Power electronics for EV/HEV 2016: market, innovations and trends
Report’s presentation
REPORT OBJECTIVES

- Provide updated market metrics and forecasts for electrified vehicles
- Analyze the differences between geographical areas, the incentives and the brakes for market growth
- Present main technological trends and ongoing developments for power electronics targeting automotive at each level (inverter, power module, power device)
- Provide updated market metrics and forecasts for power electronics (split by type of electrified vehicle)
- Present batteries evolution and its impact on power electronics
- Analyze business models evolution and supply-chain moves
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Coralie Le Bret

Coralie Le Bret has been an analyst in power electronics and compound semiconductor technologies since 2014, at Yole Développement, the "More than Moore" market research and strategy consulting company. She graduated from INSA Lyon with an engineering degree in material sciences, specializing in semiconductors and microelectronics. At Yole Développement she is in charge of electro-mobility, and she uses her expertise on materials and semiconductors to follow power devices and power packaging evolution.

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COMPANIES CITED IN THE REPORT

Report’s extract
• Renault and Dongfeng announced partnership to produce electric Fluence-based car for China
• BYD announced partnership with ASMC to produce their own IGBTs
• Toyota revealed its plan for fuel-cell vehicles: target is 30,000 hydrogen fuel cell cars sales annually by 2020
• Honda unveiled the world premiere of its fuel-cell vehicle, with start of sale forecasted for March 2016
• California announced the target of 100% zero-emission vehicles sales by 2050
• Daimler presented its fuel-cell car at Tokyo Motor Show (prototype)
• Local Motors company (US) presented its 3D printed electric car, the LM3D Swim
• Audi, BMW, Daimler, Porsche, Volkswagen and others are part of 150kW charIN CCS fast charge initiative
• China’s Government announced the target of 5,000,000 charging spots by 2020
• Volkswagen announced the increase of invest dedicated to electrification by €100M for 2016
• Cadillac CEO announced that most of new models will get PHEV version
• BMW announced an acceleration of efforts on plug-in electric cars in order to meet CO₂ emission limits
• Canada’s Government granted a $20 million help for public charging infrastructure development
• Fuel-cell technology got a $35 million boost from US Energy Department
According to Yole estimations, full electric cars should hit the 1% market shares by 2017-2018

- Even if the first electric car was born at the beginning of 20th century, the first representative sales of electrified cars started in 2013
- Since that year, vehicle electrification is growing
- Between 2014 and 2015, the amount of full electric cars sold was multiplied by 2, which is very encouraging for the future
- By 2021, we expect electrified cars to represent almost 20% of the sales
DIFFERENT TYPES OF VEHICLES AND THEIR MARKET

Top electric vehicles companies in 2015 (for EV+PHEV)

- Depending on the geographical area and on the type of electrification that is the most common (full EV or PHEV), different car makers are leading the market.
- In China, almost all electrified cars sold are made by Chinese companies (otherwise there is no incentive from the state). Considering the huge weight of China in electrified cars market, 2 of the 5 leading companies are Chinese.
- Toyota, pioneer of electrification, is not part of the top 5 mainly because of delay on launching of the new Prius.
- Although the company provided only one vehicle for most of the year, Tesla Motors’ success is confirmed by a 4th place in the 2015 ranking.

<table>
<thead>
<tr>
<th>Sales for 2015</th>
<th>Amount of vehicles in the offer</th>
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<tbody>
<tr>
<td>Tesla Motors</td>
<td>Sales only in China</td>
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<tr>
<td>~26k</td>
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<td>~38k</td>
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Despite the high selling price, Tesla Model S is leading the market:

- **Xxx** was the most popular EV in 2015 despite being a “luxury car”
- **Xxx** is still a sure value with more than 25,000 units sold
- **Xxx** became the most sold PHEV in 2015, and its growth could be even higher as it was not sold in the US in 2015
Importance of China for electrified vehicles future

• In 2015 China already represented xxx% of the market for electric vehicles (EV+PHEV, in Units). Chinese Government’s helps and dynamism of this market will help it grow in the future, to reach almost the half of the market by 2020

• Public transportation in China is very common in China and especially buses. Aggressive targets in terms of CO₂ reduction makes China the leading country for electric buses. This trend should confirm in the coming years, and we expect China to have almost 90% of electric bus market by 2020

Inverter market and forecasts for electrified vehicles (in M $)
EV/HEV will take important shares in power module market to finally represent half of the market by 2021.

Power modules considered here are mostly IGBT modules, as it is the mainstream for EV/HEV. Some MOSFET modules are also used for lower powers, and by 2021 we expect that some SiC modules will enter the market.
SPECIFIC POWER DENSITY
EV/HEV examples - kW/kg

- Inverter’s power density without taking into account the DC/DC boost:

Concerning the specific power density, here again, hybrid vehicles show the highest values.

DOE Targets:

- 2015
- 2020
- 2025

More efforts need to be done on the BEV segment to attain the targets presented by the DOE.
Presentation of different topologies and innovations at inverter level.
MILD HYBRID VEHICLES

Motor-Inverter integration

High integration is achieved with motor-inverter mechatronics in mild hybrid vehicles.

- So far, the integration of power converters on the electric motor housing has just been seeing in mild hybrid cars, as low powers are involved (5-15kW).
  - This integration between the electric motor and the inverter will be a strong trend for this category of electrified vehicles.
- The electric motors are considered an auxiliary help for the ICE traction (belt-connection mainly).

