Gas/Electric Partnership

Electric Motor Drive
Reliability Review and Lifecycle Cost Analysis

Southwest Research Institute
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- ABB
- Centerpoint Energy
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- Kinder Morgan
- El Paso Pipeline
- Enterprise Products
- FMC Direct Drive
- General Electric

- Panhandle / SUG
- Siemens
- Spectra Energy
- Striker
- TransCanada Pipeline
- Voith
- Williams Gas Pipeline
Agenda

- Project Objective
- Guideline Content
- Reliability Study Results
Project Objective

• Gas/Electric Partnership funded a research effort to:
  ▫ Develop a guideline for electric motor driven centrifugal compressors in **pipeline applications** to investigate **operational reliability** and **life cycle costs** of the various commercially available EMD technologies
Guideline Objectives

- Further understanding of EMD train components
- Create better design options from compressor station standpoint
- Understand motivation for EMD systems and when they will produce low costs/high returns
- Discuss utility requirements
- Investigate maintenance strategies
Guideline Content

• Final version of the Guideline is complete
  ▫ Guideline, life cycle cost analysis spreadsheet, and project committee comments provided December 20th, 2012

Guideline Sections

Design Details
- Substations, Electric Motor System, VFD and Other Drive Train Components
- Variable Speed Hydraulic Drives, System Design Tradeoffs

Reliability Review
- 6 data sets from 99 electric motor drives

Life Cycle Cost Analysis
- Spreadsheet tool – overview and description of how to use tool
Design Details

Substations
- Design
- Ownership
- Utility Requirements
- Purchased Power Agreement Variations

Electric Motor System
- Electric Motor
- Motor Life
- Auxiliary Equipment
- Motor Component Fault Zones

Variable Frequency Drive
- Cooling System
- Enclosures
- Harmonics and Electric Filters
- Replacement Parts

Variable Speed Hydraulic Drive

System Design Tradeoffs
Life Cycle Cost Analysis

- Total LLC Analysis
  - Scenario Options
  - Capital Cost Items
  - Ongoing Costs
  - Maintenance Activities
  - Close-out Costs
  - Total Lifecycle Costs
  - Cost Comparison Graphs
Life Cycle Cost Analysis

- Drive Power Model (calculations)
  - Operating Conditions
  - Power Required
  - Gas Properties
Reliability Study

★ Goal ★
Understand EMD reliability for pipeline centrifugal compressor applications

- Review publication on previous EMD studies
- Analyze outage data on electric motor drive systems from existing pipeline stations
Review of Previous Studies

- **Previous Studies**
  - Studies from past 3 decades on electric motors correlate motor failure with size, age, operation, and maintenance
  - Studies were primarily focused on motors smaller than 5000 hp
  - No focus on specific applications
  - Majority of work done by EPRI, IEEE, and Thorsen et al
    - EPRI - A primary function of the EPRI work was to identify the probability of a motor failure for a given set of motor parameters
    - IEEE - Presents a first order classification analysis for motor failure rate with motor parameters (age, power rating, classification).
    - Thorsen - Motor failure was analyzed for motor parameters reported by electric motor operators, where the effect of only a few parameters at a time were investigated

- **Current Study**
  - Looks for common outage types reported in data
  - Focused on specific application of centrifugal compressor at pipeline station
  - **Does not compare** EMD systems to other compressor drive systems
### Overview of Data

<table>
<thead>
<tr>
<th>Data Set</th>
<th>Motor Size Range (hp)</th>
<th>Data Period (Years)</th>
<th>Outage Data</th>
<th>Survey Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4,000 – 15,000</td>
<td>2.9 – 4.3</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>2</td>
<td>4,000 – 47,000</td>
<td>2</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>3</td>
<td>6,000 – 16,000</td>
<td>0.5 – 3.5</td>
<td>A</td>
<td>UnA</td>
</tr>
<tr>
<td>4</td>
<td>7,000 – 22,000</td>
<td>0.1 – 2.5</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>5</td>
<td>34,000</td>
<td>2.75</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>6</td>
<td>1,500 – 20,000</td>
<td>3</td>
<td>A</td>
<td>UnA</td>
</tr>
</tbody>
</table>

