Chapter 4

Troubleshooting

CONTENTS			Page

This section explains IGBT troubleshooting and failure analysis.

1 Troubleshooting

Incorrect wiring or mounting of an IGBT in an inverter circuit could cause module destruction. Because a module could be destroyed in many different ways, once the failure has occurred, it is important to first determine the cause of the problem, and then to take the necessary corrective action. Table 4-1, illustrates how to determine a module's failure modes as well as the original causes of the trouble by observing irregularities outside of the device. First of all, compare the device estimated failure mode to the table when an IGBT is destroyed. Fig.4-1(a-f) was prepared as a detailed guide (analysis chart), and should be used to help investigate the destruction when you cannot determine the cause by using Table 4-1. Typical failure modes and troubleshooting are described in section 4-3 and can be used to assist in finding the cause.

Table 4-1 Causes of device failure modes

External abnormalities		Cause		Device failure mode	Further checkpoints
Short circuit	Arm short circuit	Short circuit destruction of one element		Outside SCSOA	Confirm waveform (locus) and device ruggedness match during an arm short circuit.
	Series arm short circuit	Gate or logic Circuit malfunction	Noise, etc.	Outside SCSOA	Check for circuit malfunction. Apply the above.
		dv/dt	Insufficient gate reverse bias. Gate wiring too long	Overheating	Check for accidental turn-on caused by dv/dt.
		Dead time too short	Insufficient gate reverse bias. Date time setting error	Overheating	Check that elements t_{off} and deadtime match.
	Output short circuit	Miswiring, abnormal wire contact, or load short circuit.		Outside SCSOA	Check conditions at time of failure. Check that device ruggedness and protection circuit match. Check wiring condition.
	Ground short	Miswiring, abnormal wire contact		Outside SCSOA	
Overload		Logic circuit malfunction Overcurrent protection circuit setting error		Overheating	Check logic circuit.
					Check that overload current and gate voltage match. If necessary, adjust overcurrent protection level.
Over Voltage	Excessive input voltage	Excessive input voltage Insufficient overvoltage protection		C-E Overvoltage	If necessary, adjust overvoltage protection level.
	Excessive spike voltage	Switching turn-off		Outside RBSOA	Check that turn-off operation (loci) and RBSOA match. If necessary, adjust overcurrent protection level.
		FWD commutation	High di/dt resulting	C-E Overvoltage	Check that spike voltage and device ruggedness match. If necessary, adjust snubber circuit.
			Transient on state (Short off pulse reverse recovery)		Check logic circuit.
					Gate signal interruptions resulting from noise interference.
Drive supply voltage drop		DC-Dc converter malfunction		Overheating	Check circuit.
		Drive voltage rise is too slow.		Overheating	
		Disconnected wire		Overheating	

External abnormalities		Cause		Device failure mode	Further checkpoints
Gate overvoltage		Static electricity Spike voltage due to excessive length of gate wiring		Avalanche Overvoltage	Check operating conditions (anti-static protection). Check gate voltage.
Overheating	Overheating	Loose terminal screw or cooling fan shut down		Overheating	Check cooling conditions. Check logic circuit. Logic circuit malfunction
	Thermal runaway	Logic circuit malfunction		Overheating	
Stress	Stress	The soldering part of the terminal is disconnected by the stress fatigue.	Stress from external wiring	Disconnection of circuit	Check the stress and mounting parts.
	Vibration		Vibration of mounting parts		
Reliability (Life time)		The application condition exceeds the reliability of the module.		Destruction is different in each case.	Refer to Fig.4-1 (a-f).

