Gas/Electric Partnership

Electric Motor Drive Reliability Review and Lifecycle Cost Analysis

Southwest Research Institute

February 7, 2013

Melissa Wilcox, Brandon Ridens, Grant Musgrove, Nathan Poerner, Richard Baldwin

Thanks to the 2011 GEP Research Consortium Members and Industry Advisory Committee

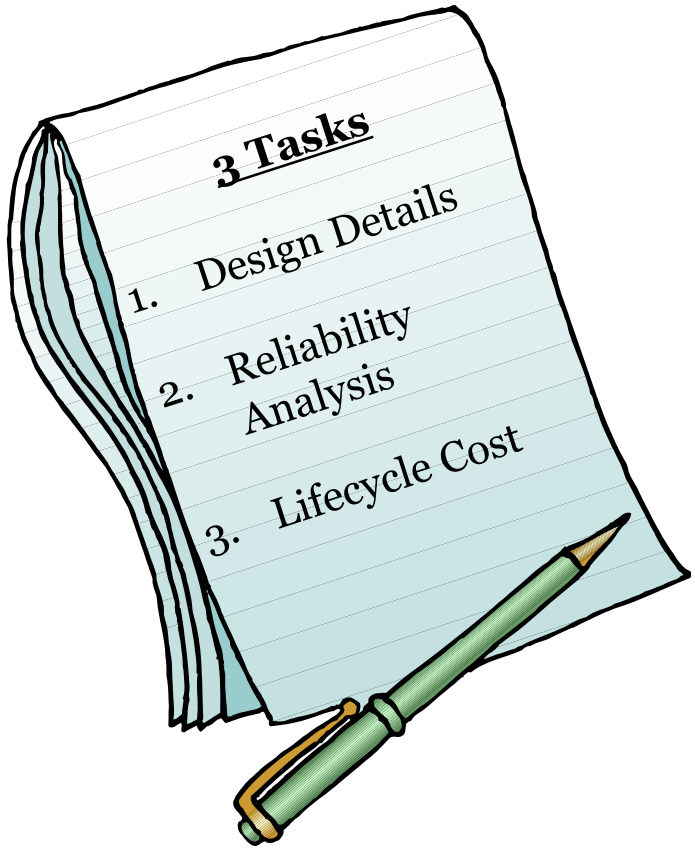
- ABB
- Centerpoint Energy
- Curtiss Wright
- Kinder Morgan
- El Paso Pipeline
- Enterprise Products
- FMC Direct Drive
- General Electric
- Panhandle / SUG
- Siemens
- Spectra Energy
- Striker
- TransCanada Pipeline
- Voith
- Williams Gas Pipeline

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

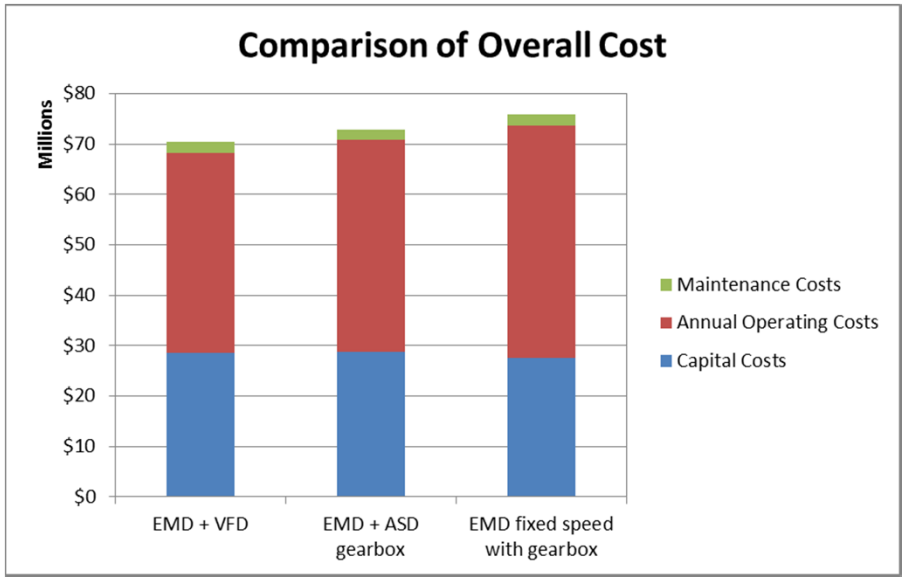
- Cooling System
- Enclosures
- Harmonics and Electric Filters
- Replacement Parts

