ROHM Solution Simulator
Power Device User's Guide
(for Inverters)

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Introduction

This user's guide summarizes basic adjustment methods and know-how for parameters to enable full utilization of the inverter circuit included in the overall "Power Device Solution circuit". Specific solutions are presented for each type of issue that could be a bottleneck in designing the inverter circuits. Use this user's guide as a reference for cases such as when the circuit is malfunctioning or further optimization of the conditions is desired.

Contents

1. List of inverter circuits

Table 1 summarizes the inverter circuit prepared in the "Power Device Solution circuit". Reference circuits, including general single-phase half- and full-bridges as well as 3-phase, 3-level, IH, and motor drives, are listed based on applications. Use this table according to your applications.

Category	Control number	Circuit specifications
IH Inverter	B-1	IH Half-Bridge Inverter Po=10kW
	B-2	IH Full-Bridge Inverter Po=20kW
Half-Bridge Inverter	B-3	Half-Bridge Inverter Vo=200V Io=100A
Full-Bridge Inverter	B-4	Full-Bridge Inverter Vo=200V Io=100A
1-Phase 3Wire Inverter	B-5	1-Phase 3-Wire Inverter Vo=100/200V Po=20kW
3-Phase Inverter	B-6	3-Phase 3-Wire Inverter Vo=200V Po=5kW
	B-7	3-Phase 4-Wire Inverter Vo=115/200V Po=20kW
Motor Drive	B-8	Motor Drive 2-Phase-Modulation Po=10kW
	B-9	Motor Drive 3-Phase-Modulation Po=10kW
	B-10	Motor Drive Step-Modulation Po=5kW
3-level Inverter	B-11	3-level Inverter type-T Vo=200V Io=50A
	B-12	3-level Inverter type-I Vo=200V Io=50A

Table 1. List of the inverter circuit included in the overall Power Device Solution circuit

2. Influence of trr

This section explains the influence of trr, which is one of the important features of inverter circuits.

2-1. Example of circuit

Circuit "B-6. 3-Phase 3-Wire Inverter Vo=200V Po=5kW" in Figure 1 is used as an example for explanation.