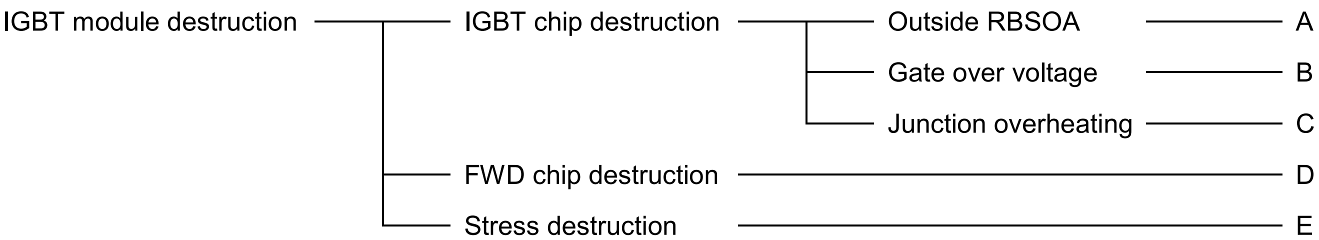


Fig.4-1 (a) IGBT module failure analysis

A. Outside RBSOA

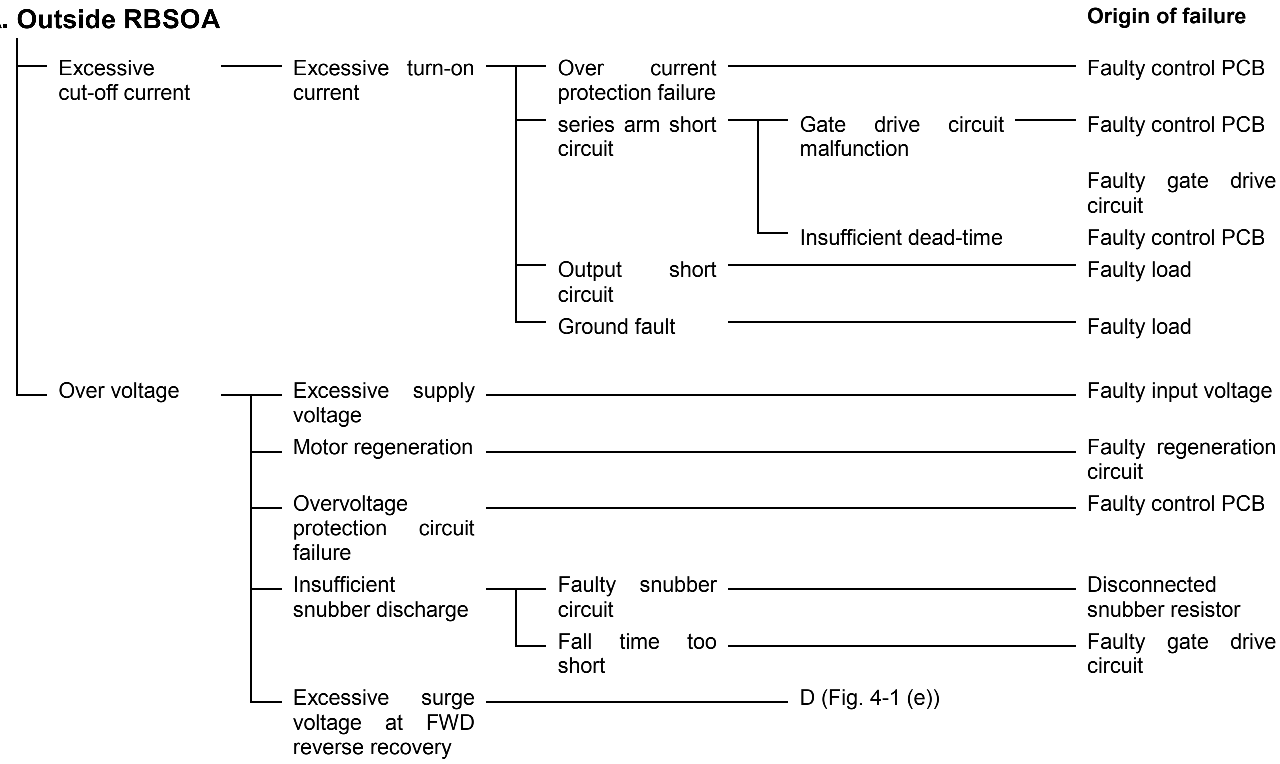


Fig.4-1 (b) Mode A: Outside RBSOA

B: Gate overvoltage — **Origin of failure**

- Static electricity → Still no antistatic protection → Manufacturing fault
- Spike voltage
  - Oscillation → Gate wiring too long
  - L･di/dt voltage → Gate wiring too long

Fig.4-1 (c) Mode B: Gate overvoltage

C: Junction overheating — Origin of failure

- Static power loss increase
  - Saturation voltage increase VCE (sat) → Insufficient forward bias gate voltage → Faulty gate drive circuit; Faulty power supply control circuit
  - Collector current increase
    - Over current
      - Over current protection circuit failure
      - Series arm short circuit
        - Gate drive circuit malfunction → Faulty gate drive circuit; Faulty control PCB
        - Insufficient dead time → Faulty control PCB
      - Output short circuit → Abnormal load
      - Ground fault → Abnormal load
    - Overload → Faulty control PCB; Abnormal load
- Switching loss increase
  - Switching increase
    - Increase in carrier frequency → Faulty control PCB
    - di/dt malfunction → Faulty snubber circuit; Faulty gate drive circuit
    - Gate drive signal malfunction → Faulty control PCB; Faulty gate drive circuit
  - Increase in turn-on loss
    - Turn-on time increase
      - Insufficient forward bias gate voltage → Faulty gate drive circuit
      - Gate resistance increase → Faulty gate drive circuit
    - Excessive turn-on current
      - Reverse bias gate voltage decrease → Faulty snubber circuit
      - Series arm short circuit → Insufficient dead time → Faulty control PCB
  - Increase in turn-off loss
    - Turn-off time increase
      - Insufficient forward bias gate voltage → Faulty gate drive circuit
      - Gate resistance increase → Faulty gate drive circuit
    - Series arm short circuit → Insufficient dead time → Faulty control PCB; Faulty gate drive circuit
- Contact thermal resistance increase
  - Device mounting force insufficient → Insufficient mounting torque
  - Excessive heat sink warping → Critical heat sink warpage
  - Insufficient thermal compound volume → Insufficient coverage of thermal compound volume
- Rise in case temperature
  - Cooling capability drop
    - Heat sink obstruction → Insufficient dust filtration
    - Cooling fan operation slow or stopped → Faulty cooling fan
  - Abnormal rise in ambient temperature → Partial overheating of stack → Faulty cooling system
  - Temperature maintenance equipment failure → Faulty temperature maintenance equipment

Fig.4-1 (d) Mode C: Junction overheating

D: FWD destruction

Origin of failure

- Excessive junction temperature rise
  - Static loss increase — Overload
    - Power factor drop
    - Power factor drop
    - Faulty PCB
  - Switch loss increase — Switching increase
    - dv/dt malfunction
      - Faulty snubber circuit
      - Gate drive circuit malfunction
    - Gate drive signal malfunction
      - Faulty PCB
      - Gate drive circuit malfunction
    - Increase in carrier frequency — Faulty PCB
  - Contact thermal resistance increase
    - Device mounting force insufficient — Insufficient mounting torque
    - Excessive heat sink warping — Bad heat sink warping
    - Unsuitable thermal compound volume — Insufficient adjustment of thermal compound volume
  - Rise in case temperature
    - Cooling capability drop
      - Heat sink obstruction — Insufficient dust prevention
      - Cooling fan operation slow or stopped — Faulty cooling fan
    - Abnormal rise in ambient temperature — Faulty cooling system
    - Temperature maintenance equipment failure — Faulty temperature maintenance equipment
- Overvoltage
  - Excessive reverse recovery surge voltage — Faulty snubber circuit
    - di/dt increase at turn-on
      - Forward bias gate voltage increase — Gate drive circuit malfunction
      - Gate resistance drop — Gate drive circuit malfunction
    - Short off pulse reverse recovery — Gate signal interruptions resulting from noise interference
      - Gate drive circuit malfunction
      - Faulty PCB
  - Excessive surge voltage at IGBT turn-off — A (Fig. 4-1 (b))
- Over current — Over charging current of rectifier — Faulty charging circuit

