Control Strategies for Multiple VFD Air Compressors

Ron Marshall, Marshall Compressed Air Consulting
Keynote Speaker

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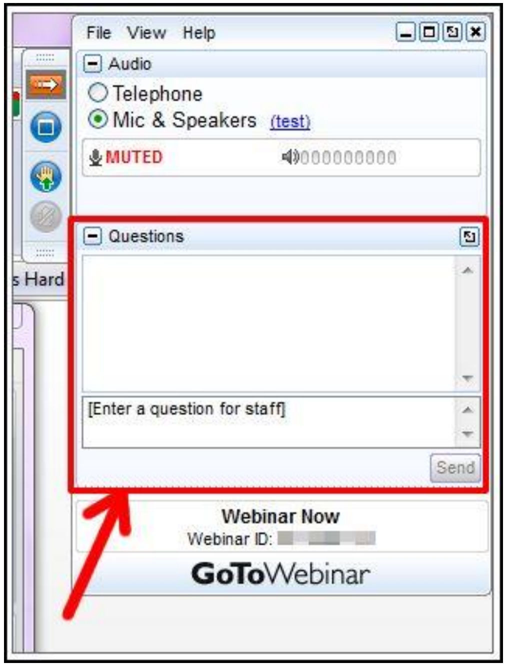
Q&A Format



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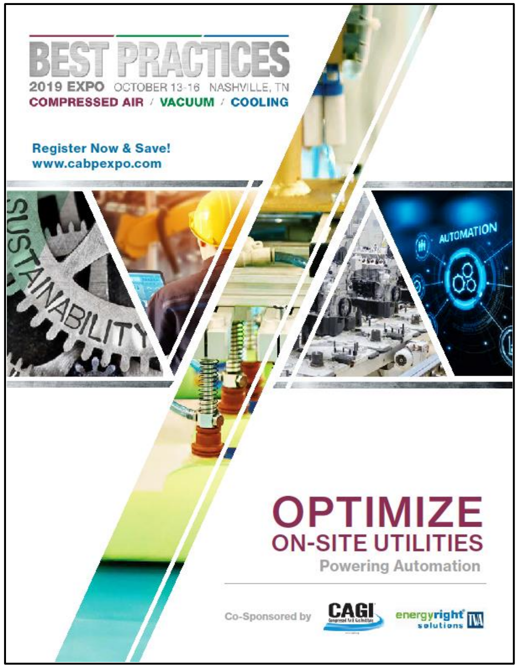
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AUTOMATION

Control Strategies for Multiple VFD Air Compressors

Introduction

Compressed Air Best Practices® Magazine

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About the Speaker

Ron Marshall
Marshall Compressed Air Consulting

- Chief Auditor, Marshall Compressed Air Consulting
- 38-year Employee of Power Utility
- 24 years Technical Compressed Air Support
- Compressed Air Challenge Level 2 Instructor
- International Trainer for United Nations Industrial Development Organization (UNIDO)

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Control Strategies for Multiple VFD Air Compressors

July 18, 2019

Ron Marshall
Marshall Compressed Air Consulting

Presenter

- Consultant MCAC
- 38 year Employee of Power Utility
- 24 years Technical CA Support
- CAC Level 2 Instructor
- International Trainer UNIDO

Presenter


-WANTED-
WINDEE BREEZE -AKA- "THE WHISTLE BLOWER"
WINDEE BREEZE, 'AIR APPARENT TO KILLER WATT' IS A MEMBER OF THE NOTORIOUS "BAD ENERGY GANG" WANTED IN RELATION TO THE FOLLOWING CRIMES:
• Pipeline air leaks.
• Inefficient air compressors.
• Poor airline distribution.
25 in 10
Chasing Energy Efficiency
IF YOU HAVE SEEN EVIDENCE OF WINDEE BREEZE'S CRIMES, LET YOUR LINE MANAGER KNOW IMMEDIATELY SO HIS DAMAGE CAN BE CORRECTED!
HELP PROTECT SIMPLOT FROM THE BAD ENERGY GANG

Coming Up

- Why use VFD compressors?
- Comparing CAGI sheets
- Reasons why multiple VFD's are installed
- Sizing rules and control gap
- Typical cascade control strategy and problems
- Simple modified local control strategy
- Intelligent single pressure band strategy
- Example of intelligent control

Why use VFD compressors?

