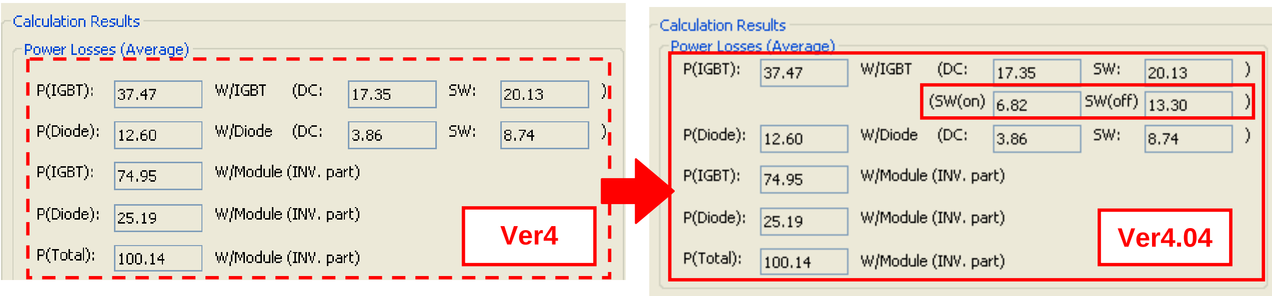
POWER LOSS SIMULATION SOFTWARE

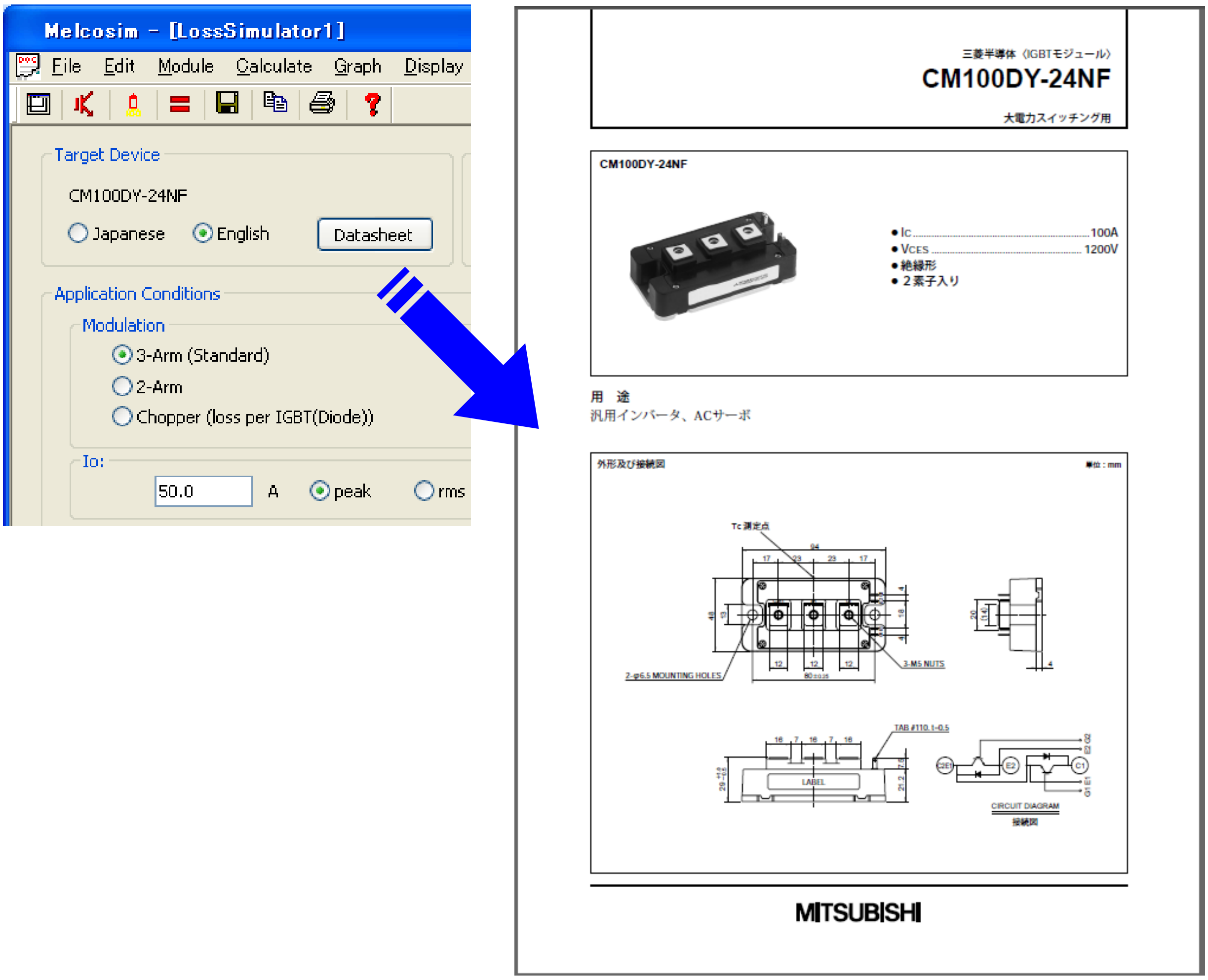
User Manual

1. Feature of Mitsubishi power module loss simulation Ver.4.04

(1) “Melcosim Ver.4.04” shows SW(on) and SW(off) of IGBT.



(2) The Japanese data sheet or English data sheet can be seen by selecting the button.

