流3xMNPC 1

 Features
- 3相混合电压组件拓扑
- 中性点钳位逆变器
- 无功功率能力
- 低电感布局

 Target Applications
- 太阳能逆变器
- UPS

 Types
- 10-FY12M3A040SH-M749F08
- 10-F112M3A040SH-M749F09

Maximum Ratings

$T_J=25^\circ C$, 除非另有说明

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Condition</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
</table>

### Half Bridge IGBT (T1,T4,T5,T8,T9,T12)

| Collector-emitter break down voltage | $V_{CE}$ | $T_J$=Tmax | 1200 | V |
| DC collector current | $I_C$ | $T_J$=Tmax | $T_J$=80°C | 31 | A |
| Pulsed collector current | $I_{PSS}$ | $I_{PSS}$ limited by $T_J$=max | 120 | A |
| Power dissipation per IGBT | $P_{tot}$ | $T_J$=Tmax | $T_J$=80°C | 75 | W |
| Turn off safe operating area | $I_C$ | $T_J$≤150°C | $V_{CE}$=$V_{CES}$ | 120 | A |
| Short circuit ratings | $t_{SC}$ | $T_J$≤150°C | $V_{CE}$=15V | 10 | μs |
| Gate-emitter peak voltage | $V_{GE}$ | | | ±20 | V |
| Maximum Junction Temperature | $T_J$=max | | | 175 | °C |

### Neutral P. FWD (D2,D3,D6,D7,D10,D11)

| Peak Repetitive Reverse Voltage | $V_{max}$ | | 600 | V |
| DC forward current | $I_F$ | $T_J$=Tmax | $T_J$=80°C | 18 | A |
| Surge forward current | $I_{FSM}$ | $I_{FSM}$ limited by $T_J$=max | 300 | A |
| Power dissipation per Diode | $P_{tot}$ | $T_J$=Tmax | $T_J$=80°C | 30 | W |
| Maximum Junction Temperature | $T_J$=max | | | 150 | °C |
## Maximum Ratings

**Tj=25°C, unless otherwise specified**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Condition</th>
<th>Value</th>
<th>Unit</th>
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</thead>
<tbody>
<tr>
<td>DC collector current</td>
<td>$I_C$</td>
<td>$T_{J}=T_{max}$</td>
<td>$23$</td>
<td>A</td>
</tr>
<tr>
<td>Pulsed collector current</td>
<td>$I_{Cpulse}$</td>
<td>$I_C$ limited by $T_{max}$</td>
<td>$90$</td>
<td>A</td>
</tr>
<tr>
<td>Power dissipation per IGBT</td>
<td>$P_{tot}$</td>
<td>$T_{J}=T_{max}$</td>
<td>$37$</td>
<td>W</td>
</tr>
<tr>
<td>Gate-emitter peak voltage</td>
<td>$V_{GE}$</td>
<td></td>
<td>$\leq 20$</td>
<td>V</td>
</tr>
<tr>
<td>Short circuit ratings</td>
<td>$I_{DC}$</td>
<td>$V_{GE}=15V$</td>
<td>$6$</td>
<td>µs</td>
</tr>
<tr>
<td>Turn off safe operating area (RBSOA)</td>
<td>$I_{on max}$</td>
<td>$I_{C E} \leq 600V$ $V_{CE} \leq 150°C$</td>
<td>$90$</td>
<td>A</td>
</tr>
<tr>
<td>Maximum Junction Temperature</td>
<td>$T_{J max}$</td>
<td></td>
<td>$175$</td>
<td>°C</td>
</tr>
</tbody>
</table>

**Half Bridge FWD (D1,D4,D5,D8,D9,D12)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Condition</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Repetitive Reverse Voltage</td>
<td>$V_{RRM}$</td>
<td></td>
<td>$1200$</td>
<td>V</td>
</tr>
<tr>
<td>DC forward current</td>
<td>$I_F$</td>
<td>$T_{J}=T_{max}$</td>
<td>$12$</td>
<td>A</td>
</tr>
<tr>
<td>Surge forward current</td>
<td>$I_{SGE}$</td>
<td>$10 ms, sin 180°, T_J = 150 °C$</td>
<td>$65$</td>
<td>A</td>
</tr>
<tr>
<td>Power dissipation per Diode</td>
<td>$P_{tot}$</td>
<td>$T_{J}=T_{max}$</td>
<td>$28$</td>
<td>W</td>
</tr>
<tr>
<td>Maximum Junction Temperature</td>
<td>$T_{J max}$</td>
<td></td>
<td>$175$</td>
<td>°C</td>
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</table>

