Inverter Technology Trends & Market Expectations

Growth, supply chain, new applications: Inverter industry is about to redefine itself

November 2014
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A Two Part Report

• Yole has conducted market and technology research on attractive application segments of the power electronics industry, and, in this report, provides an overview of the dynamics for the most attractive applications.

• The first chapter of the report is dedicated to understanding the technical breakthroughs, business evolution and to provide market forecasts for:
  – PV inverters
  – EV/HEV
  – Hybrid/Electric buses
  – Wind turbines
  – Rail traction
  – UPS
  – Industrial motor drives

• In this first chapter, we have a top-down approach and explain industry status, as well as player positioning from the inverters to the power modules and passive components.

• In the second part, Yole presents a comparative analysis between all these applications and the consequent developments at different levels:
  – Inverter components and market drivers
  – Implementation of new semiconductor materials
  – Implementation of new bundle solutions: packaging, passives, connectivity
  – Market forecasts
Overall Power Electronics Markets
The Entire Power Industry Value Chain

Silicon growth → Silicon ingot → Wafering & Polishing → Silicon wafer → Epitaxy

Silicon ingot
Silicon wafer
Epitaxy

Front-End → Front-End
Litho, deposition, etching, metallization…
Silicon epi-wafer

Back-End
Back-grinding
Dicing, Flip-chip

Back-end
Chips: dies-on-wafer

Front-end
Power device bare-die

Packaging
Binning, pick-and-place Packaging, Housing

Power module

Power Inverter

Application

Can be replaced by the use of FZ thinned wafer (NDT)

Sources: Yole Développement
Overall Power Electronics Markets
2013 – 2020 value chain analysis: wafer, device, system

- **Electronics Systems**: $117 B in 2013, $134 B in 2020 (CAGR: +1.9%)
- **Power Inverters**: $43 B in 2013, $65 B in 2020 (CAGR: +6%)
- **Semiconductor power devices (discrete and modules)**: $10.6 B in 2013, $17.9 B in 2020 (CAGR: +7.7%)
- **Power wafers**: $882 M in 2013, $1.09 B in 2020 (CAGR: +3%)
**PV Inverters**

*Classification according to input power and application*

<table>
<thead>
<tr>
<th>Input Power (DC)</th>
<th>Residential</th>
<th>Residential</th>
<th>Residential &amp; Commercial</th>
<th>Commercial &amp; Utility scale power-plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 10kW</td>
<td>~300W</td>
<td>&lt; 10kW</td>
<td>10kW – 70kW</td>
<td>&gt;70kW</td>
</tr>
<tr>
<td>Microinverters</td>
<td>• Compact design</td>
<td>• Single-phase or three-phase string inverters</td>
<td>• String inverters</td>
<td>• Central inverters</td>
</tr>
<tr>
<td></td>
<td>• Connected to each PV module</td>
<td>• Often designed for interior installation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMA</td>
<td>Ingeteam</td>
<td>Sputnik Engineering</td>
<td>SMA</td>
<td>Samil Power</td>
</tr>
<tr>
<td>Involar</td>
<td>Delta</td>
<td>Sungrow</td>
<td>Involar</td>
<td>Sungrow</td>
</tr>
<tr>
<td>ABB</td>
<td>Enphase</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>i-Energy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DELTA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Classification of PV inverters according to the input power value and application. Examples of products.

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PV Inverters

Devices

Roadmap of Integration

- 900 – 1,200V will be the targeted range, especially for over 10kW inverters
- The affordable costs and availability (stable and multiple sourcing) are currently the key requirements for the adoption of SiC and GaN technologies.

Current status
- The switching devices and diodes are still mainly silicon-based
- Technology of switching devices
  - MOSFET or Cool-MOS® transistors up to 900V
  - IGBT to 1,200V

IGBT

SiC JFETs and MOSFETs introduction

The 2 key parameters for SiC adoption:
- Availability of switching devices and diodes at affordable prices
- Strong move to 1,200V inverters and soon 1,700V → same trend as in wind turbine inverters

Silicon SJ MOSFETs

SiC and GaN introduction

Standard MOSFETs

2012 2013 2014 2015 2016 2017
The offshore wind installations are considered as promising for several reasons, but their today’s costs are still higher than the cost of onshore solutions.