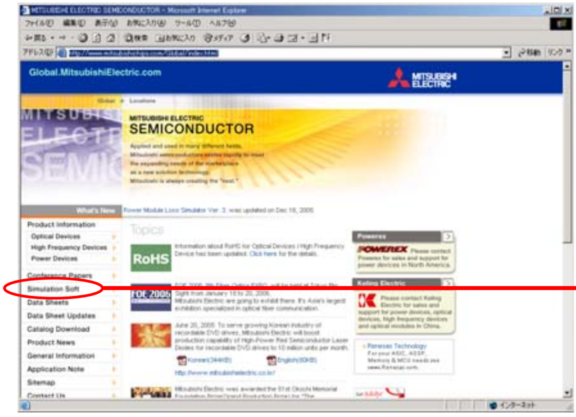


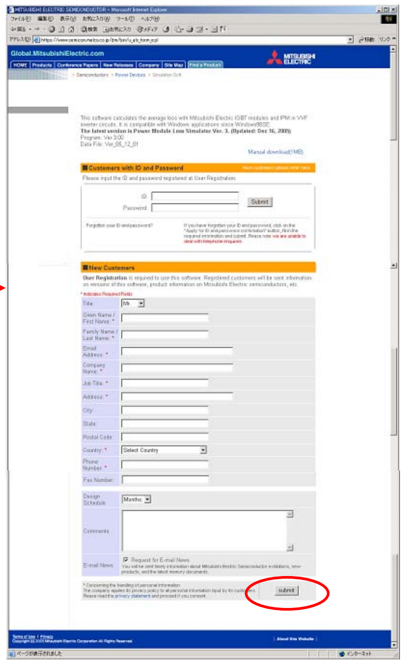
2. Setup and Execution

(1)Download

The power loss simulation software can be download free from the following Mitsubishi Electric web site.

<http://www.mitsubishichips.com/Global/index.html>





Click the Submit button after the information table is filled out.
Then, enter the download page.

*Personal information is strictly managed and only used for software version update notification.

The downloaded software is compressed in ZIP format; it can be uncompressed with various file decompression tools. There are 9 files included in the compressed ZIP file.

Melcosim.exe, Function.dll, LimitInfo.dll, MFC71.dll, msvcp71.dll, msvcr71.dll, PassInfo.dll, Simcore.dll, ReadMe.txt

Please copy or move the uncompressed files to a local directory in your PC. The software may not work from a network hard disk.

(2)Execution

Click the “START Melcosim.exe” icon to start-up the simulation software.

PC type	DOS/V PC
CPU	PentiumⅢ 500M H z or above
Memory	64MB or above
HD	20MB or more of free space
OS	Windows2000, Windows XP, Windows VISTA

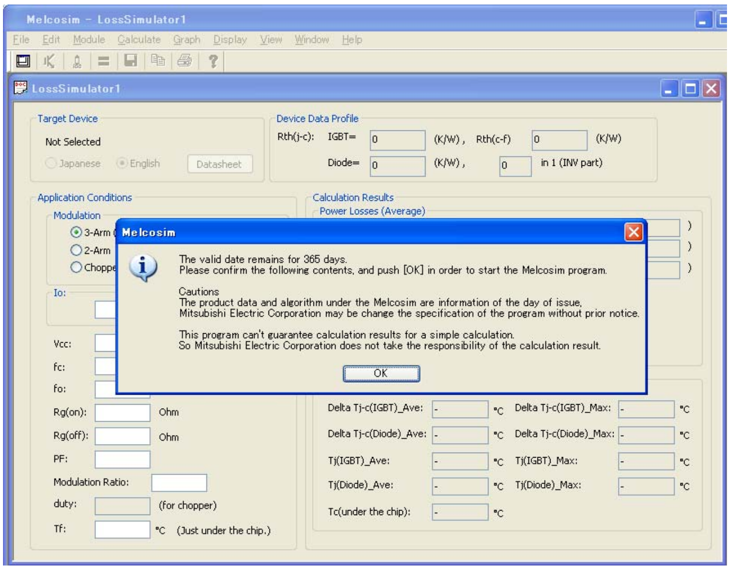
There is a validation date included in the software in order to ensure that the latest simulation data is used. The software might not work properly if the IE of your OS is not updated.
Use IE6 SP1 to update Windows2000 High Encryption Pack to update windows2000.

*) Pentium is a registered trademark of Intel Corporation in the U.S. and/or other countries.

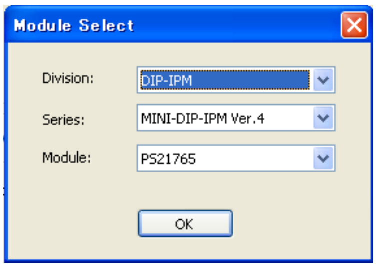
*) Windows is a registered trademark of Microsoft Corporation in the U.S. and/or other countries.

3. Operation Guidance

When the software starts up, a message window pops-up showing the number of remaining days for which the software is valid. Click OK. The software has expired if the date is overdue.



