High Power Low Inductance Module Building Blocks for Three-Level Inverters

John Donlon - Powerex, Inc.
Marco Honsberg - Mitsubishi Electric Europe
3-Level Modules

**Lower power consumption**
- About 30% lower power consumption from 2 level inverters
- Miniaturization of large-capacity industrial equipment
- Optimized power chip characteristics

**Low inductance packages**
- Well-designed new terminal of its layout and form
- Low circuit inductance with single/parallel operation

**Small and multi circuit configurations**
- Lineup with 2 package, 5 rating
- 4in1 module achieves downsize for mid-capacity inverters
- 1in1 and 2in1 models offer a wide variety of circuit layouts for larger inverters
New: Three Level Type-T Module
400A, 650V/1200V

- Small Package
- Low internal inductance
- Easy parallel connection by ingenious terminal layout
- Contribute to high efficiency for 3level inverter system
**Application**
PV, UPS, etc

**Feature**
- Low internal Ls (PN:32nH, PC/CN:27nH)
- Tjmax=175°C
- Visol=4000V
- Creepage:14.4mm, Clearance:8.0mm (UL840 for 4,000m adaptable)

- Power chips is adjusted to the best characteristics for 3 level (Half bridge:1200V- 6.1th, ACSW:650V-7th)
- Easy paralleling terminal layout and narrow width package

<table>
<thead>
<tr>
<th>Part No.</th>
<th>Rating &amp; Connection</th>
<th>Package size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM400ST-24S1</td>
<td>4in1 1200V 400A</td>
<td>115 *82 *32.4</td>
</tr>
</tbody>
</table>
Optimized Terminal Configuration = Simplified Busbar Design & Easy Paralleling

P, C, and N terminals are placed closely. AC terminal is placed in their opposite side. IGBT driver can be placed under the bus-bars, allowing simple bus-bar designed.
Area Comparison (ex. 500kW power converter)

Laminate Bus-bar

Other Company
4in1
(4 parallel)

Length: 36% DOWN
Foot space: 30% DOWN

PRX/Mitsubishi 4in1
CM400ST-24S1
(4 parallel)
Low Inductance = Reduced Surge Voltage

Package Internal Inductance

<table>
<thead>
<tr>
<th></th>
<th>P-N (nH)</th>
<th>P-C (nH)</th>
<th>C-N (nH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM400ST-24S1 (ES)</td>
<td>32.7</td>
<td>26.3</td>
<td>28.4</td>
</tr>
</tbody>
</table>

30% Lower inductance than closest competitor!!

The terminal P, C, N and AC are configured in the center because the commutation path between chips is the shortest.
Power loss simulation for T-type 3-level inverter

**Condition**

- $V_{PC}=V_{CN}=300$V
- $f_c=10$kHz
- $PF=0.8$
- Modulation=1
- $I_o=400A_{peaks}(283A_{rms})$
- RG

**CM400ST-24S1**
- $R_G=1.6\ \Omega$(HB), $R_G=0\ \Omega$(ACSW)

**Company S**
- $R_G=2\ \Omega$(HB, ACSW)

**Company I**
- $R_G=1.5\ \Omega$(HB, ACSW)

*Comparison by measurement value*
T-type 3-level inverter for 500kW class System

Condition

- \( V_{PC} = V_{CN} = 300\text{V} \)
- \( f_c = 10\text{kHz} \)
- \( PF = 0.8 \)
- Modulation = 1
- \( I_0 = 400A_{\text{peak}} \times 4(1131A_{\text{rms}}) \)

- \( \text{CM400ST-24S1} : R_G = 1.6 \Omega (HB), \)  
- \( R_G = 0 \Omega (\text{ACSW}) \)

Company F:
- \( R_G = 3.3/0.56 \Omega (HB) \)
- \( R_G = 1.8/12 \Omega (\text{ACSW}) \)