- The most efficient system is where all required fixed speed compressors are fully loaded or off
- Capacity comes in fixed size blocks, these don't often match the flow requirement
- Most systems have varying flow
- These conditions mean one or more compressors in a multiple arrangement are running at part-load (less than full capacity)
- Part loaded fixed speed compressors are usually inefficient
- Inefficiency is caused by unloaded power consumption and cycling loss
- VFD compressors minimize unloaded condition, do not typically cycle (load/unload)

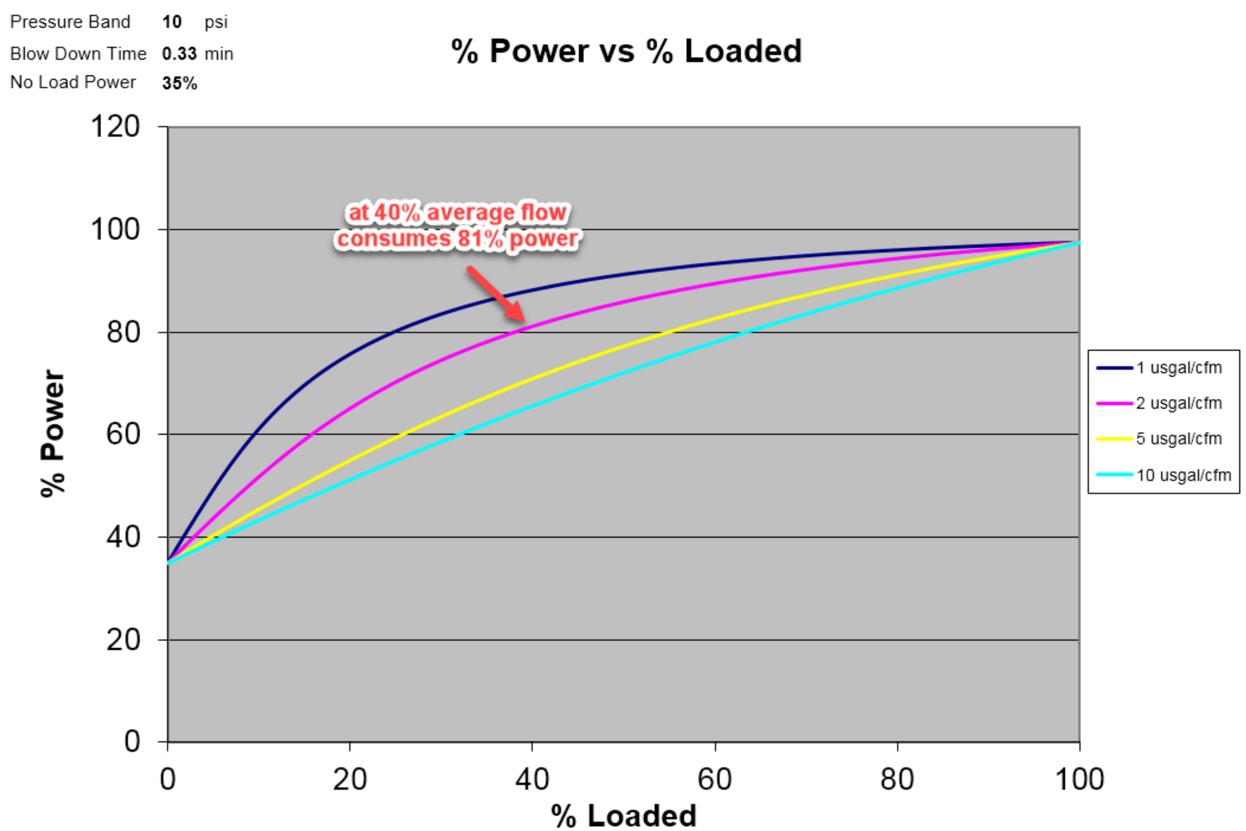
Comparing CAGI sheets

- Power/flow/efficiency characteristics can be examined by looking at Compressed Air and Gas (CAGI) data sheets, this one shows a fixed speed lubricated screw at full load