A = Data Available  
UnA = Date Unavailable

### Electrical Outages

<table>
<thead>
<tr>
<th>Category</th>
<th>Example Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utility</td>
<td>Power quality</td>
</tr>
<tr>
<td>VFD/Gearbox</td>
<td>Gearbox high vibration</td>
</tr>
<tr>
<td>Motor</td>
<td>Drive over current</td>
</tr>
<tr>
<td>Cooling system for motor/VFD</td>
<td>Ventilation fan shutdown</td>
</tr>
<tr>
<td>Natural Forces</td>
<td>Lightning strike</td>
</tr>
<tr>
<td>Other</td>
<td>Breaker failed</td>
</tr>
</tbody>
</table>

### Non-Electrical Outages

<table>
<thead>
<tr>
<th>Category</th>
<th>Example Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance</td>
<td>Maintenance</td>
</tr>
<tr>
<td>Bearing/Lubrication system</td>
<td>Lube cooler shutdown</td>
</tr>
<tr>
<td>Emergency shutdown (ESD)</td>
<td>ESD</td>
</tr>
<tr>
<td>Natural forces</td>
<td>Cold weather</td>
</tr>
<tr>
<td>Station alarm/trip event</td>
<td>High pressure trip</td>
</tr>
<tr>
<td>Other</td>
<td>Sensor failure</td>
</tr>
</tbody>
</table>
Overview of Data

- **Data Set 1**: n/a
- **Data Set 2**: Induction
- **Data Set 3**: Synchronous
- **Data Set 4**: Induction
- **Data Set 5**: Synchronous
- **Data Set 6**: Synchronous
Overview of Data

System Configuration

No.

VFD
VSHD
GBX

Data Set 1
Data Set 2
Data Set 3
Data Set 4
Data Set 5
Data Set 6
Overview of Data

![Overview of Data](image-url)
Overview of Data

The graph illustrates the distribution of data sets across different power ranges (hp). Each data set is color-coded as follows:

- Blue: Data Set 1
- Red: Data Set 2
- Green: Data Set 3
- Purple: Data Set 4
- Teal: Data Set 5
- Orange: Data Set 6

The power ranges are as follows:

- 1000-5000
- 5000-10000
- 10000-15000
- 15000-20000
- 20000-25000
- 25000-30000
- 30000-35000
- 35000-40000
- 40000-45000
- 45000-50000
- >50000
Summary of Data Set 1

- 20 EMD systems from 4K to 47K HP
- Outage data range: 3.3 to 4.3 years
- VFD, VSHD, or VFD and GB
- 16 units had more than 20% of their outage hours related to EMD system or power supply
- Outage downtime varied from 15 minutes to 78 days
- ~ 50% of downtime related to electrical systems
- Highest Outage Hours: Natural forces, VFD or GB, power supply
- Operator survey response:
  - Long downtime issues unique to individual units
  - Electric utility support was good except when the gas transmission company owned the substation
  - Variability with inspections and studies
  - Limited spare parts
  - 50% of units operating at conditions different from their design conditions
Data Set 1

Graphs for Data Set 1

- There is a high variability between outage duration for individual units for electrical and non-electrical events.
- There is also a high variability between outage duration for individual units for types of electrical events.

![Graphs showing outage duration for different units and outage types.](image-url)
Data Set 1

Graphs for Data Set 1

- 5 of the units had a mean outage per occurrence (MODO) greater than 50 hours.
- The mean time between outages (MTBO) for electrical downtime events was greater than non-electrical.
Summary of Data Set 2

- 20 EMD systems from 4K to 15K HP
- Outage data range: 2 years
- VFD, soft start VFD, VSHD, or GB
- 4 units had more than 20% of their outage hours related to EMD system or power supply
- Little electrical downtime reported
- Highest Outage Hours: Power supply (blown fuse)
- Highest Frequency of Occurrence: All data had very low frequency electrical outages
- Specific Examples: Blown fuse, switch failure, leaks on VFD cooling system
- Operator survey response:
  - No general conclusions could be made
  - Replacement parts for VFDs were on site
  - Gas transmission company owned the substation
Summary of Data Set 3

- 6 EMD systems from 6K to 16K HP
- Outage data range: 0.5 to 3.5 years
- VFD or GB
- 4 units had more than 20% of their outage hours related to EMD system or power supply
- All outage downtime greater than 8 hours
- Majority of outage data related to electrical issues
- Highest Outage Occurrence (hours and frequency): VFD/GBX, cooling, and power supply outages
- Operator survey response was not provided
Summary of Data Set 4