Variable Speed Hydraulic Drive

System Design Tradeoffs

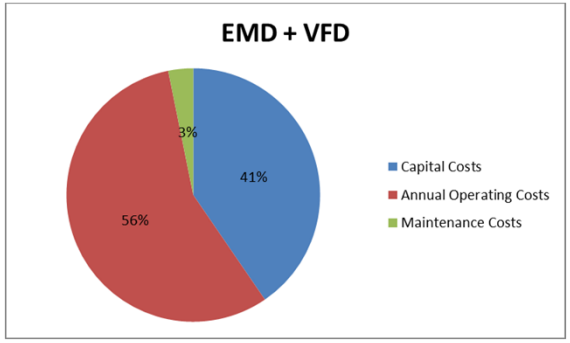
Life Cycle Cost Analysis

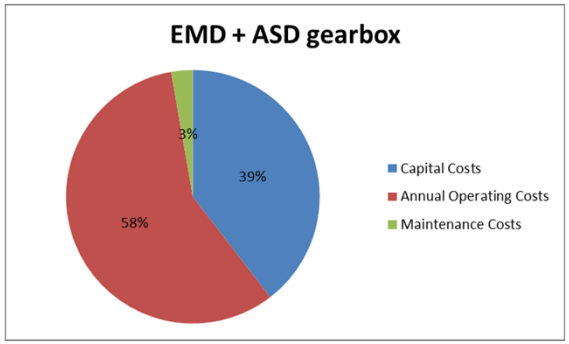
- Total LLC Analysis
  - Scenario Options
  - Capital Cost Items
  - Ongoing Costs
  - Maintenance Activities
  - Close-out Costs
  - Total Lifecycle Costs
  - Cost Comparison Graphs

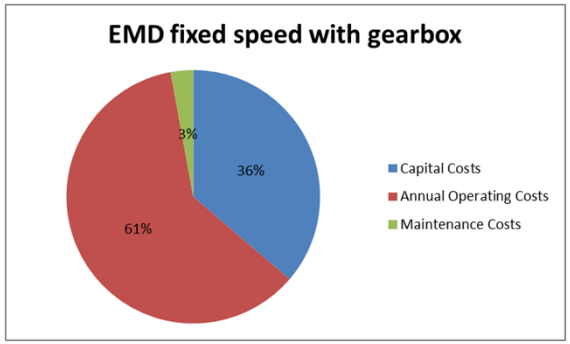


Life Cycle Cost Analysis

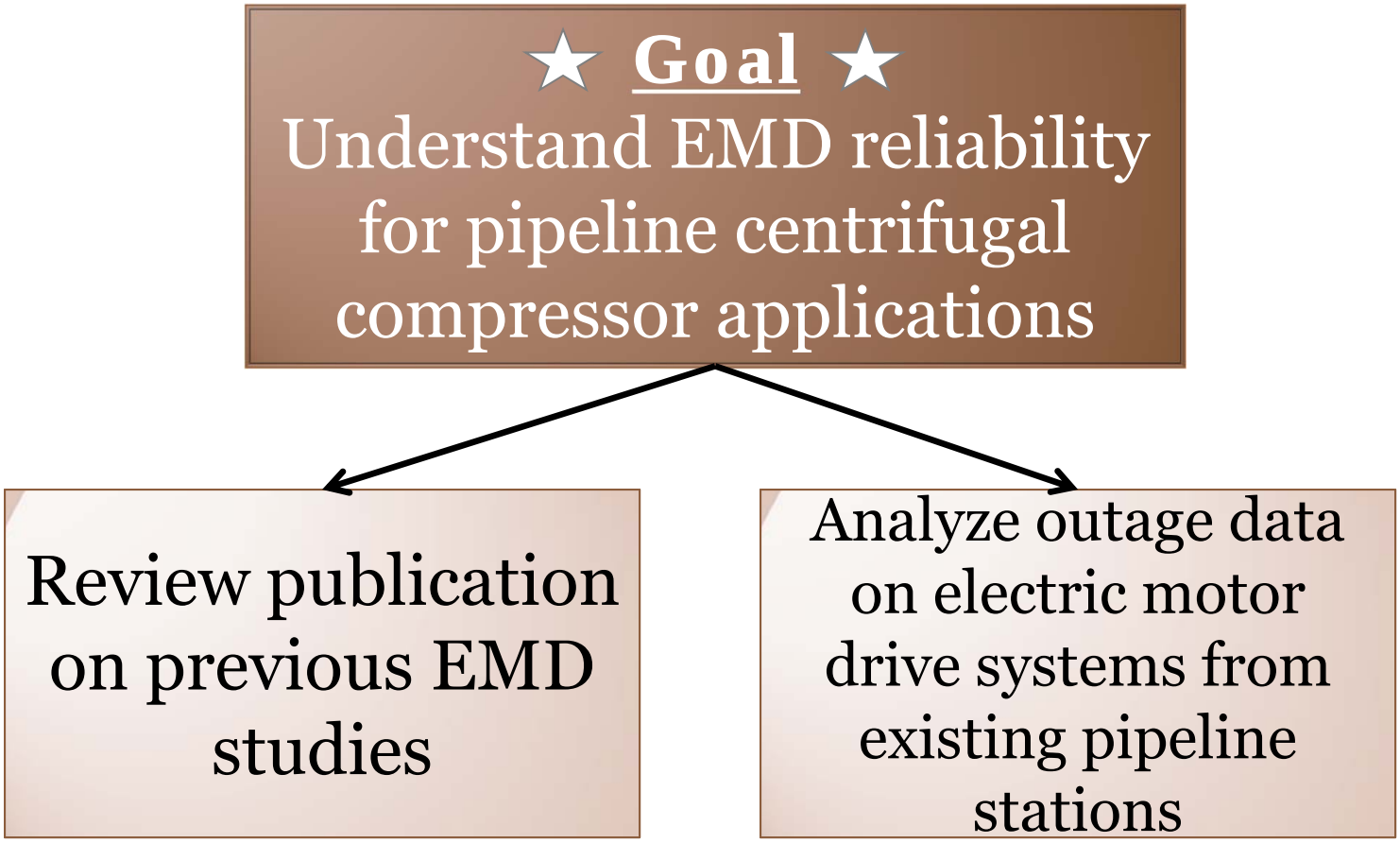
- Drive Power Model (calculations)
  - Operating Conditions
  - Power Required
  - Gas Properties