**Thermal Properties**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Condition</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage temperature</td>
<td>$T_{stg}$</td>
<td></td>
<td>$-40...+125$</td>
<td>°C</td>
</tr>
<tr>
<td>Operation temperature under switching condition</td>
<td>$T_{op}$</td>
<td></td>
<td>$-40...+(T_{J max} - 25)$</td>
<td>°C</td>
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**Insulation Properties**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Condition</th>
<th>Value</th>
<th>Unit</th>
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</thead>
<tbody>
<tr>
<td>Insulation voltage</td>
<td>$V_{in}$</td>
<td>$I=2s$</td>
<td>$4000$</td>
<td>V</td>
</tr>
<tr>
<td>Creepage distance</td>
<td></td>
<td></td>
<td>min 12.7</td>
<td>mm</td>
</tr>
<tr>
<td>Clearance</td>
<td></td>
<td></td>
<td>min 12.7</td>
<td>mm</td>
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</table>
### Characteristic Values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Conditions</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>gate-emit threshold voltage</td>
<td>$V_{GE(th)}$</td>
<td>$\pm 15$</td>
<td>350</td>
<td>28</td>
</tr>
<tr>
<td>collector-emitter saturation voltage</td>
<td>$V_{CE(sat)}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>collector-emitter cut-off current incl. Diode</td>
<td>$I_{QCE}$</td>
<td>8</td>
<td>1200</td>
<td></td>
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<tr>
<td>gate-emitter leakage current</td>
<td>$I_{GEL}$</td>
<td>20</td>
<td>0</td>
<td></td>
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<tr>
<td>integrated Gate resistor</td>
<td>$R_{g int}$</td>
<td></td>
<td></td>
<td>none</td>
</tr>
<tr>
<td>turn-on delay time</td>
<td>$t_{det}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rise time</td>
<td>$\tau$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>turn-off delay time</td>
<td>$t_{off}$</td>
<td>$R_{g off}=8\ \Omega$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>fall time</td>
<td>$\tau$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>turn-on energy loss per pulse</td>
<td>$E_{on}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>turn-off energy loss per pulse</td>
<td>$E_{off}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input capacitance</td>
<td>$C_{iss}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output capacitance</td>
<td>$C_{oss}$</td>
<td></td>
<td></td>
<td>$f=1MHz$</td>
</tr>
<tr>
<td>Reverse transfer capacitance</td>
<td>$C_{riss}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gate charge</td>
<td>$Q_{gate}$</td>
<td>$R_{g off}=8\ \Omega$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal resistance chip to heatsink per chip</td>
<td>$R_{thJH}$</td>
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</table>

### Neutral P. FWD (D2,D3,D6,D7,D10,D11)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Conditions</th>
<th>Value</th>
<th>Unit</th>
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</thead>
<tbody>
<tr>
<td>Diode forward voltage</td>
<td>$V_D$</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reverse leakage current</td>
<td>$I_L$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak reverse recovery current</td>
<td>$I_{rr}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reverse recovery time</td>
<td>$\tau_{rr}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reverse recovered charge</td>
<td>$Q_{rr}$</td>
<td>$R_{g off}=8\ \Omega$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak rate of fall of recovery current</td>
<td>$\frac{di}{dt}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reverse recovered energy</td>
<td>$E_{rec}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal resistance chip to heatsink per chip</td>
<td>$R_{thJH}$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Characteristic Values