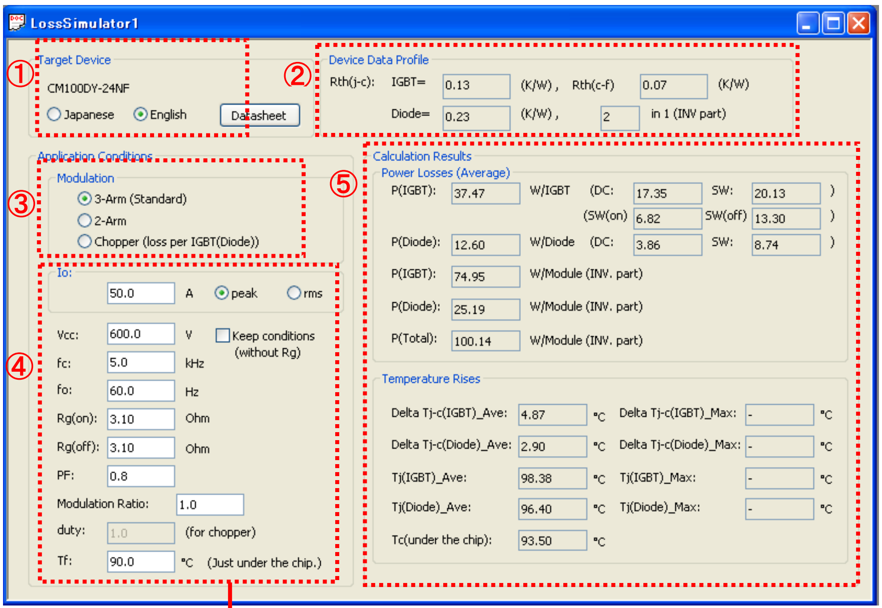
(1)Tool Bar

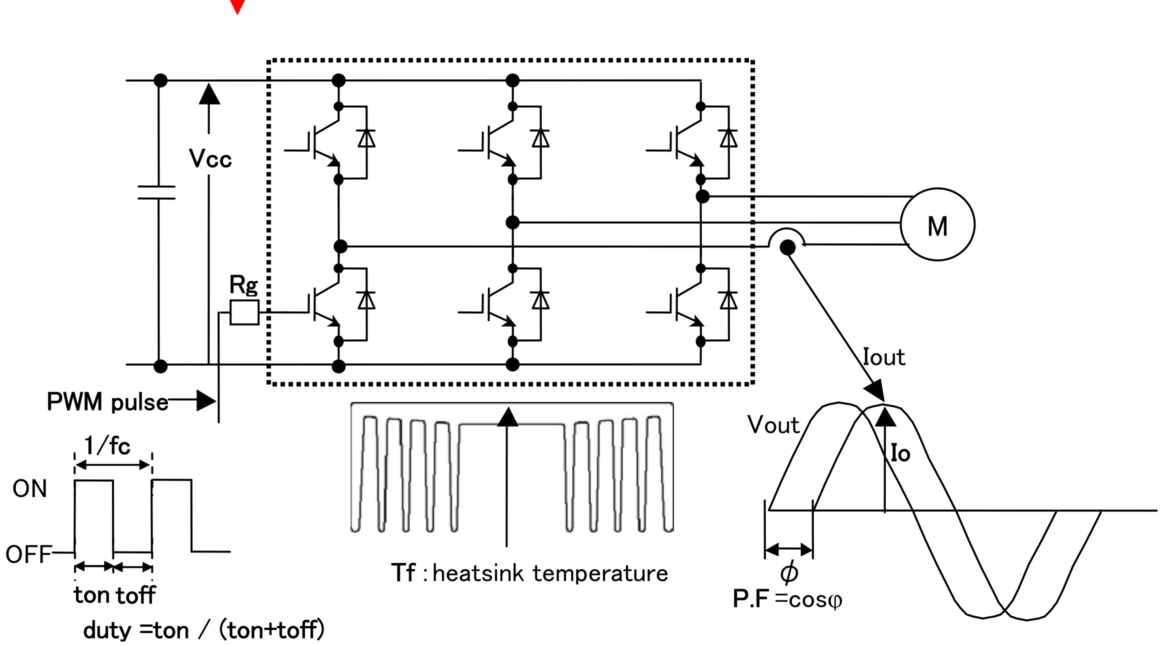
Tool bar	Menu bar	Description
	File →New	Open a new window A new condition window will open. Parallel simulation becomes possible. Select the active condition window from the menu bar windows.
	Module	Select the target module.  Module types and data are subject to update without pre-notification. Please make confirmation on our homepage. (Module selection window will appear even if the “Not Selected” button is clicked at the target device area of the initial condition window.
	Graph → Condition	Move to the condition window.
	Calculate	Start calculation.
	File →Export	Save calculated result（in txt, csv format）. Conditions and graphs are saved in txt file and csv file respectively. Therefore it is possible to edit the data with, e.g. Excel.
	Edit →Copy	Copy the condition window. The data and calculation results window is hard copied and can be pasted to a document such as a word file.
	File →Print	Print Print the condition window, or a graph.
	Help	Help

(2) Condition Window

Power loss conditions and results are displayed in the condition window.

① Target Device	Shows the target device name
② Device Data Profile	Shows the thermal resistance of the target device. The Rth(j-c) specification is the value per one IGBT switch, not per one module. Only the IGBT switches in the inverter circuit are counted, therefore the number given is "6" even for a 7 in 1 (with brake part) module.
③ Modulation	Modulation strategy selection. 3-phase PWM modulation for 3-Arm VVVF inverter; 2-phase PWM modulation for 2-Arm VVVF inverter; Special operation such as chopper control or DC brake is also possible.
④ Io (condition)	Inverter operating condition input.
⑤ Calculation Results	Click " " on the tool bar to begin the calculation





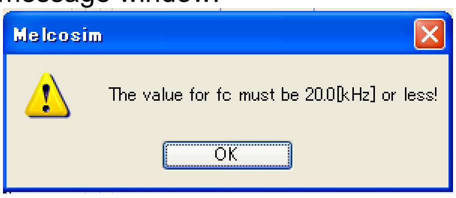
Note: Rg input is not available for IPM, and duty input is only available for chopper calculation.

(3) Range of input data

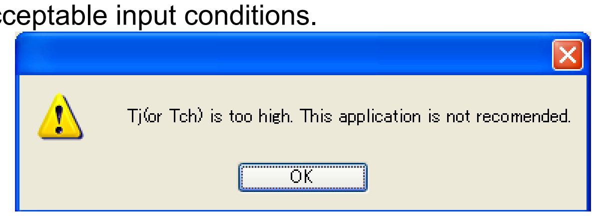
The range may be different for different modules. The following table shows a typical instance of a standard module.