Reliability Study



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

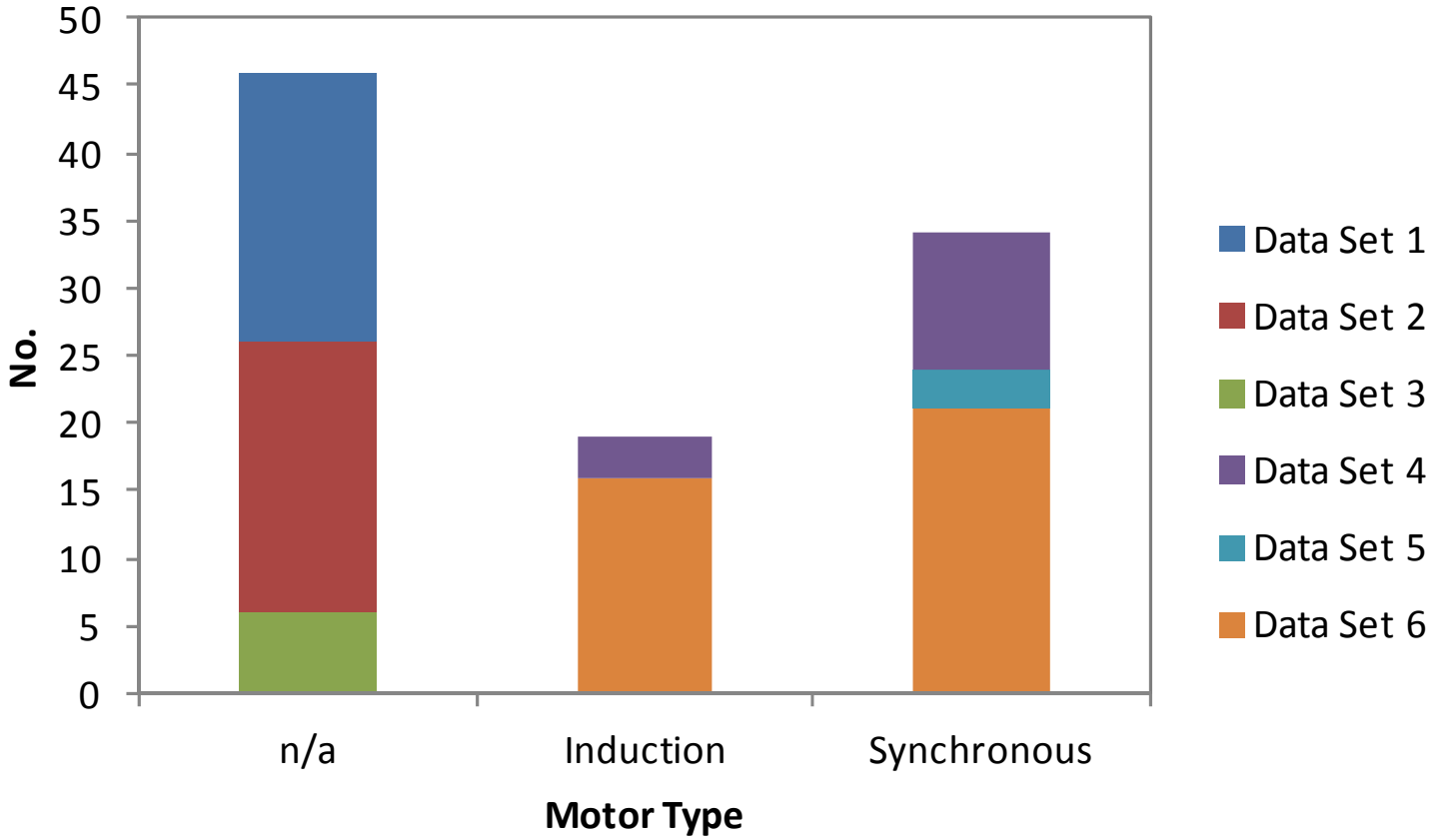
Overview of Data