- 13 EMD systems from 7K to 22K HP
- Outage data range: 0.1 to 2.5 years
- VFD or GB
- 6 units had more than 20% of their outage hours related to EMD system or power supply
- Highest Outage Occurrence (hours and frequency): Power supply
- Specific Examples: Power supply loss on shared electrical lines, RTD module failures
- Operator survey response:
  - For one unit, there were few power supply shutdowns due to dedicated feed line from substation
  - Other power supply failures accounted for 95% of shutdowns, units shared power lines with surrounding areas
Summary of Data Set 5

- 3 EMD systems with 34K HP
- Outage data range: 2.75 years
- VFD and GB
- All 3 units had more than 20% of their outage hours related to EMD system or power supply
- Highest Outage Occurrences (hours and frequencies): VFD/GBX, cooling
- Specific Examples: Communication failures, drive updates, low voltage trips, low coolant, coolant leaks, bearing/lubrication failure
- Operator survey response:
  - No support from the utility provider
  - Most downtime issues due to cooling system failures shortening VFD transformer life
  - Spare transformers and cells were available for cooling failures
Summary of Data Set 6

- 37 EMD systems from 1.5K to 20K HP
- Outage data range: 3 years
- VFD, GB, or VFD and GB
- 20 units had more than 20% of their outage hours related to EMD system or power supply
- Very little outage data reported – unable to identify any primary outage causes from data
- Operator survey response was not provided
Reliability Review Conclusions

- Significant differences between information provided in data sets
- Majority of data sets had >20% of outages reported to be related to electrical systems
- Three primary reasons for outages
  - VFD/Gearbox
  - Power Supply
  - VFD cooling system
  - Note: Some units had significant downtime due to motor failures and natural force events

<table>
<thead>
<tr>
<th>Category</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Forces</td>
<td>Lightning strikes, bad weather</td>
</tr>
<tr>
<td>VFD/Gearbox</td>
<td>Software issues, VSHD component failure, VFD component failure</td>
</tr>
<tr>
<td>Power Supply</td>
<td>Power failure, transformer leaks, substation issues (breaker failure, emergency maintenance)</td>
</tr>
<tr>
<td>VFD Cooling System</td>
<td>Water/glycol leaks, low water/glycol pressure, high conductivity, pump failure</td>
</tr>
<tr>
<td>Motor</td>
<td>Ground fault, high winding temperature</td>
</tr>
</tbody>
</table>
Reliability Review Conclusions

- Most long downtime events related to a unique issue
  - Ex. One 2700 hour outage due to high rotor vibration which results in breaking of motor rotor

### Long Downtime Event Causes

<table>
<thead>
<tr>
<th>Category</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Forces</td>
<td>Hurricane, flooding, lightning strike</td>
</tr>
<tr>
<td>VFD/Gearbox</td>
<td>VFD Relay failure, continuous VFD software issues, blown fuse on VFD, VFD failure, VSHD guide vane failure</td>
</tr>
<tr>
<td>Power Supply</td>
<td>Substation Breaker failure, Switch Gear Current Protection Relay Failure, Substation electrical issues</td>
</tr>
<tr>
<td>VFD Cooling System</td>
<td>Water leak, cooling water filter failure</td>
</tr>
<tr>
<td>Motor</td>
<td>Broken rotor bar</td>
</tr>
</tbody>
</table>
Reliability Review Conclusions

- General Observations
  - Motors were forced air cooled
  - VFDs either water or water/glycol cooled
  - Limited spare parts on site unless past experience encourages spare parts
  - No consensus on drive train inspections (some inspect yearly and some not at all)
  - Electric utility support good if electricity provider owns substation
Overall Recommendations

- **Natural Forces**
  - Cannot be avoided
  - Lightening protection and backup plans for power loss
  - Compression power redundancy (backup gas engine driver or backup power supply)

- **VFD/VSHD and Cooling**
  - Unique issues including software issues
  - Allot time and effort into VFD setup and config.
  - Staff member with VFD background or good relationship with VFD manufacturer or support team
  - Maintain spare parts or work with manufacturer on spare part support
  - Inspection and maintenance plan on cooling system
Overall Recommendations

- **Power Supply**
  - Ownership of the substation: Utility vs Pipeline Station
  - If operator owned, electrical system support expert would be advantageous including maintenance and spare part plan
  - Good working relationship with utility provider

- **Motor**
  - Ground faults and high temperatures – insulation degradation and fouling of component air
  - Maintenance of motor sensors and storage of replacement parts
  - Proper conditioning of cooling air
Questions?

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