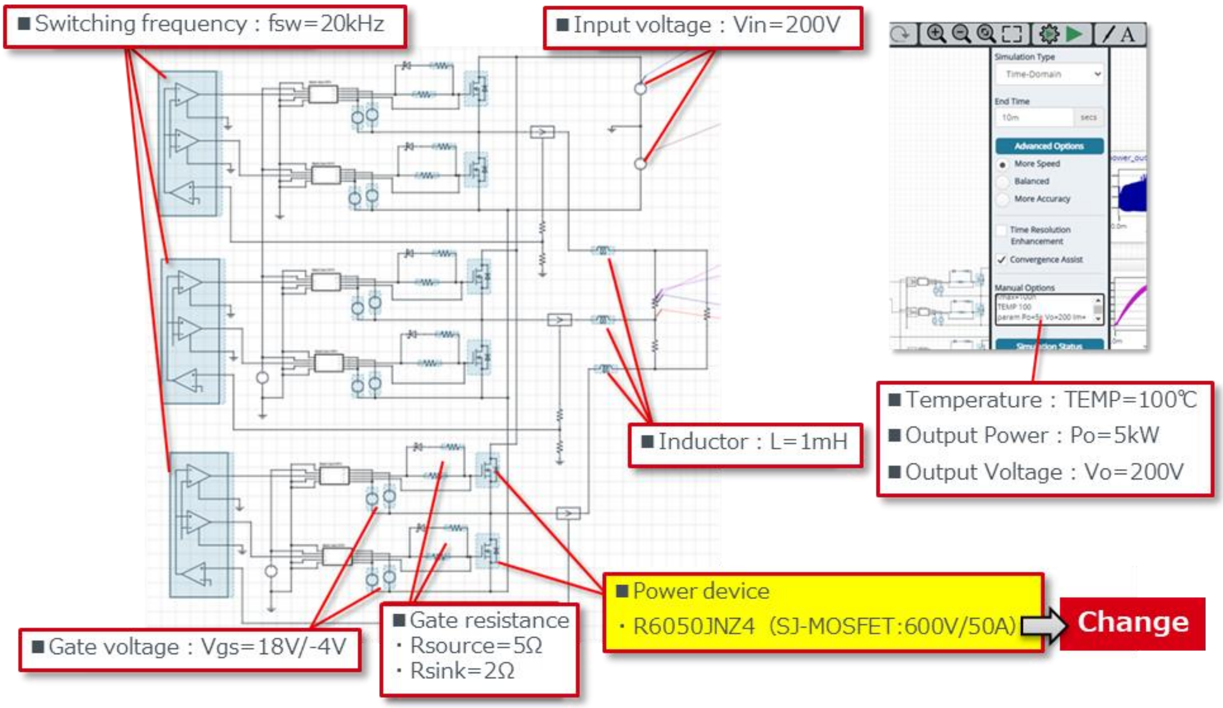


Figure 1. Example of circuit: B-6. 3-phase 3-wire inverter, Vo = 200 V, Po = 5 kW

2-2. Importance of trr characteristics

Figure 2 shows the current path in this circuit during switching.

An inverter circuit adjusts the supply power by repeating operations (1) through (5) to alternatively switch ON/OFF the High and Low sides using PWM, PFM, or other control methods. During the operation from (4) to (5), recovery current flows through the internal diode on the Low side when the High side is switched from OFF to ON. Therefore, through current flows as shown by the red line.

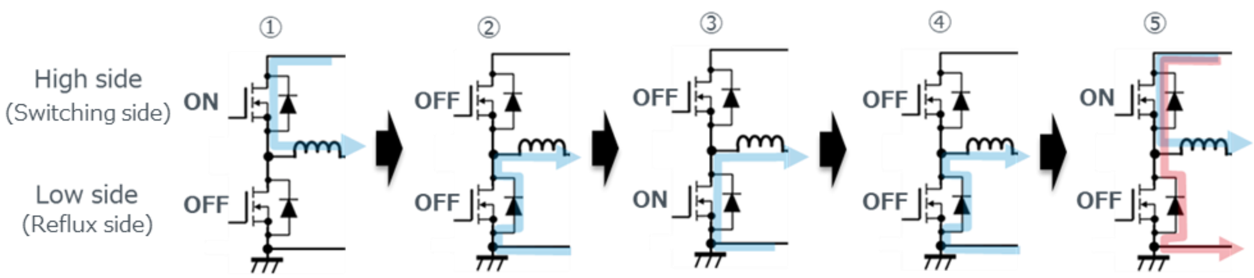


Figure 2. Current path during switching

This recovery current does not significantly affect the loss in the reflux side device itself where the recovery current is generated. However, a very large Turn ON loss occurs in the switching side device because the recovery current flows in addition to the normal switching current before the VDS change as shown in Figure 3. Therefore, for the inverter circuits, it is important to select switching devices with good trr characteristics.

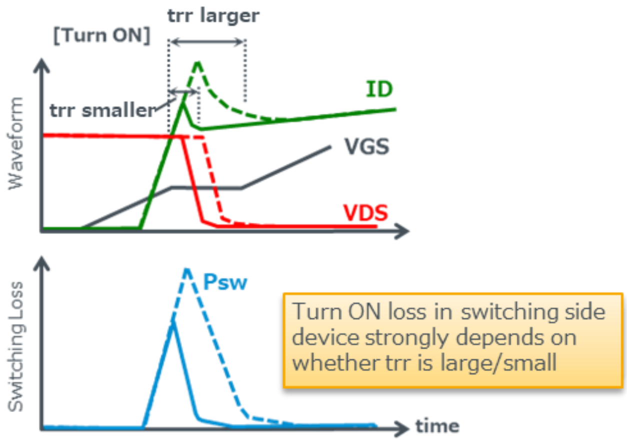


Figure 3. Turn ON waveforms of switching side device

2-3. Comparison of differences in trr characteristics

Figure 4 shows the Turn ON waveforms of the switching side devices equipped with a general diode (R6047KNZ4) and a high speed diode (R6050JNZ4) in the B-6 circuit. As described above, the differences in the trr characteristics cause a significant difference in the Turn ON losses. The Turn ON loss can be reduced approximately 5 times with the high speed diode R6050JNZ4 compared with R6047KNZ4.