Io	Output current	An input beyond the defined range will generate an alarm message; however, the calculation will still be carried out. The current value can be selected to input either in peak value or rms value. The peak value means the peak value of a sinusoidal current or the peak value of a DC current. Ripple component is not included.
VCC	DC-link voltage	An input exceeding the recommended VCC of the module will generate an alarm message; however, the calculation will still be carried out. VCC≦400V for 600V modules, VCC≦800V for 1200V modules, VCC≦1100V for 1700V modules （Note: some modules may have a different range setting）
fc	Carrier frequency	An input exceeding 20kHz will generate an alarm message, however, the calculation will still be carried out. （Note: some modules may have a different range setting）
fo	Output frequency	Input is only available for modulation of 3−Arm and 2−Arm. An input under 0.1Hz will generate an alarm message （Note: some modules may have a different range setting）
Rg(on),Rg(off)	Gate resistance	Input is only available for IGBT modules. An input beyond the defined range will generate an alarm message; however, the calculation will still be carried out.
PF	Power factor	The input range is -1≦PF≦1. An input beyond the setting range will generate an alarm message.
Modulation Ratio	Modulation depth	The input range is 0～1 for 3-arm 3-phase modulation, and 0～1.154 for 2-arm 2-phase modulation. An input beyond the setting range will generate an alarm message.
duty	Duty	This Input is only available for chopper calculations, with a range of 0～1. Duty is a function of Modulation Ratio in chopper operation Duty=Modulation Ratio/2+0.5 An input beyond the setting range will generate an alarm message.
Tf	Heat-sink temperature	Input range is the safe operation temperature range or junction temperature range of the module. An input beyond the setting range will generate an alarm message.
Keep conditions	Keep calculation conditions	Keeps calculation conditions (except Rg) when module is changed. Check box in order to keep calculation conditions.

Alarm message window:



An alarm message also appears when the calculated junction temperature exceeds the specification under acceptable input conditions.



In addition, if the VCC input exceeds the module blocking voltage, the calculation will still be carried out; however, the voltage cannot be applied in actual operation.

4. Simulation Essentials

(1) Power Loss Calculation Method

The new version of loss simulation software is capable of 3-phase sinusoidal PWM modulation, 2-phase PWM modulation and chopper (including DC brake) operation simulations. The simulations are based on the formulas below.

A) Sinusoidal PWM for VVVF inverter

Calculate the module power loss for inverter VVVF operation. The output current is sinusoidal. Although the formula for different modulation schemes is different, they can be approximated by the same basic formula as below.

■Assumptions

①PWM controlled VVVF inverter with sinusoidal output current.

②PWM signal is generated by comparing sinusoidal and triangular waveforms.

③The PWM signal duty varies within $\frac{1-D}{2} \sim \frac{1+D}{2}(\%/100)$, where D is the modulation depth.

④No ripple component is included in the output current.

⑤Inverter power factor is cos θ and the load is purely inductive.

■Formula

PWM signal duty is a function of phase angle x as $\frac{1+D\times\sin x}{2}$, which is equivalent to the output voltage variation. From the power factor, cos θ, the output current and its corresponding PWM duty at any phase angle can be obtained as below:

$$Output\ current = Icp \times \sin x$$

$$PWM\ \ Duty = \frac{1 + D\times\sin(x+\theta)}{2}$$

※2-phase modulation is different here.

On the other hand, the IGBT collector-emitter saturation voltage $V_{CE(sat)}$ and FWD forward voltage drop V_{EC} at that time are calculated by

$$Vce(sat) = Vce(sat)(@\,Icp \times \sin x)$$

$$Vec = (-1)\times Vec(@\,Iecp(=Icp)\times \sin x)$$

Therefore, the static power loss of one IGBT chip is obtained by

$$\frac{1}{2\pi}\int_0^{\pi}(Icp\times\sin x)\times Vce(sat)(@\,Icp\times\sin x)\times\frac{1+D\sin(x+\theta)}{2}\bullet dx$$

Also similarly, the FWD power loss is obtained by

$$\frac{1}{2\pi}\int_{\pi}^{2\pi}((-1)\times Icp\times\sin x)((-1)\times Vec(@\,Icp\times\sin x)\times\frac{1+D\sin(x+\theta)}{2}\bullet dx$$

The IGBT switching loss does not depend on PWM duty; it is calculated by the following formula.

$$\frac{1}{2\pi}\int_0^{\pi}(Psw(on)(@\,Icp\times\sin x)+Psw(off)(@\,Icp\times\sin x))\times fc\bullet dx$$

The FWD switching loss is calculated by

$$\frac{1}{2\pi}\int_0^{\pi}(Err(@\,Icp\times\sin x))\times fc\bullet dx$$

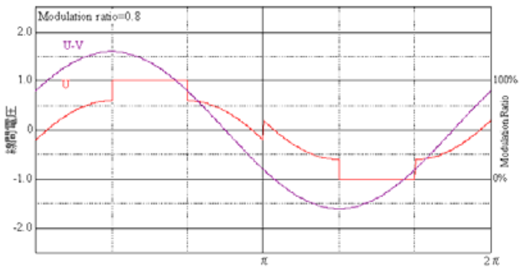
Note:

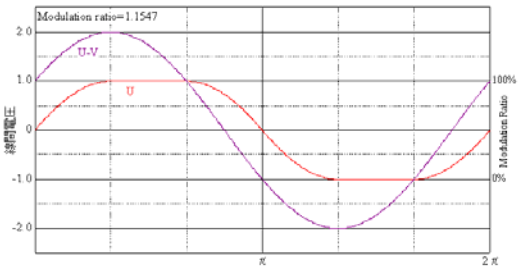
・$V_{CE(sat)}$ and V_{EC} are for T_j＝125℃.