- Continental provides a motor-inverter solution of permanently 5kW power (peak 13kW), for a 48V mild hybrid architecture.
  - The weight of the whole is 12kg.
- The mild hybrid Volkswagen Golf TSI is using this technology from Continental.

Continental’s 5kW (max. 13kW) motor + inverter used by Volkswagen
Each car manufacturer has specific strategy, and power module chosen can depend on the car model. Generic trend seems to be reducing the amount of switches in the module.

Power module types and positioning of manufacturer:

- **1 in 1 power module**
- **2 in 1 power module**
- **4 in 1 power module**
- **6 in 1 power module**
- **“all-in-1” power module**

<table>
<thead>
<tr>
<th>Year</th>
<th>Model</th>
<th>Power Module Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>2010</td>
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<td>---</td>
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<tr>
<td>2015</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>2016</td>
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</tbody>
</table>

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Overmolded modules and double side cooling: a future generalization?

- Overmolding modules were first used thanks to their low cost, especially in hybrid vehicles.
- Double-side cooling allows a better thermal management in a reduced volume, which is a key constrain in hybrid vehicles.
- In the other hand, with increase of junction temperature, thermal management is also key for full electric vehicles. Cost pressure is also very strong on this segment.
- We are confident in a strong development of overmolded double-side cooled modules in the future.

Major companies already have overmolded double-side cooled modules in their portfolio.
# POWER DEVICES: SILICON AND WBG

**Device types and power levels: opportunities for WBG**

<table>
<thead>
<tr>
<th>Converters</th>
<th>SSV</th>
<th>Mild HEV</th>
<th>Full HEV</th>
<th>PHEV (with EREV)</th>
<th>EV (BEV or FCV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Start/stop module</td>
<td>MOSFET 1.5 to 10kW Av: 3.5kW</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. DC/DC converter 14V (to</td>
<td>MOSFET – 1.5 / 3kW – Av: 2.25kW</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. DC/AC inverter ( + DC/DC booster option )</td>
<td>MOSFET or IGBT 5 /20kW Av: 15kW</td>
<td></td>
<td></td>
<td>IGBT – 20 / 150kW Av: 70kW</td>
<td></td>
</tr>
<tr>
<td>4. Generator</td>
<td></td>
<td>IGBT – 20 / 40kW Av: 30kW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Battery charger</td>
<td></td>
<td></td>
<td>MOSFET - 3/6kW – Av: 4.5kW and then IGBT - 10 / 20kW – Av: 15kW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total average power / car</td>
<td>3.5kW</td>
<td>17.25kW</td>
<td>52.25kW</td>
<td>56.75 to 102.5kW (for a single motor setup)</td>
<td></td>
</tr>
</tbody>
</table>

These applications are specific to EV/HEV. Standard ICE power device applications such as oil pump, steering, braking and HVAC are not considered. Auxiliary inverters have not been considered because they use few power devices.

WBG devices could replace Si-based IGBTs and MOSFETs in EV/HEV applications.

Could be replaced by WBG

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BATTERIES IN ELECTRIFIED VEHICLES

Different battery voltage levels in EV/HEV cars

Most EV/HEV cars batteries are based on the voltage level of about 350-400V. Only two 800V battery vehicles have been identified, of which one is at a concept stage only. HV battery can open the field to use of 1,200V IGBTs and increased use of SiC components.

Overview of recent EV/HEV and the related power electronic components

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Fuel cell vehicle in a nutshell

- A fuel cell vehicle (FCV) is a vehicle that uses a fuel cell to power an electric drive system.
- It is a Zero-Emission Vehicle, electrically powered, in which the electricity used to power electric engine is generated by converting hydrogen into electricity in fuel cell stack.
- It is not just “a hydrogen vehicle”! The vehicles which burn hydrogen to power internal combustion engine (such as BMW Hydrogen 7) do not belong to the category of FCVs.
- Fuel cells provide electricity by reacting hydrogen with heat and water as the products of the reaction.
- Hydrogen is refilled into hydrogen tanks in vehicle at a hydrogen refilling stations similarly as petrol in a ICE car.
- Fuel cell is not a new technology. Fuel cells provided spacecraft with power since 1960s.

Main parts of a fuel cell vehicle. Example of a Hyundai ix35 FCV.
Tier 1 suppliers may be specialized in auxiliary systems when car makers may be more intrusive at powertrain level.

- **Type of converter**
  - **Powertrain**
    - GM
    - BYD
    - TOYOTA
    - HYUNDAI
    - KIA MOTORS
    - TESLA
    - NISSAN
    - VOLKSWAGEN
    - DAIMLER
    - MITSUBISHI MOTORS
    - RENAULT
    - FORD
  - **Auxiliaries**
    - CONTINENTAL
    - BOSCH
    - DELPHI
    - SIEMENS
    - VALEO
    - DENSO
    - TOSHIBA
    - NIKKISO
    - SIEMENS

- **Entry of players coming from pure electronics**
  - Plug-in hybrid
  - Battery electric

- **2021**
  - Level of electrification
  - Car makers
  - Tier 1
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- MEMS & Sensors
- Compound Semi.
- LED
- Power Electronics
- Batteries / Energy Management
- Advanced Packaging
- MedTech
- Manufacturing
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