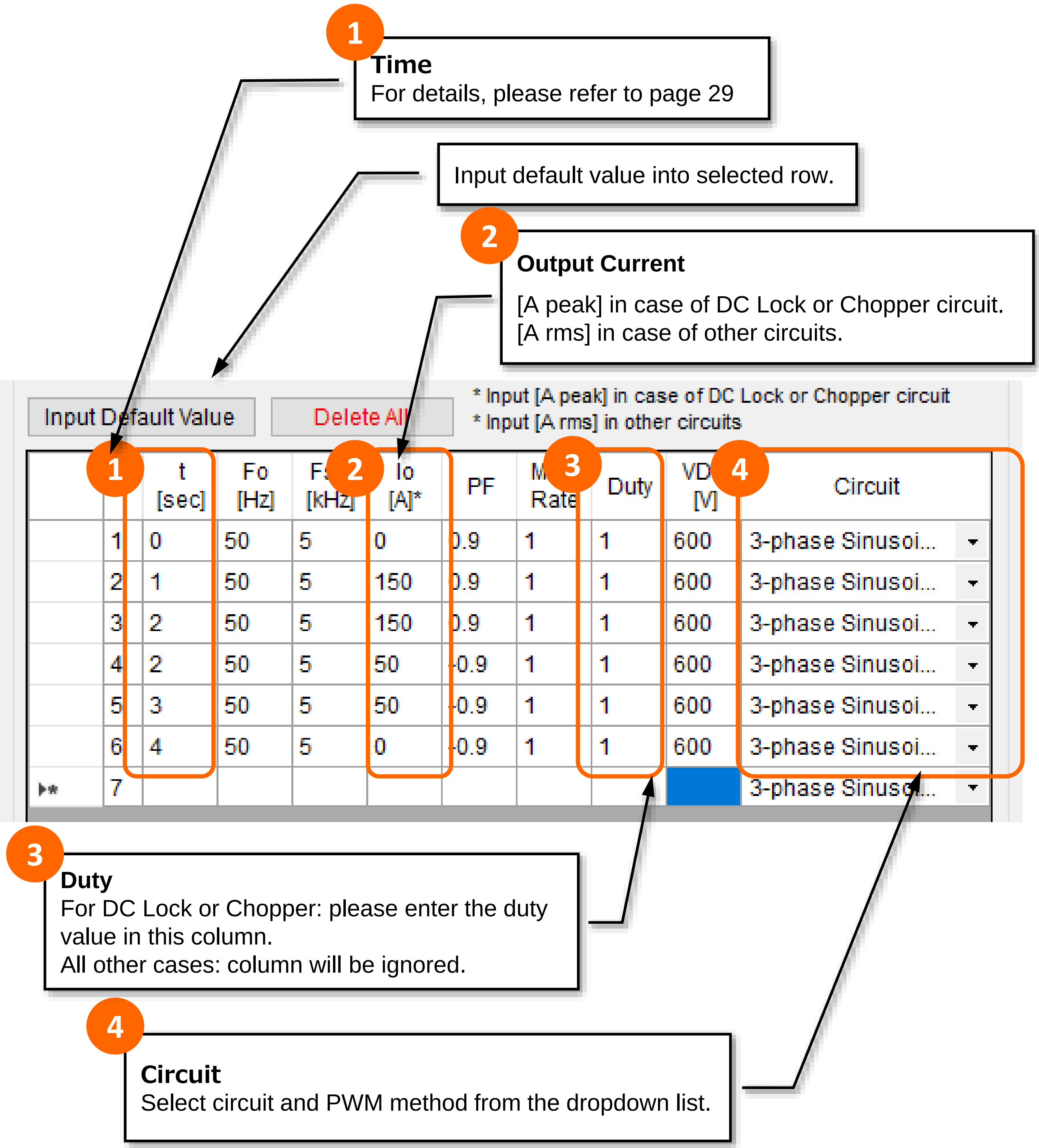
1 shot mode: The load cycle pattern is not repeated



#	t [sec]	Fo [Hz]	Fsw [kHz]	Io [A]*	PF	Mod. Rate	Duty	VDC [V]	Circuit
1	-∞≦...	50	5	0	0.9	1	1	600	3-phase Sinusoi...
2	1	50	5	450	0.9	1	1	600	3-phase Sinusoi...
3	2	50	5	450	0.9	1	1	600	3-phase Sinusoi...

Enter the initial conditions in first line.