<table>
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<th>Parameter</th>
<th>Symbol</th>
<th>Conditions</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gate emitter threshold voltage</td>
<td>$V_{GE(th)}$</td>
<td>$V_{GE}=V_{GE(th)}$</td>
<td>$T=25^\circ C$</td>
<td>5.80</td>
</tr>
<tr>
<td>Collector-emitter saturation voltage</td>
<td>$V_{CE(sat)}$</td>
<td></td>
<td>$T=125^\circ C$</td>
<td>6.5</td>
</tr>
<tr>
<td>Collector-emitter cut-off incl diode</td>
<td>$I_{CES}$</td>
<td></td>
<td>$T=125^\circ C$</td>
<td>0.00016</td>
</tr>
<tr>
<td>Gate-emitter leakage current</td>
<td>$I_{GES}$</td>
<td></td>
<td>$T=125^\circ C$</td>
<td>300</td>
</tr>
<tr>
<td>Integrated Gate resistor</td>
<td>$R_{gint}$</td>
<td></td>
<td></td>
<td>none</td>
</tr>
<tr>
<td>Turn-on delay time</td>
<td>$t_{on}$</td>
<td>$R_{goff}=16 \Omega$</td>
<td>$T=25^\circ C$</td>
<td>164</td>
</tr>
<tr>
<td>Rise time</td>
<td>$t_{r}$</td>
<td>$R_{goff}=16 \Omega$</td>
<td>$T=125^\circ C$</td>
<td>74</td>
</tr>
<tr>
<td>Turn-off delay time</td>
<td>$t_{off}$</td>
<td>$R_{gon}=16 \Omega$</td>
<td>$T=25^\circ C$</td>
<td>16</td>
</tr>
<tr>
<td>Fall time</td>
<td>$t_{f}$</td>
<td>$R_{gon}=16 \Omega$</td>
<td>$T=125^\circ C$</td>
<td>91</td>
</tr>
<tr>
<td>Turn-on energy loss per pulse</td>
<td>$E_{on}$</td>
<td></td>
<td>$T=25^\circ C$</td>
<td>0.49</td>
</tr>
<tr>
<td>Turn-off energy loss per pulse</td>
<td>$E_{off}$</td>
<td></td>
<td>$T=125^\circ C$</td>
<td>0.98</td>
</tr>
<tr>
<td>Input capacitance</td>
<td>$C_{iss}$</td>
<td>$f=1$MHz</td>
<td>$T=25^\circ C$</td>
<td>108</td>
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<tr>
<td>Output capacitance</td>
<td>$C_{oss}$</td>
<td></td>
<td>$T=25^\circ C$</td>
<td>1630</td>
</tr>
<tr>
<td>Reverse transfer capacitance</td>
<td>$C_{oss}$</td>
<td></td>
<td>$T=25^\circ C$</td>
<td>50</td>
</tr>
<tr>
<td>Gate charge</td>
<td>$Q_{gss}$</td>
<td></td>
<td>$T=25^\circ C$</td>
<td>167</td>
</tr>
<tr>
<td>Thermal resistance chip to heatsink per chip</td>
<td>$R_{thJH}$</td>
<td>None</td>
<td></td>
<td>2.56</td>
</tr>
</tbody>
</table>

### Half Bridge FWD (D1,D4,D5,D8,D9,D12)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Conditions</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diode forward voltage</td>
<td>$V_{d}$</td>
<td></td>
<td>$T=25^\circ C$</td>
<td>2.28</td>
</tr>
<tr>
<td>Reverse leakage current</td>
<td>$I_{r}$</td>
<td></td>
<td>$T=125^\circ C$</td>
<td>2.39</td>
</tr>
<tr>
<td>Peak reverse recovery current</td>
<td>$I_{rss}$</td>
<td>$R_{goff}=16 \Omega$</td>
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<td>41</td>
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<tr>
<td>Reverse recovery time</td>
<td>$t_{r}$</td>
<td>$R_{goff}=16 \Omega$</td>
<td></td>
<td>44</td>
</tr>
<tr>
<td>Reverse recovered charge</td>
<td>$Q_{r}$</td>
<td></td>
<td></td>
<td>1.47</td>
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<tr>
<td>Peak rate of fall of recovery current</td>
<td>$di/(rd)_{max}$</td>
<td></td>
<td></td>
<td>2.33</td>
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<tr>
<td>Reverse recovery energy</td>
<td>$E_{rec}$</td>
<td></td>
<td></td>
<td>3534</td>
</tr>
<tr>
<td>Thermal resistance chip to heatsink per chip</td>
<td>$R_{thJH}$</td>
<td>None</td>
<td></td>
<td>3.36</td>
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</table>

### Thermistor

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Conditions</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated resistance</td>
<td>$R$</td>
<td></td>
<td>$T=25^\circ C$</td>
<td>21511</td>
</tr>
<tr>
<td>Deviation of $R_{100}$</td>
<td>$\Delta R/R$</td>
<td>$R_{100}=1486 \Omega$</td>
<td>$T_{c}=100^\circ C$</td>
<td>4.5</td>
</tr>
<tr>
<td>Power dissipation</td>
<td>$P$</td>
<td></td>
<td>$T=25^\circ C$</td>
<td>210</td>
</tr>
<tr>
<td>Power dissipation constant</td>
<td>$B_{(5,100)}$</td>
<td></td>
<td>$T=25^\circ C$</td>
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</tr>
<tr>
<td>B-value</td>
<td>$B_{(5,100)}$</td>
<td></td>
<td>$T=25^\circ C$</td>
<td>3884</td>
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<tr>
<td>B-value</td>
<td>$B_{(50,100)}$</td>
<td></td>
<td>$T=25^\circ C$</td>
<td>3964</td>
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<tr>
<td>Vincotech NTC Reference</td>
<td></td>
<td></td>
<td></td>
<td>F</td>
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</tbody>
</table>
Buck
Half Bridge IGBT and Neutral Point FWD

**Figure 1**
Typical output characteristics
$I_C = f(V_{CE})$

At
$\tau_p = 250 \mu s$
$T_j = 25^\circ C$
$V_{CE}$ from 7 V to 17 V in steps of 1 V

