Gas Electric Partnership Research Consortium

Reliability Review of Electric Motor Drives for Pipeline Centrifugal Compressor Stations

Gas Electric Partnership Conference

Southwest Research Institute

February 9, 2012

Thanks to the 2011 GEP Research Consortium Members

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

Agenda

- Objective of GEP Research Consortium
- 2011 GEP Project Overview
  - Project Objective
  - Project Tasks
  - Guideline Outline
  - EMD Background
  - Review of Reliability Data
  - LCC Analysis

Objective of GEP Research Consortium:

Advance technology, operation, training of EMDs for pipeline industry to increase industry understanding and technology viability and applicability.

GEP R&D Needs for Research Consortium

- R&D steered by Industry advisory committee from EMD Users and OEMs
- Focus on electric motor drives for pipeline centrifugal compression for 2011 project year.
- Topics will be of general interest, not company specific, and aim to improve understanding and perception of EMD operation
- Funded by voluntary donations from industry advisory committee members
- Project for 2011 is "**Lifecycle Cost Analysis and Reliability Review of Adjustable Speed Drives for Pipeline Compressors**"

2011 GEP Project

- Lifecycle Cost Analysis and Reliability Review of EMD Adjustable Speed Drives for Pipeline Compressors
- Objective
  - 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.

Project Tasks

1. Lifecycle cost analysis to determine advantages, disadvantages and suitability of adjustable speed drives at pipeline compressor stations – centrifugal only.
2. Reliability Analysis existing electric motor driven compressors and electric utilities to study reliability issues and means of designing and operating stations for improved availability.
3. Develop a guideline which documents the above items and provides summary of design considerations for electric motor drive installation

Guideline Outline

I. Introduction and Overview

II. Design Details and Components in an Electric Motor Installation

Substation

- Utility Capacity
- Utility Voltage Regulation and impact on VFD power delivery
- Voltage for transformers, spare transformer options
- Transformer Rating in MVA
- Transformer Impedance
- Power Factor, Effect on voltage regulation and solutions (harmonic filtering, other, etc.)

Electric Motor

- Motor Power Rating and Speed Range: matching motor power and use of Service factor
- Motor Type: Synchronous vs Induction
- Torque Requirement for Compressor Shaft Power
- Compressor Operating Range Requirement
- Efficiency of Entire Drive Train over expected operation

VFD and Other Drive Train Components

- VFD / VSHD rating
- VFD type: six or twelve pulse, harmonics impact
- Housing VFD, coolers, lube oil systems

Design Differences for New vs. Retrofit centrifugal compressors from design standpoint

Guideline Outline

III. Reliability Review

- Survey Questions and Approach
- Historical review of motor operation for sites considered
- Planned Shutdowns – Causes
- Unplanned Shutdowns – Causes and corrective action
- Potential Issues to Address for Improved reliability
  - Substation design
  - Electric utility power failures
  - On-site back up power
  - Motor and VFD cooling design reliability improvements
  - Lube oil pumps and cooling
  - Replacement parts
  - Cold weather precautions and alternative designs
  - Back-up generator design
  - PLC communication issues / redundancy
  - Coming on and off generator power
- Electric Utility reliability literature review results (hopefully to include previous EPRI survey)

IV. Lifecycle Cost Analysis

- Assumptions in Analysis (cost of money, inflation, cost of gas and electricity)
- Key Factors to Consider in LCC
- Example LCC analyses

Background: "Application Guideline for Electric Motor Drives for Natural Gas Compressors,"

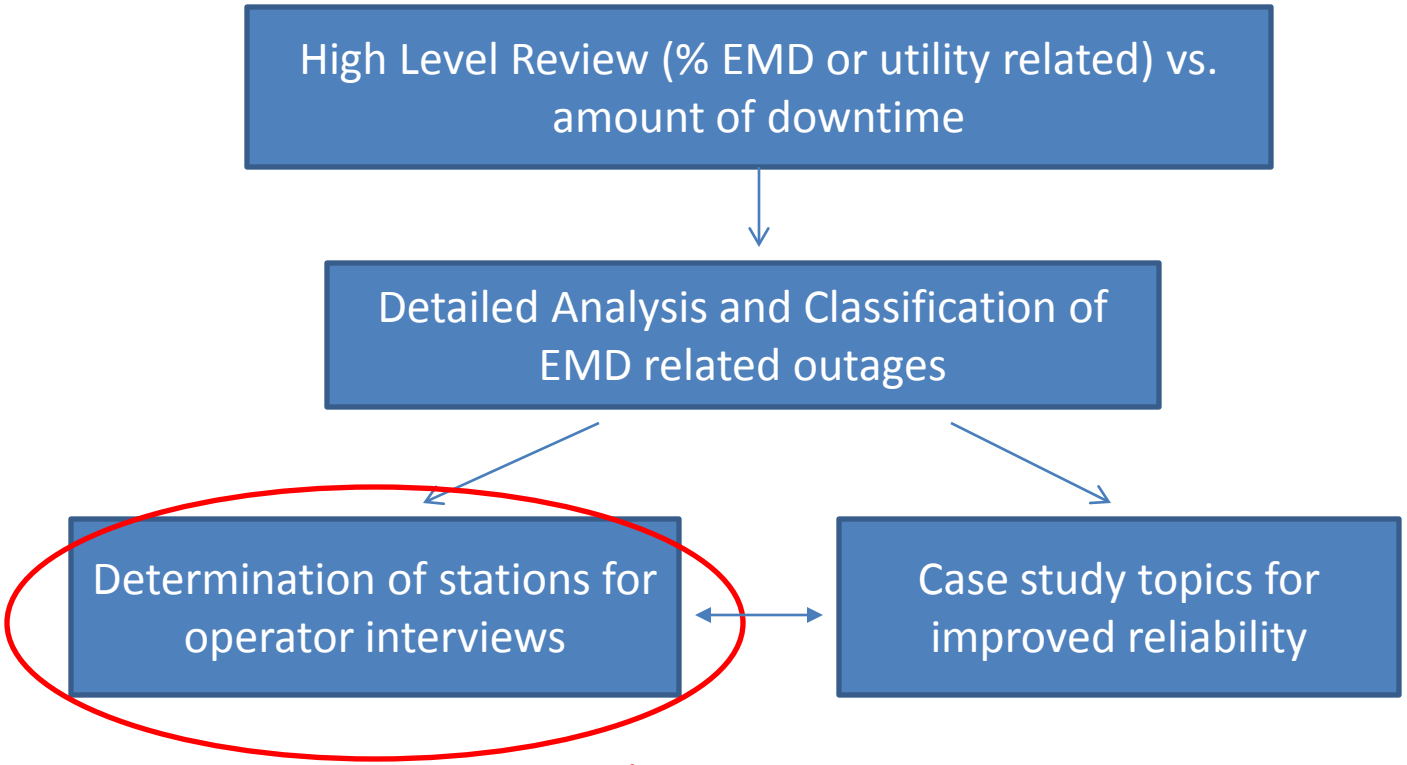
published by the Gas Machinery Research Council in 2009

- A result of industry collaboration between Southwest Research Institute and advisory group: El Paso Pipeline, Exxon Mobil, Dresser Rand, Ariel, Direct Drive Systems, Siemens, Voith and Solar Turbines
- Written for primarily oil and gas industry engineers without firm background in electrical engineering.
- Objective to provide high level overview of EMD equipment to allow project managers and operators to develop EMD projects and understanding of overall system.
- Industry guideline addresses fixed and adjustable speed drive train configurations, starting methods, basic EMD equipment components, electrical power supply issues, power factor, torque availability , drive train efficiency, centrifugal and reciprocating compressor application issues, rotordynamic considerations.
- Available as a free download from the GMRC website or from SwRI (CD's to be distributed at meeting)

Considering EMD for Pipeline Compression

- Electric motors reduce the time for a project often by many months considering air permits may not be required compared to GT or engine drive.
- The electric motor drive selection will be a way to avoid having to do a BAC review or air dispersion modeling.
- Larger interstate pipelines are already affected by longer project timelines because of FERC review and permitting. New GHG rule will more drastically affect midstream companies that have not traditionally had to wait on permits. This would favor them choosing to use electric motors to avoid long GHG permit time.
- For other criteria pollutants permitting, electric motors may also be favored more going forward since limits are being brought down again and more areas are becoming non-attainment.
- In terms of taking credit for replacement horsepower going to electric motor drive, operators can easily take credit for Nox, GHG and other pollutant reductions as an offset for entire facility to bring down total facility emissions. It is more difficult (more documentation required) but not out of the picture, to take credit for these reductions and be able trade and sell the carbon credits on the open market. This may get easier over time as this market evolves.
- **Bottom Line: At present, electric motor drives avoid uncertainty and risk of long permit / review times by negating the issue.**