(4) Enter cycle mode operating conditions

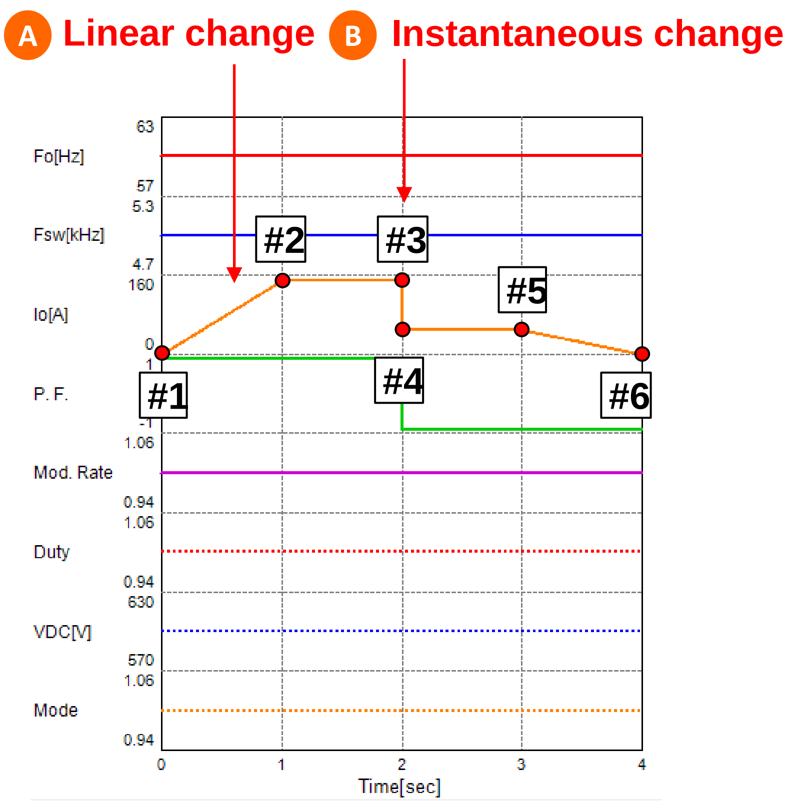


	t [sec]	Fo [Hz]	F [kHz]	Io [A]*	PF	M Rate	Duty	VD [V]	Circuit
1	0	50	5	0	0.9	1	1	600	3-phase Sinusoi...
2	1	50	5	150	0.9	1	1	600	3-phase Sinusoi...
3	2	50	5	150	0.9	1	1	600	3-phase Sinusoi...
4	2	50	5	50	-0.9	1	1	600	3-phase Sinusoi...
5	3	50	5	50	-0.9	1	1	600	3-phase Sinusoi...
6	4	50	5	0	-0.9	1	1	600	3-phase Sinusoi...
7									3-phase Sinusoi...

A **Parameter values linearly change between two operation points.**
Example: #1 → #2 [I_O]
If you enter [t=0sec, I_O=0A] in #1 and [t=1sec, I_O=150A] in #2, I_O changes linearly from #1 to #2.

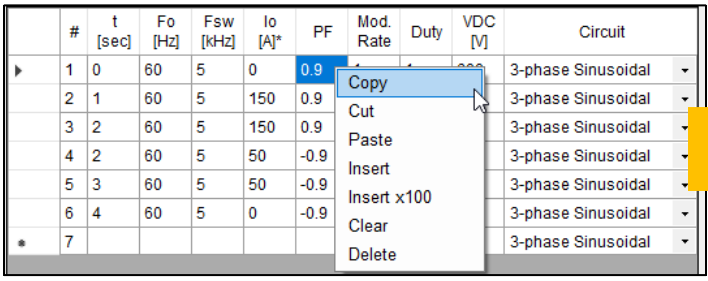
B **Parameter values change instantaneously if two operation points have same time t.**
Example: #3 → #4 [I_O, PF]
If you enter [t=2sec, I_O=150A] in #3 and [t=2sec, I_O=50A] in #4, I_O changes instantaneously from #3 to #4.

	#	t [sec]	Fo [Hz]	Fsw [kHz]	Io [A]*	PF	Mod. Rate	Duty	VDC [V]	Circuit
A	1	0	60	5	0	0.9	1	1	600	3-phase Sinusoi...
A	2	1	60	5	150	0.9	1	1	600	3-phase Sinusoi...
B	3	2	60	5	150	0.9	1	1	600	3-phase Sinusoi...
B	4	2	60	5	50	-0.9	1	1	600	3-phase Sinusoi...
	5	3	60	5	50	-0.9	1	1	600	3-phase Sinusoi...
	6	4	60	5	0	-0.9	1	1	600	3-phase Sinusoi...
▸*	7									3-phase Sinusoi...