**Figure 2**
Typical output characteristics
$I_C = f(V_{CE})$

At
$\tau_p = 250 \mu s$
$T_j = 125^\circ C$
$V_{CE}$ from 7 V to 17 V in steps of 1 V

**Figure 3**
Typical transfer characteristics
$I_C = f(V_{GE})$

**Figure 4**
Typical diode forward current as a function of forward voltage
$I_F = f(V_F)$

At
$\tau_p = 250 \mu s$
$V_{CE} = 10 V$

copyright Vincotech
Typical switching energy losses
as a function of collector current

\[ E = f(I_C) \]

With an inductive load at

\[ T_j = 25/125 \quad ^\circ C \]

\[ V_{CE} = 350 \quad V \]

\[ V_{GE} = \pm 15 \quad V \]

\[ R_{gon} = 8 \quad \Omega \]

\[ R_{goff} = 8 \quad \Omega \]

Typical reverse recovery energy loss
as a function of collector current

\[ E_{rec} = f(I_C) \]

With an inductive load at

\[ T_j = 25/125 \quad ^\circ C \]

\[ V_{CE} = 350 \quad V \]

\[ V_{GE} = \pm 15 \quad V \]

\[ I_c = 28 \quad A \]
Buck

Half Bridge IGBT and Neutral Point FWD

Figure 9

Typical switching times as a function of collector current

\[ t = f(I_c) \]

With an inductive load at

- \( T_j = 125 \, ^\circ C \)
- \( V_{CE} = 350 \, V \)
- \( V_{GE} = \pm 15 \, V \)
- \( R_{gon} = 8 \, \Omega \)
- \( R_{goff} = 8 \, \Omega \)

Figure 10

Typical switching times as a function of gate resistor

\[ t = f(R_g) \]

With an inductive load at

- \( T_j = 125 \, ^\circ C \)
- \( V_{CE} = 350 \, V \)
- \( V_{GE} = \pm 15 \, V \)
- \( I_C = 28 \, A \)

Figure 11

Typical reverse recovery time as a function of collector current

\[ t_{rr} = f(I_c) \]

At

- \( T_j = 25/125 \, ^\circ C \)
- \( V_{CE} = 350 \, V \)
- \( V_{GE} = \pm 15 \, V \)
- \( R_{ggon} = 8 \, \Omega \)

Figure 12

Typical reverse recovery time as a function of IGBT turn on gate resistor

\[ t_{rr} = f(R_{gon}) \]

At

- \( T_j = 25/125 \, ^\circ C \)
- \( V_{OE} = 350 \, V \)
- \( I_V = 28 \, A \)
- \( V_{GEB} = \pm 15 \, V \)
**Typical reverse recovery charge as a function of collector current**

\[ Q_{rr} = f(I_C) \]

**Figure 13**

At
- \( T_j = 25/125 \) °C
- \( V_{CE} = 350 \) V
- \( V_{GE} = \pm 15 \) V
- \( R_{gon} = 8 \) Ω

---

**Typical reverse recovery current as a function of collector current**

\[ I_{RRM} = f(I_C) \]

**Figure 15**

At
- \( T_j = 25/125 \) °C
- \( V_{CE} = 350 \) V
- \( V_{GE} = \pm 15 \) V
- \( I_F = 28 \) A
- \( V_{GE} = \pm 15 \) V

---

**Typical reverse recovery charge as a function of IGBT turn on gate resistor**

\[ Q_{rr} = f(R_{gon}) \]

**Figure 14**

At
- \( T_j = 25/125 \) °C
- \( V_{CE} = 350 \) V
- \( V_{GE} = \pm 15 \) V

---

**Typical reverse recovery current as a function of IGBT turn on gate resistor**

\[ I_{RRM} = f(R_{gon}) \]

**Figure 16**

At
- \( T_j = 25/125 \) °C
- \( V_{CE} = 350 \) V
- \( I_F = 28 \) A
- \( V_{GE} = \pm 15 \) V
**Buck**

Half Bridge IGBT and Neutral Point FWD

---

**Figure 17**

Typical rate of fall of forward and reverse recovery current as a function of collector current

\[
\frac{dI}{dt}, \frac{dI_{rec}}{dt} = f(I_c)
\]

**Figure 18**

Typical rate of fall of forward and reverse recovery current as a function of IGBT turn on gate resistor

\[
\frac{dI}{dt}, \frac{dI_{rec}}{dt} = f(R_{gon})
\]

---

**Figure 19**

IGBT transient thermal impedance as a function of pulse width

\[
Z_{th,JH} = f(t_p)
\]