Summary of Work to Date – Reliability Investigation



Total of Four Operators and 47 Units Reviewed to Date

Operator # 1 = 13 stations, 20 units

Operator # 2 = 5 stations, 11 units

Operator # 3 = 13 stations / units

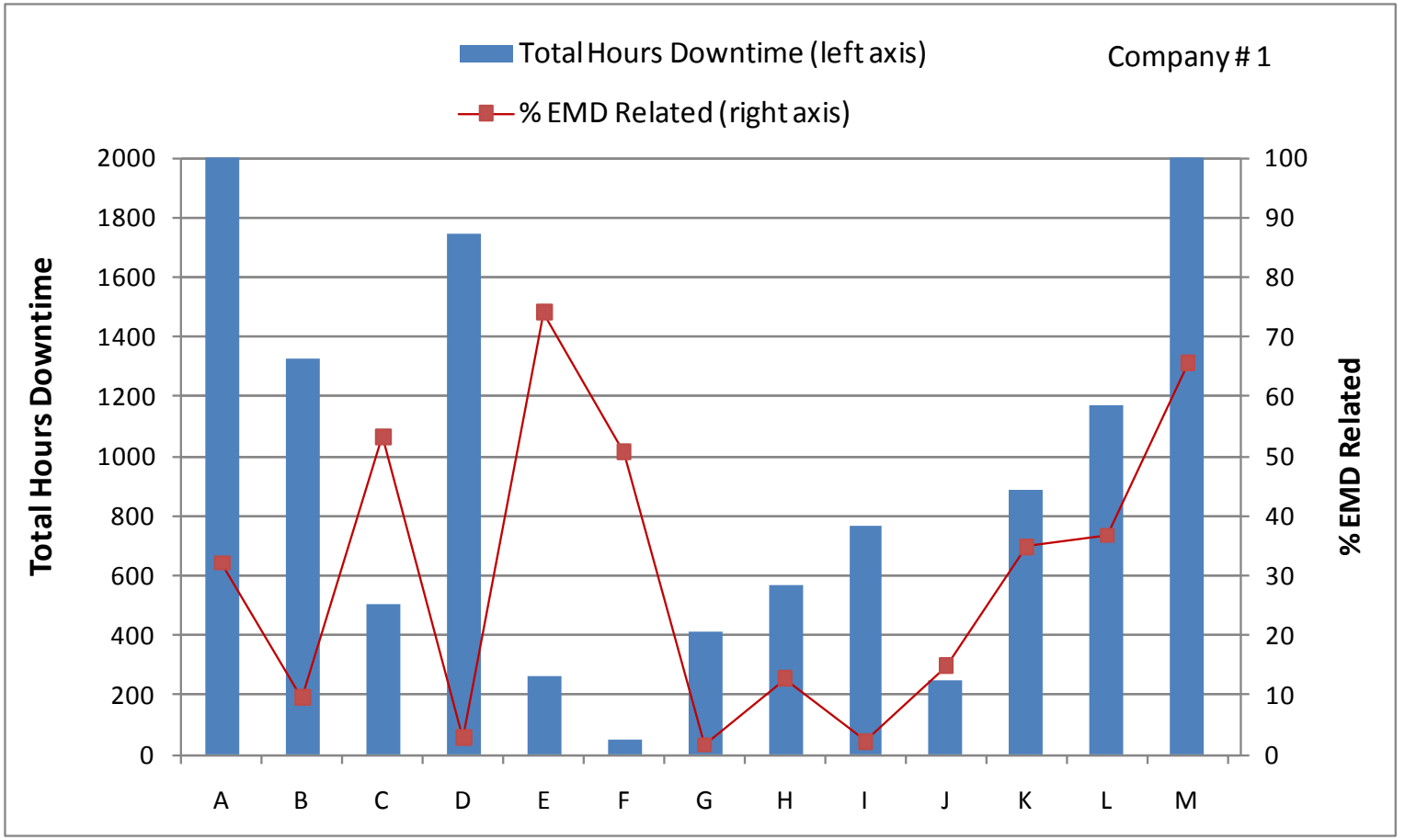
Operator # 4 = 3 units provided *to date*

Reliability Analysis Findings to Date – Company # 1

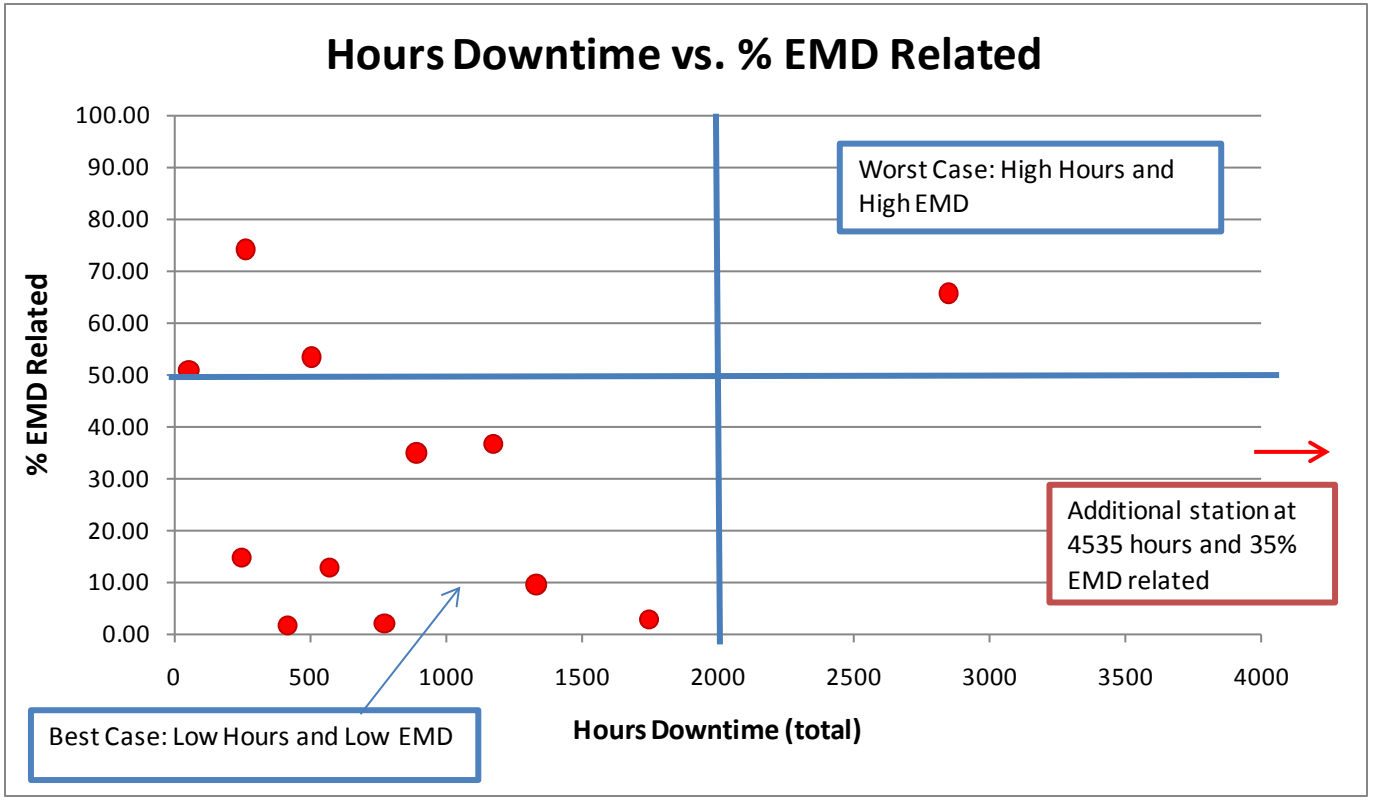
Station Name	Hours Down	Total Events / EMD related	Hours Down EMD equipment related	% EMD related	Hours Down Utility Side Related	% Hours Utility Related
A	4535.5	108 / 29	1457.25	32.13	13.25	0.29
B	1329	25 / 9	126.25	9.50	604.00	45.45
C	502.5	58 / 19	268	53.33	6.00	1.19
D	1742.75	51 / 11	48.75	2.80	30.25	1.74
E	261	32 / 16	193.5	74.14	21.75	8.33
F	50.75	28 / 7	25.75	50.74	0.00	0.00
G	414.75	43/ 7	7	1.69	3.50	0.84
H	568	76 / 15	72.25	12.72	0.00	0.00
I	770.25	49/ 8	16.75	2.17	191.00	24.80
J	247.25	85 / 22	36.75	14.86	0.00	0.00
K	889	56 / 20	310	34.87	0.00	0.00
L	1172	60 / 33	430	36.69	0.00	0.00
M	2849.5	25 / 1	1870	65.63	58.75	2.06

Seven of 13 stations had reliability related to EMD outages of greater than 20%. Many of these were related to VFD cooling issues and wiring. Two additional stations had utility side related outages greater than 20%, including some outages at substation level. Nine stations selected for operator interviews.

Reliability Analysis Findings to Date – Company # 1



Reliability Analysis Findings to Date – Company # 1



Detailed Analysis for Company # 1 (2007 – current)

Company # 1 Unplanned Shutdown Events Data (all Unplanned's > 8 hour down time*) - 2007 - Current							
	* does not include PLC or software failures, instrumentation or non -EMD related failures or natural disasters						
Station Code	VFD	Cooling systems (water for VFD or motor, lube oil cooling)	Motor	Mag Bearing	Utility side	Other Electrical components	Gearboxes
A	0	6 with 1*	7 with 1 *	0	0	1	1
B	3	2	0	0	3 with 2*	0	0
C	2	5	4	0	1*	1	0
D	6	2*	1*	0	4	1*	0
E	6 with 1*	2	0	4 with 1*	0	0	0
F	5	0	0	0	2 with 1*	0	0
G	0	0	0	0	0	0	0
H	2 with 1*	0	0	0	1	0	1
I	0	0	0	0	1*	2 with 1*	0
J	0	0	0	0	0	1	0
K	1	0	2	0	0	0	4
L	7 with 2*	8	0	0	0	0	1
M	0	0	0	0	17	1	0
Notes on common issues	Bad diode, VFD fault, VFD alarm	Cooling alarm, water pressure issue, "high water conductivity"		Panel or bearing failure	Power fault, glitch, substation failure, Power factor shutdown	Relay or wiring	
		Asterisks indicate long down time event, e.g.					
		1 = one 100-hour or longer down time event*					

Opportunity to improve down time related to cooling systems, utility side and VFD issues involving spare parts.