Fig.4-1 (e) Mode D: FWD destruction

E: Reliability issues or product mishandling destruction | **Origin of failure**

			Origin of failure
Destruction caused by handling	External force or load	Loading during product storage	Loading conditions
		Stress produced in the terminals when mounted	Stress in the terminal section
		Excessively long screws used in the main and control terminal	Screw length
	Excessive tightening torque		Clamped section
			Terminal section
	Insufficient tightening torque for main terminal screws	Increased contact resistance	Main terminal section
	Vibration	Excessive vibration during transport	Transport conditions
		Loose component clamping during product mounting	Product terminal section
	Impact	Dropping, collision during transport	Transport conditions
	Soldered terminal heat resistance	Excessive heat during terminal soldering	Assembly conditions during product mounting
	Storage in abnormal conditions	Environments where corrosive gases are present	Storage conditions
		Condensation-prone environments	Storage conditions
		Environments where dust is present	Storage conditions
	Destruction on parallel connection	Poor uniformity of main circuit wiring, causing transient current concentration or current oscillation	Uniformity of the main circuit wiring
Reliability (life time) destruction	High-temperature state	Stored at high temperatures for long periods of time	Storage conditions
	Low-temperature state	Stored at low temperatures for long periods of time	Storage conditions
	Hot and humid	Stored in hot and humid conditions for long periods of time	Storage conditions
	Temperature cycle, ΔTc power cycle		Matching between working conditions and product life time
	Thermal stress destruction caused by sharp rises or falls in product temperature		Matching between working conditions and product life time
	ΔTj power cycle		Matching between working conditions and product life time
	Voltage applied for long periods of time at high temperature (between C and E and between G and E)	Used for long periods of time at high temperature	Matching between working conditions and product life time
	Voltage applied for long periods of time in hot and humid conditions (THB)	Used for long periods of time in hot and humid conditions	Matching between working conditions and product life time

Fig.4-1 (f) Mode E: Reliability issues or mishandling destruction

2 IGBT test procedures

An IGBT module that has been found to be faulty can be checked by testing it on a transistor characteristics measuring device called a "transistor curve tracer (CT)."

(1) Leakage current between gate and emitter, and threshold voltage between gate and emitter
(2) Short circuit, breakdown voltage, open circuit between collector and emitter (Short gate and emitter.)

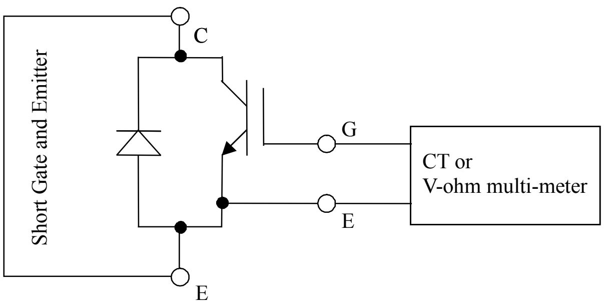


Fig. 4-1 G-E (gate) check

If a CT is not available, other test equipment, such as a Volt-ohm multi-meter that is capable of measuring voltage/resistance and so forth to determine a failure, can be used to help diagnose the destruction.

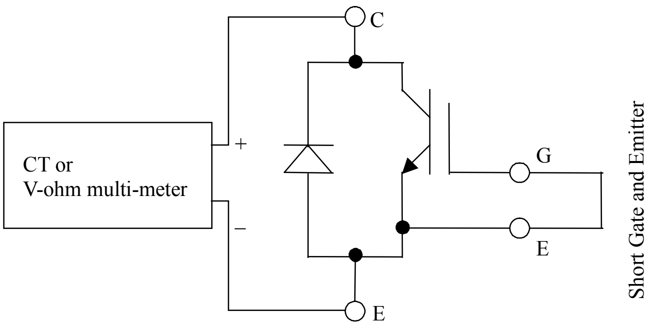


Fig. 4-2 C-E check

2.1 G-E check

As shown in Fig.4-2, measure the leakage current or resistance between G and E, with C and E shorted to each other. (Do not apply a voltage in excess of 20V between G and E). If the V-ohm multi-meter is used, verify that the internal battery voltage is not higher than 20V.)

If the product is normal, the leakage current reading should be on the order of several hundred nano-Amps. (If the V-ohm multi-meter is used, the resistance reading would range from several tens MΩ to infinite. In other situations, the device has most likely broken down. (Generally, device destruction is represented by a short between G and E.)

2.2 C-E check

As shown in Fig.4-3, measure the leakage current or resistance between C and E, with a short between G and E. Be sure to connect the collector to (+) and the emitter to (-). Reverse connections will energize the FWD, causing C and E to be shorted to each other.

If the module is normal, the leakage current reading should read below the I_{CES} maximum specified in the datasheet. (If the V-ohm multi-meter is used, the resistance reading would range from several ten MΩ to infinity. In other situations, the device has most likely broken down. (Generally, device destruction is represented by a short between C and E.)

Note:

Never perform withstand voltage measurement between the collector and gate. It might cause the dielectric destruction of the oxide layer by applying excess voltage.

