BOMBARDIER TRANSPORTATION

Propulsion System Configurations in Rail Passenger Transportation Applications

Gaëtan Bilodeau, Eng.
Senior Expert – Product Management
Bombardier Transportation Americas

October 11th, 2016
Agenda

1. INTRODUCTION TO BOMBARDIER TRANSPORTATION
2. ELECTRIC TRAINS – TYPICAL CONFIGURATIONS
3. POWER EQUIPMENT CONFIGURATIONS
4. APPLICATION OF POWER INVERTERS TO PROPULSION & DYNAMIC BRAKING
5. Q&A
Bombardier is the world’s largest manufacturer of both planes and trains, with a worldwide workforce of 70,900 people.

Bombardier is headquartered in Montréal, Canada. Our shares are traded on the Toronto Stock Exchange (BBD) and we are listed on the Dow Jones Sustainability World and North America indexes.

In the fiscal year ended December 31, 2015, we posted revenues of 18.2 billion USD.

(1) As at December 31, 2015, including contractual and inactive employees. Subsequent to the end of the fiscal year, we decided to take steps to optimize our workforce with a combination of manpower reduction and strategic hiring. These figures do not reflect the planned changes.

(2) 3,950 product development engineering, Corporate office and other employees are not allocated to a reportable segment.
(1) For fiscal year ended December 31, 2015. Consolidated revenues $18.2 billion.
(2) As at December 31, 2015, including contractual and inactive employees. Subsequent to the end of the fiscal year, we decided to take steps to optimize our workforce with a combination of manpower reduction and strategic hiring. These figures do not reflect the planned changes.
(3) 3,950 product development engineering, Corporate office and other employees are not allocated to a reportable segment.
BOMBARDIER TRANSPORTATION
A global player with a European base

Revenues 2015\(^{(1)}\): $8.3 billion

Employees\(^{(2)}\): 39,400

- **Global Headquarters**
- **Production Sites**

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(2) As at December 31, 2015, including contractual and inactive employees. Subsequent to the end of the fiscal year, we decided to take steps to optimize our workforce with a combination of manpower reduction and strategic hiring. These figures do not reflect the planned changes.
Bombardier Transportation is a global leader - we have secured strategic orders worldwide against key competitors

- 156 FLEXITY for Vienna & 24 years FlexCare
  
  $480M (2015)

- 180 AVENTRA cars and 35 years of maintenance for Transport for London
  
  $558M (2015)

- 15 CRH380D for China Railways
  
  $381M (2015)

- 30 years maintenance on FLEXITY for Toronto
  
  $308 M (2015)

- 19 Francilien trains for STIF and SNCF
  
  $141 M (2015)

- 80 high speed sleeper trains for China Railway Corp.
  
  $165 M (2015)

- INTERFLO 450 Signalling for V/HS lines of ADIF
  
  $185 M (2015)

- Option for 47 FLEXITY LRVs for Berlin Transport Authority
  
  $190 M (2015)

- Option for 40 FLEXITY LRVs for Ghent & Antwerp
  
  $107 M (2015)

- 62 FLEXITY LRVs for Rheinbahn AG ($135 M) and KVB ($ 68 M)
  
  (2015)

- 162 MOVIA metro cars for India’s Delhi Metro
  
  $228 M (2015)

- INNOVIA APM for Chicago O’Hare International Airport
  
  $180 M (2015)

- 62 TRAXX Locomotives for Israel Railways
  
  $262 M (2015)

- 1,362 Double Deck trains for SNCB
  
  $3.6 B (2015)

- 19 Francilien trains for STIF and SNCF
  
  $141 M (2015)

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1. Bombardier Sifang Transportation, a Chinese entity in which Bombardier holds a 50% interest, has been awarded a contract with China Railway Corp. (CRC) to supply 15 CRH380D very high-speed trains valued at $381 million
2. BT share valued at $2.3 billion
3. BT share valued at $86 million
# OUR PRODUCTS AND SERVICES

The broadest portfolio in the rail industry

<table>
<thead>
<tr>
<th>Rail Vehicles</th>
<th>Transportation Systems</th>
<th>Services</th>
<th>Rail Control Solutions</th>
<th>Propulsion &amp; Controls</th>
<th>Bogies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light rail vehicles</td>
<td>Driverless Systems: Monorails, Metros, People Movers</td>
<td>Fleet Management</td>
<td>Integrated control systems</td>
<td>Traction converters</td>
<td>Portfolio to match entire range of rail vehicles</td>
</tr>
<tr>
<td>Metros</td>
<td>Light rail systems</td>
<td>Asset Life Management</td>
<td>Automatic train protection and operation</td>
<td>Auxiliary converters</td>
<td>Full scope of service over the lifetime of a bogie</td>
</tr>
<tr>
<td>Commuter trains</td>
<td>Metro Systems</td>
<td>Material Solutions</td>
<td>Interlocking systems</td>
<td>Traction drives</td>
<td></td>
</tr>
<tr>
<td>Regional trains</td>
<td>Intercity Systems</td>
<td>Component re-engineering and overhaul</td>
<td>Wayside equipment</td>
<td>Control and communication</td>
<td></td>
</tr>
<tr>
<td>Intercity trains</td>
<td>E-mobility Solutions</td>
<td>Operations and Maintenance</td>
<td>Services</td>
<td></td>
<td></td>
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<tr>
<td>High speed trains</td>
<td>Locomotives</td>
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</table>
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2. Electric Trains – Typical Configurations
3. Power Equipment Configurations
4. Application of Power Inverters to Propulsion & Dynamic Braking
5. Q&A
Typical Propulsion Configurations