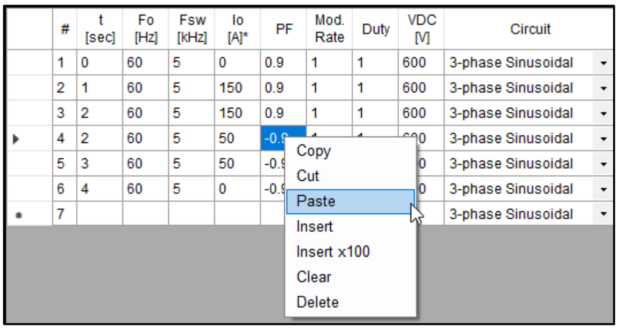


Copy & Paste cell(s) value

Select a cell or range of cell(s) → Right click → Copy

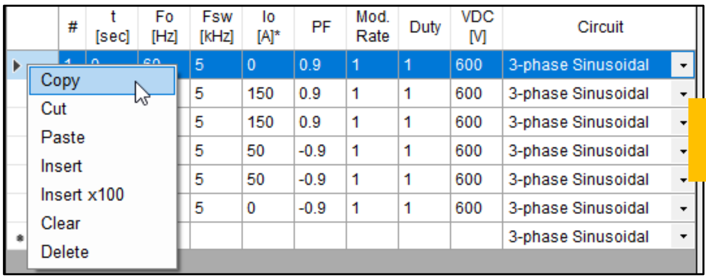


Select cell(s) → Right click → Paste

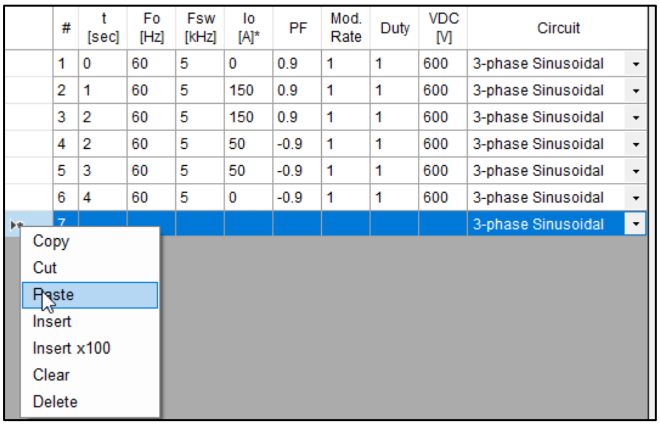


Copy & Paste line

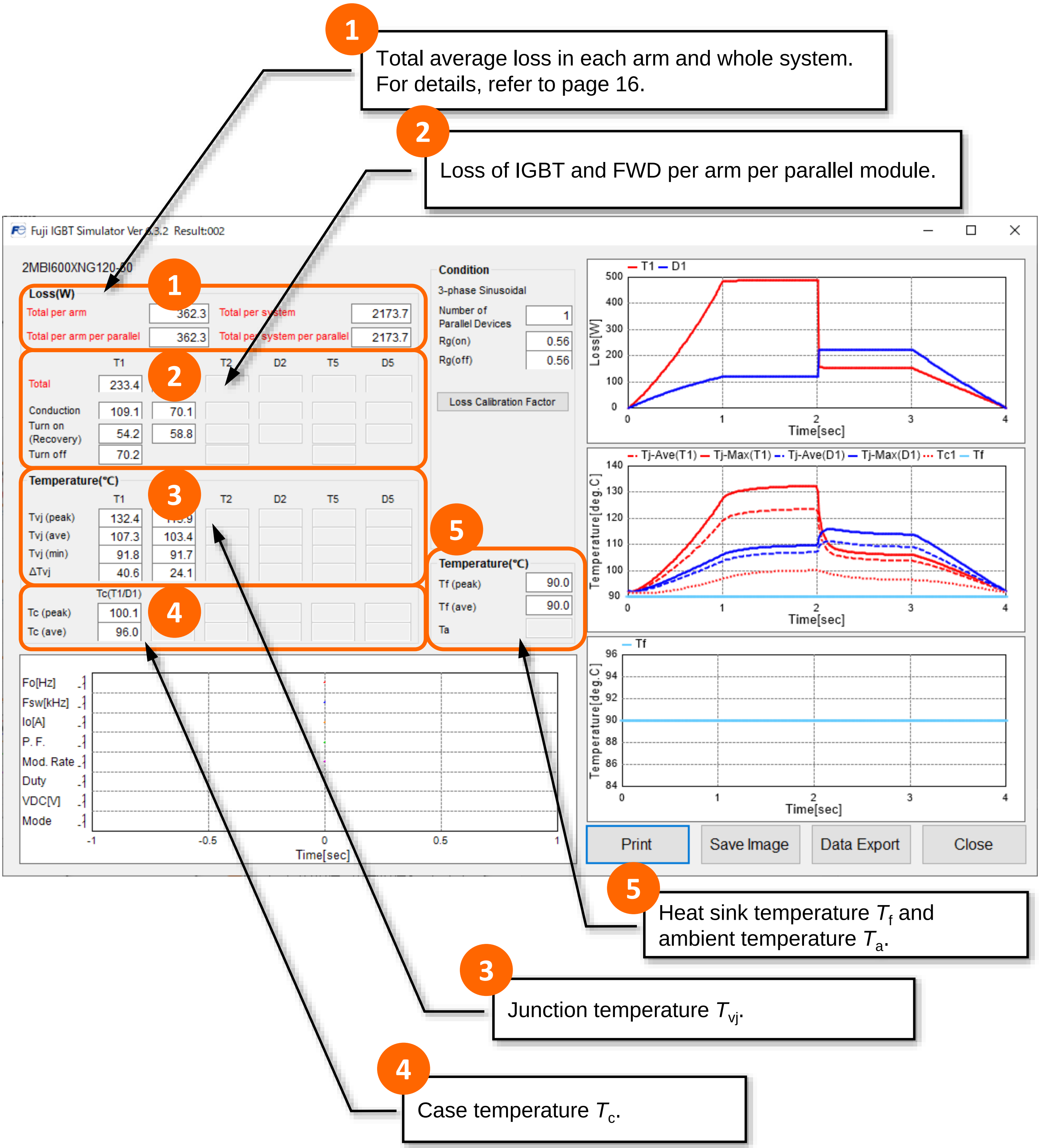
Select a line (click 1st column) → Right click → Copy