3 Typical trouble and troubleshooting

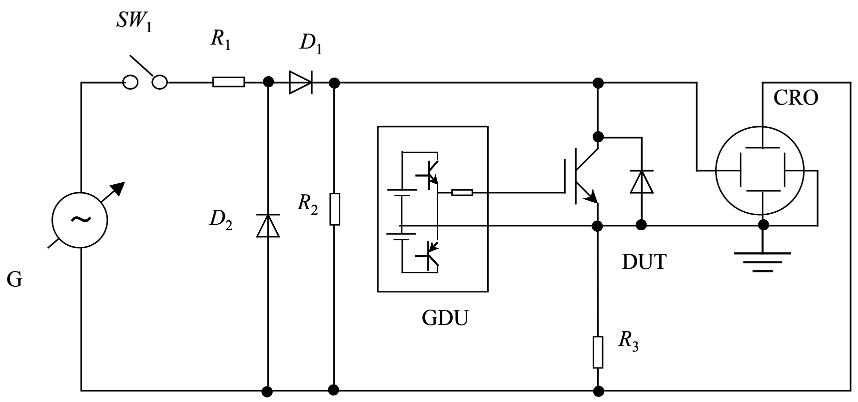
3.1 Energizing a main circuit voltage when the circuit between G and E is open

If a voltage is applied to the main circuit with the circuit between the gate and emitter open, the IGBT would be turned on autonomously, triggering large current flow to cause device destruction. Be sure to drive the device with a signal placed between G and E. This phenomenon occurs when the gate-emitter capacitance is charged through feedback capacitance Cres of the IGBT at the application of a main voltage with the circuit between G and E open, causing the IGBT to be turned on.

If the signal line is switched using a mechanical switch, such as a rotary switch, during product acceptance testing or on similar occasions, the circuit may open instantaneously between G and E at the time of switching could cause device destruction (the phenomenon described above).

When the mechanical switch chatters, a similar period is generated, leading to device destruction. To guard against such risks, be sure to discharge the main circuit voltage (between C and E) to 0V before switching the gate signal. When performing characteristics testing, such as acceptance testing, on a product comprising multiple devices (two or more), keep the gate and emitter shorted to each other on the devices other than the one under test.

Fig.4-4 shows an example of an on-voltage measurement circuit. The measurement sequence is described with reference to this measurement circuit. First, turn off the gate drive unit (GDU) (V_{GE} = 0V) and then turn on SW_1 to apply a voltage between C and E. Next, apply a predefined forward bias voltage between G and E from the GDU to energize the IGBT for measuring the on voltage. Lastly, turn off the gate circuit and then SW_1. Such sequencing will allow for safe measurement of device characteristics without risking destruction.



DUT: IGBT under test, GDU: Gate drive unit, G: Variable AC power supply
CRO: Oscilloscope, R_1, R_2: Protective resistance, R_3: Current measurement non-inductive resister
D_1, D_2: Diode, SW_1: Switch

Fig. 4-4 On voltage measurement circuit

3.2 Destruction caused by mechanical stress

If the terminals or pins are subjected to stress from a large external force or vibration, the internal electrical wiring of the product could be destroyed. Be careful by not mounting the device in an application that might be strenuous, minimize the chances of such destruction by reducing stress.

Fig.4-5 shows an example of mounting a gate drive printed circuit board (PCB) on top of the IGBT module.

As shown in (1), if the gate drive printed circuit board is mounted without clamping the PCB, the any PCB vibration could cause flexing possibly, stressing the module pins causing pin damage or internal electrical wiring damage. As shown in (2), the PCB needs to be clamped to prevent this problem. When taking this corrective action, use a dedicated fixing material having sufficient strength.

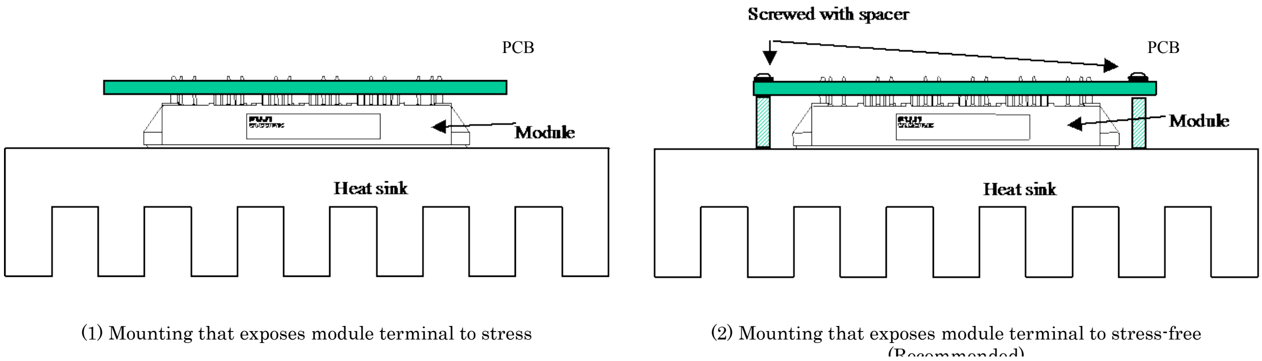


Fig. 4-5 Clamping a PCB

Fig.4-6 shows an example of main circuit wiring using a laminated bus bar. If there is a step difference between the (+) and (-) electrical wiring conductors as shown in (1), the terminals are continually exposed to upward tensile stress, causing a disconnect of the internal electrical wiring. To prevent this problem, it is necessary to insert a conductive spacer to eliminate the step difference between the conductors on the parallel plate. Furthermore, a gap in the wiring height location could also generate large tensile stress or external force to the terminals in the PCB structure. From this point, laminated bus bar or PCB needs to be mounted without tensile stress.