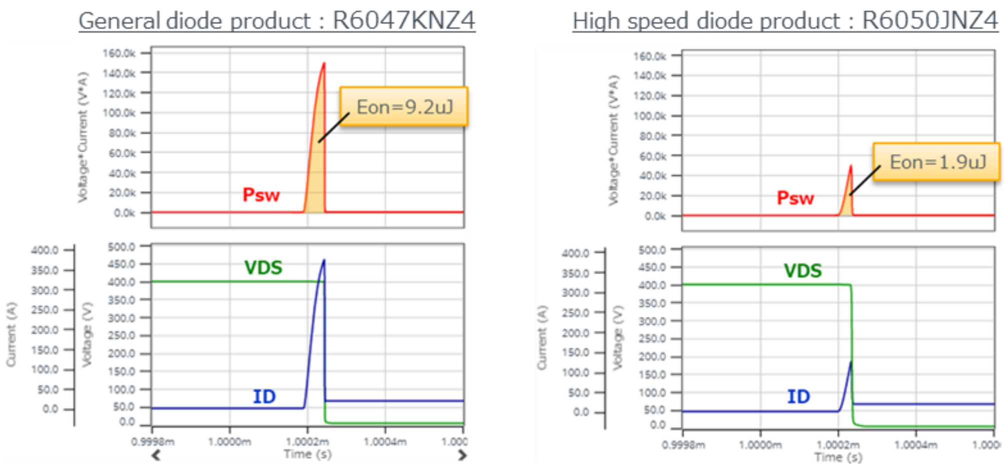


Figure 4. Comparison of simulation waveforms between general and high speed diode products.

Furthermore, an analysis of the MOSFET loss throughout the inverter circuit operation shows that the loss due to trr has a significant influence as shown in Figure 5.

This result also demonstrates that it is important to select high speed diodes for the inverter circuits.

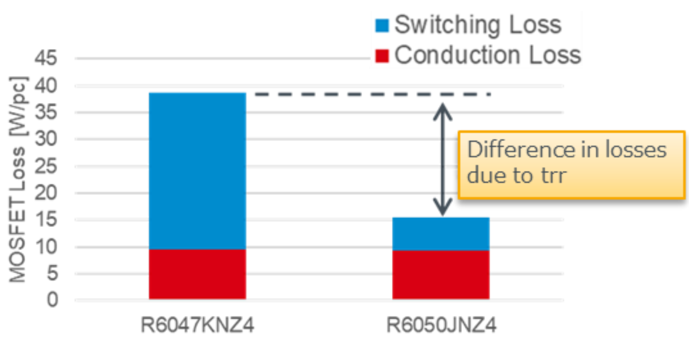


Figure 5. Loss analysis for general/high speed diode products

3. Selection of optimum device based on loss analysis

This section introduces methods of selecting optimum devices based on analysis of the device loss by separating it into the switching loss and the conduction loss.

3-1. Example of circuit

Circuit "B-9. Motor Drive 3-Phase-Modulation Po=10kW" in Figure 6 is used as an example for explanation. Change each condition in the yellow boxes and replace power devices to consider the optimum device.

