20 Years of High-Speed Adjustable-Speed Electric drive Motor Systems: Case Studies, Reliability, Energy Savings, Opportunities

Anselectric LLC
2011 Gas/Electric Partnership Conference XIX
Houston, Texas - February 9-10th, 2011
With over a century of experience, our domain expertise & systems know-how allow us to customize solutions to meet your needs.
Principal Partner, **Ms. Lynn Tilton**

**About Patriarch**

Patriarch LLC is an Investment fund with approximately 6 billion USD in assets under its management.

Patriarch provides portfolio management services to 8 closed funds and one private equity fund. Funds include credit lines and equity positions in more than 65 companies.

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**On July 31st 2005 Patriarch Partners purchased 100% shares of ASIRobicon SpA’s holding company Hveasi Holding BV**

May 2006, **ASIRobicon SpA changed its name to Ansaldo Sistemi Industriali SpA**
Monfalcone Manufacturing Facility

Total Area: 90,000 m²
Buildings: 38,000 m² + ...

N. employees: 495
288 Blue Collars / 207 White Collars
ISO 9001:2000 & ISO 14001 certified

+ 5,000 additional m² in progress
<table>
<thead>
<tr>
<th>End User, Location</th>
<th>Qty</th>
<th>Coupled Machine</th>
<th>[kW]</th>
<th>[rpm]</th>
<th>[V]</th>
<th>Commissioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRANSCO -USA</td>
<td>2</td>
<td>Centr. compressor</td>
<td>5220</td>
<td>3200/5500</td>
<td>4600</td>
<td>1991</td>
</tr>
<tr>
<td>PGT-PG&amp;E, CA-USA</td>
<td>2</td>
<td>Centr. compressor</td>
<td>6570</td>
<td>4200÷5200</td>
<td>5500</td>
<td>1993</td>
</tr>
<tr>
<td>TRANSCO -USA</td>
<td>2</td>
<td>Centr. compressor</td>
<td>8955</td>
<td>5800/7300</td>
<td>7800</td>
<td>1993</td>
</tr>
<tr>
<td>TENNECO GAS TN-USA</td>
<td>2</td>
<td>Centr. compressor</td>
<td>5000</td>
<td>4000/6000</td>
<td>4530</td>
<td>1994</td>
</tr>
<tr>
<td>TRANSCO -USA</td>
<td>2</td>
<td>Centr. compressor</td>
<td>5220</td>
<td>3200/5500</td>
<td>4600</td>
<td>1994</td>
</tr>
<tr>
<td>TENNECO TX-USA</td>
<td>1</td>
<td>Centr. compressor</td>
<td>9550</td>
<td>5800/7800</td>
<td>10500</td>
<td>1995</td>
</tr>
<tr>
<td>CHEVRON, CA-USA</td>
<td>3</td>
<td>Centr. compressor</td>
<td>2610</td>
<td>8350/11130</td>
<td>2800</td>
<td>1996</td>
</tr>
<tr>
<td>OLEODUCTO CENTRAL S.S., Colombia</td>
<td>4</td>
<td>Centr. pump</td>
<td>7460</td>
<td>3000/3960÷4180</td>
<td>6600</td>
<td>1998</td>
</tr>
<tr>
<td>PETROCANADA, Canada</td>
<td>1</td>
<td>Centr. compressor</td>
<td>11200</td>
<td>4100/4500+5000</td>
<td>2x4400</td>
<td>1998</td>
</tr>
<tr>
<td>ANSALDO TRASPORTI, Italy</td>
<td>1</td>
<td>Test room gen.</td>
<td>400</td>
<td>2660+6000</td>
<td>340</td>
<td>1999</td>
</tr>
<tr>
<td>GENERAL ELECTRIC, France</td>
<td>1</td>
<td>Test room bench</td>
<td>1440</td>
<td>100/2400÷5750</td>
<td>580</td>
<td>2001</td>
</tr>
<tr>
<td>GENERAL ELECTRIC, France</td>
<td>1</td>
<td>Test room bench</td>
<td>1800</td>
<td>100/3000+5800</td>
<td>580</td>
<td>2003</td>
</tr>
<tr>
<td>GENERAL ELECTRIC, Italy</td>
<td>1</td>
<td>Test room bench</td>
<td>34200</td>
<td>1500/3000+3300</td>
<td>3200</td>
<td>2006</td>
</tr>
<tr>
<td>MINISTERO DIFESA / NAVARM, Italy</td>
<td>1</td>
<td>Gas turbine gen.</td>
<td>2000</td>
<td>5490/6300</td>
<td>2x1200</td>
<td>2008</td>
</tr>
<tr>
<td>QATARGAS, Qatar</td>
<td>13</td>
<td>Centr. compressor + gas turbine gen.</td>
<td>45000</td>
<td>2880/3000+3060</td>
<td>4x7200</td>
<td>≥2008</td>
</tr>
<tr>
<td>RASGAS, Qatar</td>
<td>7</td>
<td>Centr. compressor + gas turbine gen.</td>
<td>45000</td>
<td>2880/3000+3060</td>
<td>4x7200</td>
<td>≥2009</td>
</tr>
<tr>
<td>HITACHI, Japan</td>
<td>1</td>
<td>Centr. compressor</td>
<td>1330</td>
<td>0÷13300</td>
<td>5320</td>
<td>2009</td>
</tr>
<tr>
<td>SHANXI INSTITUTE, China</td>
<td>2</td>
<td>Centr. compressor</td>
<td>2x5000</td>
<td>5000/13000</td>
<td>6000</td>
<td>2010</td>
</tr>
<tr>
<td>RETE FERROVIARIA ITALIANA, Italy</td>
<td>2</td>
<td>Test Room gen.</td>
<td>2320</td>
<td>0/1500÷4500</td>
<td>2810</td>
<td>2010</td>
</tr>
<tr>
<td>MINISTERO DIFESA / NAVARM, Italy</td>
<td>1</td>
<td>Gas turbine gen.</td>
<td>1700</td>
<td>19000/225000</td>
<td>4x620</td>
<td>2011</td>
</tr>
</tbody>
</table>
### Key technical features:
- Flexible grooved one-piece steel-forged solid rotor with stainless-steel alloy retaining rings and **aluminum fabricated cage**
- Pedestal tilting pad bearings with forced oil lubrication
- **API Std. 541**
- System back-to-back load tested
- Thyristor CSI driven
- **"Development of an 11,000 rpm, 3,500 hp Induction Motor and Adjustable Speed Drive for Refinery Service"**
- Mass 9000 kg
- **Uninterrupted operation since 1995**: 93°C hot spot, < 0.09 in/s / 0.48 mils p-p radial, < 0.13 in/s axial, critical speeds 2200 and 6800 rpm