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

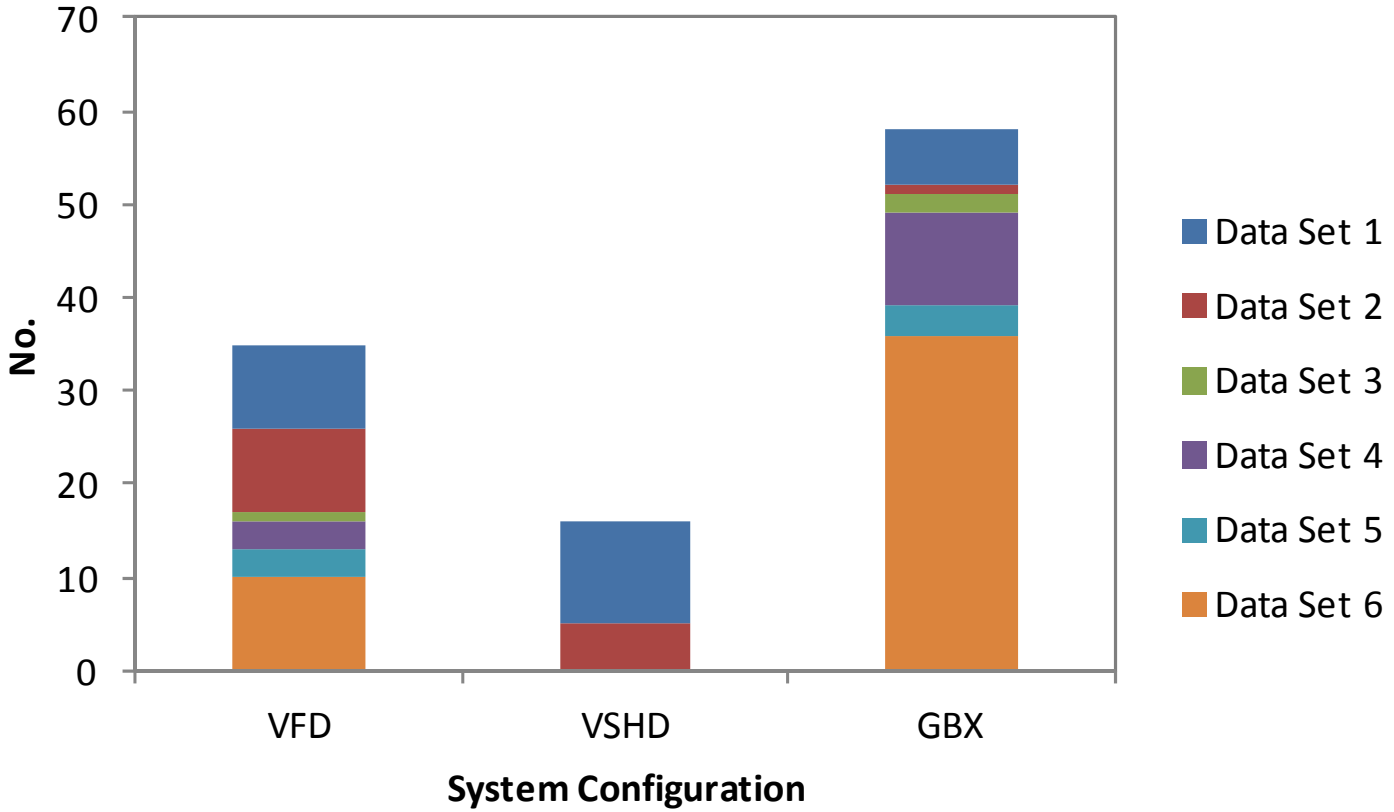
A = Data Available
UnA = Date Unavailable