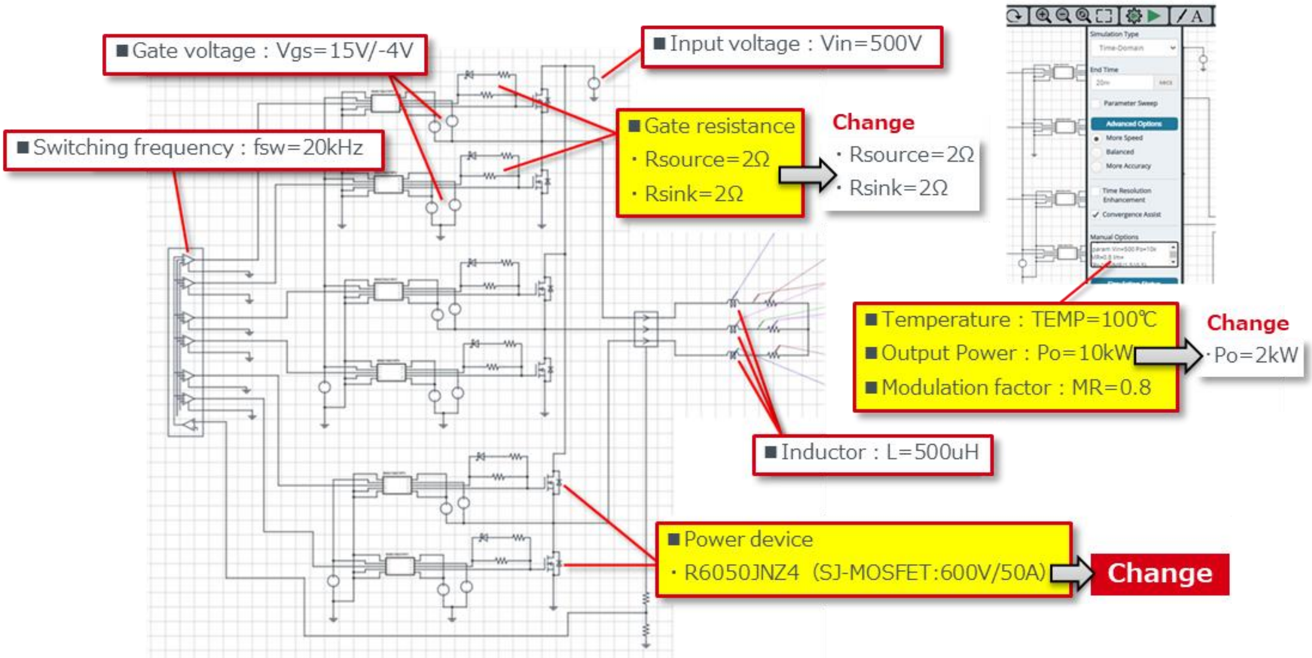


Figure 6. Example of circuit: B-9. Motor drive 3-phase-modulation, Po = 10 kW

3-2. Methods of loss analysis

Figure 7 shows the simulation waveforms of VDS, ID, the loss (Pd), and the energy (E), which is the time integration of loss, during the MOSFET switching.
The ROHM Solution Simulator can easily output energy waveforms by integrating the losses using waveform calculation function "Waveform Analyzer". The energy waveform clearly shows the energy consumptions in the switching section (Eon, Eoff) and the conduction section (Econd). In addition, the energy consumptions can be output as a numerical value by reading differences in the cursor positions.
If the input and output are constant, as with DC-DC converters, the switching loss and the conduction loss can be calculated by multiplying the respective energies in one period and the switching frequency.

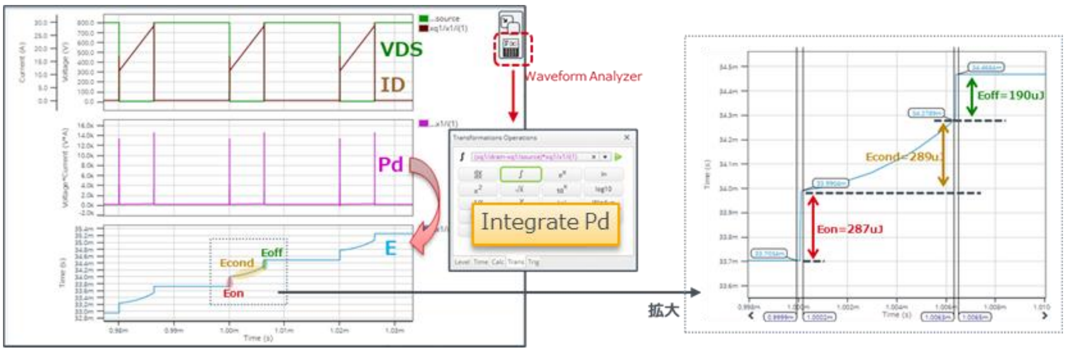


Figure 7. MOSFET waveforms of DC-DC converter circuit

However, since the load fluctuates in inverter circuits as shown in Figure 8, the loss in the entire circuit operation cannot be calculated by looking at a part of the switching waveform.

For a circuit operation with inconstant device loss as in this case, it is possible to consider the conduction loss and the switching loss separately by dividing the loss waveform into cases and extracting specific parts.