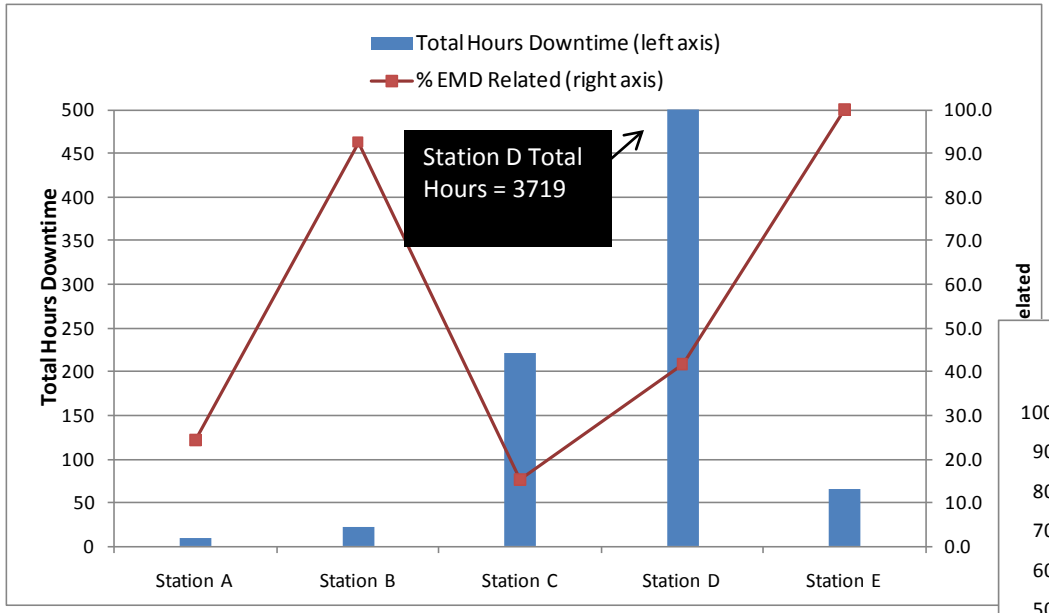
Reliability Analysis Findings to Date – Company # 2

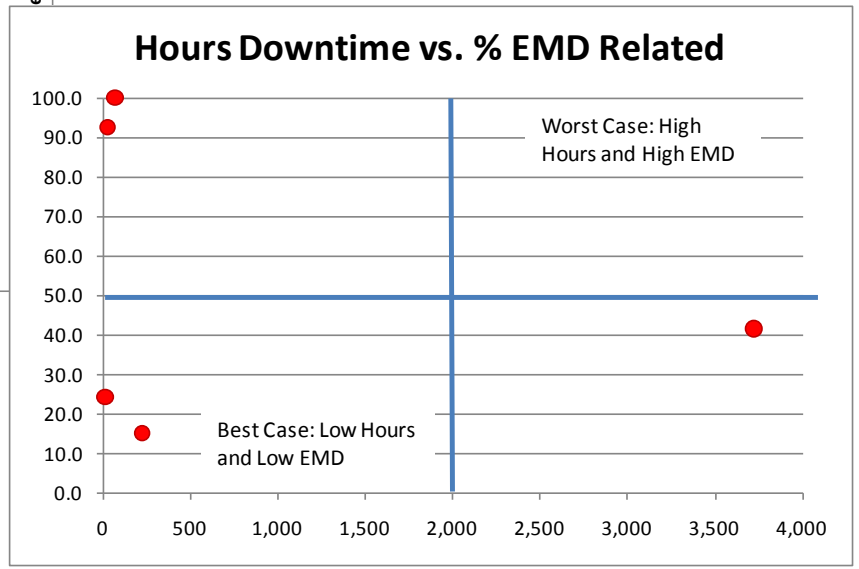
Company #2: Unplanned Down Time since 2009 (5 EMD centrifugal stations)

Station Name	Hours Down	Total Events / EMD related	Hours Down EMD equipment related	% EMD related	Hours Down Utility Side Related
Station A	10	3 / 1	3	24.4	0
Station B	23	3 / 2	21	92.6	0
Station C	222	7 / 2	34	15.3	0
Station D	3,719	9 / 1	1,551	41.7	0
Station E	66	2 / 2	66	100.0	0

Four of 5 stations had reliability of less than 250 hours down time in 2.5 year period. One of the 5 stations showed high down time (< 90% availability) with 41% EMD related shutdowns. Four stations selected for operator interviews.

Reliability Analysis Findings to Date – Company # 2





* Less than 2000 hours downtime since January 2009 = 92% availability

Detailed Analysis for Operator # 2

Company # 2 Unplanned Shutdown Events Data (all Unplanned's > 8 hour down time*) - 2007 - Current							
	* does not include PLC or software failures, instrumentation or non -EMD related failures or natural disasters						
Station Code	**VFD**	**Cooling systems (water for VFD or motor, lube oil cooling)**	**Motor**	**Mag Bearing**	**Utility side**	**Other Electrical components**	**Gearboxes**
Station A	0	1	0	0	0	0	0
Station B	0	0	2	0	0	0	0
Station C	0	0	0	0	0	2	0
Station D	0	0	0	0	0	1*	0
Station E	0	0	0	0	0	0	2
Notes on common issues		Water leak for water pump on LCI cooling	Battery charger failure and motor purge low			Bad fuse, electrical switches	guide vane control
		Asterisks indicate long down time event, e.g.					
		1 = one 100-hour or longer down time event*					

Opportunity to improve down time related to water cooling pumps, motor system, ASD gear box and spare parts.

Operating Company # 3 - Data for 13 stations are provided, as far back as January 2009

Data for each Unit is provided as:

- Unit description
- Outage date
- Outage description
- Outage duration
- Operator comments

The data is grouped into outage causes due to:

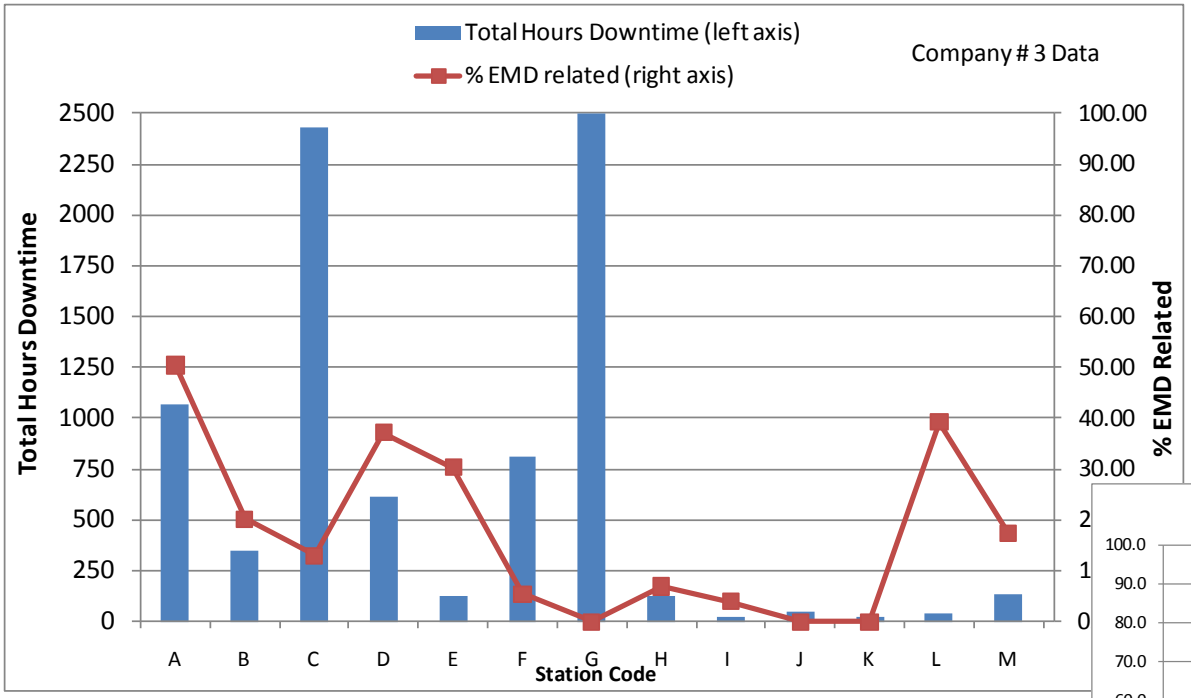
- Motor drive
- VFD
- Utility
- Electrical Miscellaneous
- Weather conditions
- Maintenance
- Oil lube system