CM400ST-24S1 × 4 parallel vs Company F(900A product) × 2 parallel

Graph showing 32% down at 9.72kW vs 14.3kW for CM400ST-24S1 compared to Company F (900A) product.
SHIZUKI ELECTRIC CO., INC.
Typename : SKUNITSPZ2692A

2in1 package
Rating Capacitance : 5 uF × ±10 %
Rating voltage : DC 630 V
Operation Temp. : -40 ℃ to +85 ℃
Reference stack circuit

<table>
<thead>
<tr>
<th>Item</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circuit</td>
<td>3 level T type 3 phase</td>
</tr>
<tr>
<td>Rated Capacity</td>
<td>139kVA (125kW, PF=0.9)</td>
</tr>
<tr>
<td>Rating Voltage</td>
<td>$315V_{\text{rms}}$</td>
</tr>
<tr>
<td>Rating Current</td>
<td>$255A_{\text{rms}}$</td>
</tr>
<tr>
<td>DC Voltage</td>
<td>480-850V</td>
</tr>
<tr>
<td>Over Load</td>
<td>110% (60s)/125% instant</td>
</tr>
<tr>
<td>Cooling</td>
<td>Air force</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>8-10kHz</td>
</tr>
</tbody>
</table>

Under development by Beijing Jiaotong University

国家能源主动配电网技术研发中心
High Power Low Inductance Module Building Blocks for Three-Level Inverters

Under development by Beijing Jiaotong University

CM400ST-24S1

Pre-gate driver
Gate driver
Current sense
Luminated bus bar
Film capacitor
Snubber capacitor
Air flow
GAU405P-15252 4ch Gate Drive Prototype Board

FEATURE
> Built in the isolated DC-DC converter for gate drive
> Output peak current is +/-5A(max)
> Built in short circuit protection
> Electrical isolation voltage is 2500Vrms (for 1 minute)
> Two way power supply system for drivers and input signal
  (VD=15V, VIN=5V)
> CMOS compatible input interface

BLOCK DIAGRAM

Gate Driver : VLA551-01R

Size : 120 x 100 x 44t
New: High Power Three-Level Building Blocks

CM1400HA-24S
RM1400HA-24S
CM1000HA-34S
CM500C2Y-24S

Advantage!!

◆ Small Package
◆ Low internal inductance
◆ Easy parallel connection by ingenious terminal layout
◆ Contribute to high efficiency for 3level inverter
APEC 2016        High Power Low Inductance Module Building Blocks for Three-Level Inverters

Application
PV, UPS, etc

Feature
• Low internal Ls
  1in1:8nH, 2in1:12nH
  (between terminal 1 and 2)
• Visol=4000V
• Tjmax=175°C

➢ 1200V 6th Chip and 1700V 6th Chip
➢ Easy to construct high power 3 level inverter

<table>
<thead>
<tr>
<th>Connection &amp; Rating</th>
<th>Package size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>1in1</td>
<td></td>
</tr>
<tr>
<td>IGBT</td>
<td>1200V</td>
</tr>
<tr>
<td>IGBT</td>
<td>1700V</td>
</tr>
<tr>
<td>Di</td>
<td>1200V</td>
</tr>
<tr>
<td></td>
<td>130 *67 *30</td>
</tr>
<tr>
<td>2in1</td>
<td></td>
</tr>
<tr>
<td>IGBT</td>
<td>1200V</td>
</tr>
<tr>
<td>EE common</td>
<td>500A</td>
</tr>
</tbody>
</table>

Internal connection

1in1, IGBT type
2in1, IGBT type
1in1, Diode type

Package Outline

1in1 type
Symmetry signal terminals in both side
Low Inductance T-Type Three Level Layout (~500KW)

Suitable for up to 1000V+ DC bus: Tr1&Tr4 1700V, 1000A, Tr2&Tr3 2pc. 500A, 1200V common emitter.
**Layout example (1 arm)**

Circuit configuration (1 arm)