MODEL DATA - FOR COMPRESSED AIR			
1	Manufacturer:		
2	Model Number: 100 - 125 psig / 460V/3ph/60Hz	Date:	5/16/2019
	[X] Air-cooled [ ] Water-cooled	Type:	Screw
	[X] Oil-injected [ ] Oil-free	# of Stages:	1
3*	Rated Capacity at Full Load Operating Pressure [a, e]	494	acfm [a,e]
4	Full Load Operating Pressure [b]	115	psig [b]
5	Maximum Full Flow Operating Pressure [c]	125	psig [c]
6	Drive Motor Nominal Rating	100	hp
7	Drive Motor Nominal Efficiency	95.0	percent
8	Fan Motor Nominal Rating (if applicable)	1.3	hp
9	Fan Motor Nominal Efficiency	75	percent
10*	Total Package Input Power at Zero Flow [e]	21.7	kW [e]
11	Total Package Input Power at Rated Capacity and Full Load Operating Pressure [d]	89.9	kW [d]
12*	Specific Package Input Power at Rated Capacity and Full Load Operating Pressure [e]	18.20	kW/100 cfm [e]

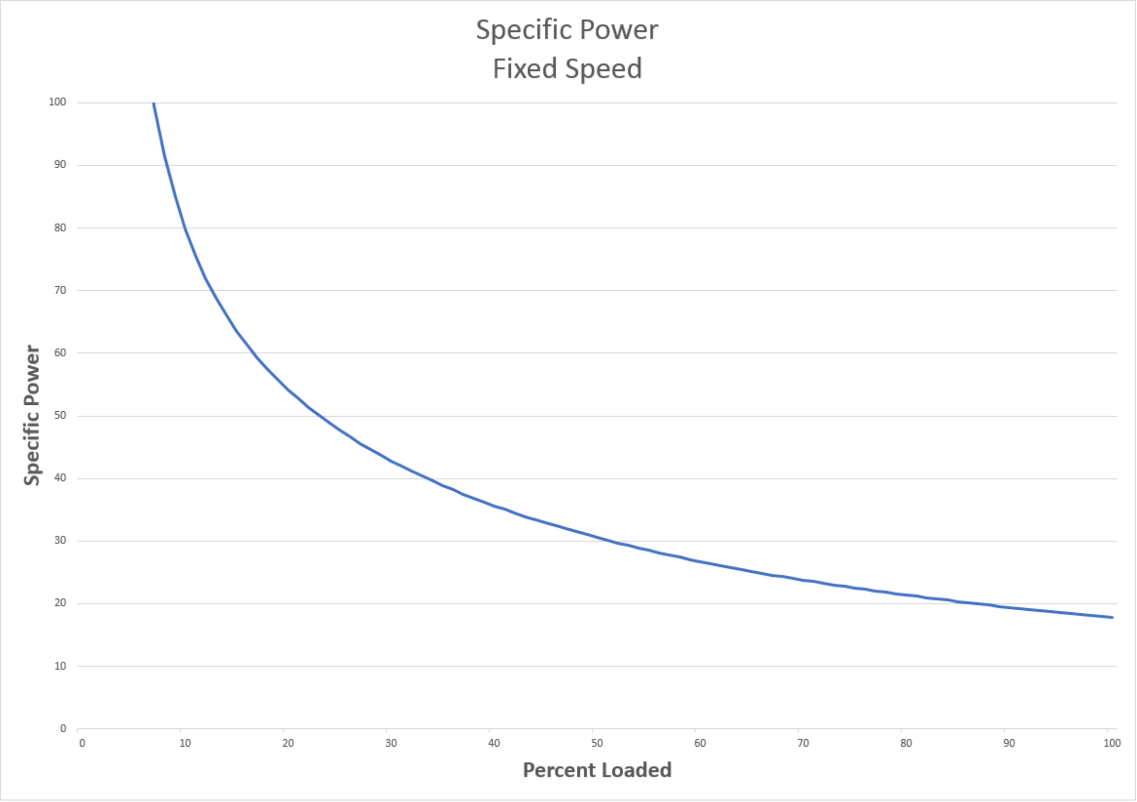
Comparing CAGI sheets

- But at part load conditions change. Efficiency numbers not published at part loads.



Comparing CAGI sheets

- Users are left to calculate part load efficiency based on site conditions. Very poor at light loads.