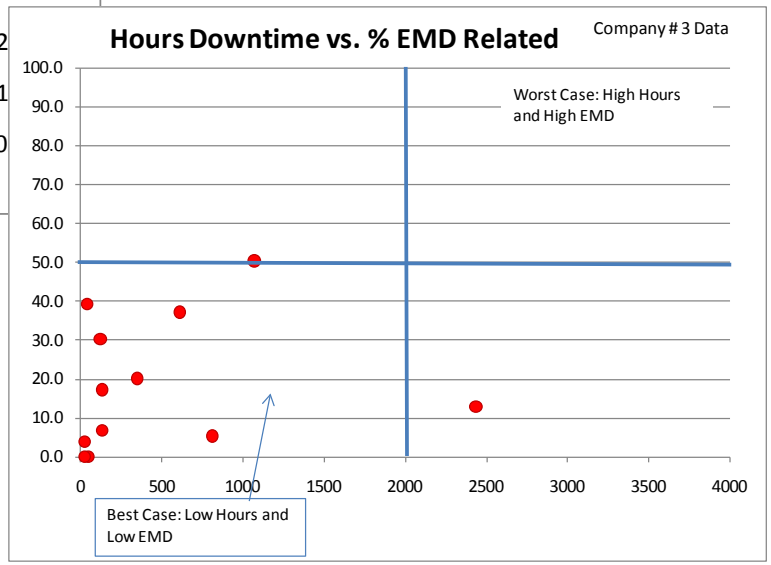
Unit	Motor	VFD / Gearbox	Power (HP)	Data period (hr)
A	Induction	VFD	9,000	20,904
B	Induction	VFD	9,000	18,480
C	Induction	VFD	7,000	21,576
D	Synchronous	Gearbox	8,500	17,664
E	Synchronous	Gearbox	8,500	9,120
F	Synchronous	Gearbox	15,000	13,968
G	Synchronous	Gearbox	15,000	21,360
H	Synchronous	Gearbox	15,000	21,192
I	Synchronous	Gearbox	22,000	3,552
J	Synchronous	Gearbox	22,000	3,864
K	Synchronous	Gearbox	22,000	3,888
L	Synchronous	Gearbox	22,000	672
M	Synchronous	Gearbox	22,000	2,016

Reliability Analysis Findings to Date – Company # 3

Company #3: Unplanned Down Time since 2009 (13 EMD centrifugal stations)						
Station Code	Hours Down	Total Events / EMD related	Hours Down EMD side related	% EMD related	Hours Down Utility Side Related	% Utility Side Related
A	1068	59 / 14	538	50.4%	105	9.83%
B	347	56 / 2	70	20.2%	10	2.88%
C	2433	73 / 13	316	13.0%	1768	72.67%
D	610	12 / 2	227	37.2%	0	0.00%
E	122	5 / 1	37	30.3%	0	0.00%
F	811	26 / 2	44	5.4%	4	0.49%
G	53225	17 / 3	1.1	0.0%	0	0.00%
H	130	26 / 11	9	6.9%	0.5	0.38%
I	25	3 / 1	1	4.0%	0	0.00%
J	47	5 / 0	0	0.0%	0	0.00%
K	27	7 / 0	0	0.0%	0	0.00%
L	42	5 / 1	16.5	39.3%	0	0.00%
M	133	5 / 2	23	17.3%	0	0.00%

Reliability Analysis Findings to Date – Company # 3

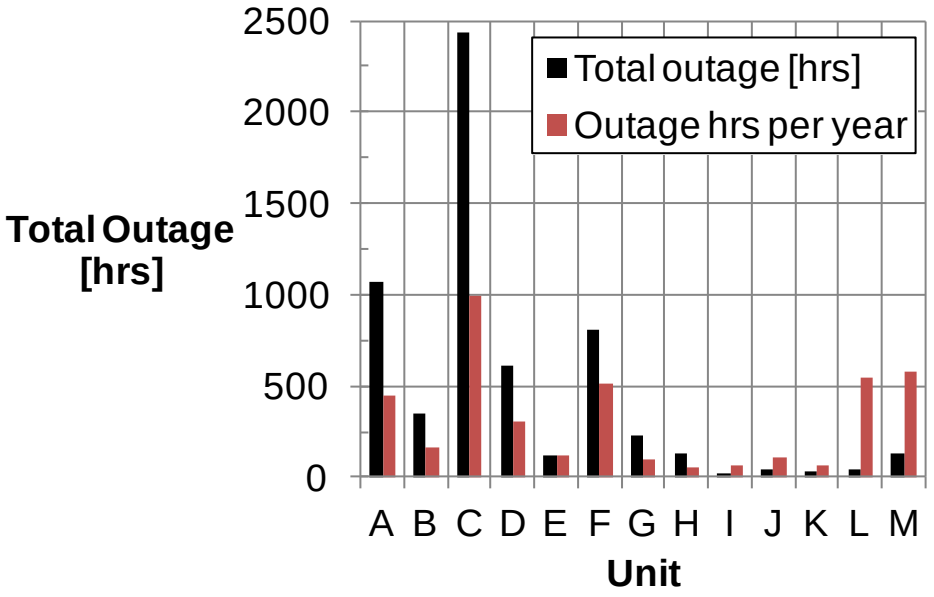


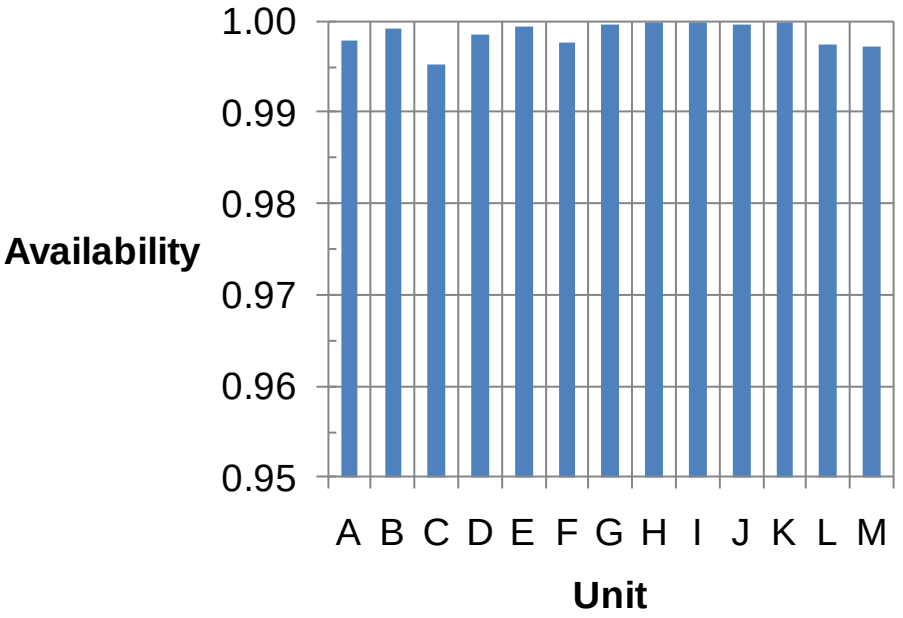


Majority of stations fell into low downtime, low EMD related issues. Utility side outages more common for this company. Six stations selected for operator interviews.

* Less than 2000 hours downtime since January 2009 = 92% availability

The reported outage data shows that all 13 units are achieving 99.5% availability

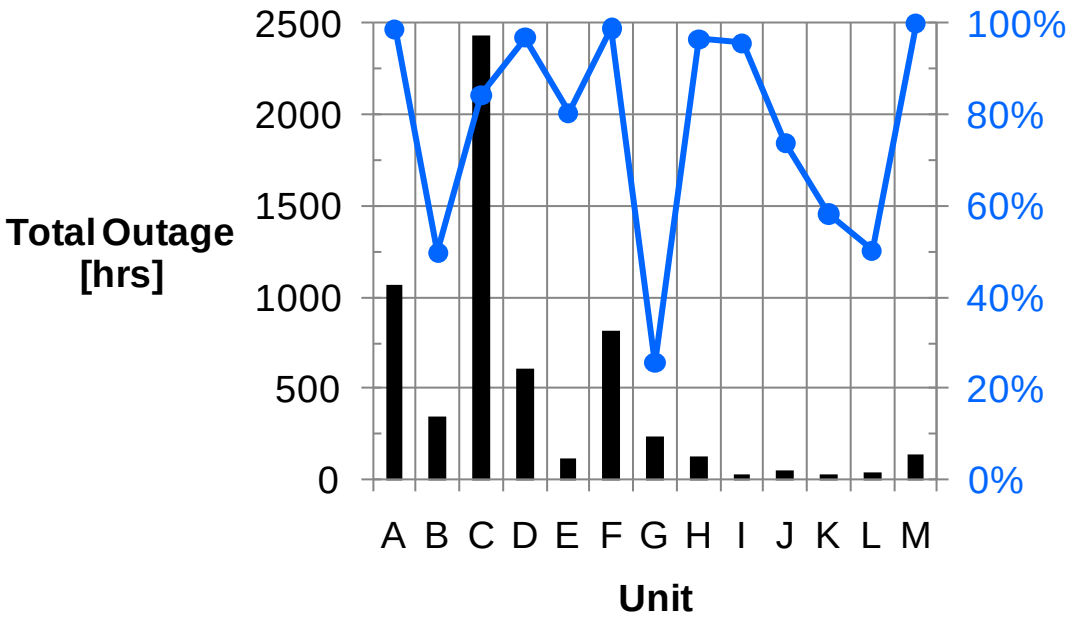




$$\text{Availability} = \frac{[(\text{Total hours}^*) - (\text{Outage hours})]}{(\text{Total hours})}$$