- Tr1
- CM1000HA-34S

- Mod.A
- CM500C2Y-24S

- Mod.B
- Mod.C

AC

- Tr2
- Tr3

- Tr4
- Mod.D

3 layer Laminate Bus-bar

- Tr4

**Single + Emitter common Dual (4 modules for 1 arm)**

- Tr4 Mod.D

- Tr2/Tr4 Mod.C

- Tr2/Tr4 Mod.B

- Tr1 Mod.A

AC bus bar

Pre-Driver

Parallel connection 2in1
To reduce circuit inductance
**Power loss simulation for T-type 3-level inverter**

**Condition:** Output Power 1MW

- PF=1
- $V_{OUT}=690\, V_{rms}$
- $I_{O}=840\, A_{rms}$
- $V_{PN}=V_{PC}+V_{CN}=1127\, V$ (M=1)

Tr1, Tr4 : CM1000HA-34S
Tr2, Tr3 : CM500C2Y-24S $\times$ 2 parallel

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### Power loss [W / inverter]

- $f_{c}=2\, kHz$: 7,299W
- $f_{c}=5\, kHz$: 9,663W
- $f_{c}=15\, kHz$: 17,544W

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**RG**

CM1000HA-34S : $R_{G}=0\, \Omega$ (HB),
CM500C2Y-24S : $R_{G}=0\, \Omega$ (ACSW)
### Power Loss Simulation for T-type 3-Level Inverter

**Condition**

\[ V_{PC} = V_{CN} = 600V,\; f_c = 10kHz,\; PF = 0.8 \]

Modulation = 1, \( I_o = 1400A_{\text{peak}} \)

BR(Tr1, Tr4): CM1000HA-34S
\[ 1000A/1700V \text{ (company I)} \]

AC(Tr2, Tr3): CM500C2Y-24S *2para
\[ 1400A/1200V \text{ (company I)} \]

| Company I: \( R_{\text{on}} = 1.0\Omega, \; R_{\text{off}} = 1.0\Omega \) |
| CM1000HA-34S/CM500C2Y-24S: \( R_{\text{on}} = 0\Omega, \; R_{\text{off}} = 0\Omega \) |

**Diagram:**

- **P**: 600V
- **C**: 600V
- **N**: 600V
- **1arm**
- **Tr**: 1arm

**Bar Chart:**

- **5449W**
- **Δ1553W/\text{mod}**
- **3896W**

- **Company I**: chip performance of same rating products from datasheet value

- **Mitsubishi**
Easy design
Mounting Area (≈ Circuit inductance) comparison

Company I 2in1 (3 modules)

Mitsubishi single (6 modules)

Area 20% reduction

Circuit Ls reduction

Pre-Driver
**Power loss simulation for Itype 3level inverter**

**Condition**: Output Power 1MW

- PF=1
- $V_{OUT}=690 \ V_{rms}$
- $I_o=840 \ A_{rms}$

**Case1**: $V_{PN}=V_{PC}+V_{CN}=1200 \ V$ ($M=0.94$)

**Case2**: $V_{PN}=V_{PC}+V_{CN}=1500 \ V$ ($M=0.75$)

- $\text{Tr1} \sim \text{Tr2'}': \text{CM1400HA-24S}$
- $\text{Clamp D, D'}': \text{RM1000HA-24S}$

**Case1**: 1200V

<table>
<thead>
<tr>
<th>Conditions</th>
<th>fc= 2 kHz</th>
<th>fc= 5 kHz</th>
<th>fc= 15 kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>1MW output</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{PN}=1200V, \ PF=1$</td>
<td>8,674W</td>
<td>10,897W</td>
<td>18,308W</td>
</tr>
<tr>
<td>$V_o=690V_{rms}, \ I_o=640A_{rms}$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Case2**: 1500V

<table>
<thead>
<tr>
<th>Conditions</th>
<th>fc= 2 kHz</th>
<th>fc= 5 kHz</th>
<th>fc= 15 kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>1MW output</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$V_{PN}=1500V, \ PF=1$</td>
<td>8,991W</td>
<td>11,771W</td>
<td>21,034W</td>
</tr>
<tr>
<td>$V_o=690V_{rms}, \ I_o=640A_{rms}$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Power loss simulation for Itype 3level inverter