### Past: Chevron (California, 1995)

<table>
<thead>
<tr>
<th>Q.ty / Model - Type</th>
<th>3 / HSCR 450 Y 2 – <strong>induction motor</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated power</td>
<td>2610 kW (3500 HP) @ 11130 rpm</td>
</tr>
<tr>
<td>Ratings</td>
<td>2.8 kV / 135 A / 186 Hz</td>
</tr>
<tr>
<td>Speed range</td>
<td>Constant torque @ 8350 to 11130 rpm</td>
</tr>
<tr>
<td>Mounting / Cooling</td>
<td>IM 7313 / IC 86W (TEWAC forced ventilated)</td>
</tr>
<tr>
<td>Type of protection</td>
<td>Pressurised Ex-p, for installation in hazardous area Class I, Division 2, groups B &amp; D</td>
</tr>
<tr>
<td>Coupled machine</td>
<td>Centrifugal compressor</td>
</tr>
<tr>
<td>Location / Customer</td>
<td>El Segundo, CA, USA / Chevron</td>
</tr>
<tr>
<td>Commissioning year</td>
<td>1996</td>
</tr>
</tbody>
</table>

Running 24/7

**99.9% Availability**

Vibration level unchanged in 16 years

**Mass 9000 kg**
Past: Petrocanada (Canada, 1998)

Q.ty / Model – Type: 1 / MSCR 900 Y 2 – synchronous motor
Rated power: 11200 kW (15000 HP) @ 4500 rpm
Ratings: 2x4.4 kV / 2 x 850 A - 75 Hz – dual winding
Speed range: constant torque @ 4100 to 4500 rpm /
constant power @ 4500 to 5000 rpm
Mounting / Cooling: IM 7211 / IC 86W (TEWAC forced ventilated)
Type of protection: pressurised Ex-p, for installation in hazardous area
Class I, Division 2, group D
Coupled machine: centrifugal compressor
Location / Customer: Empress, AB, Canada / Petrocanada, Calgary
Commissioning year: 1998

Running 24/7
99.9% Availability
Vibration level unchanged in 13 years

Key technical features:

- flexible grooved cylindrical one-piece steel-forged solid rotor with stainless-steel alloy retaining rings
- only 2 pedestal tilting pad bearings with forced oil lubrication and outboard brushless induction exciter and rotating rectifier
- API Std. 546
- thyristor LCI driven
- 45000 kg
- uninterrupted operation since 1998: 53 K hot spot, 0.69 mils p-p radial, critical speed 2400 rpm
Present : Shanxi Institute (China, 2010)

Q.ty / Model – Type : 2 / HSCR 500 Y 2 – induction motor
Rated power : 2 x 5000 kW @ 13000 rpm – mechanical tandem
Ratings : 6000 V - 135 A - 217 Hz
Speed range : constant torque @ 5000 to 13000 rpm
Mounting / Cooling : IM 7314 / IC 86W (TEWAC forced ventilated)
Coupled machine : test bench centrifugal machines
Location / Customer : Shanxi, China / Shanxi Institute
Commissioning year : 2010

Key technical features :
- tandem assembly with flexible coupling
- flexible grooved one-piece steel-forged solid rotor with stainless-steel alloy retaining rings and aluminum fabricated cage
- pedestal tilting pad bearings with forced oil lubrication,
- IEC Std.
- VSI PWM IGBT driven
- mass 12000 kg
- tandem system no-load tested
- since commissioned : 43 K hot spot, < 0.89 mils p-p radial, critical speeds 3200, 8200, 14200 rpm (< 1.5 mils p-p)
**Key technical features:**