*Total hours was assumed to be "24-7" operation for two year period

Most unit outages fall into the defined categories



Categories of unit outage:

- Motor drive
- VFD
- Utility
- Electrical Miscellaneous
- Weather conditions
- Maintenance
- Oil lube system

Other reasons for outages

Unit B:

High discharge gas temperature – due to low flow

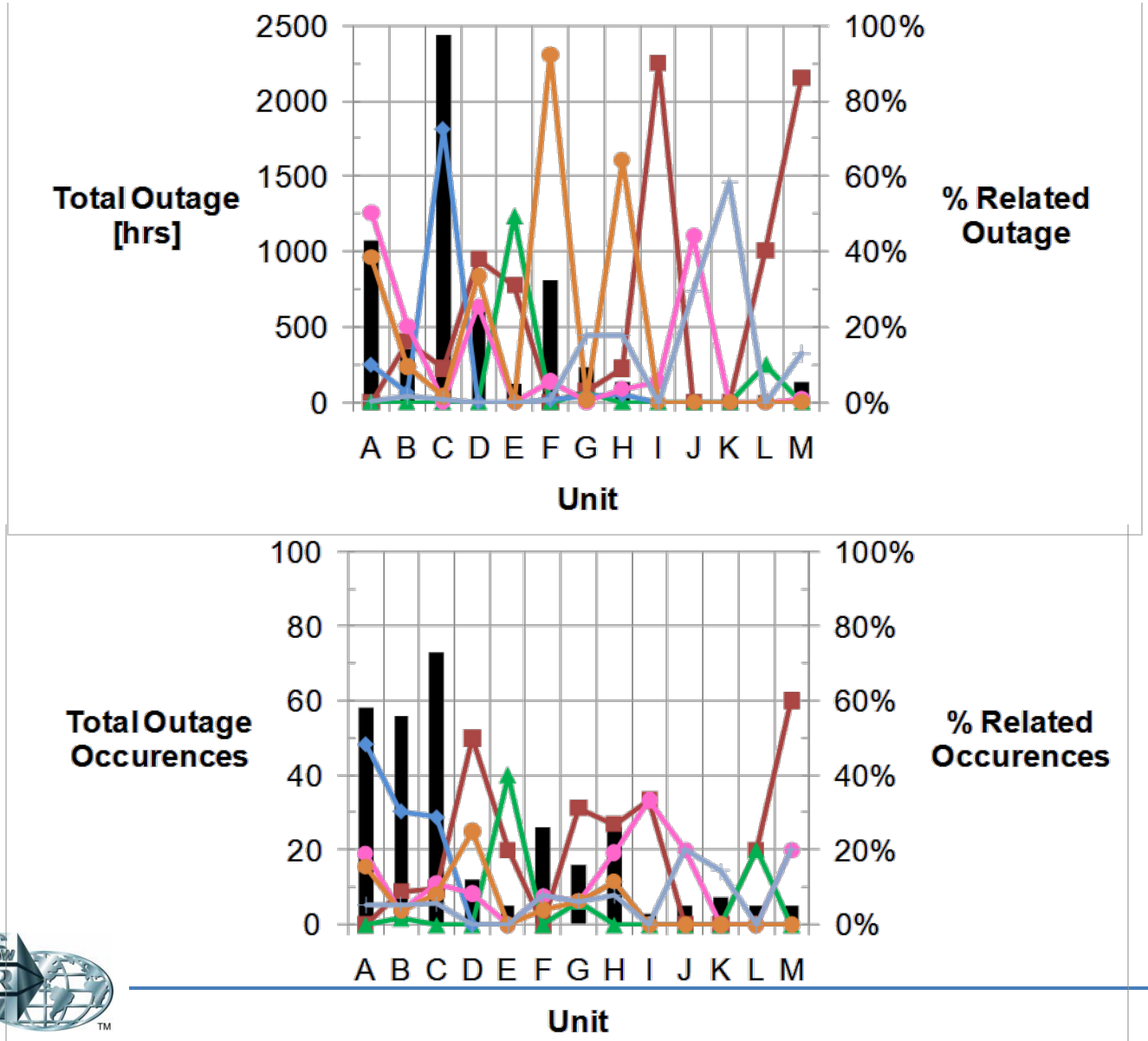
Unit G:

Emergency shutdown - no reason specified

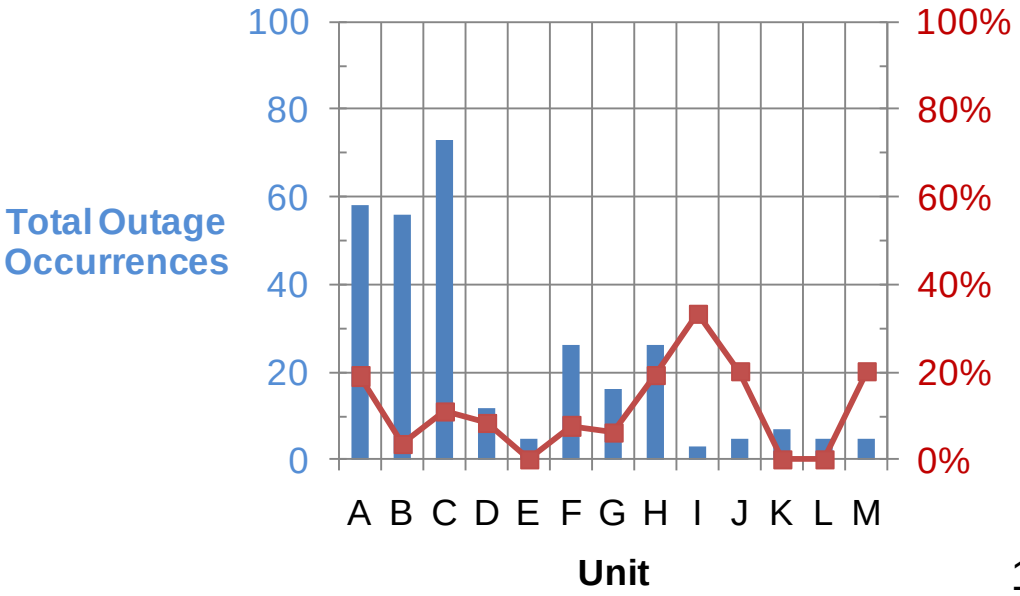
Unit J, K, L:

High discharge temperature / pressure trip

The reason for most outages at each unit is used to focus the operator surveys

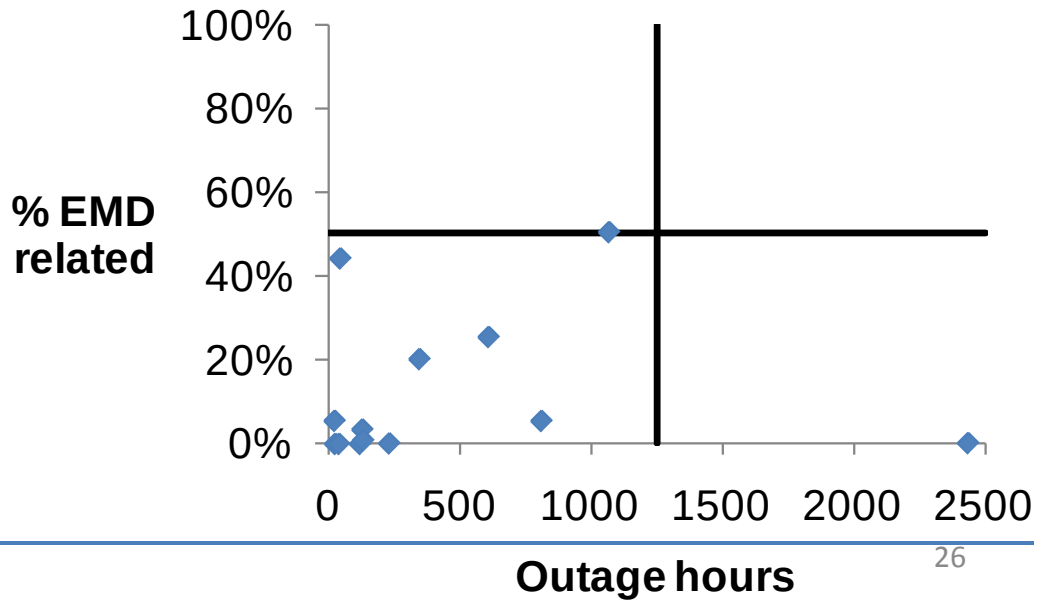


EMD related outages are responsible for as much as 50% outage time for some units