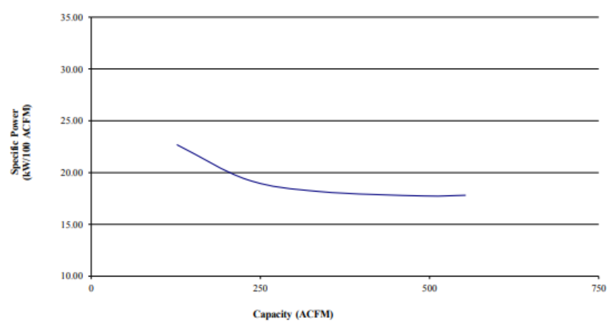
Comparing CAGI sheets

- VFD compressors have much better efficiency at part load

MODEL DATA - FOR COMPRESSED AIR

1	Manufacturer:			
2	Model Number: 125 psig / 460V/3ph/60hz		Date:	02/13/17
	X Air-cooled ☐ Water-cooled		Type:	Screw
	X Oil-injected ☐ Oil-free		# of Stages:	1
3	Rated Operating Pressure		125	psig[b]
4	Drive Motor Nominal Rating		100	hp
5	Drive Motor Nominal Efficiency		96.2	percent
6	Fan Motor Nominal Rating (if applicable)		3 / 1	hp
7	Fan Motor Nominal Efficiency		89.5 / 82.5	percent
8*	Input Power (kW)		Capacity (acfm)[a,d]	Specific Power (kW/100 acfm)[d]
	98.5	Max	553	17.81
	87.3		492	17.74
	61.4		338	18.17
	44.6		231	19.31
	28.8	Min	127	22.68
9*	Total Package Input Power at Zero Flow[c, d]		0.0	kW

10

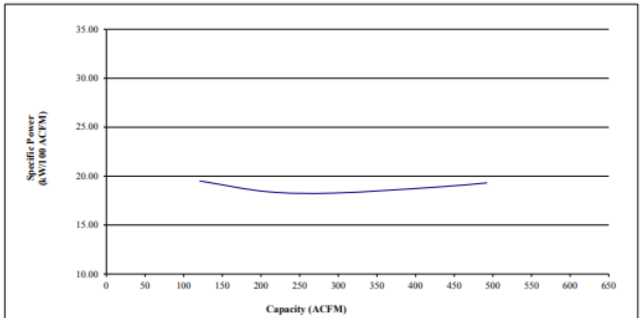


Note: Graph is only a visual representation of the data in Section 8
Note: Y-Axis Scale, 10 to 35, + 5kW/100acfm increments if necessary above 35
X-Axis Scale, 0 to 25% over maximum capacity

Comparing CAGI sheets

- VFD efficiency curves have different shapes. This has control implications.

MODEL DATA - FOR COMPRESSED AIR				
1	Manufacturer: [redacted]			
2	Model Number: [redacted] 125 psig / 460V/3ph/60Hz		Date:	**5/16/2019**
	[X] Air-cooled [ ] Water-cooled		Type:	**Screw**
	[X] Oil-injected [ ] Oil-free		# of Stages:	**1**
3	Rated Operating Pressure		**125**	psig[b]
4	Drive Motor Nominal Rating		**100**	hp
5	Drive Motor Nominal Efficiency		**95.0**	percent
6	Fan Motor Nominal Rating (if applicable)		**1.3**	hp
7	Fan Motor Nominal Efficiency		**75.0**	percent
8*	Input Power (kW)		Capacity (acfm)[a,d]	Specific Power (kW/100 acfm)[d]
	95.0	Max	**492**	**19.31**
	80.4		**426**	**18.87**
	53.9		**295**	**18.27**
	38.3		**208**	**18.41**
	23.6	Min	**121**	**19.50**
9*	Total Package Input Power at Zero Flow[c, d]		**0.0**	kW
10				



Note: Graph is only a visual representation of the data in Section 8
Note: Y-Axis Scale, 10 to 35, + 5kW/100acfm increments if necessary above 35
X-Axis Scale, 0 to 25% over maximum capacity