Select a line → Right click → Paste



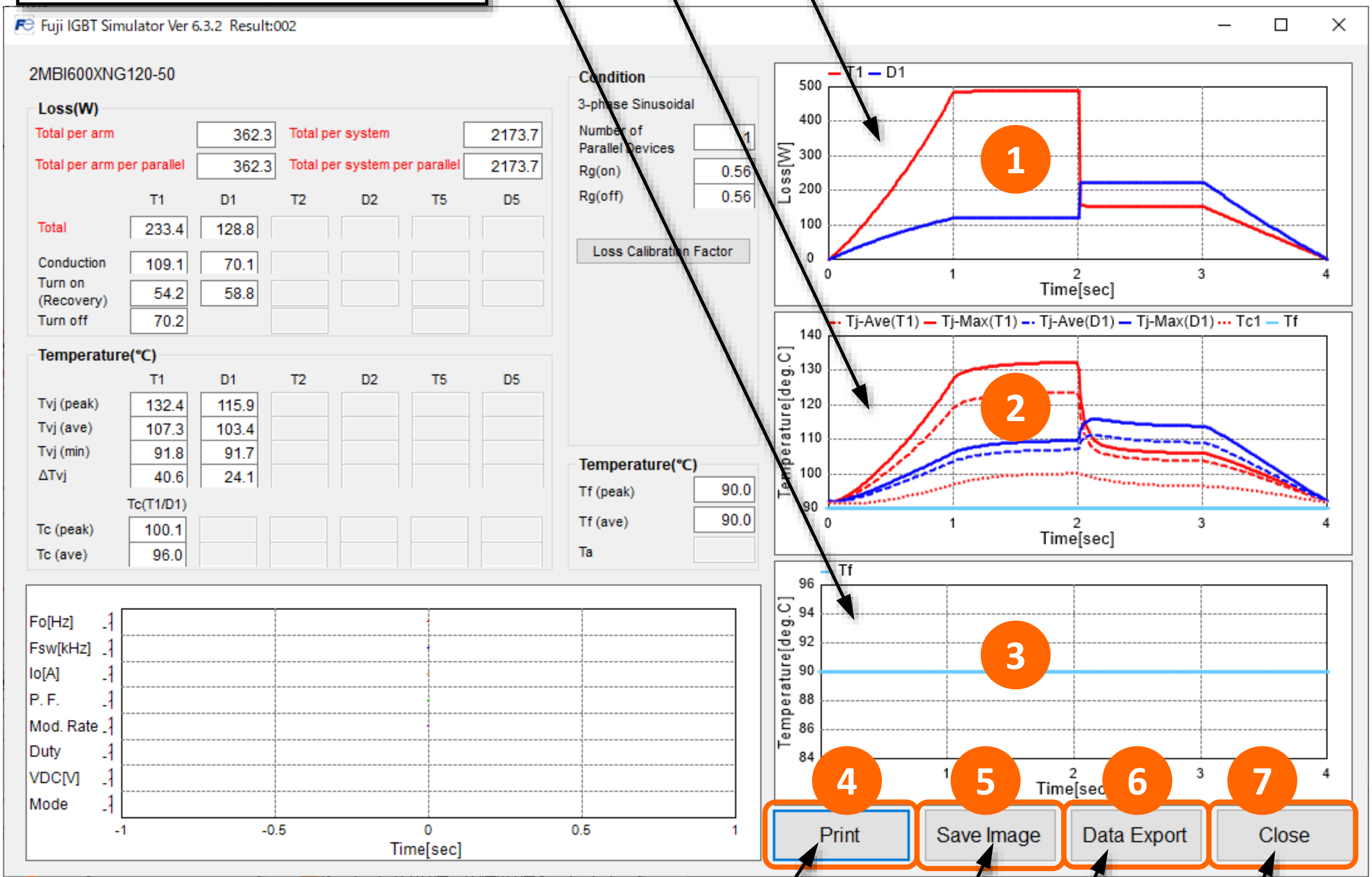
(5) Simulation Results(Cycle Mode Calculation)



1 Loss waveforms

2 Temperature waveforms

3 Temperature waveforms



4 Print the window

5 **Save the window**
Filename: ****.bmp

6 Export the results
Filename: *.csv

7 Close the window

Application circuit and PWM control

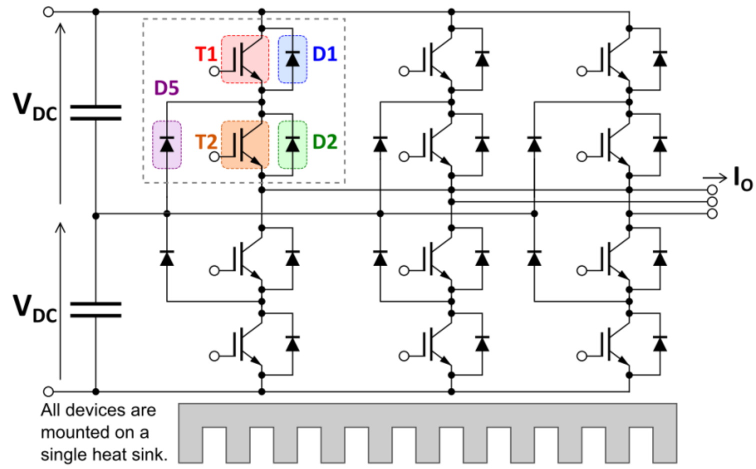
8. Application circuit and PWM control

This page shows a list of applicable circuits and PWM methods that are supported by the simulator.

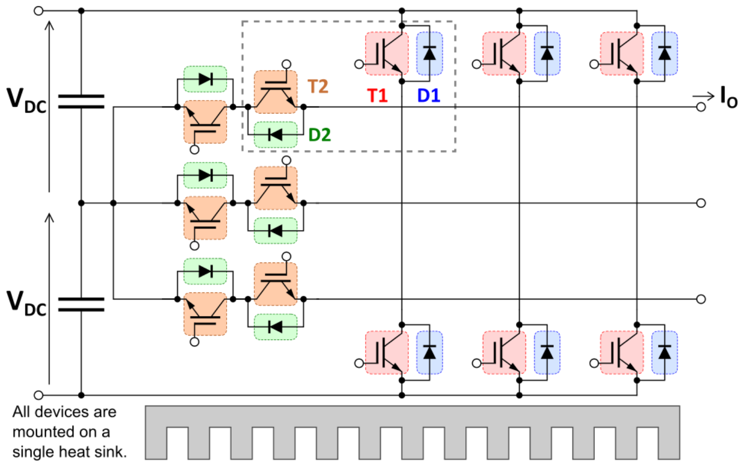
Circuit	PWM Method
3-Phase 2-Level Inverter	Sinusoidal
	Space Vector
	3rd Harmonic Injection
	2-Phase (A)– DPWM1
	2-Phase (B)– DPWMMin
	DC Lock
3-Phase 3-Level I-type	Sinusoidal
	Space Vector
	3rd Harmonic Injection
3-Phase 3-Level AT-type	Sinusoidal
	Space Vector
	3rd Harmonic Injection
DC Chopper	Boost Chopper
	Buck Chopper
3-Phase 3-Level T-type	Sinusoidal
	Space Vector
	3rd Harmonic Injection
3-Phase 3-Level A-NPC-type	Sinusoidal (PWM1)
	Space Vector (PWM1)
	3rd Harmonic Injection (PWM1)