Electrical Outages	
Category	***Example Description***
Utility	*Power quality*
VFD/Gearbox	*Gearbox high vibration*
Motor	*Drive over current*
Cooling system for motor/VFD	*Ventilation fan shutdown*
Natural Forces	*Lightning strike*
Other	*Breaker failed*
Non-Electrical Outages	
Category	***Example Description***
Maintenance	*Maintenance*
Bearing/Lubrication system	*Lube cooler shutdown*
Emergency shutdown (ESD)	*ESD*
Natural forces	*Cold weather*
Station alarm/trip event	*High pressure trip*
Other	*Sensor failure*

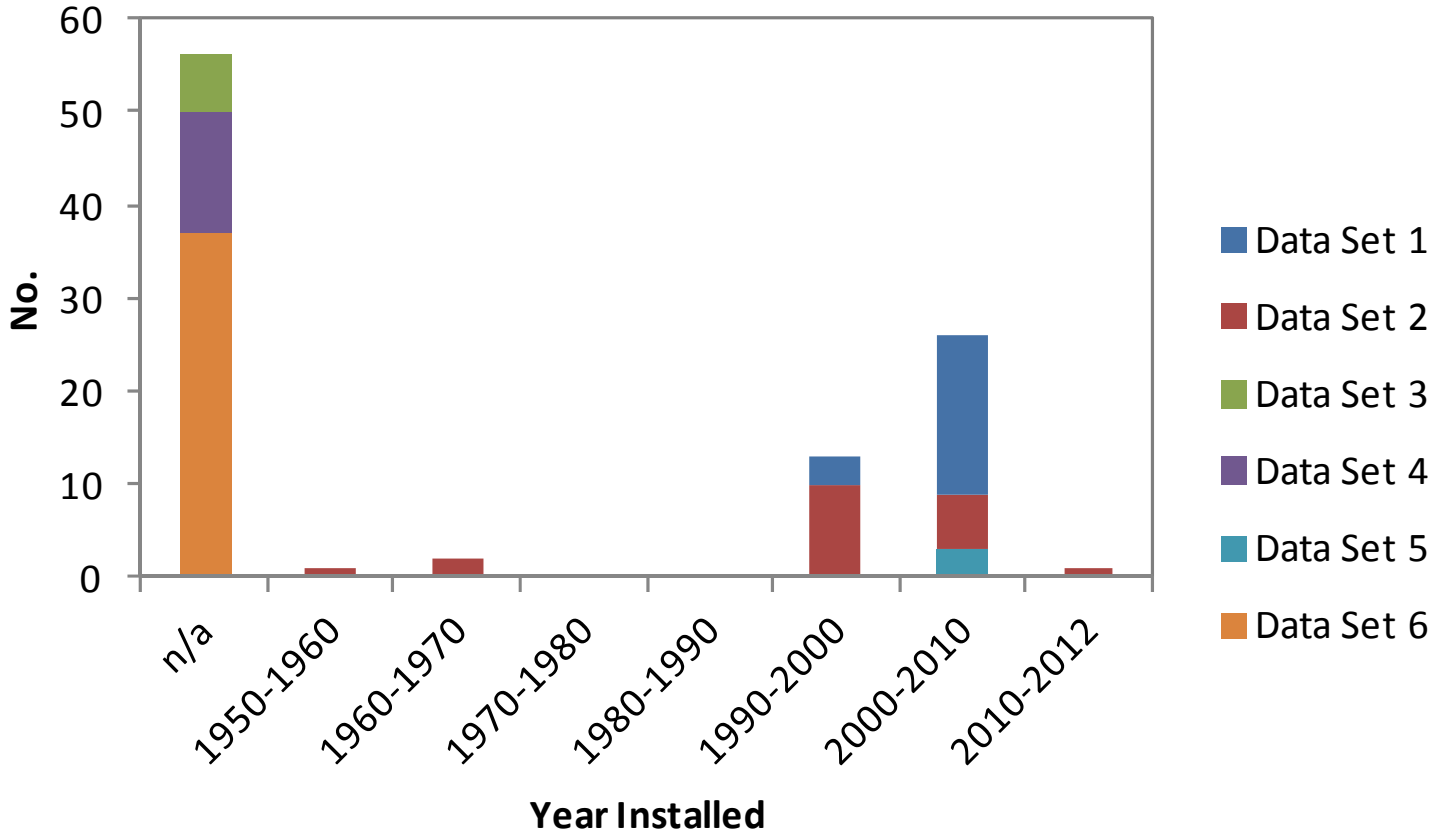
Overview of Data



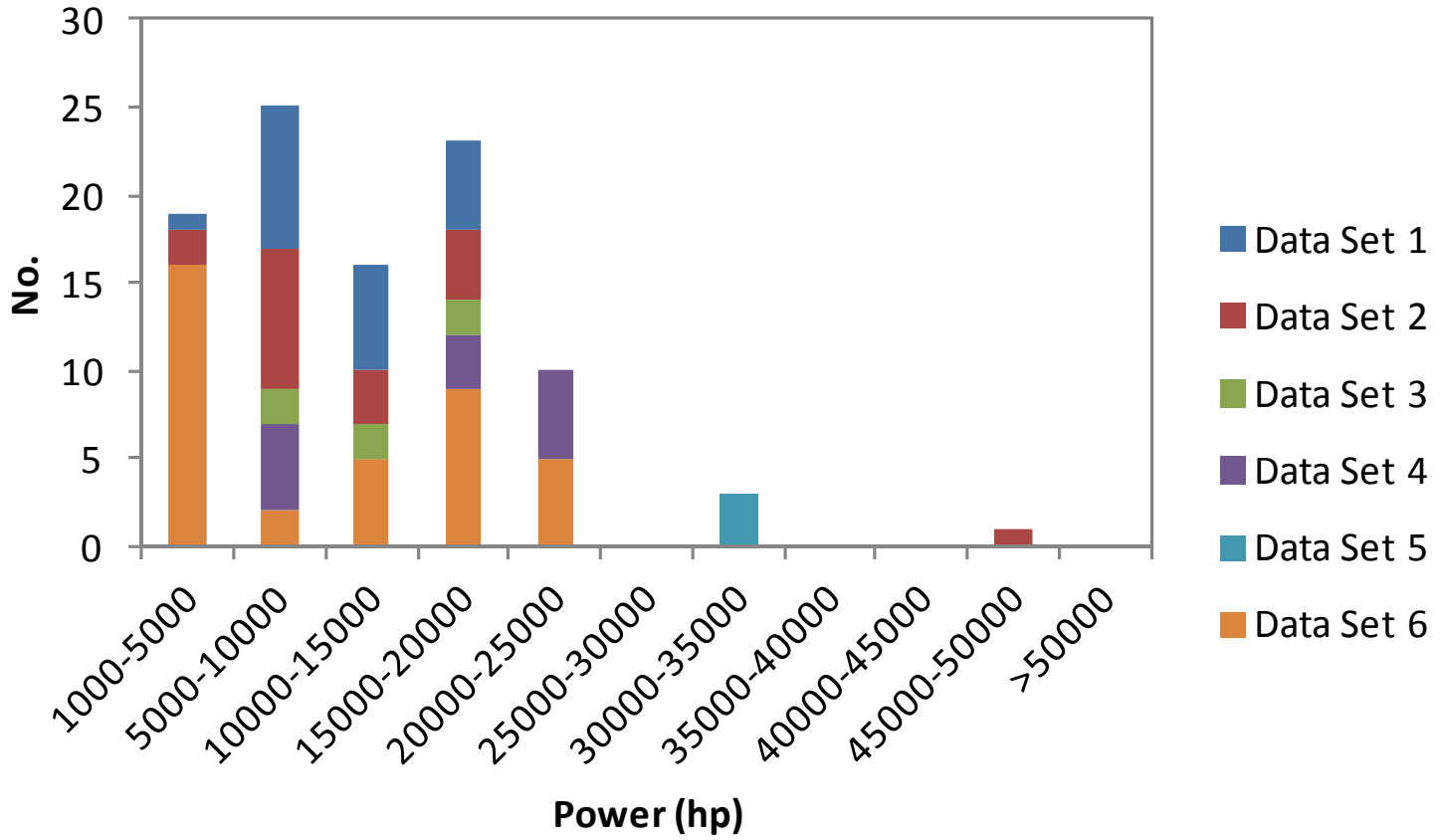
Overview of Data



Overview of Data



Overview of Data



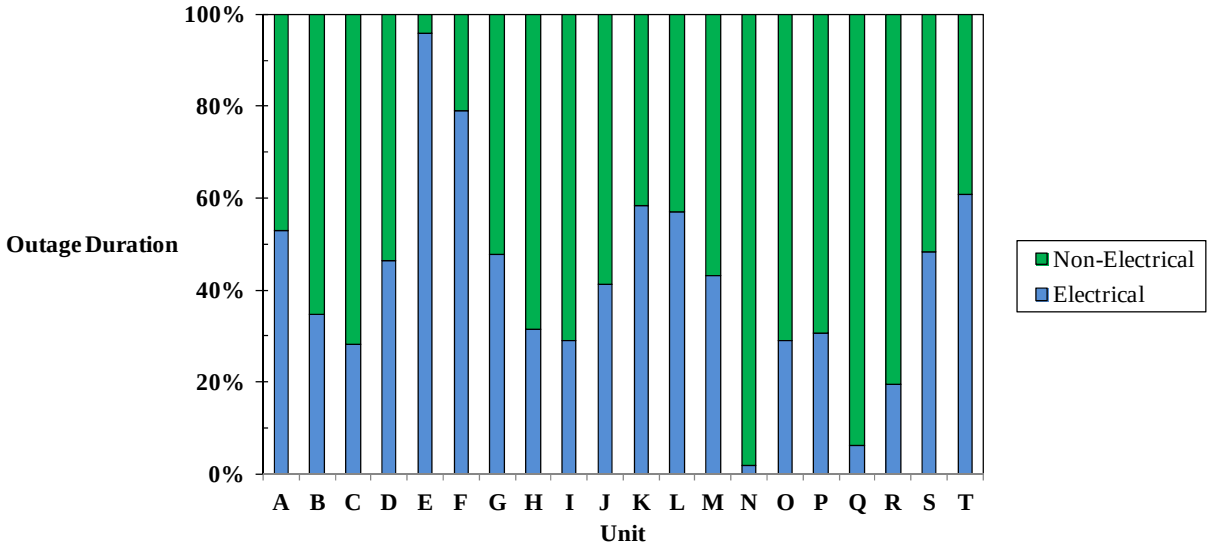
Summary of Data Set 1

