IEMDC
Inline Electric Motor Driven Compressor

GMRC Conference
Salt Lake City, UT

October 5, 2003
IEMDC - What is it?

- Inline Electric Motor Driven Compressor
  - Inline - Pipe flange connections inline
  - Electric Motor - Driven by high speed direct drive induction motor that operates in process gas environment and is powered by Variable Frequency Drive
  - Compressor - Single stage overhung compressor stage directly mounted on motor shaft
IEMDC - Applications

- New pipelines
- Existing pipelines with low pressure ratios
- Pipelines near low cost power
- De-bottlenecking of plant process
IEMDC Highlights

- No building required
- Very quiet operation
- No on-site emissions
- Minimal piping
- Small site - Short construction time
- Below grade - lightning avoidance
- Battery of the Future?
The Subterranean IEMDC

- Out of sight, out of mind
- Improved Security
- “Good Neighbor Concept” - Low noise, Out of sight

Compliments of El Paso Natural Gas Co.
**IEMDC - Economics**

- Reduction in piping $150K
- Building Reductions $100K
- Piping Pressure Loss $50K
- Emissions Fees $20K
- Higher Global Energy Efficiency
  - Open cycle gas turbine efficiency = 35%
  - Combined cycle power generation = 52%
    - Includes gas and electrical transmission costs
IEMDC Status Update

- Initial system cost estimates confirm commercial viability of the IEMDC
- Design work confirms technical targets are achievable
- Study commissioned to better define market requirements and growth potential of the application.
Costs - Installation Ranges

- Gas Turbines / Centrifugals
  - $1300/bhp  Industrial, 20 MW
  - $1000/bhp  Aeroderivative, 10 MW
- Reciprocating Engine / Compressor
  - $1400/bhp  Low Speed, 8 MW
  - $750/bhp  Medium Speed, 4 MW
- IEMDC
  - $550/bhp  4 - 10 MW
**Costs - Maintenance Ranges**

- **Gas Turbine / Centrifugal**
  - $19  Industrial Turbine,  20 MW
  - $25  Aeroderivative,  10 MW

- **Reciprocating Engine / Compressor**
  - $21  Low Speed,  8 MW
  - $33  Medium Speed,  4 MW

- **IEMDC and Conventional Motor**
  - $ 7  High Speed  4-10 MW
Speed Control with a VFD

Reducing Speed to lower flow results in higher efficiency and lower hp.
HP: 11,000 ⇒ 5,000
Q: from 650 ⇒ 400 MM

- Fine Control
- 40% Savings over Throttling under similar conditions
IEMDC - Making it happen...

- Advanced VFD Controller
- New Motor Designs
  - Scaled Family of Frames
  - Rugged Induction Motor
- Magnetic Bearings
  - Standardization of Design
Magnetic Bearings
IEMDC Concept
The IEMDC is a self-contained module designed to be installed directly into the pipeline. Intrinsically safe because the motor is in an oxygen-free environment.

The IEMDC's unique features are:

- Small construction footprint
- Minimal piping
- Low capital cost
- Power Generation Potential

IEMDC the Concept

Main Pipe
Overall Project Scope

Phase 1  Design & Development - (In-Process)
Phase 2  Prototype Manufacture - (Proposed)
Phase 3  Demonstration Testing - (Proposed)
Phase 4  Fuel Cell Integration - (Proposed)
Statement of Project Objectives

A. Objectives

- The project objective is to design a direct-coupled, seal-less, in-line motor driven compressor (IEMDC).
- Progress design to the point of starting detailed manufacturing drawings
Statement of Project Objectives

B. Scope of Work

- Development of the compressor aerodynamic flowpath and pressure containment
- Development of the high-speed gas-cooled motor
- Development of the motor drive specification
- Definition and engineering of the compressor/motor interfaces, including cable penetrations, gas-cooling configuration, motor mounting, system rotordynamics and system controls
**Project Technical Requirements**

- Totally enclosed design.
- No shaft seals to the outside environment to create an emissionless design (no site leakage or emissions)
- Potential for Installation in an underground bunker
- Compressor direct coupled to the electric motor
- Eliminate oil and lubrication hazards
- Increased operating flexibility with variable speed motor
- Reduced installation costs over alternative systems
- Application of field proven technologies
- Capable of being directly installed in the pipeline
**Important Design and Commercialization Factors**

