T-type **Advanced 3-level Inverter Module**

Power dissipation and comparison tables

1. Introduction of Advanced 3-level Inverter Module
2. Inverter Mode comparison in 300A modules
3. Rectifier Mode comparison in 300A modules
4. RB-IGBT device characteristics

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Fuji Electric Co., Ltd.

Electronic Device Business headquarters,

Technology Division
2-level, NPC and A-NPC 3-level control

A-NPC 3-level is suitable topology for High efficiency alternative Energy systems.

<table>
<thead>
<tr>
<th>Type</th>
<th>2-level Inverter</th>
<th>NPC 3-level Inverter</th>
<th>A-NPC 3-level with Reverse series</th>
<th>A-NPC 3-level with RB-IGBT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circuit</td>
<td><img src="image1" alt="2-level Inverter diagram" /></td>
<td><img src="image2" alt="NPC 3-level Inverter diagram" /></td>
<td><img src="image3" alt="A-NPC 3-level Inverter with Reverse series diagram" /></td>
<td><img src="image4" alt="A-NPC 3-level Inverter with RB-IGBT diagram" /></td>
</tr>
<tr>
<td>Device</td>
<td>IGBT:1200V</td>
<td>IGBT:600V</td>
<td>IGBT:1200V +600V(Reverse series)</td>
<td>IGBT:1200V +600V(RB-IGBT)</td>
</tr>
<tr>
<td>Output Voltage</td>
<td><img src="image5" alt="Output Voltage graph" /></td>
<td><img src="image6" alt="Output Voltage graph" /></td>
<td><img src="image7" alt="Output Voltage graph" /></td>
<td><img src="image8" alt="Output Voltage graph" /></td>
</tr>
<tr>
<td>On-loss</td>
<td>Small</td>
<td>Large</td>
<td>Large</td>
<td>Small</td>
</tr>
<tr>
<td>SW-loss</td>
<td>Large</td>
<td>Small</td>
<td>Small</td>
<td>Small</td>
</tr>
<tr>
<td>Filter loss</td>
<td>Large</td>
<td>Small</td>
<td>Small</td>
<td>Small</td>
</tr>
<tr>
<td>Composing</td>
<td>Easy</td>
<td>Complication</td>
<td>Easy</td>
<td>Easy</td>
</tr>
<tr>
<td>Total</td>
<td>Normal</td>
<td>Normal</td>
<td>Good</td>
<td>Excellent</td>
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</table>
2-level, NPC and A-NPC 3-level control comparison, in Inverter Mode

A-NPC 3-level is suitable topology for High efficiency alternative Energy systems.

<table>
<thead>
<tr>
<th>2-level Inverter (2L)</th>
<th>NPC 3-level Inverter (NPC)</th>
<th>A-NPC 3-level</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1, T2, T3, T4</td>
<td>T1, T2, T3, T4</td>
<td>Reverse series</td>
</tr>
<tr>
<td>IGBT: 1200V</td>
<td>IGBT: 600V</td>
<td>RB-IGBT: 600V</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Losses in Inverter Mode (W)</th>
<th>2-level</th>
<th>NPC 3-level</th>
<th>A-NPC 3-level (Reverse series)</th>
<th>A-NPC 3-level (RB-IGBT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2500</td>
<td>2109.1</td>
<td>1799.7</td>
<td>1526.6</td>
<td>1504.8</td>
</tr>
<tr>
<td>2000</td>
<td>1799.7</td>
<td>1526.6</td>
<td>1504.8</td>
<td></td>
</tr>
<tr>
<td>1500</td>
<td>1526.6</td>
<td>1504.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>1504.8</td>
<td>1504.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>500</td>
<td>1504.8</td>
<td>1504.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1504.8</td>
<td>1504.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- 2-level: 100% efficiency
- NPC 3-level: 85.3% efficiency
- A-NPC 3-level (Reverse series): 72.4% efficiency
- A-NPC 3-level (RB-IGBT): 71.3% efficiency

IGBT: 1200V, IGBT: 600V, IGBT: 1200V/600V, RB-IGBT: 600V
2-level, NPC and A-NPC 3-level control comparison, in Rectifier Mode

A-NPC 3level is suitable topology for High efficiency alternative Energy systems.