**Figure 20**

FWD transient thermal impedance as a function of pulse width

\[
Z_{th,JH} = f(t_p)
\]

---

**IGBT thermal model values**

<table>
<thead>
<tr>
<th>R (C/W)</th>
<th>Tau (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.18</td>
<td>8.2E-01</td>
</tr>
<tr>
<td>0.64</td>
<td>1.3E-01</td>
</tr>
<tr>
<td>0.30</td>
<td>4.8E-02</td>
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<tr>
<td>0.10</td>
<td>9.3E-03</td>
</tr>
<tr>
<td>0.06</td>
<td>8.0E-04</td>
</tr>
</tbody>
</table>

**FWD thermal model values**

<table>
<thead>
<tr>
<th>R (C/W)</th>
<th>Tau (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.11</td>
<td>2.4E-00</td>
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<tr>
<td>0.36</td>
<td>3.0E-01</td>
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<tr>
<td>1.41</td>
<td>6.5E-02</td>
</tr>
<tr>
<td>0.28</td>
<td>1.1E-02</td>
</tr>
<tr>
<td>0.19</td>
<td>1.6E-03</td>
</tr>
</tbody>
</table>
Power dissipation as a function of heatsink temperature

\[ P_{\text{tot}} = f(T_h) \]

Collector current as a function of heatsink temperature

\[ I_C = f(T_h) \]

At

\[ T_j = 175 \degree C \]

Power dissipation as a function of heatsink temperature

\[ P_{\text{tot}} = f(T_h) \]

Forward current as a function of heatsink temperature

\[ I_F = f(T_h) \]

At

\[ T_j = 150 \degree C \]
Figure 25  
Safe operating area as a function of collector-emitter voltage  
\[ I_C = f(V_{CE}) \]

- **D**: single pulse  
- **Th**: \( 80 \) °C  
- **V_{GE}**: \( \pm 15 \) V  
- **T_j**: \( T_{j_{\text{max}}} \) °C

Figure 26  
Gate voltage vs Gate charge  
\[ V_{GE} = f(Q_g) \]

Figure 27  
Reverse bias safe operating area  
\[ I_C = f(V_{CE}) \]

- **T_j**: \( T_{j_{\text{max}}}-25 \) °C  
- **DC link minus**: DC link plus

Switching mode: 3 level switching
Figure 1: IGBT
Typical output characteristics
$I_C = f(V_{CE})$

At
$\tau_p = 250 \mu s$
$T_j = 25 \degree C$
$V_{GE}$ from 7 V to 17 V in steps of 1 V

Figure 2: IGBT
Typical output characteristics
$I_C = f(V_{CE})$

At
$\tau_p = 250 \mu s$
$T_j = 125 \degree C$
$V_{GE}$ from 7 V to 17 V in steps of 1 V

Figure 3: IGBT
Typical transfer characteristics
$I_C = f(V_{GE})$

At
$\tau_p = 250 \mu s$
$V_{CE} = 10 \ V$

Figure 4: FWD
Typical diode forward current as a function of forward voltage
$I_F = f(V_F)$

At
$\tau_p = 250 \mu s$

$T_j = T_{jmax} - 25 \degree C$
Figure 5  IGBT
Typical switching energy losses
as a function of collector current
\[ E = f(I_C) \]

With an inductive load at
\[ T_j = 25/125 \, ^\circ\text{C} \]
\[ V_{CE} = 350 \, \text{V} \]
\[ V_{GE} = \pm 15 \, \text{V} \]
\[ R_{gon} = 16 \, \Omega \]
\[ I_C = 28 \, \text{A} \]

Figure 6  IGBT
Typical switching energy losses
as a function of gate resistor
\[ E = f(R_G) \]

With an inductive load at
\[ T_j = 25/125 \, ^\circ\text{C} \]
\[ V_{CE} = 350 \, \text{V} \]
\[ V_{GE} = \pm 15 \, \text{V} \]
\[ I_C = 28 \, \text{A} \]

Figure 7  FWD
Typical reverse recovery energy loss
as a function of collector current
\[ E_{rec} = f(I_C) \]

With an inductive load at
\[ T_j = 25/125 \, ^\circ\text{C} \]
\[ V_{CE} = 350 \, \text{V} \]
\[ V_{GE} = \pm 15 \, \text{V} \]
\[ R_{gon} = 16 \, \Omega \]

Figure 8  FWD
Typical reverse recovery energy loss
as a function of gate resistor
\[ E_{rec} = f(R_G) \]