・Psw(on), Psw(off) and Err are for half bridge switching at T_j＝125℃.

B) 2-phase PWM modulation

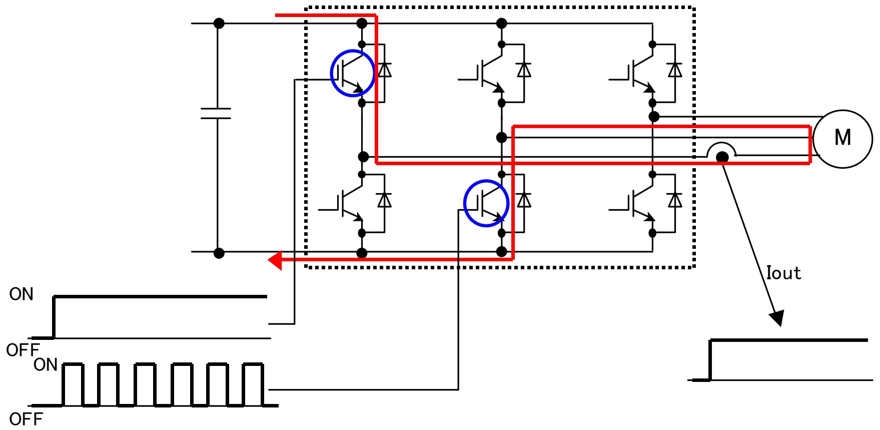
In 2-phase modulation drive mode, simulation for modulation depth over 1, but below 1.154, becomes possible. Comparing to general 3-phase modulation, the voltage conversion ratio is higher, and the power loss is lower due to the non-switching period, such as ON-hold or OFF-hold, occurring in 60 degrees of the cycle. The calculation method is the same as that for 3-phase modulation.





C) Chopper Operation

In DC chopper or brake mode, an IGBT in a certain phase will do continuous switching while other phase IGBTs are kept ON or OFF. The output current is supposed to be a DC current.



The power loss for chopper operation is calculated with the formulas shown below. No ripple component is included.

The average power loss of the IGBT and FWD at current Io are:

$$P_{DC} = Io \times Vce(sat)(@\,Io) \times Duty$$
$$P_{SW} = Psw(@\,Io) \times fc$$
$$P(IGBT) = P_{DC} + P_{SW}$$

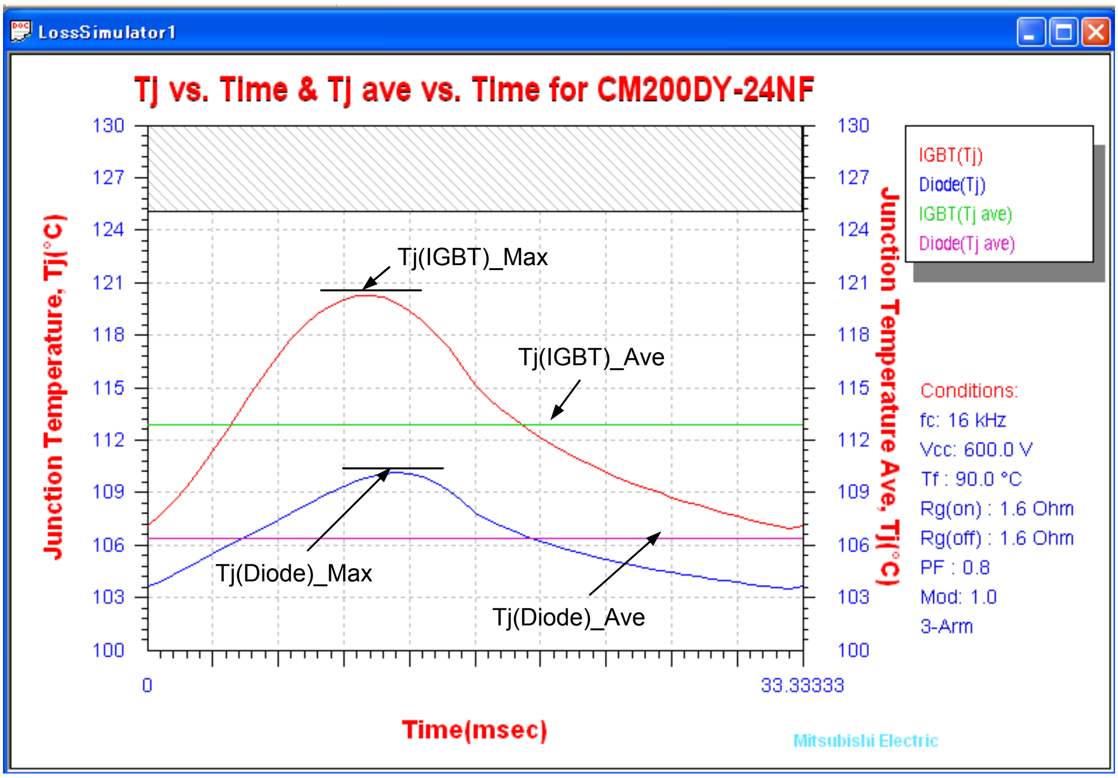
for the IGBT, and

$$P_{DC} = Io \times Vec(@\,Io) \times (1 - Duty)$$
$$P_{SW} = Err(@\,Io) \times fc$$
$$P(Diode) = P_{DC} + P_{SW}$$

for the FWD.

■ The following items need to be considered when making power loss and thermal calculations:
①Use the power loss value for the worst case working condition.

②When Tj_Max is over 125°C, the temperature ripple calculation may be underestimated because all device data is for Tj=125°C. Also, consider that there is additional margin under conditions that are Tj_Ave≤125°C and Tj_max≤125°C. In case of Tj_Ave>125°C or Tj_max>125°C, consider adding margin since the temperatures may be underestimated.