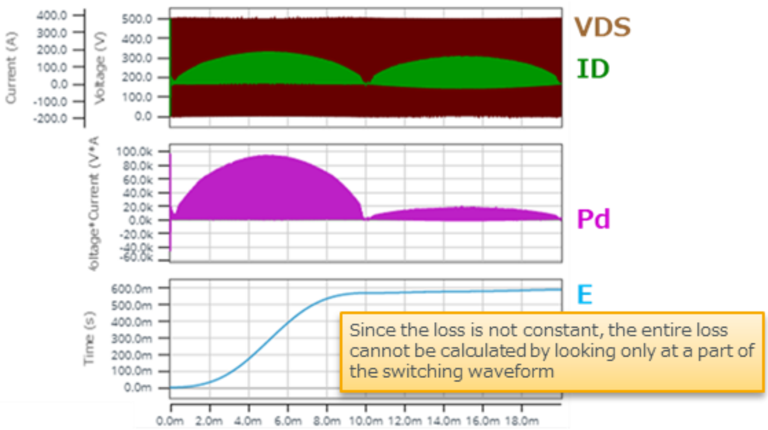


Figure 8. MOSFET waveforms of inverter circuit

The yellow line in Figure 9 is the waveform to which the conduction loss is extracted.

To extract only the conduction loss, the waveform is divided into cases so that the power is extracted if "VGS is High" and "the power is lower than the maximum value of the conduction loss". After extracting the specific waveform, calculate the average value over one period to analyze the ratio of the losses. In the case of Figure 9, since the total loss and the conduction loss are 29.5 W and 20.5 W, respectively, the switching loss is 9.0 W. Therefore, it can be seen that the ratio of loss is 70% and 30% for the conduction loss and the switching loss, respectively.

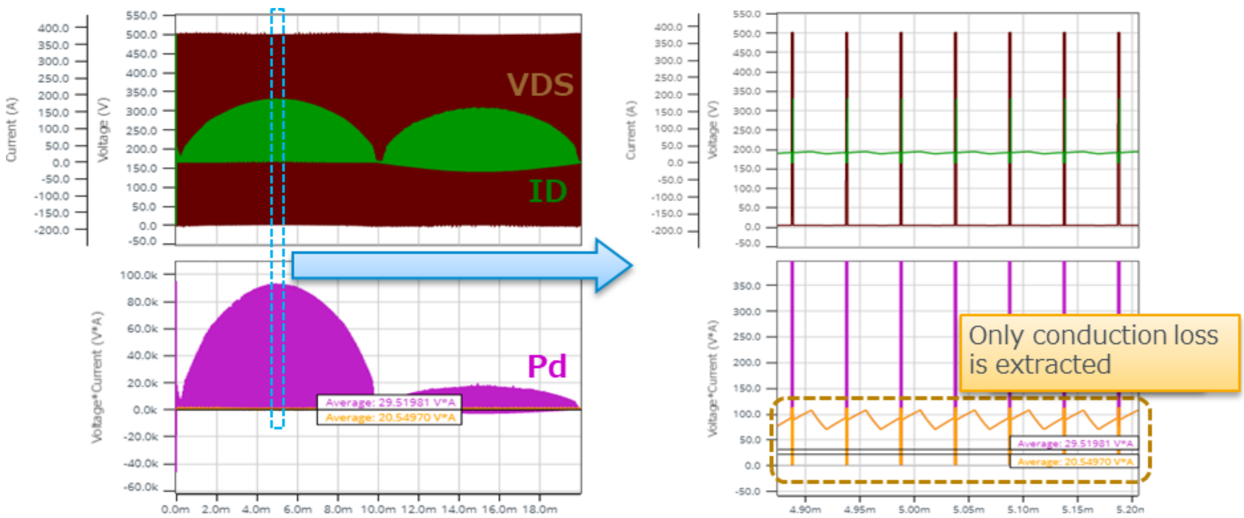


Figure 9. MOSFET waveforms of inverter circuit (conduction loss extracted)

In the example above, the waveform is divided into the switching loss and the conduction loss only. However, by setting the division conditions more finely, it is also possible to further subdivide the loss into the Turn ON loss, Turn OFF loss, recovery loss, parasitic diode loss, and so on.