(1) Type of Circuit Topology

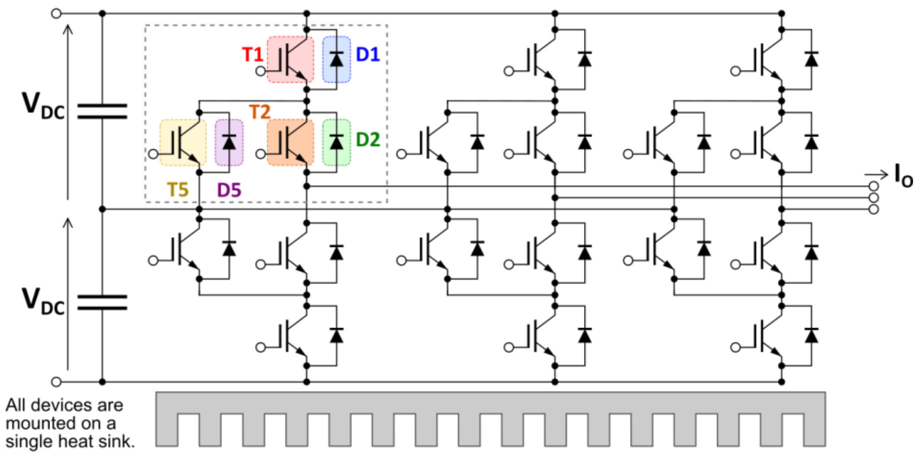
3-Phase 3-Level I-type



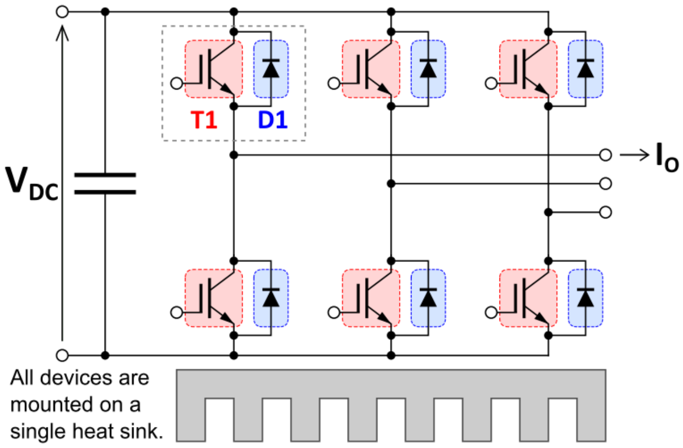
3-Phase 3-Level T-type



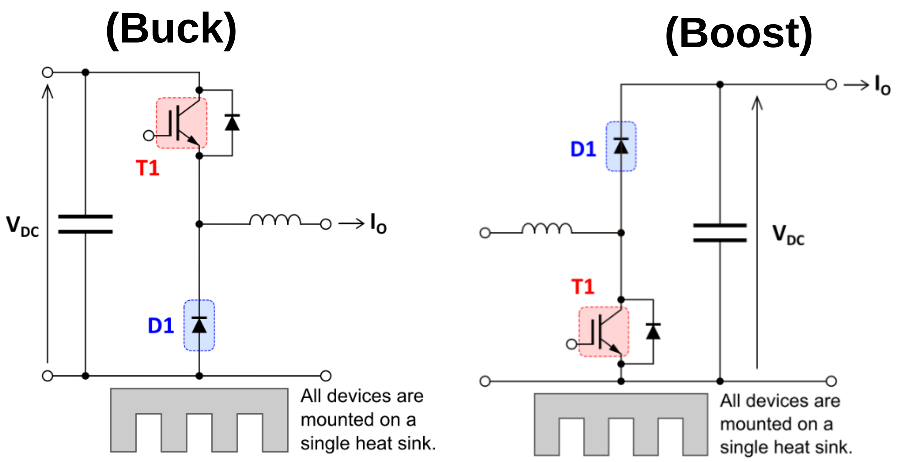
3-Phase 3-Level A-NPC-type



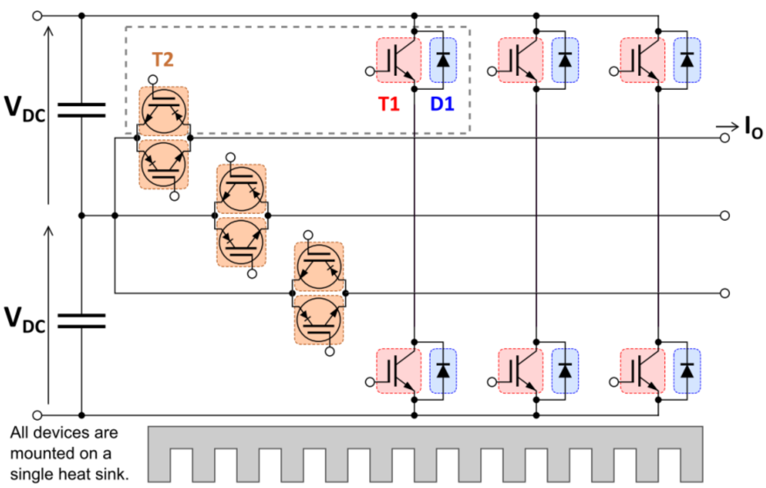
3-Phase 2-Level



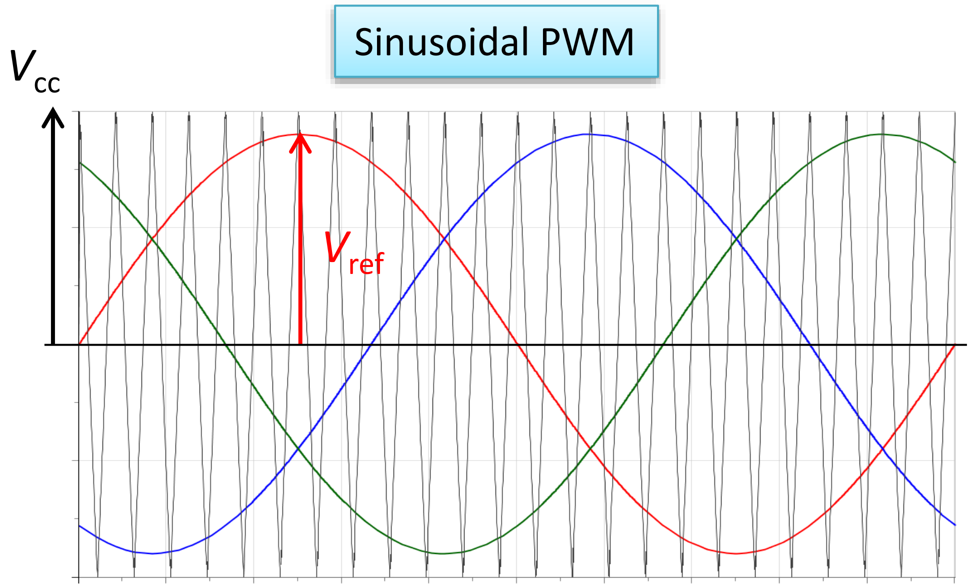
DC Chopper



3-Phase 3-Level AT-type



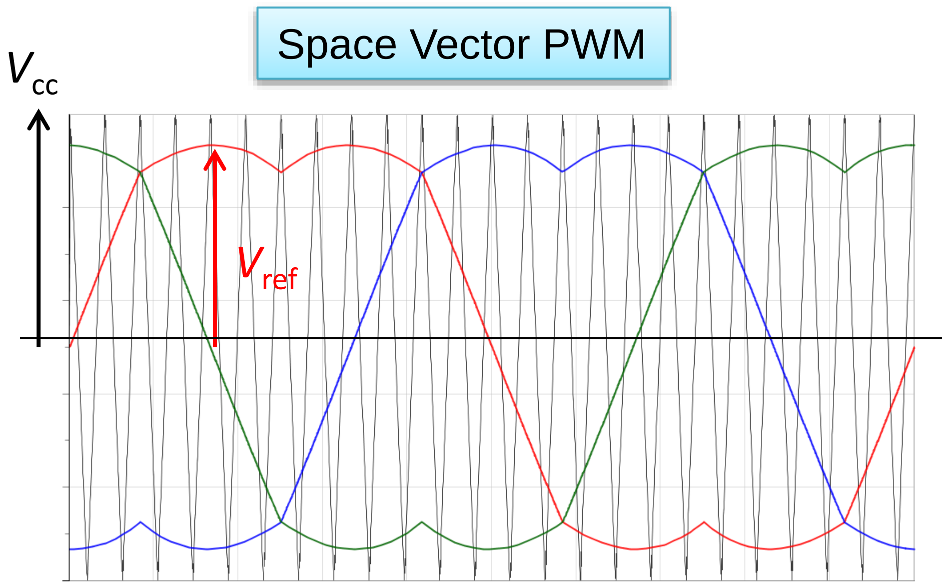
(2) PWM Method (SPWM, SVPWM)



The reference voltage is a sinusoidal waveform.