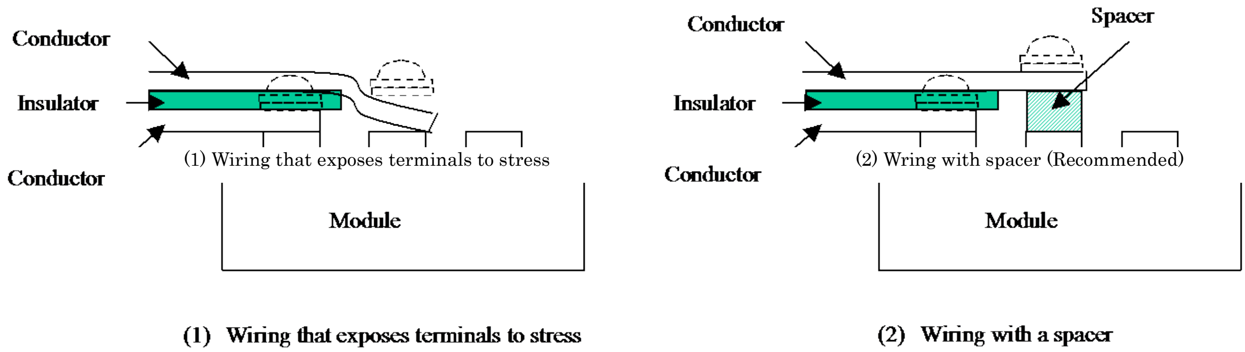


Fig. 4-6 Mounting in laminated bus bar is used

3.3 Accidental turn-on of the IGBT caused by insufficient reverse bias gate voltage $-V_{GE}$

Insufficient reverse bias gate voltage $-V_{GE}$ could cause both IGBTs in the upper and lower arms to be turned on after accidental turn-on, resulting in a short-circuit current flowing between them. A surge voltage or loss arising when this current is turned off may result in product destruction. In designing a circuit, make sure that no short-circuit currents are generated as a result of a short circuit between the upper and lower arms (recommended $-V_{GE}$ = 15V).

The occurrence of this phenomenon is described below with reference to Figs. 4-7 and 4-8.

An IGBT with $-V_{GE}$ applied is shown in Fig. 4-7. Assume that an IGBT is connected in series on the opposing arm as well, though it is not depicted. When the IGBT on the opposing arm is turned on, the FWD shown in Fig.4-7 recovers in reverse direction. Fig.4-8 shows the schematic waveform of V_{CE}, I_{CG} and V_{GE} at reverse recovery. As shown in Fig.4-8, when voltage sustained by FWD is lowered at reverse recovery, dv/dt is generated by raising the voltage between C and E at this time. This dv/dt causes current i_{CG} to flow through feedback resistance Cres between C and G and through gate resistance R_G as shown in Fig.4-7. This i_{CG} induces a potential difference of $\Delta V = R_G \times i_{CG}$ across the R_G, pushing up the V_{GE} towards the + side as shown in Fig.4-8. If the peak voltage of V_{GE} exceeds $V_{GE\ (th)}$, the IGBT is turned on, introducing short-circuit current flow through the upper and lower arms. Conversely, no short-circuit current will flow through the upper and lower arms unless the peak voltage of V_{GE} exceeds $V_{GE\ (th)}$. This problem can be suppressed by applying a sufficient reverse bias voltage ($-V_{GE}$). Because the required value of V_{GE} depends on the drive circuit used, gate wiring, R_G and the like, check for the presence or absence of a short-circuit current flow through the upper and lower arms when designing a circuit.

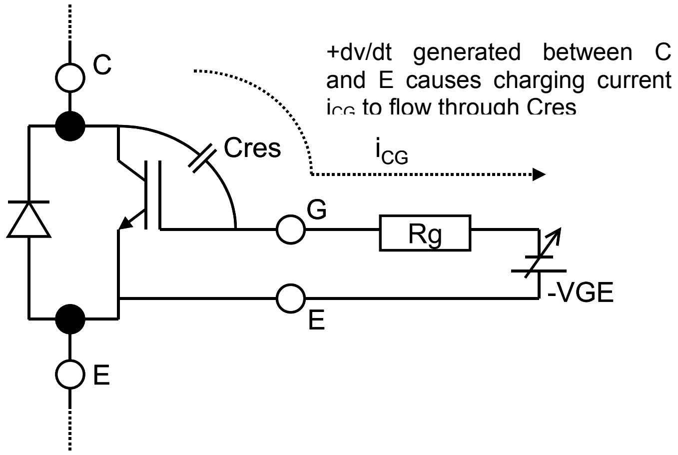


Fig. 4-7 Principles of dv/dt malfunctioning

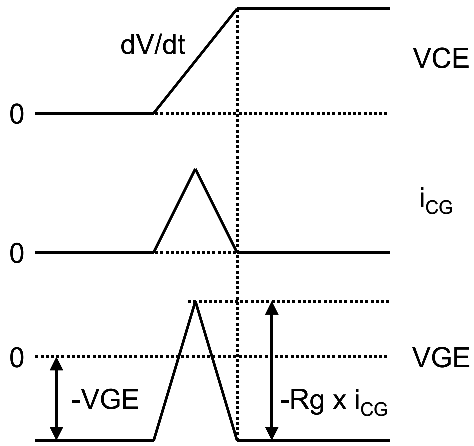


Fig.4-8 Waveforms during reverse recovery

Fig 4-9 shows an example of the method of checking for the presence or absence of the short-circuit current flow through the upper and lower arms. First, open the inverter output terminals (U, V, W) (that is, leave them under no load) as shown. Next, activate the inverter to drive the individual IGBTs. The presence or absence of the short-circuit current flow through the upper and lower arms can be determined by detecting current flow from the power line as shown. If a sufficient reverse bias current is applied, a very weak pulse current (about 5% of the rated current) that charges the device junction capacitance will be detected. With insufficient reverse bias voltage $-V_{GE,}$ this current increases.

To ensure correct determination, we recommend first detecting this current with the applied voltage $-V_{GE}$ = -15V. This eliminates the risk of false firings. Then measure the same current with the predefined value of $-V_{GE}$. If the two measurements of the current are equal, no false turn-on has occurred. In case that false turn-on is observed, a recommended solution is to increase the reverse bias voltage $-V_{GE}$ until the short-circuit current is eliminated or inserting a capacitance (C_{GE}) about half the Cies value between G and E near the module terminals. Verify the applicability of the method of the C_{GE} insertion beforehand, because it will significantly affect the switching time and switching losses. If you would like to have the similar switching losses and switching time before C_{GE} insertion, selection of approximately half R_G before C_{GE} insertion would be recommended. In this condition, no issue must be fully confirmed.