- Aerodynamic design.
  - High level of efficiency
  - Wide operating range
  - Quiet operation
  - Flexible configuration for performance optimization
  - Proven aerodynamic performance predictability
- Reliable, maintainable, and serviceable
- Cost Effectiveness
  - Low manufacturing cost
  - Low capital investment and installation cost
  - Low life cycle cost
IEMDC - Case Design
**Status - Configuration**

- Motor Cooling Configuration

```
\[ T_{\text{discharge}} \]
\[ P_{\text{discharge}} \]
\[ T_{\text{mcin}} \]
\[ P_{\text{mcin}} \]
\[ T_{\text{mcout}} \]
\[ P_{\text{mcout}} \]
\[ T_{\text{slout}} \]
\[ P_{\text{slout}} \]
\[ \Delta P \]
\[ \dot{m}_{\text{mc}} \]
\[ \dot{m}_{\text{sl}} \]

Compressor

\[ \Delta P \]

Flow control device

\[ \dot{m}_{\text{process}} \]

Motor

\[ Qin \]

\[ R \]

\[ \dot{m}_{\text{in}} \]

\[ T_{\text{in}} \]

\[ P_{\text{in}} \]

\[ T_{\text{process}} \]

\[ P_{\text{process}} \]
```
Status - Compressor Flowpath

- Flowpath Surfaces

Discharge

Inlet
Streamline of radial inlet
Status - Compressor

- Volute design - evaluating several configurations

Scroll Style  |  Scroll Style - Full Tongue  |  Collector

Static pressure on volute wall
High Speed Induction Motor Design
Curtiss-Wright EMD - History

- EMD formed in 1953 - a division of Westinghouse Electric Corp.
- Initial products related to Nuclear components
  - Main coolant pumps for Navy shipboard reactors
  - Pumps, valves, control rods for Westinghouse PWR plants
Product mix expanded as Westinghouse Corp. restructured

- 1987 – Assigned responsibility for design and manufacture of Navy Generators, originally done at W East Pittsburgh facility
- 1998 – Absorbed the Advanced Electro-mechanical systems group from Westinghouse R&D
- A significant portion of Westinghouse rotating electric machine capability and technology transferred to EMD

EMD bought by Curtiss-Wright in 2001
MOTOR HIGHLIGHTS

- Design
  - Solid rotor – FEA designed
  - Compact size: about 9’ long by 3.5’ diameter
  - Single stage impeller overhung from motor shaft so as to eliminate need for additional bearings
  - Custom thermal management
Motor Design Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Motor Type</td>
<td>Induction</td>
</tr>
<tr>
<td>Output Power (hp/MW)</td>
<td>13,400/10</td>
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<tr>
<td>L-L Voltage (Volts)</td>
<td>6,900</td>
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<tr>
<td>Speed (rpm-sync.)</td>
<td>12,000</td>
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<tr>
<td>Slip (%)</td>
<td>0.517</td>
</tr>
<tr>
<td>Torque (ft-lb/N-m)</td>
<td>5895/7992</td>
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<tr>
<td>Pole Number</td>
<td>2</td>
</tr>
<tr>
<td>Frequency (Hertz)</td>
<td>200</td>
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<tr>
<td>Cooling System</td>
<td>Forced Ventilation w/ Methane Gas</td>
</tr>
<tr>
<td>Bearings</td>
<td>Active Magnetic</td>
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<tr>
<td>Efficiency (%)</td>
<td>94.9</td>
</tr>
<tr>
<td>Power Factor</td>
<td>0.788</td>
</tr>
<tr>
<td>Stator Core Outside Diameter (in./cm)</td>
<td>34.724/88.20</td>
</tr>
</tbody>
</table>
MOTOR HIGHLIGHTS (Contd.)

- **Motor Operation**
  - 10MW at 12,000 rpm
  - Excellent Life
  - Over 5000 start-stop cycles
  - Class H insulation for class F temperature

- **Robustness**
  - Optimized rotordynamic design that meets API 541 and API 617 requirements. Rotor is levitated on two radial magnetic bearings. Residual thrust loads controlled by magnetic thrust bearing.
  - Multiple ventilation/cooling system passages designed to preclude the possibility of obstruction by contaminants
  - Specifically designed for use with VFD for direct drive applications
MOTOR HIGHLIGHTS (Contd.)