The amplitude V_{ref} of the reference voltage for Sinusoidal PWM is defined by the following equation using modulation ratio *m*.

$$V_{ref} = mV_{dc}$$

The maximum value of *m* is 1.



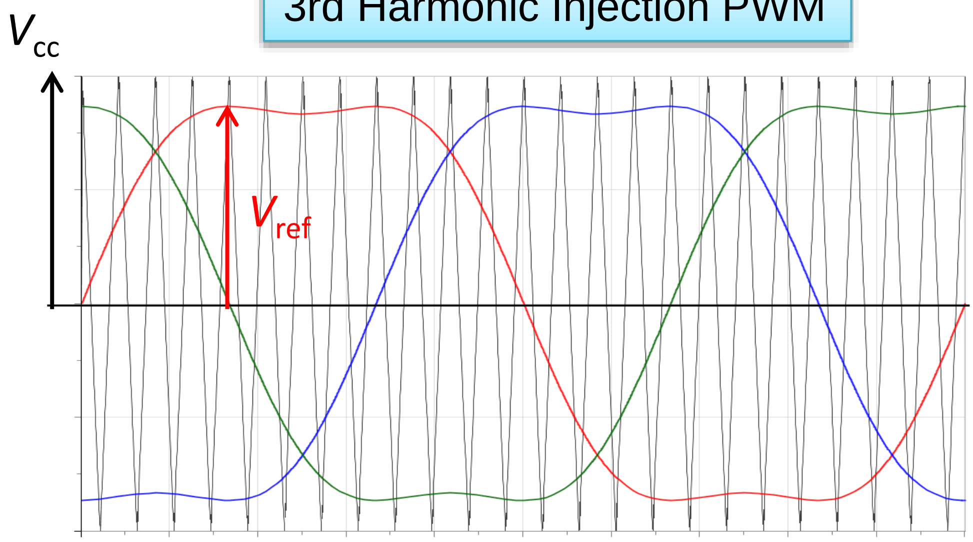
The amplitude V_{ref} of the reference voltage for Space Vector PWM is defined by the following equation using modulation ratio *m*

$$V_{ref} = \frac{\sqrt{3}}{2} mV_{dc}$$

m is defined to be the same output voltage to the sinusoidal PWM.
The maximum value of *m* is 2/√3 = 1.1547

(3) PWM Method (3rd harmonic injection)