The short-circuit current flow through the upper and lower arms is caused by insufficient dead time, as well as accidental turn-on during dv/dt described above. A short-circuit current can be observed by running the test shown in Fig.4-9 while this phenomenon is present. If increasing the reverse bias voltage-V_{GE} does not help reduce the short-circuit current, take relevant action, such as increasing the dead time. (More detailed instructions can be found in Chapter 7.)

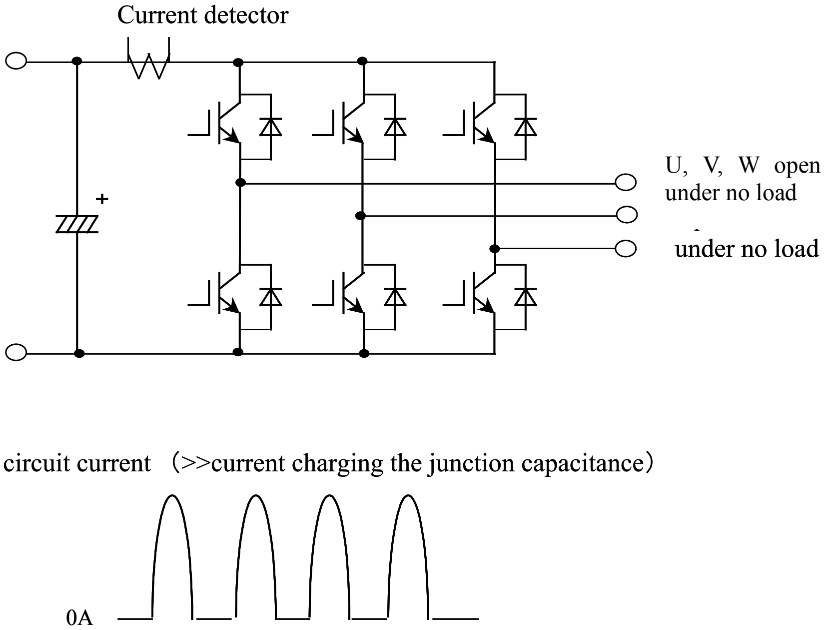


Fig. 4-9 Short-circuit current measuring circuit

3.4 Diode reverse recovery from a transient on state (Short off pulse reverse recovery)

The IGBT module contains a FWD. Paying full attention to the behavior of the FWD is very important for designing a dependable circuit. This section focuses on the less known phenomenon of short off pulse reverse recovery that could lead to product destruction.

Fig. 4-10 shows a timing chart in which an excessive surge voltage arises from short off pulse reverse recovery. According to this phenomenon, an extremely excessive reverse recovery surge voltage arises between C and E of the FWD on the opposing arm when very short off pulses (Tw) like those shown are generated after gate signal interruptions resulting from noise interferences during IGBT switching.

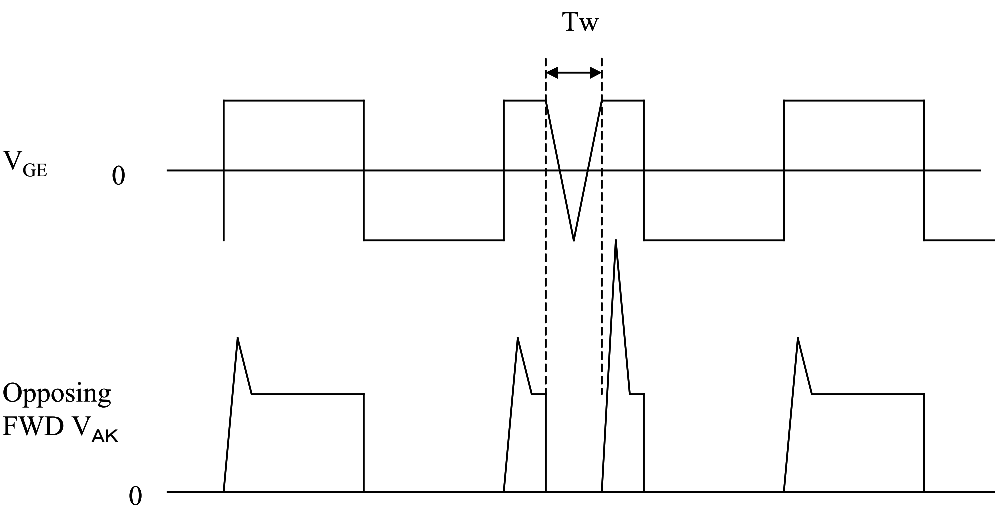


Fig. 4-10 Waveforms at short off pulse reverse recovery

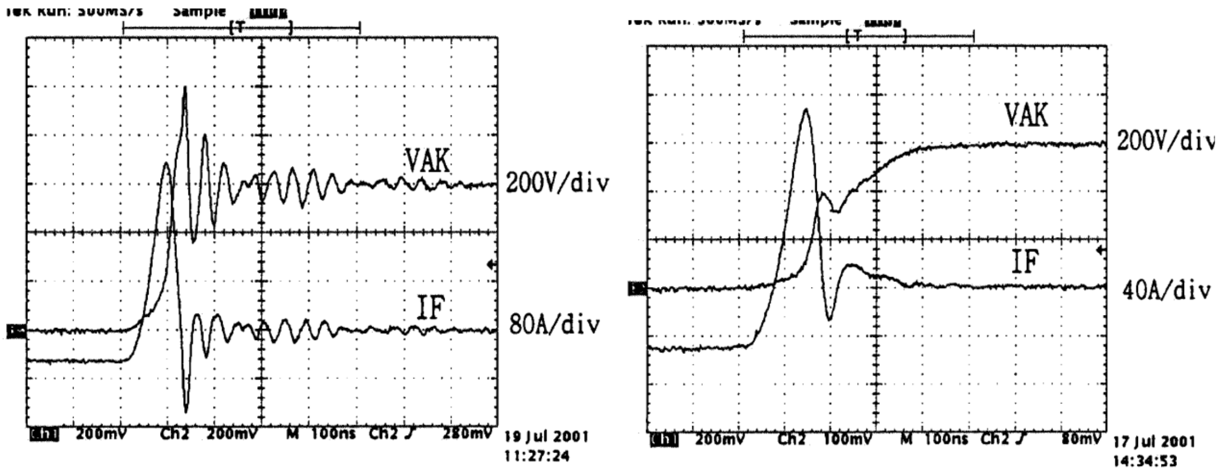
A surge voltage exceeding the guaranteed rated withstand voltage level of the module is most likely to lead to device destruction. Testing has confirmed a sharp increase in surge voltage when Tw < 1μs. Be sure not to design a circuit that will generate such short gate signal off pulses.