3-3. Consideration of optimum device

Figure 10 shows the result of the loss analysis for each device when replacing the power devices in circuit "B-9. Motor Drive 3-phase-modulation, Po = 10 kW" in 3-1.

"**" in R60**JNZ4 represents the rating. You can see a trend indicating that the higher the current rating, the smaller the conduction loss, while the lower the current rating, the smaller the switching loss. When selecting a device with a small loss under these circuit conditions, the results of the analysis suggest that R6030JNZ4 is the optimum device.

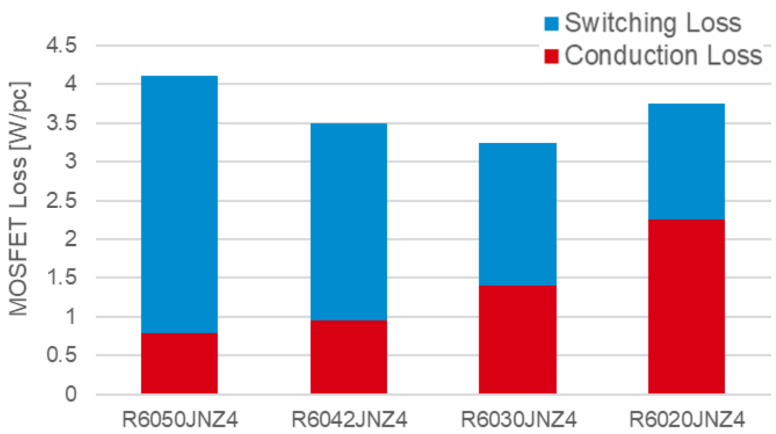


Figure 10. Result of MOSFET loss analysis

4. Features of half- and full-bridges

This section explains the features of half- and full-bridge inverter circuits.

4-1. Example of circuit

Circuit "B-3. Half-bridge inverter, Vo = 200 V, Io = 100 A" in Figure 11 and circuit "B-4. Full-bridge inverter, Vo = 200 V, Io = 100 A" in Figure 12 are used as examples for explanation.