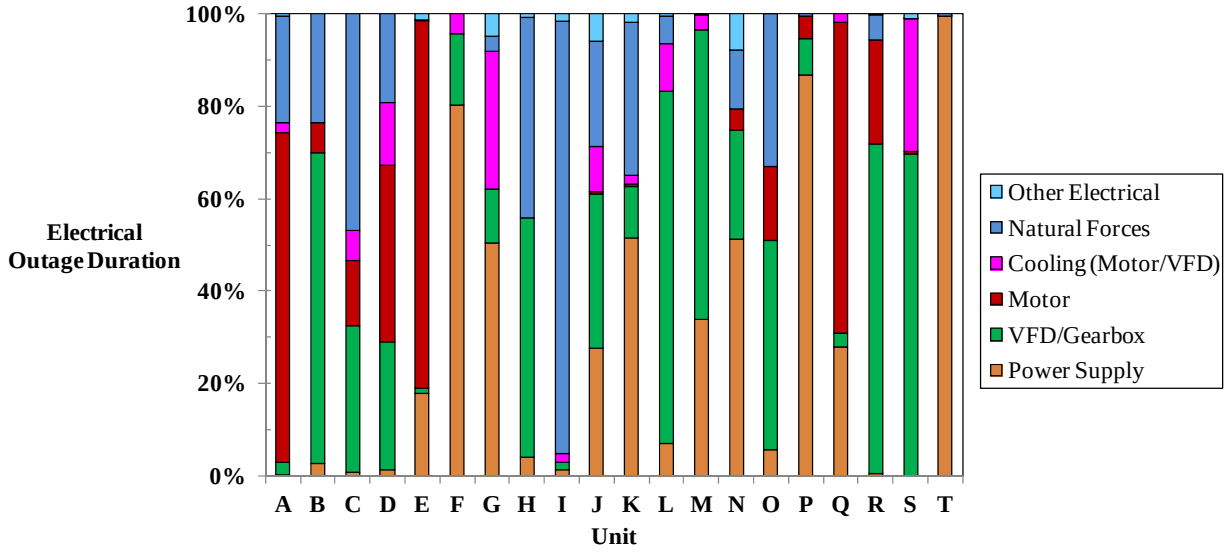
- 20 EMD systems from 4K to 47K HP
- Outage data range: 3.3 to 4.3 years
- VFD, VSHD, or VFD and GB
- 16 units had more than 20% of their outage hours related to EMD system or power supply
- Outage downtime varied from 15 minutes to 78 days
- ~ 50% of downtime related to electrical systems
- Highest 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