**Onshore**
- Lower construction costs
- Lower maintenance costs
- Lower electricity transport costs
- Lower wind speed
- More wind turbulences due to relief, trees and buildings
- Less area available
- Complex transportation logistics for large turbines
- NIMBY effect

**Offshore**
- Higher wind speed
- Less wind turbulence (more consistent wind resource)
- Turbine size less limited by transportation constraints
- More area available
- Visual and noise effects less critical
- Conflictual issues with fishing and recreational areas
- More complex and costly installation and maintenance
- Issues related to aggressive environment (salt, humidity...)

NIMBY: Not In My BackYard
Chinese players are rapidly growing within China and looking for foreign markets. Some Chinese players have chosen the strategy of JV with key EU technology players in order to speed-up their development.

All players are looking for new market opportunities: some by developing large turbines in 6MW+ size for offshore applications other by focusing on promising new markets especially in South America.
EV/HEV
Power assembly evolution
Key elements for power assembly evolution

- In the automotive industry *cost, weight* and *space* are the key drivers.

### Power Assembly Architecture
- Converter Topologies (mainly for LV-HV DC/DC and AC/DC)
- Inverter has to be developed according to the electric motor

### Passive Elements (Cooling, capacitors, busbars, etc...)
- High Temperature Capacitors, Laminated Busbars
- Enhanced cooling of the power converter

### Power Packaging
- Low stray inductance packaging
- High Temperature and reliable assemblies

### Wide Band gap Semiconductors
- High Temperature operation
- More compact inverters

---

Report Sample
EV/HEV Supply Chain description
HEV/EV Industrial supply-chain and typical market prices from module to power train

Si devices
- Toyota (JP)
- XXXXXXX (JP)
- Infineon (DE)
- XXXX(FR)
- XXX(JP)
- Toshiba (JP)
- XXXXX (JP)

Power module Manufacturers
- XXXX (JP)
- XXXX (JP)
- Infineon (DE)
- XXXX (DE)
- Danfoss (DE)
- XXXX (US)
- Denso (JP)
- XXXX (CN)

Tier one suppliers
- Europe: Valeo (FR), XXXX(DE), XXXX (DE)...
- USA: Delphi
- Asia: XXXX (JP)
- Hitachi (JP)
- XXXX (JP)
- BYD (CN)

Car Manufacturers
- Europe: XXXX
- XXXX, Volvo, Renault
- USA: Ford, GM, Tesla Motors
- Japan: Toyota, Honda, Nissan
- China: BYD, XXXX, XXX
Tier 1 et chip makers are willing to acquire power module manufacturing, and pure power module makers have to develop their competences to stay in the game.

Car manufacturers see electric motors as a know-how to master, and are capturing competencies from tier ones ➔ the goal is to manufacture the overall powertrain.

Some car makers are also working on batteries to complete this value chain integration.
Hybrid & Electric Bus
Architecture and Technical Aspects
Series / parallel comparison

• Architecture choice dependent on application, vocation and duty cycle

**Serial Hybrid**
- Sized for full all-electric mobility
- No mechanical coupling of engine to road enables maximum control over engine operation
- Applicable for fuel cell or battery powered vehicles
- Ideal for urban transit buses

**Parallel Hybrid**
- Sized for desired braking energy capture
- Engine still mechanically coupled to road; enables higher efficiency at highway speeds
- Scalable for a wide range of duty cycles
- Ideal for trucks
Most of hybrid and electric bus manufacturers are European. In China, many companies are on the market, XXXXX is the leader. In Japan companies are focused on electric and hybrid cars (such as Toyota or Nissan, for instance) and are not willing to develop buses. It is the same phenomena in the USA, where there are very few manufacturers with small amount of vehicles.
## Rail Traction