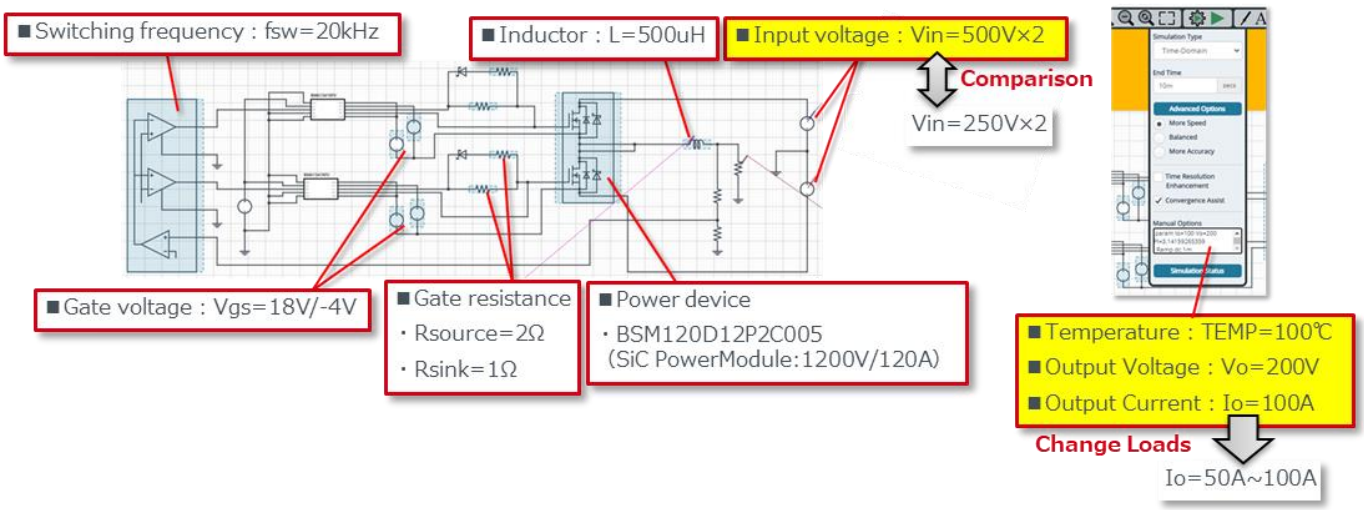


Figure 11. Example of circuit: B-3. Half-bridge inverter, Vo = 200 V, Io = 100 A

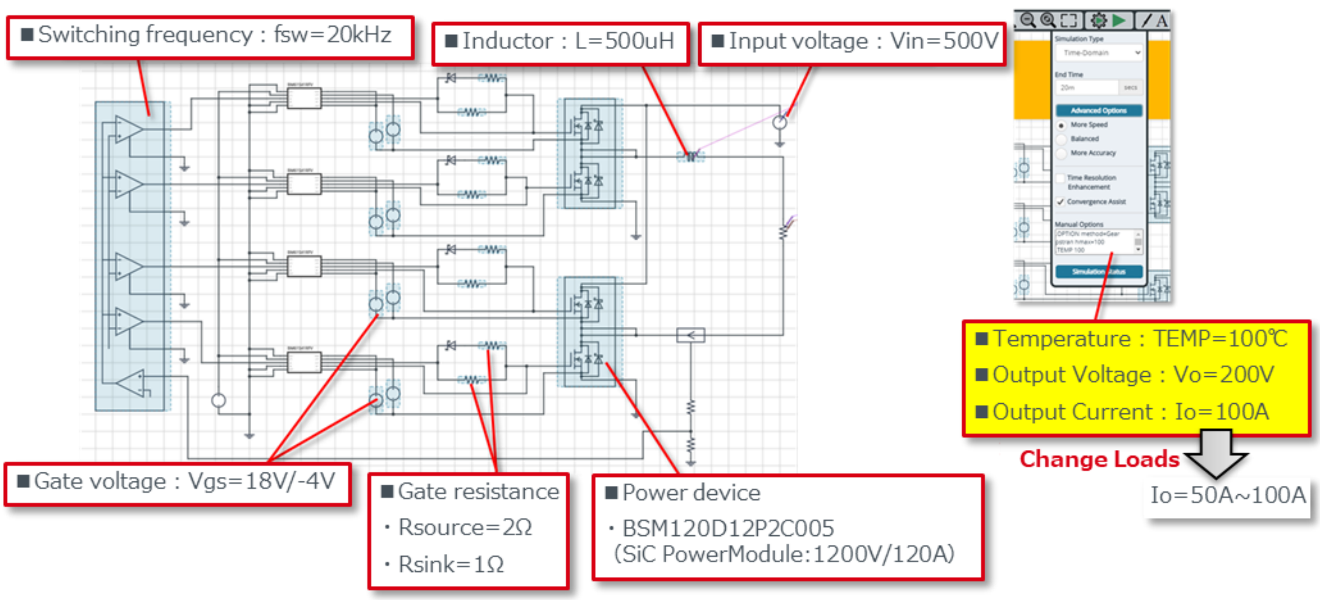


Figure 12. Example of circuit: B-4. Full-bridge inverter, Vo = 200 V, Io = 100 A

4-2. Features of half- and full-bridges

Table 2 shows the features of half- and full-bridge inverter circuits.

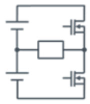
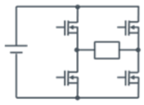
	Advantages	Disadvantages
Half Bridge 	• The bridge can be configured with two switch devices • One switch in the current path is preferred in large current applications	• Two DC voltage supplies are required • High breakdown voltage is required for the switch device because the voltage from two power supplies is applied • The bridge can output only up to the voltage of one DC voltage supply
Full Bridge 	• The bridge can be configured with one DC voltage supply • Voltage from one power supply is applied to the switch	• Four switch devices are required • Since the current path contains two switches, the conduction loss in the switches is large

Table 2. Features of half- and full-bridges

Although it depends on the conditions, it can be suggested that the half-bridge is suitable for low voltage/large current applications, while the full-bridge is suitable for high voltage/high power applications.

4-3. Comparison of operations of half- and full-bridges

Figure 13 shows the result of comparison of the module losses in the initial state (Vin = 500 V) of the circuits in 4-1.