**Condition**

\[ V_{PC}=V_{CN}=600V, \quad fc=10kHz, \quad PF=0.8 \]

Modulation=1, \( I_o=1400A_{peak} \)

Tr1~Tr4 : CM1400HA-24S
D1, D2 : RM1400HA-24S

**Company I :**

- \( R_{GON}=1.0\Omega, \quad R_{GOFF}=1.0\Omega \)
- CM1400HA-24S : \( R_{GON}=0\Omega, \quad R_{GOFF}=15\Omega \)

![Diagram of power loss simulation for Itype 3level inverter](image)

Company I : chip performance of same rating products from datasheet value

- \( 6710W \)
- \( \Delta 861W/\text{mod} \)
- \( 5849W \)

-13%

Mitsubishi
### Application example for 3 level inverter

<table>
<thead>
<tr>
<th>3 level type</th>
<th>Capacity</th>
<th>$V_{PN}$</th>
<th>Applied module</th>
<th>Connection</th>
</tr>
</thead>
<tbody>
<tr>
<td>T type</td>
<td>125kW ~ 500kW</td>
<td>$\leq 850V$</td>
<td>CM400ST-24S1</td>
<td>4in1 Parallel connection is possible.</td>
</tr>
<tr>
<td>I type</td>
<td>500kW ~</td>
<td>$\leq 1500V$</td>
<td>CM1400HA-24S, RM1400HA-24S</td>
<td>1in1 2in1</td>
</tr>
<tr>
<td>T type</td>
<td>500kW ~</td>
<td>$\leq 1200V$</td>
<td>CM1000HA-34S, CM500C2Y-24S</td>
<td></td>
</tr>
</tbody>
</table>

### Power Module Line-up for 3 level inverter

<table>
<thead>
<tr>
<th>Model</th>
<th>Module type</th>
<th>Specification</th>
<th>Connection</th>
<th>Dimensions $W \times D \times H$ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM400ST-24S1</td>
<td>IGBT</td>
<td>400A/1200V (ACSW part: 650V)</td>
<td>4in1</td>
<td>115 $\times$ 82 $\times$ 32.4</td>
</tr>
<tr>
<td>CM1400HA-24S</td>
<td>IGBT</td>
<td>1400A/1200V</td>
<td>1in1</td>
<td>130 $\times$ 67 $\times$ 30 (same package)</td>
</tr>
<tr>
<td>RM1400HA-24S</td>
<td>Diode</td>
<td>1400A/1200V</td>
<td>1in1</td>
<td></td>
</tr>
<tr>
<td>CM1000HA-34S</td>
<td>IGBT</td>
<td>1000A/1700V</td>
<td>1in1</td>
<td></td>
</tr>
<tr>
<td>CM500C2Y-24S</td>
<td>IGBT</td>
<td>500A/1200V</td>
<td>2in1 (Emitter Common)</td>
<td></td>
</tr>
</tbody>
</table>
# Latest Modules added to Line-up to support 3-level Inverter

<table>
<thead>
<tr>
<th>Model</th>
<th>Module type</th>
<th>Specification</th>
<th>Connection</th>
<th>Dimensions W x D x H (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM600HA-34S</td>
<td>IGBT</td>
<td>600A/1700V</td>
<td>1in1</td>
<td>130 x 67 x 30 (same package)</td>
</tr>
<tr>
<td>CM800HA-34S</td>
<td>IGBT</td>
<td>800A/1700V</td>
<td>1in1</td>
<td></td>
</tr>
</tbody>
</table>
CONCLUSION

New building block modules have been developed with low internal inductance to support 3-level inverter topologies.
Q & A

Diagram showing electrical components and circuitry related to power electronics, with labels for inputs, outputs, and connections. Text blocks are not transcribed as they are not legible in the image.