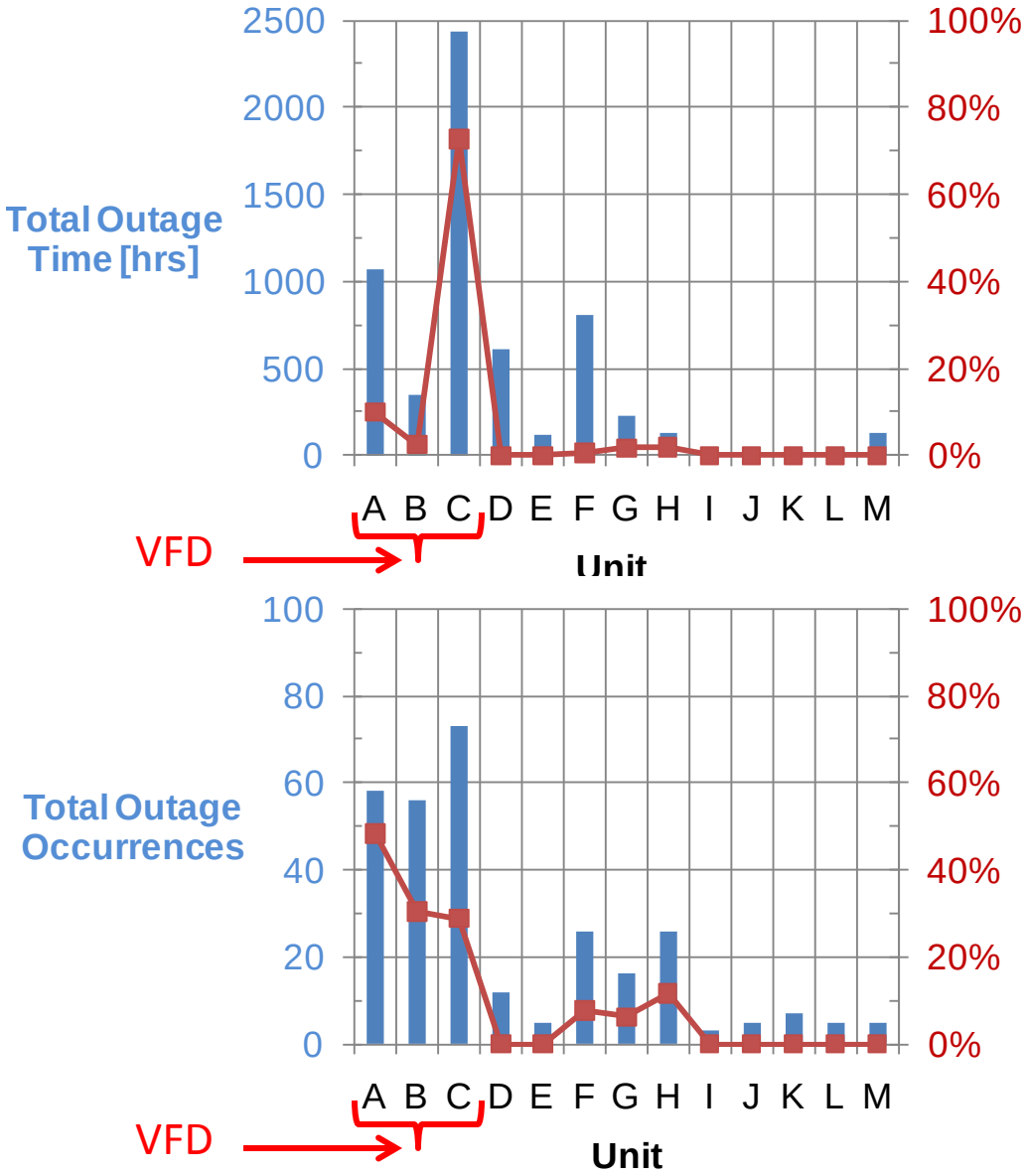


EMD related outages:

- Usually infrequent, but cause significant outage time
- Cause more than 20% outage time at 4 out of 13 units

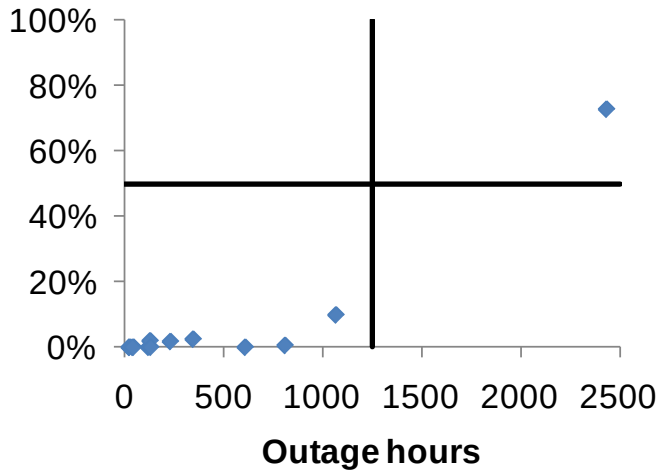


Utility related outages are most common at units with VFDs



Utility related outages:

- Usually result in low outage time for frequent occurrences



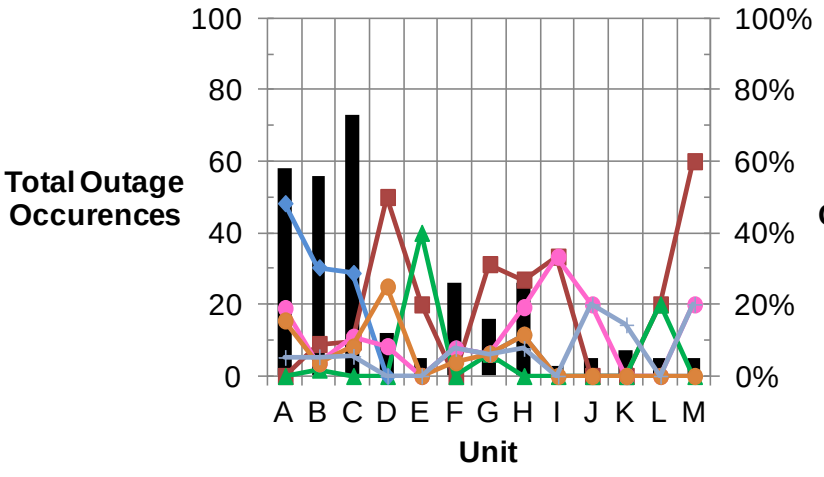
In summary, the operation data shows that EMDs are not the major cause for outages

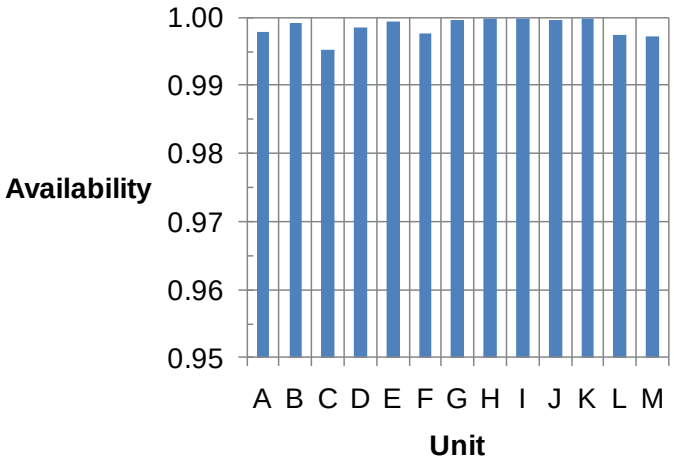
EMD outage time is never more than 10% of any other reason for outage

Primary reasons for outage are:

Oil lube system
Utility
Maintenance
Electrical Misc.

Including all outages, station availability remains above 99% for all stations





Operating Company # 4 - Data for 3 units are provided as far back as January 2009

Data for each Unit is provided as:

- Unit name
- Outage date
- Outage description
- Outage duration
- Operator comments

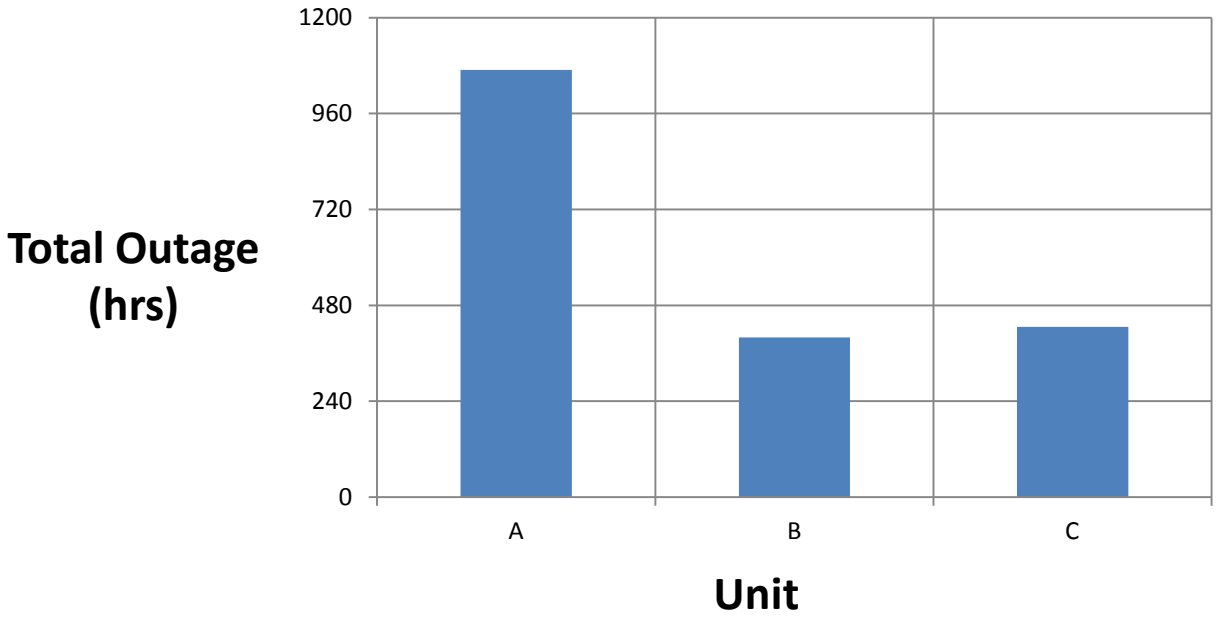
Unit	Motor	VFD / Gearbox	Power (HP)	Data period (hr)
A	Induction	VFD	Unknown	Unknown
B	Induction	VFD	Unknown	Unknown
C	Synchronous	Gearbox	Unknown	Unknown