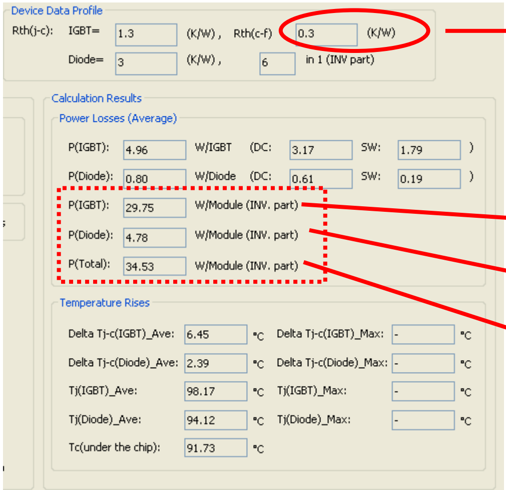
■ Limitations of Ver.4.04 power loss simulation software:
① The performance data used for simulations is obtained by linear approximation from several points of measured data. Therefore, calculation errors occur for Vce(sat) at low current, switching loss near 0A, etc. The calculation results are overestimated under these conditions, please consider it as margin.

In addition, if the input parameters are outside of the specified range, the error produced from the linear approximation will become large, and an exact calculation result cannot be obtained. Therefore, please input each parameter within its acceptable range. If the parameter input is outside of the acceptable range an alarm message will be displayed; however, the calculation will still continue and the results will be shown.

② Temperature ripple calculation is possible with Ver.4.04, but calculation errors can occur, especially with a small sample rate. This calculation is possible only under the following conditions:
1)Modulation is 3-Arm or 2-Arm, and fo is under 30Hz
2)Modulation is Chopper

(2) Temperature Rise Calculation

Example: PS21765 in 3-phase PWM operation



Thermal resistance per one switch (Some devices indicate this value as per one module in their spec.)

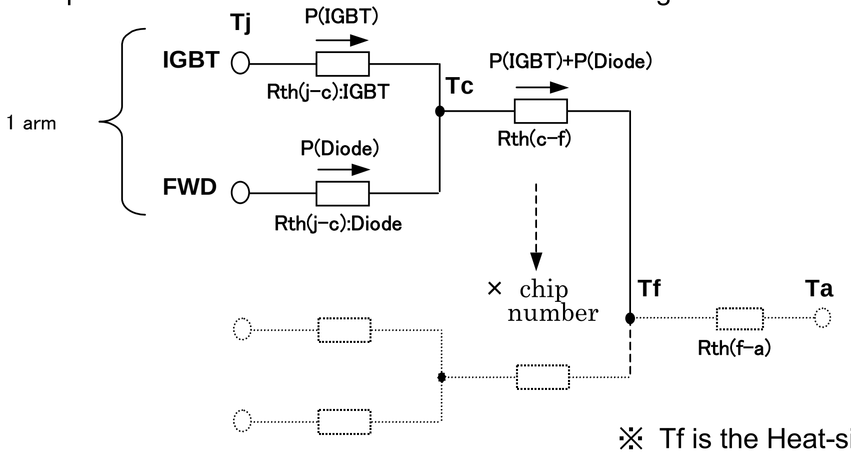
Total IGBT power loss of one module
P(IGBT)(W/IGBT)×chip number

Total FWD power loss of one module
P(Diode)(W/Diode)×chip number

Total power loss of a module
P(IGBT)(W/Module)+P(Diode)(W/Module)

Note) The power loss per one module is not calculated in chopper operation.

The temperature rise is calculated based on the following thermal flow chart.



※ Tf is the Heat-sink temperature

<u>Temperature rise between junction (IGBT&FWD) and case is calculated to be</u>

Delta-Tj-c(IGBT): P(IGBT)*Rth(j-c):IGBT = 4.96(W)*1.3(k/W) = 6.45°C

Delta-Tj-c(Diode): P(Diode)*Rth(j-c):Diode = 0.80(W)*3.0(k/W) = 2.39°C

<u>Case temperature is calculated to be</u>

Tc = Tf + P(Total) * Rth(c-f)/(number of switches) = 90°C + 156.04(W/Module) * 0.228(k/W) / 6 = 91.73°C

Where P(Total) is the total loss of one module and Rth(c-f) is the contact thermal resistance of one switch. (The heat is supposed to distribute across the full module in inverter operation)

Note: for chopper operation calculation, the case temperature is calculated by

Tc = Tf + (P(IGBT) + P(Diode)) * Rth(c-f)

However, there is only one IGBT or one FWD working per one arm in chopper operation, therefore, the calculated value is larger than the actual temperature rise.