With an inductive load at
\[ T_j = 25/125 \, ^\circ\text{C} \]
\[ V_{CE} = 350 \, \text{V} \]
\[ V_{GE} = \pm 15 \, \text{V} \]
\[ I_C = 28 \, \text{A} \]
Figure 9
Typical switching times as a function of collector current
\[ t = f(I_C) \]
With an inductive load at
\[ T_j = 125 \, ^\circ C \]
\[ V_{CE} = 350 \, V \]
\[ V_{GE} = \pm 15 \, V \]
\[ R_{gon} = 16 \, \Omega \]
\[ R_{goff} = 16 \, \Omega \]

Figure 10
Typical switching times as a function of gate resistor
\[ t = f(R_G) \]
With an inductive load at
\[ T_j = 125 \, ^\circ C \]
\[ V_{CE} = 350 \, V \]
\[ V_{GE} = \pm 15 \, V \]
\[ I_C = 28 \, A \]

Figure 11
Typical reverse recovery time as a function of collector current
\[ t_{rr} = f(I_C) \]
At
\[ T_j = 25/125 \, ^\circ C \]
\[ V_{CE} = 350 \, V \]
\[ V_{GE} = \pm 15 \, V \]
\[ R_{gon} = 16 \, \Omega \]

Figure 12
Typical reverse recovery time as a function of IGBT turn on gate resistor
\[ t_{rr} = f(R_{gon}) \]
At
\[ T_j = 25/125 \, ^\circ C \]
\[ V_{CE} = 350 \, V \]
\[ I_V = 28 \, A \]
\[ V_{GE} = \pm 15 \, V \]
Typical reverse recovery charge as a function of collector current

\[ Q_{rr} = f(I_C) \]

\[ Q_{rr} \text{ (mC)} \]

\[ Q_{rr \; \text{low } T} \]

\[ Q_{rr \; \text{high } T} \]

\[ 0 \quad 1 \quad 2 \quad 3 \quad 4 \]

\[ I_C \text{ (A)} \]

\[ 0 \quad 10 \quad 20 \quad 30 \quad 40 \quad 50 \quad 60 \]

At

\[ T_j = 25/125 \; ^\circ \text{C} \]

\[ V_{CE} = 350 \; \text{V} \]

\[ V_{GE} = \pm 15 \; \text{V} \]

\[ R_{gon} = 16 \; \Omega \]

Typical reverse recovery current as a function of collector current

\[ I_{RRM} = f(I_C) \]

\[ I_{RRM \; \text{low } T} \]

\[ I_{RRM \; \text{high } T} \]

\[ 0 \quad 10 \quad 20 \quad 30 \quad 40 \quad 50 \quad 60 \quad 70 \]

\[ I_C \text{ (A)} \]

\[ 0 \quad 15 \quad 30 \quad 45 \quad 60 \]

At

\[ T_j = 25/125 \; ^\circ \text{C} \]

\[ V_{CE} = 350 \; \text{V} \]

\[ V_{GE} = \pm 15 \; \text{V} \]

\[ I_{F} = 28 \; \text{A} \]

\[ V_{GE} = \pm 15 \; \text{V} \]

Typical reverse recovery current as a function of IGBT turn on gate resistor

\[ I_{RRM} = f(R_{gon}) \]

\[ I_{RRM \; \text{low } T} \]

\[ I_{RRM \; \text{high } T} \]

\[ 0 \quad 10 \quad 20 \quad 30 \quad 40 \quad 50 \quad 60 \quad 70 \]

\[ R_{gon} \text{ (\Omega)} \]

\[ 0 \quad 15 \quad 30 \quad 45 \quad 60 \]

At

\[ T_j = 25/125 \; ^\circ \text{C} \]

\[ V_{CE} = 350 \; \text{V} \]

\[ V_{GE} = \pm 15 \; \text{V} \]

\[ I_{F} = 28 \; \text{A} \]

\[ V_{GE} = \pm 15 \; \text{V} \]
Figure 17
Typical rate of fall of forward and reverse recovery current as a function of collector current
\[ \frac{dI_0}{dt}, \frac{dI_{rec}}{dt} = f(I_c) \]

At
- \( T_j = 25/125 \) °C
- \( V_{CE} = 350 \) V
- \( V_{GE} = \pm 15 \) V
- \( R_{gon} = 16 \) Ω

Figure 19
IGBT transient thermal impedance as a function of pulse width
\[ Z_{thJH} = f(t_p) \]

At
- \( D = 0.5 \)
- \( 0.2 \)
- \( 0.1 \)
- \( 0.05 \)
- \( 0.02 \)
- \( 0.01 \)
- \( 0.005 \)
- \( 0.000 \)

IGBT thermal model values

<table>
<thead>
<tr>
<th>R (C/W)</th>
<th>Tau (s)</th>
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<tbody>
<tr>
<td>0.10</td>
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<td>0.11</td>
<td>5.1E-04</td>
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</table>