Mainline trains with electric locomotives
Typical Propulsion Configurations

Metro cars or Electric Multiple Unit

Montréal AZUR

Toronto TTC-Rocket

Montréal MR-73

New-York R-142

New-York M-7

Montréal MR-90
Typical Propulsion Configurations

Tramways and Light Rail Vehicles

Toronto TTC Streetcars

Toronto Metrolinx LRV
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Power Equipment Configurations

Typical Propulsion System for a Metro Motorised Car
Power Equipment Configurations
Bombardier – TTC Rocket Subway Cars
Power Equipment Configurations
Bombardier – Region2N (OMNEO)
# MITRAC Propulsion and Controls

**ALP-45 Dual-Power (NAFTA)**

**Most important facts at a glance:**
- 3 System AC application and diesel-electric propulsion
- 1-phase auxiliary and 1176kW Head end power (HEP)
- Very compact design due to limited space
- Optimized for high availability and reliability

## Technical Information

<table>
<thead>
<tr>
<th>Units/vehicle:</th>
<th>1 center unit, 4x1x2m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of modules:</td>
<td>4.5 kV HVIM, water-cooled</td>
</tr>
<tr>
<td>Line voltages:</td>
<td>12 kV 25 Hz, 25 kV 60 Hz, 12.5 kV 60Hz and/or DIESEL</td>
</tr>
<tr>
<td>DC links (quantity, voltage):</td>
<td>2, 2.8 kV regulated. Can be separated into 2 links in case of failure</td>
</tr>
<tr>
<td>Ttractive effort and max. speed:</td>
<td>316 kN; 200km/h and Diesel up to 160km/h</td>
</tr>
<tr>
<td>Auxiliary/trains supply:</td>
<td>Integrated 1-phase auxiliary outputs 140kVA and 1176kW HEP 1-phase</td>
</tr>
</tbody>
</table>

## Traction converter 3360 DP V01

<table>
<thead>
<tr>
<th>Technical information</th>
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</thead>
<tbody>
<tr>
<td>Technology:</td>
</tr>
<tr>
<td>Type of suspension:</td>
</tr>
<tr>
<td>Motor housing:</td>
</tr>
<tr>
<td>Insulation Class:</td>
</tr>
<tr>
<td>Temp. Range:</td>
</tr>
</tbody>
</table>

## Drive 3700F

## TCMS (Safe and regular control)

<table>
<thead>
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<th>Technical information</th>
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<tbody>
<tr>
<td>TCMS:</td>
</tr>
<tr>
<td>UIC 556 5th edition:</td>
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<tr>
<td>Vehicle Communication:</td>
</tr>
<tr>
<td>Train to Wayside Communication:</td>
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<tr>
<td>Safe Data Visualization:</td>
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<tr>
<td>Homologation:</td>
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</tbody>
</table>
Power Equipment Configurations
Bombardier ALP-45DP Dual Mode Locomotive

12 / 25 kV AC supply

Electrical diagram showing various components such as TR 1, TR 2, Lsk, Cs, BAT, RBrake, and 1600 kW G for the locomotive.
MITRAC Permanent Magnet Motor
Advantages at a Glance

Wide range performance
Low losses
Mechanically robust rotor
Electrically robust
Low voltage/current demand

Simplified cooling
High speed
Converter utilization
Electrical compatibility
Re-use of motor design

Compact drive system
Mechanical compatibility

Vehicle optimization
Energy efficiency
High reliability

Electrical compatibility

BOMBARDIER
the evolution of mobility
MITRAC Permanent Magnet Motor

MITRAC TM1810PW permanent magnet motor for TWINDEXX

Characteristics
- Rotor must not be magnetised in service
- No rotor losses
- Better weight / torque relations compared to inductions motors

Advantages
- Compact motor design gives space in the bogie
- Higher efficiency: 2.6% better than inductions motors

Disadvantage
- 15 to 25% higher initial costs
- Single converter necessary (every motor needs a converter for control)
- Maintenance workshop has to be trained (slipping in a rotor => forces up to 1t)

Lab test: PM-motor eta at max torque and rated power
Induction motor eta max guaranteed power ~300 kW

- 85
- 87
- 89
- 91
- 93
- 95
- 97
- 99
0 1000 2000 3000 4000 5000 rpm

Efficiency %

eta ASM  eta PM  eta ASM rated  eta PM rated
The switching of the VVVF inverter allows the use of the induction motor in propulsion or in dynamic braking.

Mechanical rotation of the motor versus the frequency switching (rotating field) allows this control.
Application of Power Inverters to Propulsion & Dynamic Braking

Typical traction torque curve of a propulsion system using a VVVF inverter combined with asynchronous traction motors

- **Constant torque**
- **Constant power**
- **Reduction of power by software**
Power Equipment Configurations
Example one: TTC Rocket Subway Car

W4 STANDARD RATE Electric Acceleration - Deceleration Performance
Level Tangent

Acceleration
Deceleration
Power Equipment Configurations

Example two: ALP-46A Locomotive

![Graph showing the relationship between Tractive Effort (kN) and Speed (mph). The graph indicates that breaking effort is limited by software.](image-url)
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