<u>IGBT/FWD junction temperature Tj is obtained by</u>

Tj(IGBT) = Tc + Delta-Tj-c(IGBT) = 91.73°C + 6.45°C = 98.17°C

Tj(Diode) = Tc + Delta-Tj-c(Diode) = 91.73°C + 2.39°C = 94.12°C

<u>Note: Precaution of MOS module and RC-IGBT_MOD calculation</u>

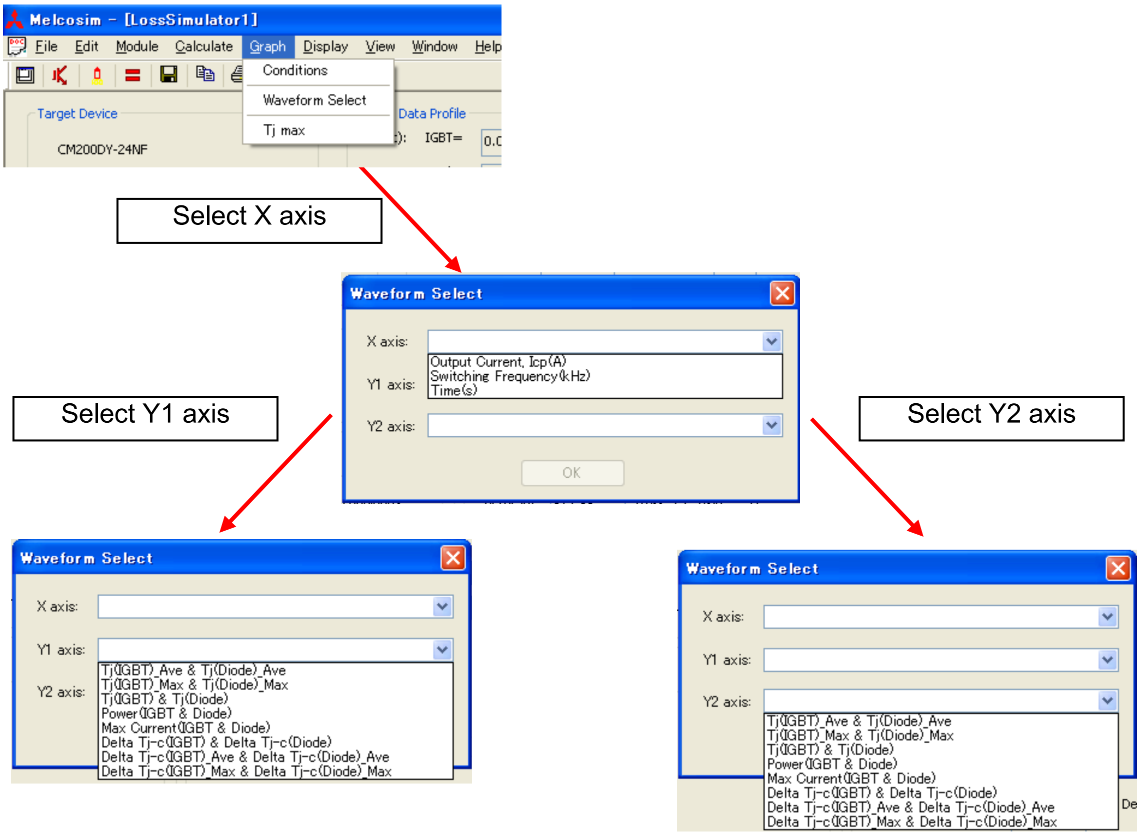
The diodes of MOSFETs and RC-IGBTs are body diodes. Power loss and temperature rise for MOSFET and RC-IGBT are calculated by following equations.

MOS_MOD: Delta-T(j-c)=Rth(j-c)*(P(MOS) + P(Diode)) (MOSFET)

RC-IGBT_MOD: Delta-T(j-c)= Rth(j-c)*(P(IGBT) + P(Diode)) (RC-IGBT)

5. Graph Display Function

The simulated results can be confirmed simply by using the graphing function. Select the “graph” menu in the menu bar to display a graph.



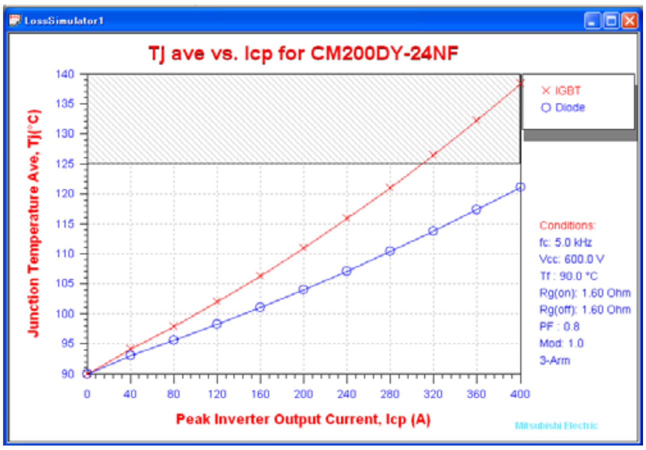
Combination table

X axis	Y1 axis	Y2 axis
Output Current, Icp(A)	Tj(IGBT)_Ave & Tj(Diode)_Ave Tj(IGBT)_Max & Tj(Diode)_Max Power(IGBT & Diode) Delta_Tj(IGBT)_Ave & Delta_Tj(Diode)_Ave Delta_Tj(IGBT)_Max & Delta_Tj(Diode)_Max	Tj(IGBT)_Ave & Tj(Diode)_Ave Tj(IGBT)_Max & Tj(Diode)_Max Power(IGBT & Diode) Delta_Tj(IGBT)_Ave & Delta_Tj(Diode)_Ave Delta_Tj(IGBT)_Max & Delta_Tj(Diode)_Max
Switching Frequency(kHz)	Tj(IGBT)_Ave & Tj(Diode)_Ave Tj(IGBT)_Max & Tj(Diode)_Max Power(IGBT & Diode) Max Current(IGBT & Diode) Delta_Tj(IGBT)_Ave & Delta_Tj(Diode)_Ave Delta_Tj(IGBT)_Max & Delta_Tj(Diode)_Max	Tj(IGBT)_Ave & Tj(Diode)_Ave Tj(IGBT)_Max & Tj(Diode)_Max Power(IGBT & Diode) Max Current(IGBT & Diode) Delta_Tj(IGBT)_Ave & Delta_Tj(Diode)_Ave Delta_Tj(IGBT)_Max & Delta_Tj(Diode)_Max
Time(s)	Tj(IGBT)_Ave & Tj(Diode)_Ave Tj(IGBT) & Tj(Diode) Delta_Tj(IGBT)_Ave & Delta_Tj(Diode)_Ave Delta_Tj(IGBT) & Delta_Tj(Diode)	Tj(IGBT)_Ave & Tj(Diode)_Ave Tj(IGBT) & Tj(Diode) Delta_Tj(IGBT)_Ave & Delta_Tj(Diode)_Ave Delta_Tj(IGBT) & Delta_Tj(Diode)