*Power devices in different type of trains*

<table>
<thead>
<tr>
<th>Power range</th>
<th>Train architecture</th>
<th>Power devices</th>
<th>Power module $/train value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metros/Trams</td>
<td>100 – 700kW</td>
<td>xxxxxxxxxxxxxxxx</td>
<td>1.7kV IGBTs</td>
</tr>
<tr>
<td>Regional/Commuters</td>
<td>xxxxxxxxxxxxxx</td>
<td>Mostly EMUs (up to 20 inverters per train)</td>
<td>xxxxxxxxxxxxxxxx</td>
</tr>
<tr>
<td>High-speed trains (HST)</td>
<td>1 to 2MW</td>
<td>xxxxxxxxxxxxxx</td>
<td>xxxxxxxxxxxxxxxx</td>
</tr>
</tbody>
</table>

Power cars (less and less common)
# Rail Traction

*Main Voltage Ranges Implemented by Major Train Manufacturers*

<table>
<thead>
<tr>
<th>Voltage Range</th>
<th>Manufacturers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.7kV</td>
<td>Alstom (F)</td>
</tr>
<tr>
<td>2.5kV</td>
<td>xxxx (IT)</td>
</tr>
<tr>
<td>3.3kV</td>
<td>Bombardier (CA)</td>
</tr>
<tr>
<td>4.5kV</td>
<td>xxxx (J)</td>
</tr>
<tr>
<td>6.5kV</td>
<td>xxxx (US)</td>
</tr>
<tr>
<td></td>
<td>Hitachi (J)</td>
</tr>
<tr>
<td></td>
<td>xxxxxxx (J)</td>
</tr>
<tr>
<td></td>
<td>Siemens (D)</td>
</tr>
<tr>
<td></td>
<td>xxxx (J)</td>
</tr>
<tr>
<td></td>
<td>xxxxxxx (J)</td>
</tr>
</tbody>
</table>

*Report Sample*

- **Drivers**
- **Water plate**
- **Laminated busbar**

*Source: Alstom*
• Majority of motor drive operate at low voltage (DC link below 1kV), and use 600V, 1,200V or 1,700V devices.
• IGBT are widely used (more than 80%), but face a small competition from IGCT at higher voltage (+3.3kV), and MOSFET for lower voltage (600V).
Power Stacks
Where Are the Synergies (1/2)

Inverters are an assembly of modules and passive components.
There is a technical synergy between close components. It means that they are physically close, and their functions are complementary. This synergy strongly impacts the supply chain evolution:

- Partnerships between capacitor and busbar manufacturers are created
- Partnerships or joint developments between power module and power stack manufacturers

Integration trend
- Capacitor
- Laminated busbar /PCB
- Cooling system
- Resistor
- Technical link
- Power module
- IGBT driver
- Semiconductor die
- Power connectors
- Inductors, Current sensors (CT)
- Inverter
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Inverter Technology Trends & Market Expectations

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Date:

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Name of the Card Holder:
Credit Card Number:
Card Verification Value: (3 digits except AMEX: 4 digits):
Expiration date:

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BANK INFO: HSBC, 1 place de la Bourse, F-69002 Lyon, France, Bank code: 30056, Branch code : 00170
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4.6 After an additional inspection, it is acknowledged that the Products contain defects, the Seller undertakes to replace the defective products as far as the supplies allow and without indemnity or compensation of any kind for labor costs, delays, and any other costs. The replacement is guaranteed for a maximum of two months starting from the delivery date. Any replacement is excluded for any event as set out below (except in the event of breach of the defective warranty).

4.7 The deadlines that the Seller is asked to state for the mailing of the Products are given for information only and are not guaranteed. The Seller shall not be liable for any delay in the mailing of the Products, for any damages or cancellations of the orders, except for non acceptable delays exceeding [4] months from the stated deadline, without information from the Seller. In such case only, the Buyer shall be entitled to ask for a reimbursement of its first down payment to the exclusion of any further damages.

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