<table>
<thead>
<tr>
<th>2-level Inverter (2L)</th>
<th>NPC 3-level Inverter (NPC)</th>
<th>A-NPC 3-level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Reverse series</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IGBT:1200V</td>
<td>IGBT:600V</td>
<td>IGBT:1200V/600V, RB-IGBT:600V</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Losses in Rectifier Mode (W)</th>
<th>100%</th>
<th>84.0%</th>
<th>73.4%</th>
<th>72.2%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2086.2</td>
<td>1752.9</td>
<td>1531.3</td>
<td>1508.1</td>
</tr>
<tr>
<td>1500</td>
<td>573.5</td>
<td>635.0</td>
<td>602.1</td>
<td>602.1</td>
</tr>
<tr>
<td>1000</td>
<td>562.7</td>
<td>326.3</td>
<td>336.0</td>
<td>336.0</td>
</tr>
<tr>
<td>500</td>
<td>950.0</td>
<td>326.3</td>
<td>570.0</td>
<td>570.0</td>
</tr>
<tr>
<td>0</td>
<td>570.0</td>
<td>570.0</td>
<td>570.0</td>
<td>570.0</td>
</tr>
</tbody>
</table>

IGBT: 1200V / 600V / 1200V/600V / RB-IGBT: 600V
Fuji A-NPC 3-level inverter  Module “100A Type”

Type name : 12MBI100VN-120-50
12MBI100VX-120-50
T1,T2 : 1200V/100A
T3,T4 : 600V/100A
For 400V class AC output

Equivalent circuit
Fuji A-NPC 3-level inverter Module “300A Type”

Type name : 4MBI300VG-120R-50
T1, T2 : 1200V/300A
T3, T4 : 600V/300A
For 400V class AC output

Equivalent circuit
(T3 and T4 are RB-IGBT)

Package outline
Inverter Mode comparison in 300A modules

2-level; 2MBI300VH-120-50
NPC 3-level; 2MBI300VB-060-50 series
Advanced 3-level; 4MBI300VG-120R-50

Conditions;
100kVA Inverter
AC 400V, Io=145A, cosθ=1
Vdc=660V(330V+330V), Modulation rate =0.98
Tj=125deg,
Rg(T1,T2)=+10/-1ohm, Rg(T3,T4)=+8.2/-39ohm
Total Loss Comparison in “Inverter Mode”

✓ Advanced 3-level module achieves lowest loss in 30kHz and less carrier frequency
Device Loss comparison in “Inverter Mode”

✓ Advanced 3-level module achieves lowest loss in 30kHz and less carrier frequency
Loss Comparison in fc=5kHz “Inverter Mode”

- Total loss of A-3level Inverter is lowest in 5kHz “Inverter Mode”
- 30% loss reduction from 2-level Inverter
- 17% loss reduction from NPC 3-level Inverter
**Device Loss Analysis in fc=5kHz “Inverter Mode”**

- T1 and T4 FWD of A-3 level is not flowed the current.