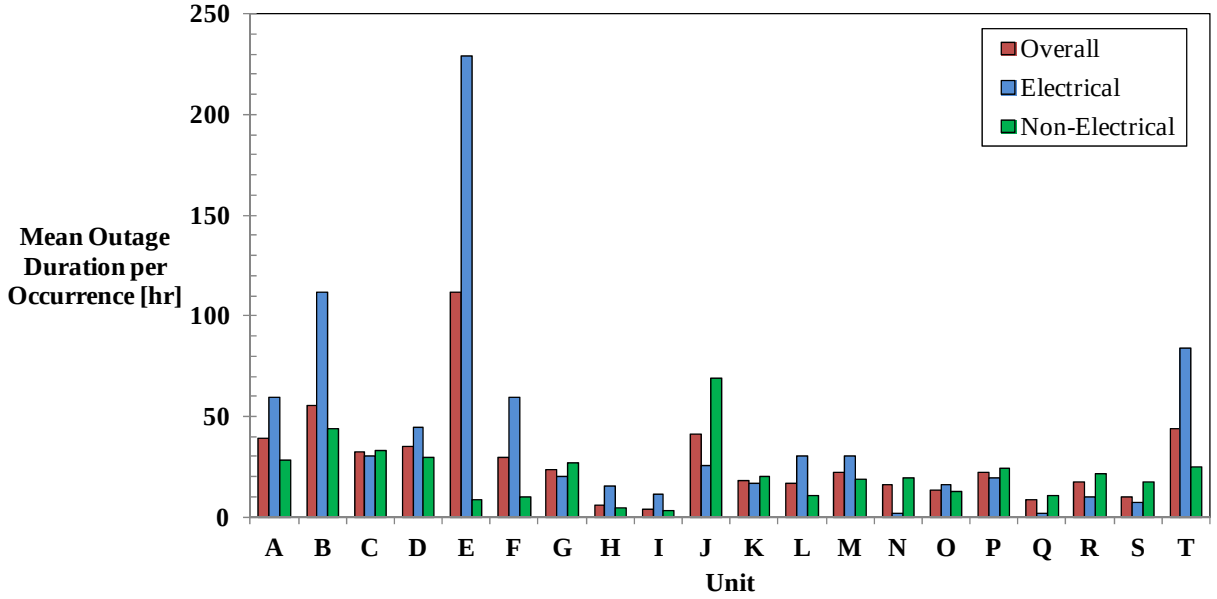


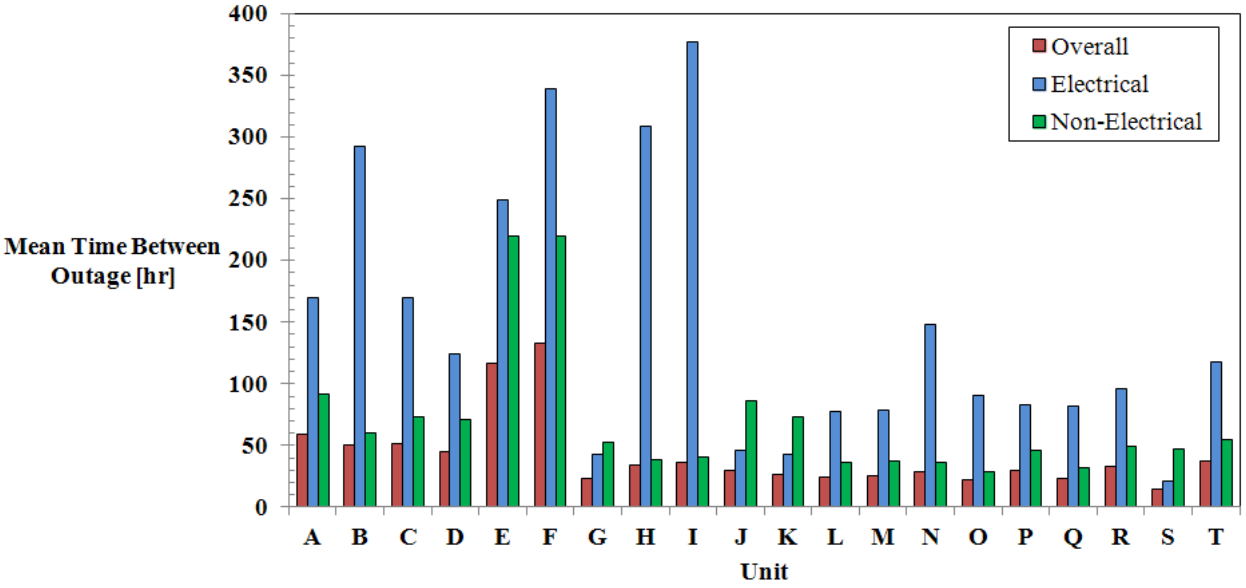


Data Set 1

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

Common Unplanned Downtime Causes

Category	Reason
Natural Forces	Lightning strikes, bad weather
VFD/Gearbox	Software issues, VSHD component failure, VFD component failure
Power Supply	Power failure, transformer leaks, substation issues (breaker failure, emergency maintenance)
VFD Cooling System	Water/glycol leaks, low water/glycol pressure, high conductivity, pump failure
Motor	Ground fault, high winding temperature

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

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

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?

- Melissa Wilcox
  - melissa.wilcox@swri.org
  - 210-522-6046
- Brandon Ridens
  - brandon.ridens@swri.org
  - 210-522-3459