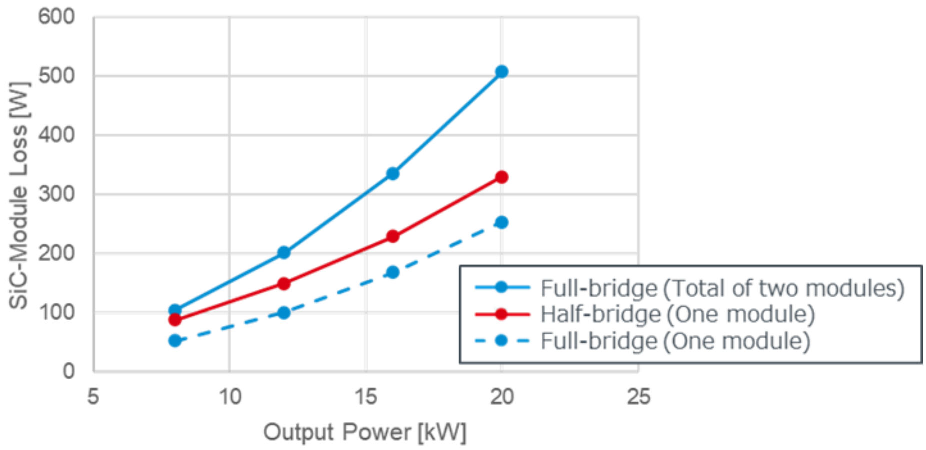


Figure 13. Comparison of module losses in half- and full-bridge circuits

When the losses are compared, the half-bridge has a larger switching loss because the voltage from two power supplies is applied to the switching device. The loss per module is larger for the half-bridge than the full-bridge. However, if you look at the total losses, the loss in the full-bridge is larger because the conduction loss in two modules is even larger.

Next, consider a case where the half-bridge (Vin = 500 V) has only one power supply and Vin is divided into 250 V × 2. Figure 14 shows the output waveforms for Vin = 500 V × 2 and Vin = 250 V × 2. From this figure, it can be seen that Vo plateaus at 250 V for Vin = 250 V × 2. This can be attributed to a disadvantage of the half-bridge circuit that means it can output only up to the voltage of one power supply as described above. Since the setting of output voltage Vo = 200 V is the effective value and the peak voltage is 282 V, the voltage is insufficient with Vin = 250 V × 2.

Vin = 500 V × 2 | Vin = 250 V × 2

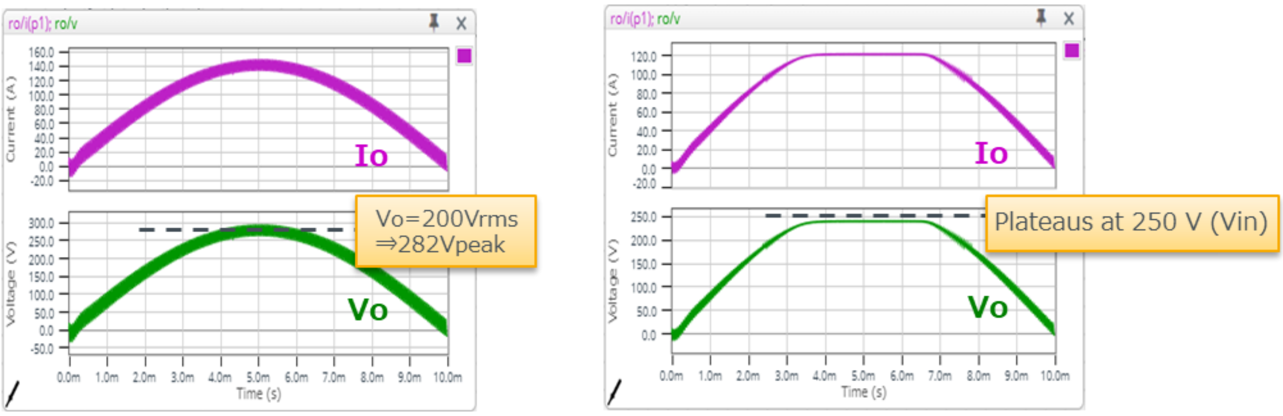


Figure 14. Output waveform of half-bridge

Thus, the half- and full-bridges have their own advantages and disadvantages, making it impossible to say either is superior in general.
It is important to understand their features and properly select them according to applications.

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