This phenomenon occurs because the FWD enters a state of reverse recovery very shortly after it is turned on, so that voltage application begins without a sufficient quantity of carrier stored in the FWD, with the depletion layer spreading rapidly to generate steep di/dt and dv/dt. With devices supporting an operation mode in which Tw is 1μs or shorter, verify that the surge voltage in the minimum period of Tw does not exceed the device withstand voltage.

If the surge voltage exceeds the device withstand voltage rating, take action to reduce surge voltages as follows.

- Increasing the R_G
- Cutting the circuit inductance
- Building up the snubber circuit
- Installing a C_{GE}
- Adding the clamping circuit

Fig. 4-11 shows the diode reverse-recovery waveforms when a short off pulse of 6MBI450U-120 (1200V, 450A). As shown below, surge voltage can be decreased by enlarging R_G from 1.0Ω to 5.6Ω



(1) Ron=1.0Ω (2) Ron=5.6Ω

Ed=600V, IF=50A, Tj=125°C, Tw=1μs

6MBI450U-120

Fig. 4-11 Waveforms of reverse recovery at short off pulse

Fuji Electric
Innovating Energy Technology

Fuji Electric Co., Ltd.

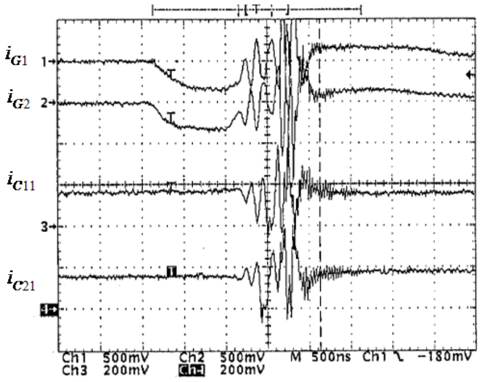
3.5 Oscillation from IGBTs connected in parallel

When products are connected in parallel, the uniformity of the main circuit wiring is very important. Without balanced wiring, concentrated transient currents could occur on the device having a shorter wiring path during switching, which could cause device destruction or degrade long-term reliability. In a main wiring circuit in which the wiring is not uniform or balanced the overall main circuit inductance will also be out of balance among the devices.

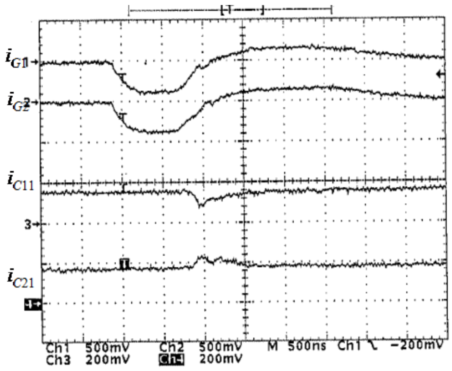
Consequently, voltages of varied potentials are generated in the individual wiring inductances from di/dt during switching, producing an abnormal oscillating current, such as a loop current, leading to possible device destruction.

Fig.4-12 (1) shows the oscillation phenomenon when the wiring inductance of the emitter portion is made extremely unbalanced. An IGBT can generate this oscillation current at the wiring loop in the emitter portion connected in parallel, this influences the gate voltage and the oscillation phenomenon which is generated by the high speed switching. A ferrite core (common mode) can be inserted in each gate emitter wiring circuit to reduce or eliminate the loop current in the emitter portion. Fig.4-12 (2)shows the waveforms with the common mode core. Note the elimination of the previous oscillation.

Give full consideration to maintaining circuit uniformity when designing main circuit wiring.



(1) When emitter inductance is unbalanced



(2) When the common mode core is inserted in gate emitter wiring

i_{G1}, i_{G2}:5A/div, i_{C11}, i_{C21}:100A/div, t:0.5μs/div, Ed=600V 1200V, 300A IGBT 2 parallel connection

Fig. 4-12 Waveforms of 2 parallel connection

3.6 Notes on the soldering process

Problems, such as melting case resin material, could result if excessive soldering temperature is applied when soldering a gate driver circuit or control circuit to the terminals of the IGBT module. Stay within normal soldering processes, avoid high exposure that exceeds maximum recommended terminal soldering defined in the specifications. (Terminal heat resistance test conditions that are covered in the general product specifications documents are listed below for reference.)

Solder temperature: 260±5°C
Dwell time: 10±1s
Cycles: 1

3.7 IGBT Module converter application

Diodes used in the IGBT modules have an I^2t rating. I^2t is a scale of the forward, non-repetitive overcurrent capability of current pulses having a very short duration (less than 10ms). Current (I) denotes the effective current, and time (t) indicates the pulse duration. If the IGBT module is used in a rectifier circuit (or converter circuit), do not exceed the maximum I^2t limits. If you approach the I^2t limits, insert a starter circuit having a resistance and a contactor connected in parallel, for example, between the AC power supply and the IGBT module. If fuse protection is used, select a fuse not exceeding rated I^2t.