3rd Harmonic Injection PWM



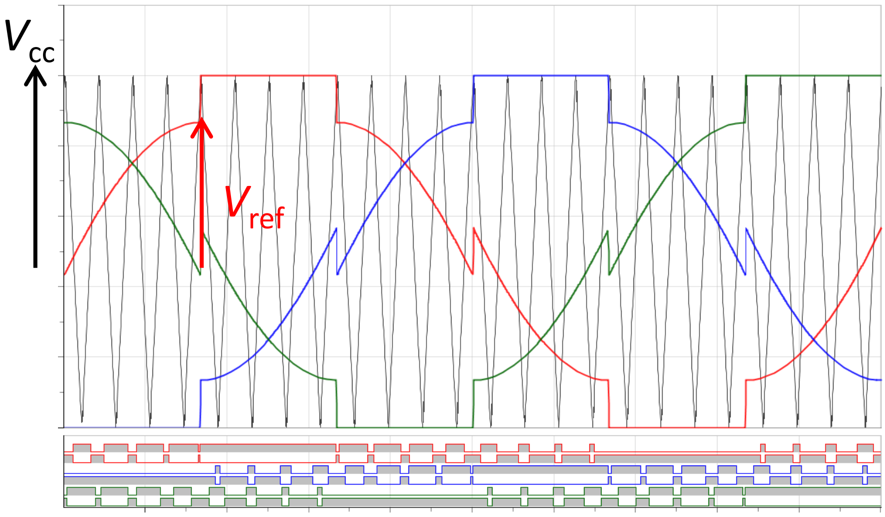
The amplitude V_{ref} of the reference voltage for 3rd Harmonic Injection PWM is defined by the following equation using modulation ratio *m*

$$V_{ref} = \frac{\sqrt{3}}{2} m V_{dc}$$

m is defined to be the same output voltage to the sinusoidal PWM.
The maximum value of *m* is 2/√3 = 1.1547

(4) 2-Phase Modulation (Discontinues PWM: DPWM)

2-Phase (A) – DPWM1

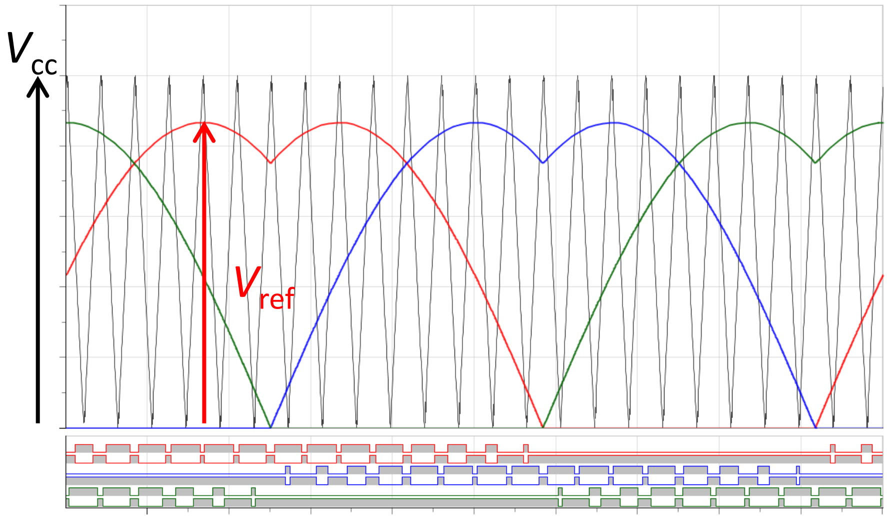


The amplitude V_{ref} of the reference voltage for 2-Phase (A) – DPWM1 is defined by the following equation using modulation ratio *m*.

$$V_{ref} = \frac{\sqrt{3}}{2} m V_{dc}$$

m is defined to be the same output voltage to the sinusoidal PWM.
The maximum value of *m* is 2/√3 = 1.1547

2-Phase (B) – DPWMMin



The amplitude V_{ref} of the reference voltage for 2-Phase (B) – DPWMMin is defined by the following equation using modulation ratio m.

$$V_{ref} = \frac{\sqrt{3}}{2} m V_{dc}$$

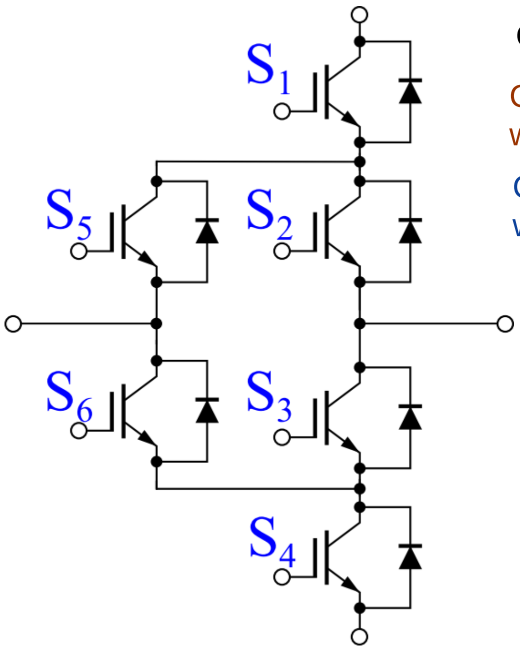
m is defined to be the same output voltage to the sinusoidal PWM.
The maximum value of *m* is 2/√3 = 1.1547

(5) PWM Method (A-NPC circuit)