Comparing CAGI sheets

- Sometimes VFD's are more efficient than fixed speed compressors at full load
- Often the VFD numbers are reported at higher pressure, power needs to be adjusted down for comparison
- The shape of the VFD curve may make compressor more or less desirable during certain conditions
- Optimum control would keep the VFD at its best efficiency point when possible
- All fixed speed compressors should be fully loaded or off

Reasons why multiple VFD’s are installed

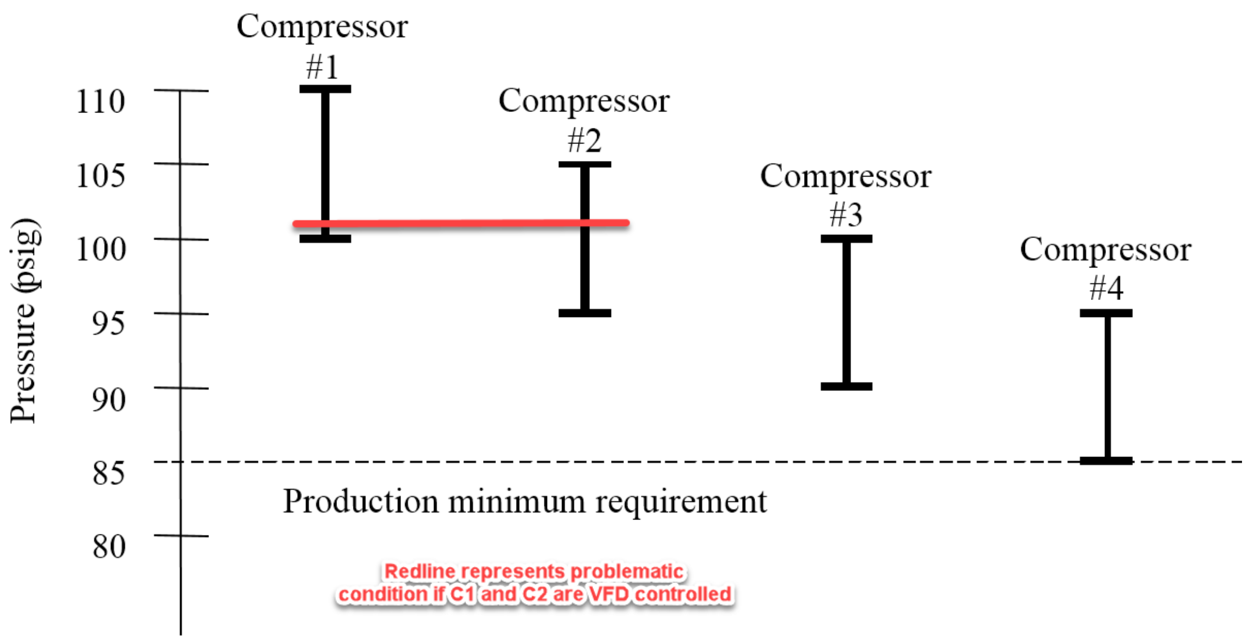
- Typically only one properly sized VFD air compressor is required in any system
- Often the VFD gets the most hours
- Maintenance personnel like to balance the hours
- Incentives may be available for VFD but not other compressor types
- The VFD might be running at minimum speed for most of its hours, use of a second smaller VFD may be needed to avoid this condition
- Minimum speed operation can prematurely age the compressor and cause higher than normal oil carryover.

Sizing rules and control gap

- In most cases the system VFD needs to be about 25 percent larger than the largest base compressor to avoid control gap and avoid start/stop operation below minimum speed
- If this condition is not met, then control gap will occur where the VFD compressor will fight the larger fixed speed compressor for control
- This condition can be corrected with intelligent compressor control and multiple sizes of compressors
- For example, a small fixed speed compressor and a smaller than desired VFD can be controlled like a larger VFD