- 95% motor efficiency
  - Reduced eddy current stator core losses by using thin laminations
  - Minimized stator coil eddy loss by optimizing the strand sizes in both the top and bottom coils
  - Eliminated circulating currents between coil strands through strand transposition
  - Increased rotor-stator air gap to control rotor surface losses
  - Reduced bearing losses due to use of magnetic bearings
Summary

- The design feasibility of a direct drive, robust, highly efficient, and high-speed motor has been demonstrated. The motor is powered by a variable speed drive. It is capable of delivering 13,400 HP, at 12,000 rpm, to the integral pipeline compressor that is mounted on the motor shaft.
- The motor is cooled by a portion of the high pressure discharge gas from the compressor, thereby eliminating the need for extra blower fans and heat exchangers.
- The motor-compressor system is levitated by active magnetic bearings, thus eliminating lubrication hazards. Because of the use of magnetic bearings, the health of the pipeline compressor station can be monitored from a remote location, providing economic benefits.
Multilevel Series PWM
Medium Voltage
Adjustable Speed Drive

Overview
A Proven & Integrated ASD System

- Isolation Transformer
- Harmonic Filtering
- Power Factor Correction
- Power Converter
- Motor Filter

- Included
- Inherent
- Included
- Inherent
POWER TOPOLOGY

6600–7200 Volt Drive

Input Power
3 Phase AC,
Any Voltage

AC Motor

DRESSER-RAND

EMD

ASI Robicon
ASD INPUT VOLTAGE & CURRENT WAVEFORMS

Phase A to B Voltage, 1500 Volts/Div
Phase C Current, 45 Amps/Div

Milliseconds
Total power factor includes distortion and displacement power factor.
ADDITION OF THREE CELL OUTPUTS TO CREATE PHASE VOLTAGE

CELL 1

CELL 2

CELL 3

COMPOSITE
ASD OUTPUT VOLTAGE & CURRENT WAVEFORMS

Phase A to B Voltage, 1500 Volts/Div  Phase C Current, 45 Amps/Div
Available Power Ratings / Output Voltage

400 HP   to      5,500 HP    @    2,300 VAC
400 HP   to      8,000 HP    @    3,300 VAC
400 HP   to      10,000 HP   @    4,160 VAC
1,000 HP  to     60,000 HP   @    7,200 VAC
1,000 HP  to     75,000 HP   @    13,800 VAC

400 HP   to      8,500 HP    Air Cooled
4,000 HP  to     75,000 HP   Liquid Cooled
Air Cooled Power Cell
Water Cooled Power Cell
2 x 100% Water-To-Water Heat Exchanger
Water-To-Air Heat Exchanger
11,000 HP, 13.8/6.6 kV ASD
Integrated System Delivery
Multilevel Series PWM ASD
Proven Performance

- First System Delivered - 1994
- Products in Use > 2000
- Products Installed per Year > 300
- High Capacity Products (5,000 HP +) > 1 per wk
- Current Product Generation - 3
- Output Voltages Available (2.3 to 13.8 kV)
- Largest Unit - 60,000 HP
- Critical To Process Experience
  - 5 Year Continuous Service with 4 - 9 Availability
  - (ref. IEEE - PCIC-2001-09)
Other Related Experience

- 12 Mag Bearing Supported Compressors Built
- Over 60 motor / compressor packages with VFD’s
- The IEMDC is the marriage of these two proven technologies
IEMDC - Compressor Summary

- Proven Aerodynamic Design
- No Rotating Seals against Atmosphere
  - Improved Reliability
  - Reduced Maintenance
- Modular Construction for ease of Installation
- Future Uprate-ability
Faster Response & Flexible

- Electric Drives can Start & Stop as needed
- Zero to full load in minutes
- Adjustable output
- Able to meet the needs of volatile power generation applications
- VFD reduces transmission system impacts
- Clean and Green, no on-site emissions
Fuel Cell Implications

- Future on-site, high-efficiency generation
- Hydrogen extracted form methane to run fuel cell
- Assumes capital cost and technical issues will be overcome
- Improved reliability
- Not subject to power outage
- Received proposal from SWRI for independent project
IEMDC Highlights

- No building required
- Very quiet operation
- No site emissions
- Interchangeability
- No external cooling required
- Minimal piping
- Small site
IEMDC Summary

- Lowest capital cost
- Lowest Operating Cost
- Minimal Environmental Impact
- Conserves Energy Resources
  - Global energy efficiency 52% up from 35%
- Application is any clean, dry, oxygen free pipeline