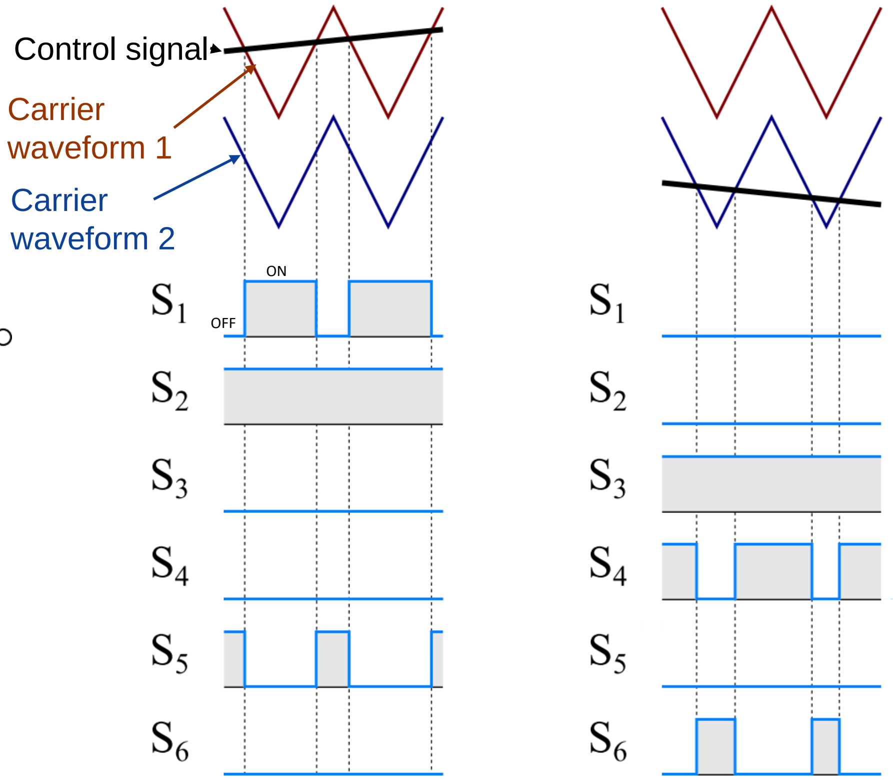
Several methods have been proposed for the PWM method of the A-NPC circuit.

This simulator performs simulation with the PWM method (PWM 1) shown below.

A-NPC circuit diagram



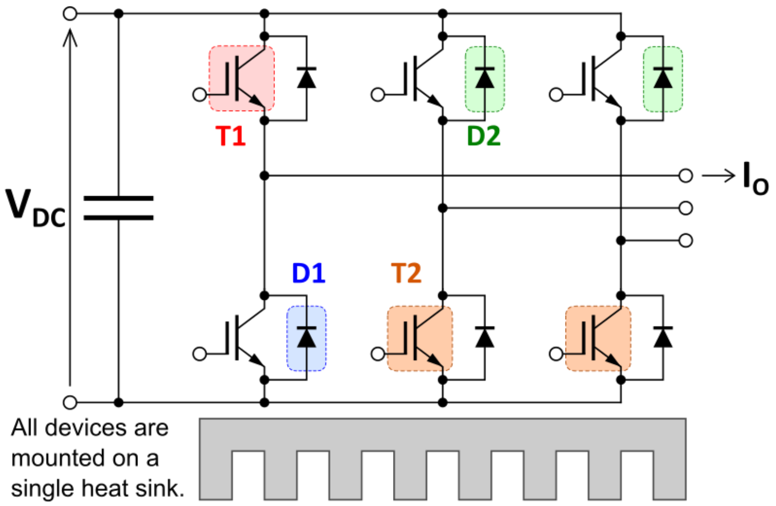
Switching pattern (PWM1)



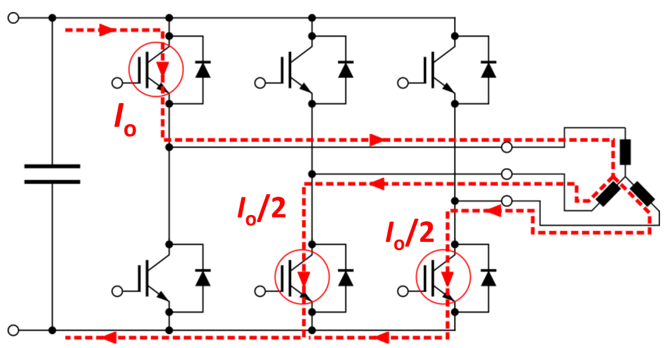
(6) Motor DC Lock Operation

Calculate the IGBT / FWD loss when locking the motor rotation with a servo drive or the like.

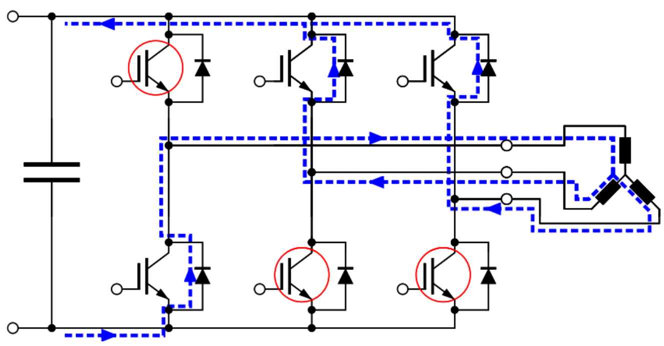
As shown in the figure below, one IGBT of the upper arm (or the lower arm) of one phase and the IGBT of the other arm of the other two phases are switching controlled.



Note : The heat sink temperature T_f is calculated based on the assumption that the surface temperature distribution of the heat sink's area, which is in contact with the module, is uniform.
In the motor lock operation, only specific elements generate heat. Thus the heat does not spread optimally on the heat sink's surface and the heat sink's thermal resistance increases. As a result, T_f and Tc might become high.



Current path when IGBT is on.



Current path when IGBT is off.

If you have any questions, please contact us.

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