Typical cascade control strategy and problems

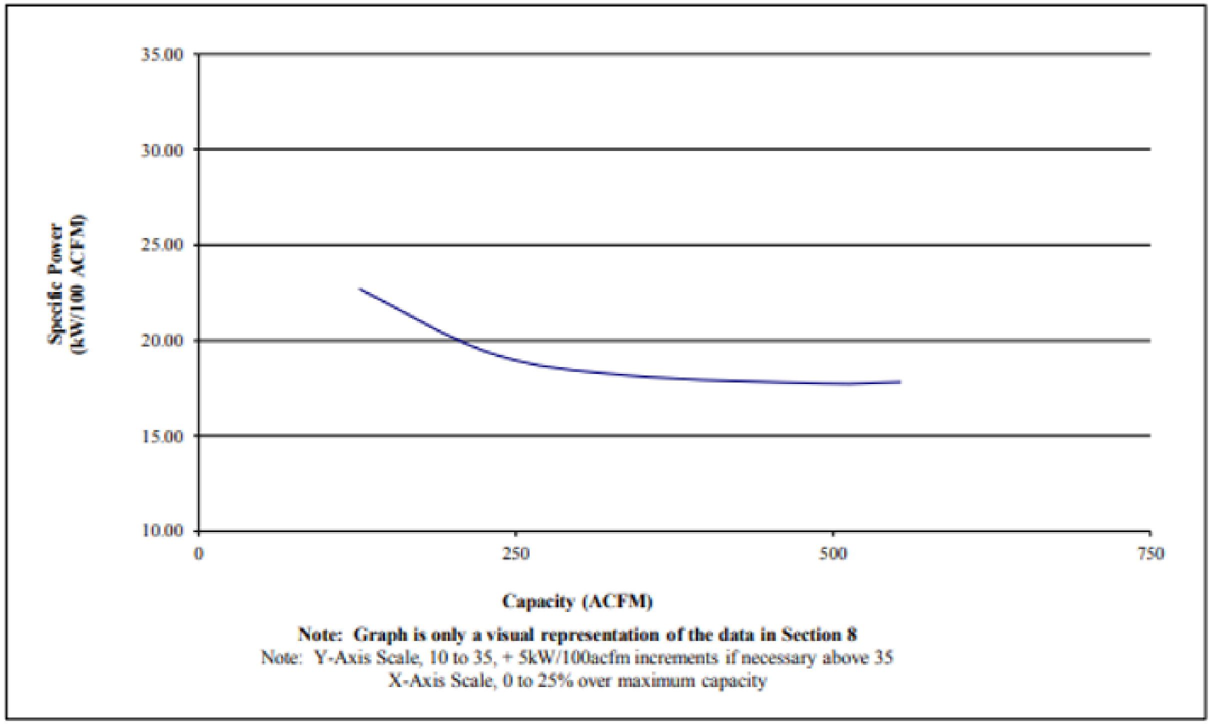
- Without central control the typical way to control fixed speed compressors is through cascaded pressure bands but if cascade has multiple VFD's then problems