The data is grouped into outage causes due to:

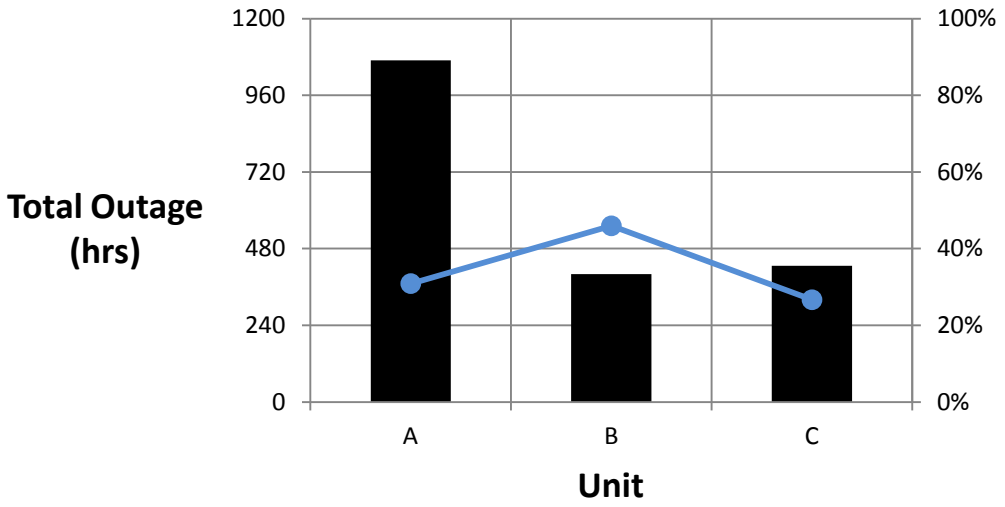
- Motor drive
- VFD
- Utility
- Electrical Miscellaneous
- Weather conditions
- Maintenance
- Oil lube system

** Company plans to provide further historical data on EMD units once data is available*

The reported outage data for all 3 units



Most unit outages do not fall into the defined categories



Categories of unit outage:

- Motor drive
- VFD
- Utility
- Electrical Miscellaneous
- Weather conditions
- Maintenance
- Oil lube system

Other reasons for outages

Unit A:

Replacing FSR and compressor seals

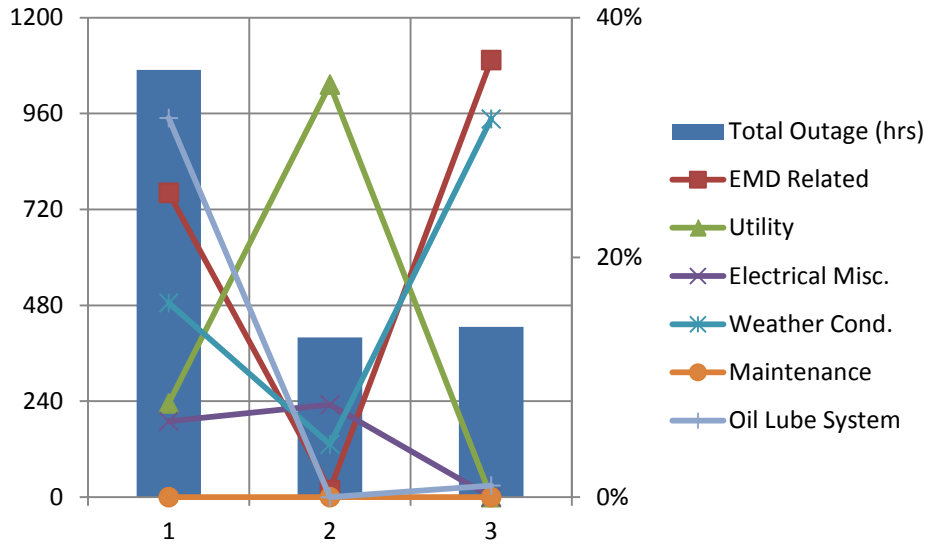
Unit B:

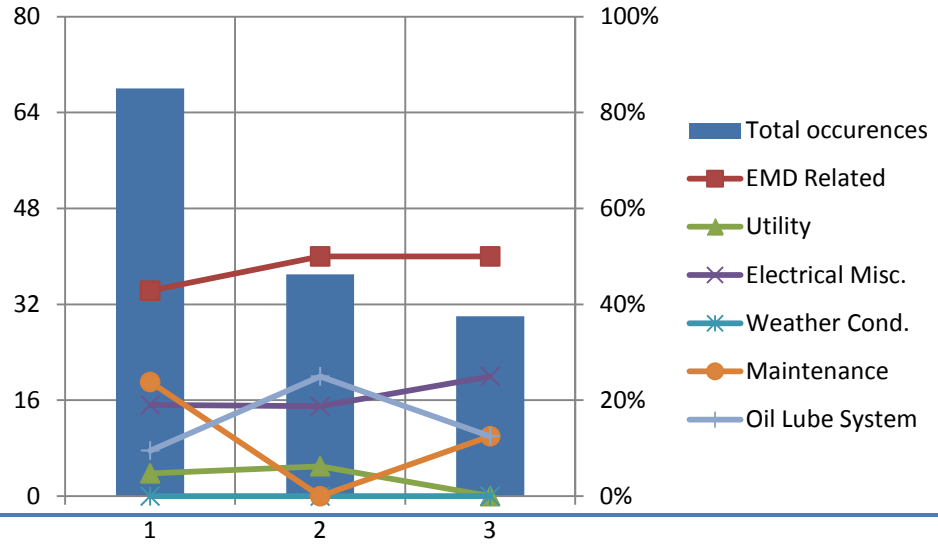
Discharge check valve failed

Unit C:

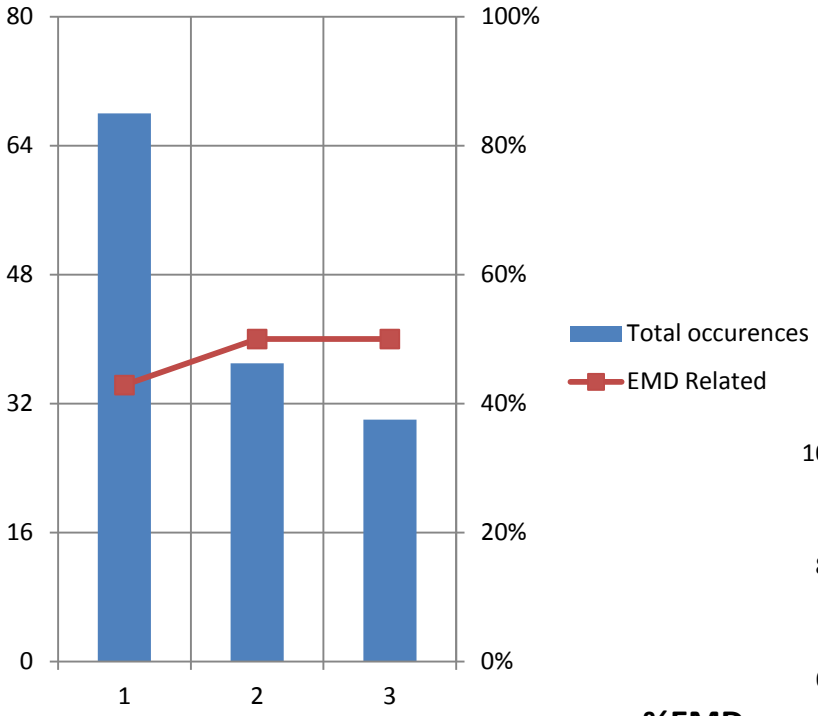
Compressor thrust bearings failure

The reason for most outages at each unit is used to focus the operator surveys



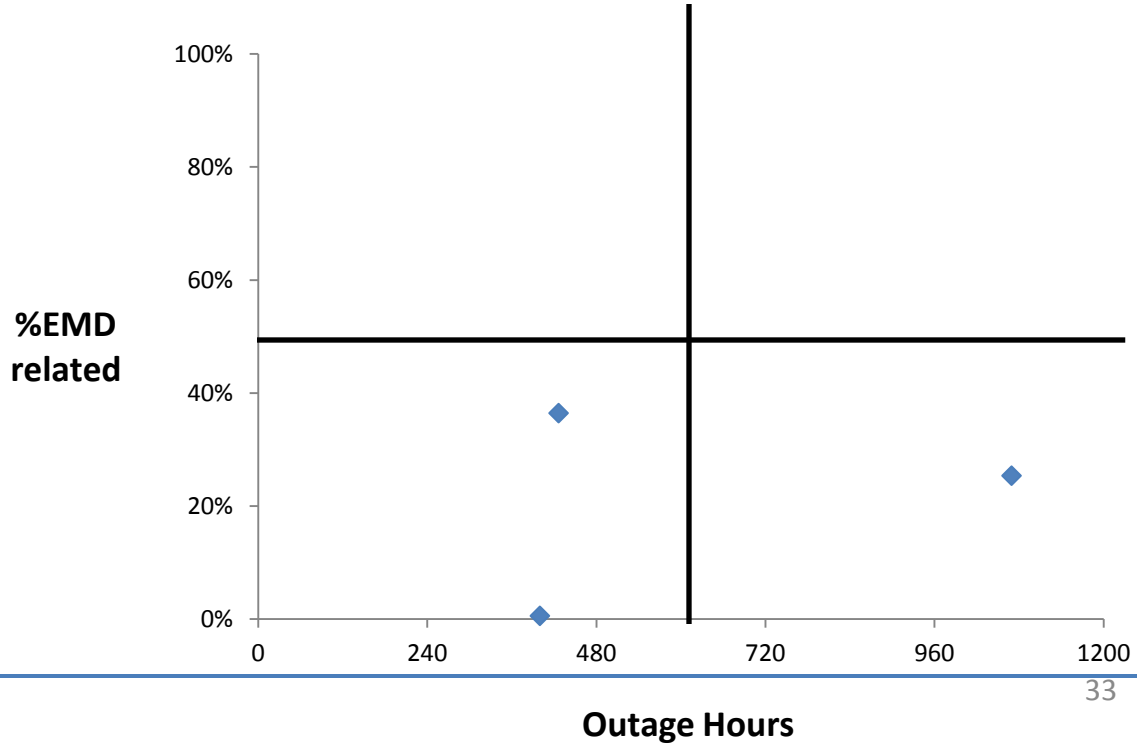


EMD related outages are responsible for as much as 63% outage time for some units



EMD related outages:

- Usually infrequent, but cause significant outage time for units 1 and 3
- Cause more than 20% outage time at 2 out of 3 units



Relevant case study topics to pursue…

Utility and VFD interaction –

Could the utility have restructured the substation design or interconnect

Is the VFD causing current ripples or is the grid more sensitive to these ?

Electrical issues (minor design issues with major impact) –

Investigate station electrical issues and spare parts strategy

Emergency shutdowns –

Is the EMD system affecting these?

Effective maintenance for EMD compression –

Prescribed maintenance intervals, inspections and activities

VFD cooling options -

Reliability, advantages, and disadvantages of glycol, DI water, air cooling

Software updates to EMD controls -

Effect on downtime and strategies for quality and reducing upgrade issues

Torsional analysis studies with VFD interaction -

Early analysis and after repairs (harmonic filtering, torque measurements)

Motor and VFD lubrication and seals -

How to specify, test and replace

Lifecycle Cost Analysis

- Must consider capital cost items, ongoing maintenance expenses, variations between maintenance for EMD systems.
- Cost of natural gas and electricity will be user defined variables.
- Operating profile of station and availability should also be user inputs and will vary by station location and operation.
- Also include project management expenses and additional costs of utility agreements.
- Will consider efficiency of EMD drive at station to determine compression power expense.

Lifecycle Cost Analysis

Lifecycle Cost Analysis - EMD systems with compressor horsepower of 10-15 MW size

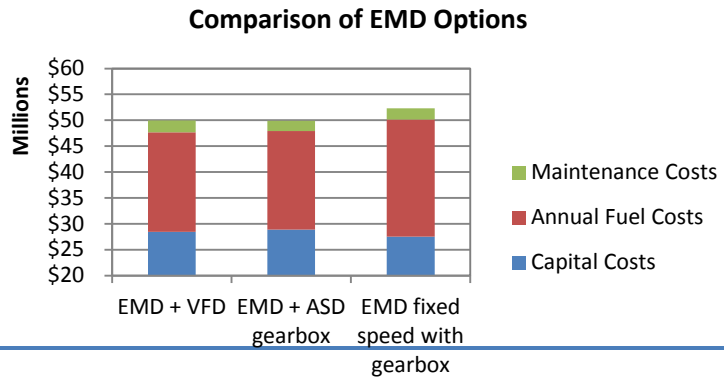
Blue highlighted cell indicates required input for calculations

Description of Analysis	Scenario Options				
	EMD + VFD	EMD + ASD gearbox	EMD fixed speed with gearbox	GT Drive system (no EMD)	Additional System (EMD + GT dual)
Analysis Parameters					
No of Years to Operate	20				
Depreciation Rate	6%				
Capital Cost Items (in thousands)					
Drive system (not including centrifugal compressor)	$ 6,500	$ 6,500	$ 5,500	$ 4,200	$ 9,250
Gearbox	$ -	$ -	$ -	$ -	$ -
ASD equipment	$ -	$ 500	$ -	$ -	$ -
Aux systems	$ 25	$ 25	$ 25	$ 55	$ 80
Pumps and coolers	$ 200	$ 80	$ 20	$ 80	$ 250
Substation	$ 1,750	$ 1,750	$ 1,750	$ -	$ 1,750
Power lines	$ -	$ -	$ -	$ -	$ -
Starting equipment	$ -	$ -	$ 250	$ 150	$ 250
Construction + other station piping, compressor, etc.	$ 20,000	$ 20,000	$ 20,000	$ 20,000	$ 25,000
Total Capital Costs	**$ 28,475,000**	########	**$ 27,545,000**	########	**$ 36,580,000**
Ongoing costs (annual)					
Avg. annual compression horsepower	8828	8828	10437	8828	8828
Avg. Station drive efficiency	94.08	95.06	93.1	83.632	5678.253
Fuel gas consumed by driver - MMBtu per month	0	0	0	124008	54784
Avg. drive electric power consumed per month - MwHr	4075	4037	4796	0	6901
Annual fuel cost	**$ 1,676,045**	**$ 1,660,337**	**$ 1,971,231**	**$ 6,055,196**	**$ 5,378,451**
NPV for annual fuel cost	**$ 19,224,106**	########	**$ 22,609,864**	########	**$ 61,690,409**
Maintenance activities (annual)					
Spare parts + labor	$ 30,000	$ 10,000	$ 25,000	$ 45,000	$ 75,000
Station operating labor	$ 150,000	$ 150,000	$ 150,000	$ 675,000	$ 775,000
Annual added costs (downtime, project mgmt, contractors)	$ 15,000	$ 15,000	$ 15,000	$ 67,500	$ 77,500
Emissions cost + labor	$ -	$ -	$ -	$ 15,000	$ 15,000
Availability (%)	95.00	98.00	96.00	95.00	95.00
Lost Capacity	$ 625,000	$ 250,000	$ 500,000	$ 625,000	$ 625,000
Maintenance costs	**$ 195,000**	**$ 175,000**	**$ 190,000**	**$ 802,500**	**$ 942,500**
NPV for maintenance costs	**$ 2,236,635**	**$ 2,007,236**	**$ 2,179,285**	**$ 9,204,612**	**$ 10,810,401**
Gas Price ($/MMBtu)	*$ 4.00*	*$ 4.00*	*$ 4.00*	*$ 4.00*	*$ 4.00*
Close-out Costs					
Environmental costs	$ -	$ -	$ -	$ -	$ -
Resale value	$ -	$ -	$ -	$ -	$ -
Disposal costs	$ -	$ -	$ -	$ -	$ -
Total Close-out Costs (cost-value)	$ -	$ -	$ -	$ -	$ -
NPV for close-out costs	$ -	$ -	$ -	$ -	$ -
Total Lifecycle Cost					
Total Net Present Value	#########	########	#########	########	#########
Comparison to EMD + VFD system	**$ -**	**$ 29,568**	**$ (2,398,409)**	########	**$ (59,145,070)**

Analysis considers 5 different options

- EMD+VFD
- EMD+ASD and G/B
- EMD fixed speed with G/B
- GT drive system (no EMD)
- Dual drive system

Tool calculates NPV for specified time period and discount factor



Possible Future EMD Research Topics

- Spare parts and units strategies
- Retrofit best practices for stations replacing legacy horsepower systems
- Safety best practices for electrical compression systems
- Reciprocating compressor reliability analysis for EMD driven
- Training assessment for operators and utility companies
- Reciprocating / centrifugal compressor interaction (both on electrical side and compressor flow side)
- Best operating & maintenance practices
- Reliability centered and condition based maintenance
- Backup power technology options and hybrid stations
- Reduced first cost through optimized station design practices
- Pipeline routing, station placement for coordination with utility
- Optimized unit / station control
- Startup and short-circuit torsional analysis / modeling improvements for better accuracy

Thank You Very Much.

If you are interested in participating in the 2012 GEP Research Consortium, please contact:

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