3.8 Countermeasure of EMC noise

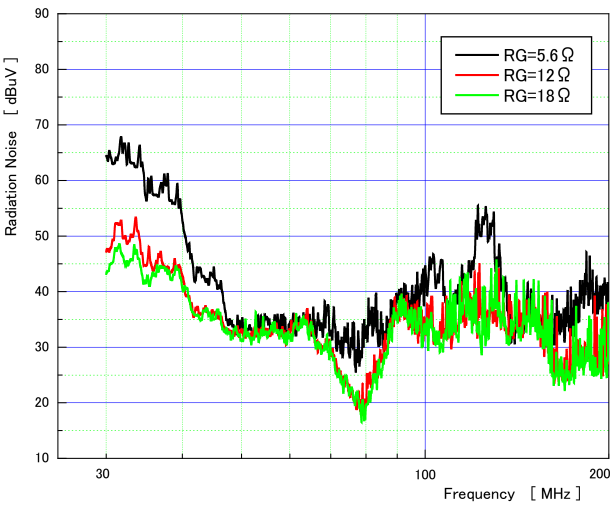
Amid the ongoing effort to comply with European CE marking for IGBT module-based converters, such as inverters and UPS, and with VCCI regulations in Japan, electromagnetic compatibility (EMC), particularly, holding down noise interferences (conductive and radiating noises emitted from devices in operation) to specifications or below, has become an essential aspect of circuit design.

As IGBT modules continue to offer enhanced characteristics, including faster switching and less loss, from generation to generation, high dv/dt and di/dt generated from their switching action is more frequently becoming a source of radiating noise interferences.

Radiation noises are primarily associated with harmonic LC resonance between stray capacitances, such as semiconductor device junction capacitances, and wiring stray inductances, triggered by high dv/dt and di/dt generated from the IGBTs during turn-on (reverse recovery of the FWD in the opposing arm).

Fig.4-14 shows examples of radiation noise of 1200V IGBT modules (2MBI150SC-120, 1200V, 150A). The radiation noise with twice standard gate resistance (12Ω) can decrease about 10dB or more.

A soft-waveform implementation of the switching characteristics to decrease radiation noises, however, tends to increase the switching loss. It is important to design the drive conditions to keep them balanced with the device operating conditions, module cooling conditions and other relevant conditions.



Motor driver:15kW, Molule:2MBI150SC-120

Fig. 4-14 Radiation noise of motor drivers

Moreover, a general example of countermeasures of radiation noise is shown in Table 4-2. Because the generation factor and noise level are different according to the wiring structure of the device and the material and the circuit composition, etc., it is necessary to verify which of the countermeasures is effective.

Table 4-2 Countermeasures of radiation noise

Action	Description	Remarks
Review drive conditions (cut dv/dt and di/dt)	Increase the gate resistance (particularly, turn-on side) to two to thee times the standard value listed in the datasheet.	The switching loss increases. The switching time lengthens.
	Insert a small capacitor between the gate and emitter. Its capacitance should be somewhere from the feedback capacitance to the input capacitance (Cres to Cies).	The switching loss increases. The switching time lengthens.
Minimize the wiring between the snubber capacitor and the IGBT module	Minimize the wiring distance between the snubber capacitor and the IGBT module (connect to the module pins).	Also useful for canceling surge voltages during switching and dv/dt.
Cut wiring inductances	Use laminated bus bars to reduce inductances.	Also useful for canceling surge voltages during switching and dv/dt.
Filtering	Connect noise filters to device input and output.	Various filters are commercially available.
Shield wirings	Shield the I/O cables to cut radiating noise from the cables.	
Metalize the device case	Metalize the device cabinet to suppress noise emissions from the device.	

WARNING

1. This Catalog contains the product specifications, characteristics, data, materials, and structures as of January 2017.
   The contents are subject to change without notice for specification changes or other reasons. When using a product listed in this Catalog, be sur to obtain the latest specifications.

2. All applications described in this Catalog exemplify the use of Fuji's products for your reference only. No right or license, either express or implied, under any patent, copyright, trade secret or other intellectual property right owned by Fuji Electric Co., Ltd. is (or shall be deemed) granted. Fuji Electric Co., Ltd. makes no representation or warranty, whether express or implied, relating to the infringement or alleged infringement of other's intellectual property rights which may arise from the use of the applications described herein.

3. Although Fuji Electric Co., Ltd. is enhancing product quality and reliability, a small percentage of semiconductor products may become faulty. When using Fuji Electric semiconductor products in your equipment, you are requested to take adequate safety measures to prevent the equipment from causing a physical injury, fire, or other problem if any of the products become faulty. It is recommended to make your design failsafe, flame retardant, and free of malfunction.

4. The products introduced in this Catalog are intended for use in the following electronic and electrical equipment which has normal reliability requirements.
   - Computers
   - OA equipment
   - Communications equipment (terminal devices)
   - Measurement equipment
   - Machine tools
   - Audiovisual equipment
   - Electrical home appliances
   - Personal equipment
   - Industrial robots etc.

5. If you need to use a product in this Catalog for equipment requiring higher reliability than normal, such as for the equipment listed below, it is imperative to contact Fuji Electric Co., Ltd. to obtain prior approval. When using these products for such equipment, take adequate measures such as a backup system to prevent the equipment from malfunctioning even if a Fuji's product incorporated in the equipment becomes faulty.
   - Transportation equipment (mounted on cars and ships)
   - Trunk communications equipment
   - Traffic-signal control equipment
   - Gas leakage detectors with an auto-shut-off feature
   - Emergency equipment for responding to disasters and anti-burglary devices
   - Safety devices
   - Medical equipment

6. Do not use products in this Catalog for the equipment requiring strict reliability such as the following and equivalents to strategic equipment (without limitation).
   - Space equipment
   - Aeronautic equipment
   - Nuclear control equipment
   - Submarine repeater equipment

8. If you have any question about any portion in this Catalog, ask Fuji Electric Co., Ltd. or its sales agents before using the product.
   Neither Fuji Electric Co., Ltd. nor its agents shall be liable for any injury caused by any use of the products not in accordance with instructions set forth herein.