Source: Compressed Air Challenge

Typical cascade control strategy and problems

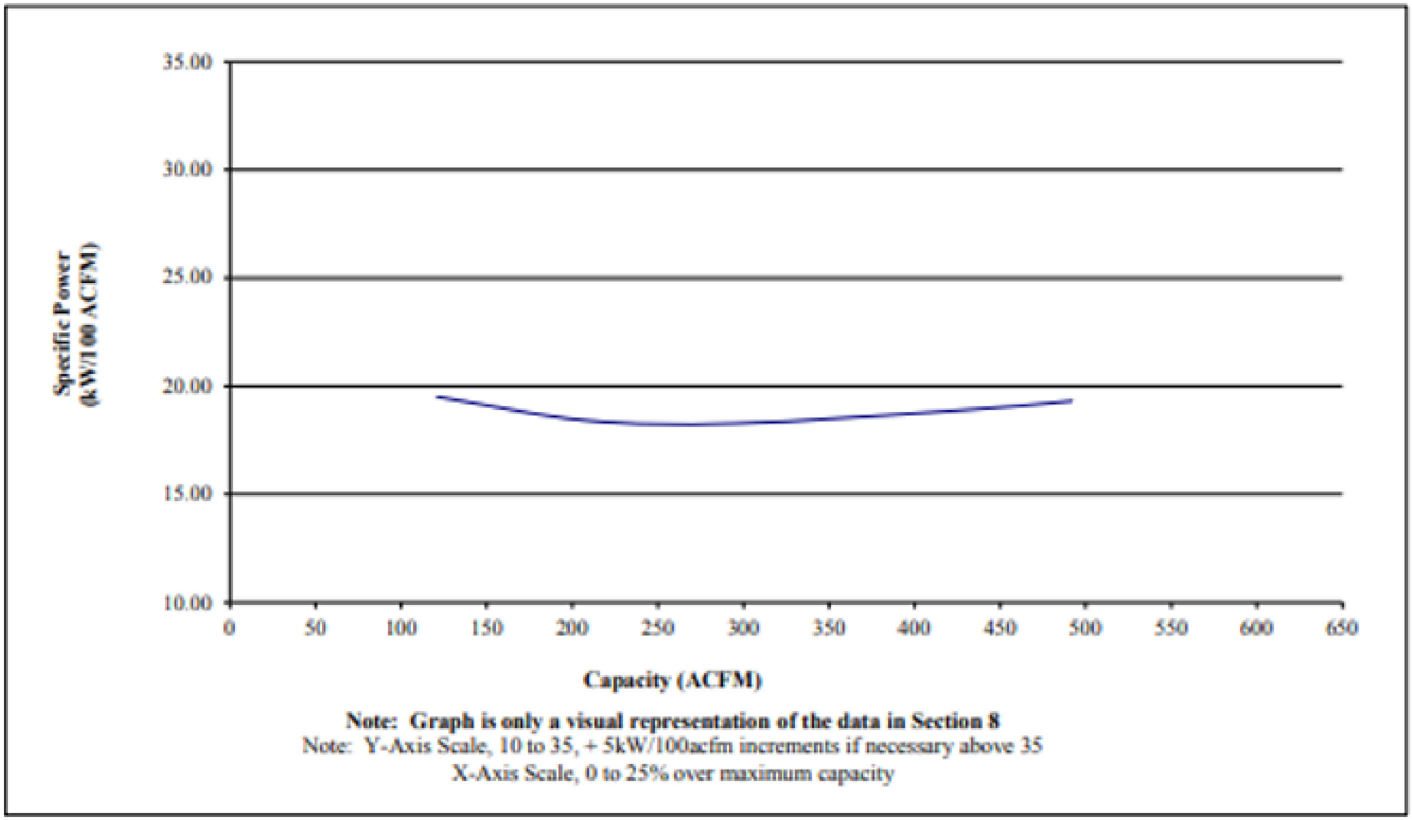
- Two compressors running at minimum speed is less efficient than one at higher load for tilted curve



Source: Compressed Air Challenge

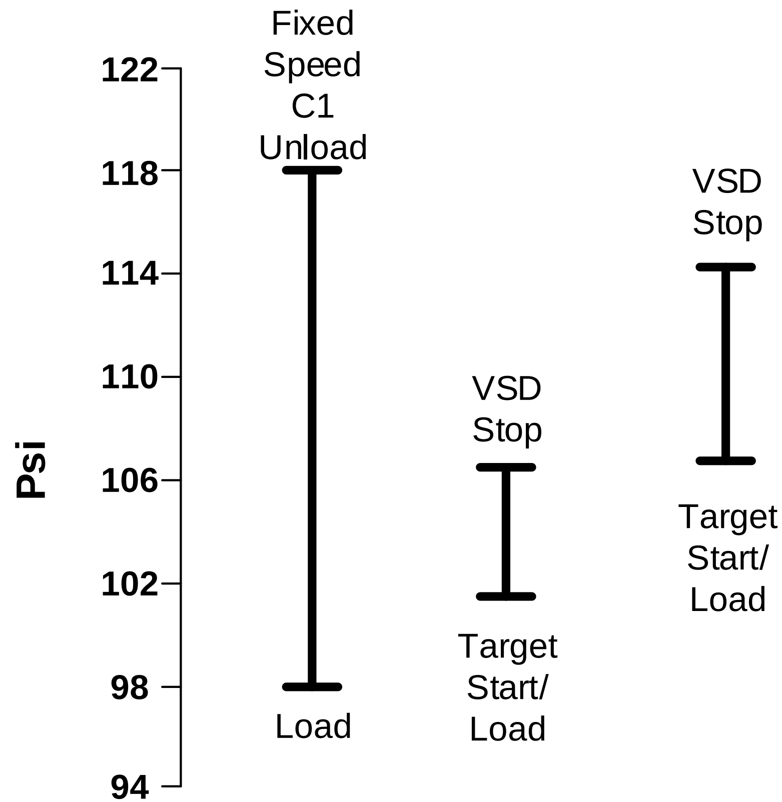
Typical cascade control strategy and problems