<table>
<thead>
<tr>
<th>Device Loss (W)</th>
<th>2-Level</th>
<th>NPC 3-Level</th>
<th>A-3 Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1,T2 FWD</td>
<td>29.1 Prr</td>
<td>9.8 Pf</td>
<td>9.0 Prr</td>
</tr>
<tr>
<td></td>
<td>9.8 Pf</td>
<td>84.0 Psat</td>
<td>24.7 Psat</td>
</tr>
<tr>
<td></td>
<td>25.7 Pon</td>
<td>16.3 Poff</td>
<td>20.7 Poff</td>
</tr>
<tr>
<td></td>
<td>89.6 Psat</td>
<td>10.9 Pon</td>
<td>17.4 Pon</td>
</tr>
<tr>
<td>T1,T2 IGBT</td>
<td>29.1 Prr</td>
<td>84.0 Psat</td>
<td>83.9 Psat</td>
</tr>
<tr>
<td>T2,T3 IGBT</td>
<td>9.8 Pf</td>
<td>16.3 Poff</td>
<td>20.7 Poff</td>
</tr>
<tr>
<td>CD1,2 FWD</td>
<td>17 Pf</td>
<td>10.9 Pon</td>
<td>17.4 Pon</td>
</tr>
<tr>
<td>T3,T4 RB-IGBT</td>
<td>9.0 Prr</td>
<td>17.4 Pon</td>
<td>83.9 Psat</td>
</tr>
</tbody>
</table>
Rectifier Mode comparison in 300A modules

2-level; 2MBI300VH-120-50
NPC 3-level; 2MBI300VB-060-50 series
Advanced 3-level; 4MBI300VG-120R-50

Conditions;
100kVA Inverter
AC 400V, Io=145A, cosθ=1
Vdc=660V(330V+330V), Modulation rate =0.98
Tj=125deg
Rg(T1,T2)=+10/-1ohm, Rg(T3,T4)=+8.2/-39ohm
Total Loss Comparison in “Rectifier Mode”

✓ Advanced 3-level module achieves lowest loss in 20kHz and less carrier frequency
Device Loss comparison in “Rectifier Mode”

✓ Advanced 3-level module achieves lowest loss in 20kHz and less carrier frequency

Device Loss as 5kHz loss 100%
Loss Comparison in fc=5kHz “Rectifier Mode”

- Total loss of A-3level Inverter is lowest in 5kHz “Rectifier Mode”
- 30% loss reduction from 2-level Inverter
- 14% loss reduction from NPC 3-level Inverter

![Diagram showing dissipation losses for different inverters at different frequencies.](image-url)
Device Loss Analysis in fc=5kHz “Rectifier Mode”

✓ T1 and T4 FWD of A-3 level is not flowed the current.

- T1 and T4 FWD of A-3 level is not flowed the current.

---

Device Loss (W)

<table>
<thead>
<tr>
<th>2level</th>
<th>NPC 3level</th>
<th>A-3level</th>
</tr>
</thead>
<tbody>
<tr>
<td>85.5</td>
<td>61.1</td>
<td>75.6</td>
</tr>
<tr>
<td>29.1</td>
<td>17.1</td>
<td>21.5</td>
</tr>
<tr>
<td>39.0</td>
<td>10.9</td>
<td>14.0</td>
</tr>
<tr>
<td>10.1</td>
<td>17.3</td>
<td>24.7</td>
</tr>
<tr>
<td></td>
<td>13.4</td>
<td>20.5</td>
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<td>16.3</td>
<td></td>
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<tr>
<td></td>
<td>16.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>11.1</td>
<td></td>
</tr>
</tbody>
</table>

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- T1, T2 FWD
- T2, T3 FWD
- T3, T4 RB-IGBT
- T1, T2 IGBT
Reduction control of RB-IGBT leakage current
RB-IGBT Leakage Current Loss in “300A type”

- RB-IGBT leakage Current loss is extremely low at Tj=125deg
- Junction temperature, Tj, must be below 125deg

![Bar chart showing device losses (W) for A-3 Level module with and without leakage current reduction control]

A-3 Level module
- With Leakage Current Reduction Control
- Without Leakage Current Reduction Control

Device losses (W)