- VSI type
- IGBT based
- PWM controlled
- 4.16 up to 7.2 kV
- 250 Hz, extended range up to 330 Hz
- Air cooling (TH) ≤ 3000 kVA / water cooling (NH) ≤ 18700 kVA
- Higher power on request for water cooling (NH)
- Diode front-end, multipulse (power factor ≥ 0.96)
- Input transformer integrated or close to the electric cabinet
- Induction or synchronous motor control
- Centrifugal loads (pumps, compressors, fans), revamping of existing motor, high-speed applications, …
Q.ty / Model - Type : 1 / HSCR 450 Y 2 – *induction motor*
Rated power : 1330 kW @ 13300 rpm
Ratings : 6000 V - 213 A - 217 Hz
Speed range : constant torque @ 0 to 13300 rpm
Mounting / Cooling : IM 1001 / IC 86W (TEWAC)
Coupled machine : test bench centrifugal machines
Location / Customer : Hitachi Test Room, Japan / Hitachi
Commissioning year : 2009

**Key technical features:**
- active magnetic bearings
- flexible grooved one-piece steel-forged solid rotor with stainless-steel alloy retaining rings and aluminum fabricated cage
- IEC Std.
- VSI PWM IGBT driven
- mass 7500 kg
- system no-load tested
- since commissioned : 52 K hottest, radial < 1.60 mils p-p
<table>
<thead>
<tr>
<th>Q.ty / Model - Type</th>
<th>20 / <strong>MGSCR 1120 Z4</strong> – <em>synchronous motor-generator</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated power</td>
<td>45000 kW @ 3000 rpm</td>
</tr>
<tr>
<td>Ratings</td>
<td>4 x 7200 V - 917 A - 100 Hz</td>
</tr>
<tr>
<td>Speed range</td>
<td>quadratic torque @ 2880 to 3000 rpm</td>
</tr>
<tr>
<td></td>
<td>constant power 3000 to 3060 rpm</td>
</tr>
<tr>
<td>Mounting / Cooling</td>
<td>IM 7316 / IC 81W (TEWAC self ventilated)</td>
</tr>
<tr>
<td>Coupled machine</td>
<td>LNG refrigeration string gas turbine and centrifugal compressor</td>
</tr>
<tr>
<td>Location / Customer</td>
<td>Ras Laffan, Qatar / GE Oil&amp;Gas for QatarGas - RasGas</td>
</tr>
<tr>
<td>Commissioning years</td>
<td>since 2008</td>
</tr>
</tbody>
</table>
Present: QatarGas / RasGas (Qatar, since 2008)

Key technical features:

- starter and motor and/or generator machine with double shaft-end
- 4 pole / 100 Hz (no twice-line frequency)
- flexible grooved cylindrical one-piece steel-forged solid rotor with stainless-steel alloy retaining rings
- 4 form-wound stator winding x 4 VSI PWM IGBT converter supply
- 3 of 4 fault tolerance @ continuous operation and +33% peak capability capability @ full-pressure restart
- 150 MW drive-through capability
- lateral rotordynamics
- 2 pedestal tilting pad bearings with forced oil lubrication
- brushless induction exciter with rotating rectifier
- IEC Std.
- back-to-back and string tested @ full load
- < 1% p-p torque ripple (PWM, 4 pole with reduced bearing span no twice-line frequency)
- 100,000 kg mass
- Since early commissioning in 2008: 59 K hottest, 98.1% η, radial < 1.0 mils p-p, critical speeds 1850 and 4000 rpm
Qty / Model - Type : 1 / PMUHS 280 L4 – PM generator
Rated power : 1700 kVA @ 22500 rpm
Ratings : 4 x 620 V - 396 A - 750 Hz
Speed range : 19000 ÷ 22500 rpm
Mounting / Cooling : IM 1001 / water jacket + forced ventilation
Coupled machine : high-efficiency gas turbine
Customer : Ministero Difesa / NAVARM - RasGas
Commissioning year : 2010

Key technical features :
- Permanent Magnet Rotor
- 4 pole / 750 Hz w low-loss stator laminations
- 4 litzwire stator winding vs 4 chopping rectifiers
- flexible one-piece steel-forged solid SPM rotor w carbon fiber bandaging
- shield-mounted tilting pad brgs w forced oil lubrication
- system full-load tested : 96.0% η, temperature < B
- mass 2000 kg
**Key technical features:**

- Trapezoidal slotless Halbach configuration
- Rotor sleeve retention bandaging
- Active magnetic bearings
- Speed > 15000 rpm
- $\eta > 98.5\%$
- Maximum fatigue and thermal reliability
- NdFeB or SmCo permanent magnets
- MTBF = 20 years (motor) or 100000 h (magnetic bearing drive)
- MTTR = 24 h (motor replacement) or 0.5–1.0 h (magnetic bearing drive)
Present and future: High-Speed Capability