Figure 18
Typical rate of fall of forward and reverse recovery current as a function of IGBT turn on gate resistor
\[ \frac{dI_0}{dt}, \frac{dI_{rec}}{dt} = f(R_{gon}) \]

At
- \( T_j = 25/125 \) °C
- \( V_{CE} = 350 \) V
- \( I_F = 28 \) A
- \( V_{GE} = \pm 15 \) V

Figure 20
FWD transient thermal impedance as a function of pulse width
\[ Z_{thJH} = f(t_p) \]

At
- \( D = 0.5 \)
- \( 0.2 \)
- \( 0.1 \)
- \( 0.05 \)
- \( 0.02 \)
- \( 0.01 \)
- \( 0.005 \)
- \( 0.000 \)

FWD thermal model values

<table>
<thead>
<tr>
<th>R (C/W)</th>
<th>Tau (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.11</td>
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<td>0.34</td>
<td>7.0E-04</td>
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</table>
Power dissipation as a Collector current as a function of heatsink temperature

\[ P_{tot} = f(T_h) \]

\[ I_C = f(T_h) \]

At

\[ T_j = 175 \, ^\circ\text{C} \]

Power dissipation as a Forward current as a function of heatsink temperature

\[ P_{tot} = f(T_h) \]

\[ I_F = f(T_h) \]

At

\[ T_j = 175 \, ^\circ\text{C} \]

\[ V_{GE} = 15 \, \text{V} \]
Figure 1

Typical NTC characteristic as a function of temperature

$R_T = f(T)$
Switching Definitions Neutral Point

General conditions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_J$</td>
<td>125 °C</td>
</tr>
<tr>
<td>$R_{son}$</td>
<td>16 Ω</td>
</tr>
<tr>
<td>$R_{off}$</td>
<td>16 Ω</td>
</tr>
</tbody>
</table>

Figure 1: Boost IGBT
Turn-off Switching Waveforms & definition of $t_{doff}$, $t_{Eoff}$

$V_{GE}(0\%) = -15$ V
$V_{GE}(100\%) = 15$ V
$V_{C}(100\%) = 350$ V
$I_{C}(100\%) = 28$ A
$t_{doff} = 0.19$ µs
$t_{Eoff} = 0.39$ µs

Figure 2: Boost IGBT
Turn-on Switching Waveforms & definition of $t_{don}$, $t_{Eon}$

$V_{CE}(0\%) = -15$ V
$V_{CE}(100\%) = 15$ V
$V_{C}(100\%) = 350$ V
$I_{C}(100\%) = 28$ A
$t_{don} = 0.11$ µs
$t_{Eon} = 0.26$ µs

Figure 3: Boost IGBT
Turn-off Switching Waveforms & definition of $t_f$

$V_{C}(100\%) = 350$ V
$I_{C}(100\%) = 28$ A
$t_f = 0.09$ µs

Figure 4: Boost IGBT
Turn-on Switching Waveforms & definition of $t_r$

$V_{C}(100\%) = 350$ V
$I_{C}(100\%) = 28$ A
$t_r = 0.02$ µs
Switching Definitions Neutral Point

**Figure 5**  
**Boost IGBT**  
**Turn-off Switching Waveforms & definition of t\textsubscript{Eoff}**

- P\textsubscript{off} (100%) = 9.70 kW
- E\textsubscript{off} (100%) = 0.98 mJ
- t\textsubscript{Eoff} = 0.39 \mu s

**Figure 6**  
**Boost IGBT**  
**Turn-on Switching Waveforms & definition of t\textsubscript{Eon}**

- P\textsubscript{on} (100%) = 9.70 kW
- E\textsubscript{on} (100%) = 0.66 mJ
- t\textsubscript{Eon} = 0.26 \mu s

**Figure 7**  
**Boost IGBT**  
**Gate voltage vs Gate charge (measured)**

- V\textsubscript{GEoff} = -15 V
- V\textsubscript{GEon} = 15 V
- V\textsubscript{C} (100%) = 350 V
- I\textsubscript{I} (100%) = 28 A
- Q\textsubscript{g} = 277 nC

**Figure 8**  
**Buck FWD**  
**Turn-off Switching Waveforms & definition of t\textsubscript{rr}**

- V\textsubscript{f} (100%) = 350 V
- I\textsubscript{f} (100%) = 28 A
- I\textsubscript{f} (100%) = -44 A
- t\textsubscript{rr} = 0.11 \mu s
Switching Definitions Neutral Point

Figure 9  Boost IGBT
Turn-on Switching Waveforms & definition of $t_{Qrr}$
($t_{Qrr}$ = integrating time for $Q_{rr}$)