1504.8
1521.2
651.9
570.0

Leakage Current Loss
Von Loss
SW Loss
Filter Loss

+0.01%
Only
100%
100.01%
RB-IGBT Leakage current

Leakage current can be reduced with $V_{g}=+15V$

$V_{g}=0V$ ~ $-15V$

$V_{g}=+15V$
RB-IGBT device characteristics
Cross sectional diagram of RB-IGBT

Carrier generation at dicing surface
Blocking voltage characteristics of RB-IGBT

![Graph showing blocking voltage characteristics of RB-IGBT (V_{GE} = +15V) and Conventional NPT-IGBT (V_{GE} = +15V). The graph includes blocking voltage characteristics at Tj=25°C.](image)
Trade-off relationship for RB-IGBT

600V/100A device

Vce(sat) @Tj=125degC

Eoff (mJ) @Tj=125degC

RB-IGBT

IGBT + FWD
The switching waveforms of RB-IGBT

Condition:
T3 switching T1-FWD recovery mode
Tj=RT, Vcc2=400V, Ic=300A, RG=+8.2/-39ohm
VGE(T3)=+/-15V, VGE(T4)=+15V, snubber=1.84uF, Ls=34nH

Condition:
T1 switching T4 RB-IGBT recovery mode
Tj=RT, Vcc2=400V, Ic=300A, RG=+10ohm
VGE(T1)=+/-15V, VGE(T4)=+15V, snubber=1.84uF, Ls=34nH

Fuji RB-IGBT can be realized of fast switching operation same as normal IGBT and FWD.
RB-IGBT Turn-On, Turn-OFF measurement Circuit

- Wiring Inductance
- $V_{cc2}$ 400V
- $L_s = 34\text{nH}$
- $1.8\mu\text{F}$

Diagram:
- $V_{GE} = +15\text{V}$
- $V_{GE} = -15\text{V}$
- $I_c$ (current flow indicator)
- $V_{ce}$
- $V_{cc2}$
- $T_1$, $T_2$, $T_3$, $T_4$
- M403

Diode $D$ notation and connections.
RB-IGBT Reverse Recovery measurement Circuit

Wiring Inductance

Vcc2

400V

1.8uF

Ls=34nH

VGE = -15V

T3

T1

T4

VGE = +15V

VGE = -15V

Vce

M403

M

N

IGBT

Reverse Recovery measurement Circuit

Ic
Mechanism of RB-IGBT Leakage current

Mechanism at reverse voltage

Generation of hole at Reverse voltage area
- Electron flow through the emitter area
- This electron is base current of PNP transistor
- Generation of Hole at P-layer
- Generation of Large leakage current

Reverse voltage area
Reduction method of Leakage current

(i) G-E short

- $V_{GE} = +15V$
- Electron flows the $n^+$ of Emitter
- Not generation of Hole
- “pn diode operation”
- Small Leakage current

(ii) $V_{GE} = +15V$

- Electron flows the $n^+$ of Emitter
- Not generation of Hole
- “pn diode operation”
- Small Leakage current

$pnp$ Base Open

⇒ Generation of hole from emitter
⇒ Large Leakage current

Reverse Voltage
When RB-IGBT uses the FWD mode, please input the Vge = +15V. Because the Leakage current of RB-IGBT is larger when the Vge=0V. RB-IGBT leakage current can be reduced with Vge=+15V.

When T3 uses the FWD mode, please input the Vge = +15V of T3.
12 in 1, 100A type module
Comparison of Device Loss (12in1 module “100A Type”)

- “100A Type” switching loss is same level of NPC 3level.
- The Total loss of “100A Type A-3level” is the smallest in all the frequency ranges.
- There is no crossing point.

Conditions:
- 20kVA Inverter
- AC 400V, Io=30A, cosθ=0.9
- Vdc=700V(350V+350V)
- Modulation rate =0.8
- Tj=125C, Rg=datasheet value

Graph:
- 2-Level: 7MBR100VN120-50
- NPC 3-level: 7MBR100VZ060-50
- A-NPC 3-level : 12MBI100VN-120-50
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