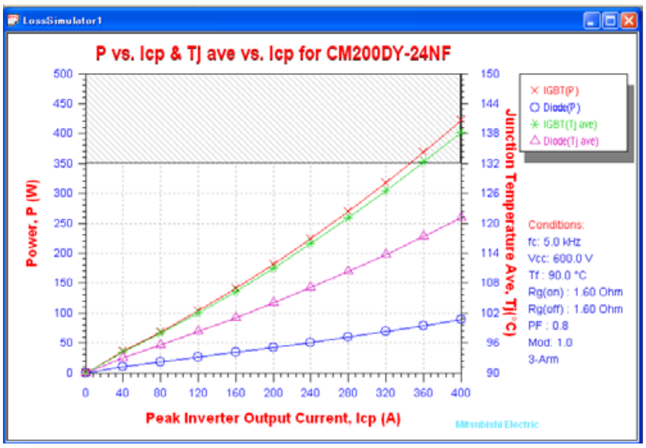
Note) “Tj(IGBT) & Tj(Diode)” and “Delta_Tj(IGBT) & Delta_Tj(Diode)” are possible under following conditions.
1)Modulation is 3-Arm or 2-Arm, and fo is under 30Hz
2)Modulation is Chopper

Graph Display

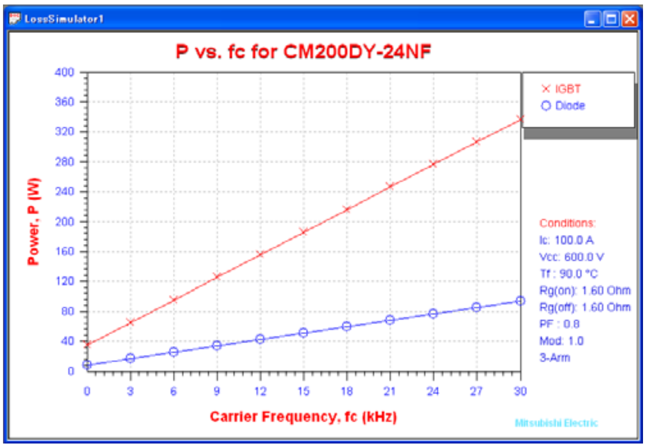
A) Temperature vs. Current curve



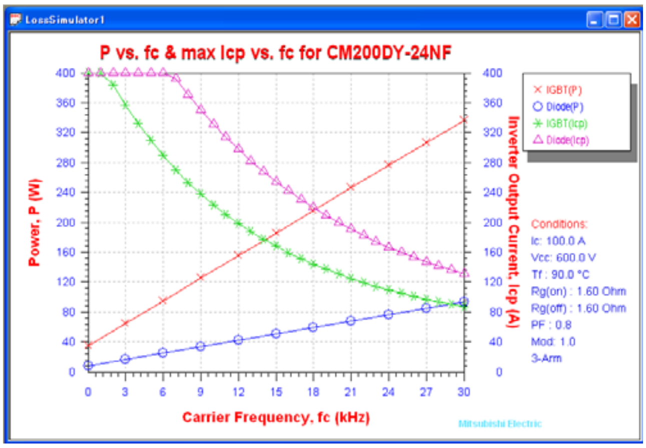
B) Power, Temperature vs. Current curve



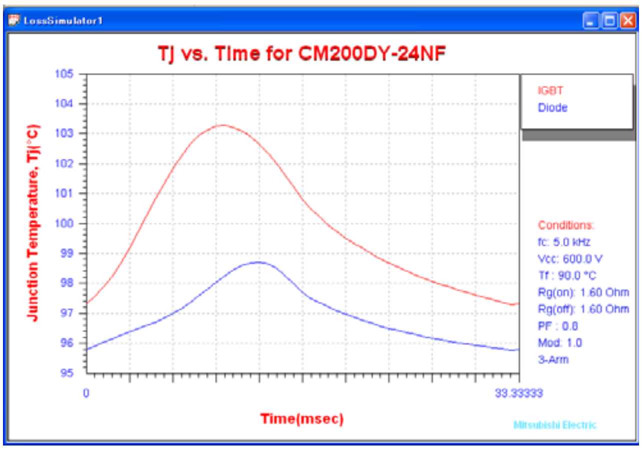
C) Power vs. Carrier Frequency curve



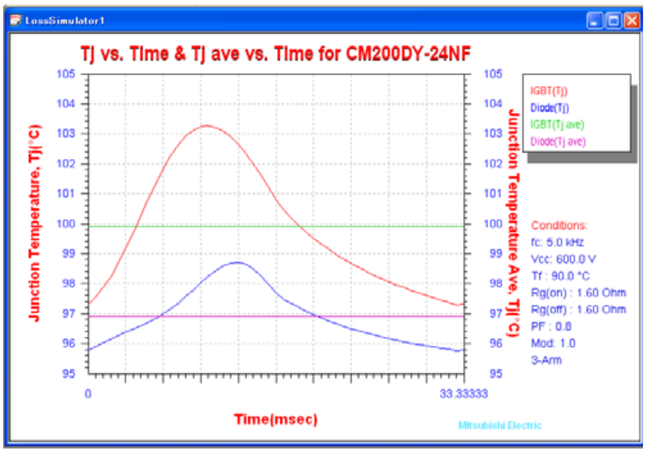
D) Power, Max. Current vs. Carrier Frequency curve



E) Temperature vs. Time curve



F) Temperature vs. Time curve



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Power Device Works, Mitsubishi Electric
Drawing : 13. Jan. '05
Revision : 16. April. '10