1. $I_{d}$ (100%) = 28 A
2. $Q_{rr}$ (100%) = 2.73 µC
3. $t_{Qrr}$ = 1.00 µs

Figure 10  Buck FWD
Turn-on Switching Waveforms & definition of $t_{Erec}$
($t_{Erec}$ = integrating time for $E_{rec}$)

1. $P_{rec}$ (100%) = 9.70 kW
2. $E_{rec}$ (100%) = 0.71 mJ
3. $t_{Erec}$ = 1.00 µs

Measurement circuits

Figure 11  Neutral Point stage switching measurement circuit
Switching Definitions Half Bridge

General conditions

\[ T_J = 125 \, ^\circ\text{C} \]
\[ R_{\text{on}} = 8 \, \Omega \]
\[ R_{\text{off}} = 8 \, \Omega \]

Figure 1
Turn-off Switching Waveforms & definition of \( t_{\text{doff}}, t_{\text{Eoff}} \)

\( t_{\text{doff}} \) = integrating time for \( E_{\text{off}} \)

- \( V_{\text{GE}}(0\%) = -15 \, \text{V} \)
- \( V_{\text{GE}}(100\%) = 15 \, \text{V} \)
- \( I_{\text{C}}(100\%) = 28 \, \text{A} \)
- \( t_{\text{Eoff}} = 0.61 \, \mu\text{s} \)
- \( t_{\text{doff}} = 0.22 \, \mu\text{s} \)

Figure 2
Turn-on Switching Waveforms & definition of \( t_{\text{don}}, t_{\text{Eon}} \)

\( t_{\text{Eon}} \) = integrating time for \( E_{\text{on}} \)

- \( V_{\text{GE}}(0\%) = -15 \, \text{V} \)
- \( V_{\text{GE}}(100\%) = 15 \, \text{V} \)
- \( I_{\text{C}}(100\%) = 28 \, \text{A} \)
- \( t_{\text{Eon}} = 0.20 \, \mu\text{s} \)
- \( t_{\text{don}} = 0.07 \, \mu\text{s} \)

Figure 3
Turn-off Switching Waveforms & definition of \( t_{\text{f}} \)

- \( V_{\text{CE}}(100\%) = 350 \, \text{V} \)
- \( I_{\text{C}}(100\%) = 28 \, \text{A} \)
- \( t_{\text{f}} = 0.08 \, \mu\text{s} \)

Figure 4
Turn-on Switching Waveforms & definition of \( t_{\text{r}} \)

- \( V_{\text{CE}}(100\%) = 350 \, \text{V} \)
- \( I_{\text{C}}(100\%) = 28 \, \text{A} \)
- \( t_{\text{r}} = 0.02 \, \mu\text{s} \)

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Switching Definitions Half Bridge

Figure 5  Buck IGBT
Turn-off Switching Waveforms & definition of $t_{\text{Eoff}}$

- $P_{\text{off}}$ (100%) = 9.75 kW
- $E_{\text{off}}$ (100%) = 1.16 mJ
- $t_{\text{Eoff}}$ = 0.61 µs

Figure 6  Buck IGBT
Turn-on Switching Waveforms & definition of $t_{\text{Eon}}$

- $P_{\text{on}}$ (100%) = 9.75 kW
- $E_{\text{on}}$ (100%) = 0.52 mJ
- $t_{\text{Eon}}$ = 0.20 µs

Figure 7  Buck IGBT
Gate voltage vs Gate charge (measured)

- $V_{\text{GEoff}}$ = -15 V
- $I_{\text{d(fitted)}}$ = 299.41 nC

Figure 8  Boost FWD
Turn-off Switching Waveforms & definition of $t_{\text{rr}}$

- $V_{\text{GEon}}$ = 15 V
- $I_{\text{C1}}$ (1%) = 28 A
- $V_{\text{C}}$ (100%) = 350 V
- $I_{\text{rr}}$ (100%) = -41 A
- $Q_{\text{g}}$ = 299.41 nC
- $Q_{\text{g}}$ = 299.41 nC

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Switching Definitions Half Bridge

**Figure 9** Buck IGBT
Turn-on Switching Waveforms & definition of $t_{Qrr}$
($t_{Erec}$ = integrating time for $E_{rec}$)

- $i_s (100\%) = 28$ A
- $Q_{rr} (100\%) = 0.92$ µC
- $t_{Qrr} = 0.08$ µs

**Figure 10** Boost FWD
Turn-on Switching Waveforms & definition of $t_{Erec}$
($t_{Erec}$ = integrating time for $E_{rec}$)

- $P_{rec} (100\%) = 9.75$ kW
- $E_{rec} (100\%) = 0.12$ mJ
- $t_{Erec} = 0.08$ µs

**Measurement circuits**

**Figure 11** Half Bridge stage switching measurement circuit
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