- Less problem with flat curve, but optimum efficiency would be in middle of curve, not possible with cascade



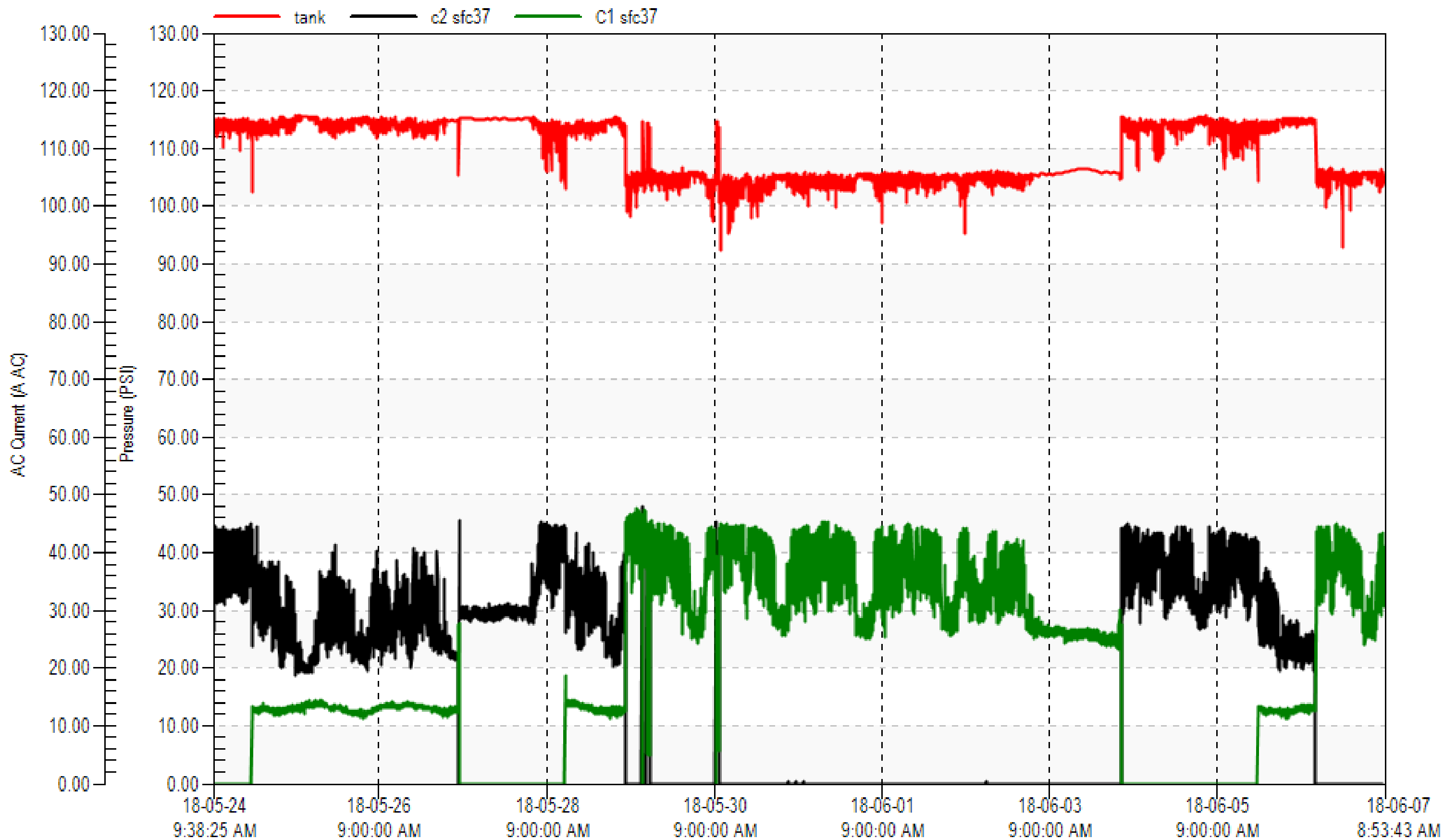
Simple modified local control strategy

- Stacking VFD pressure settings avoids the problem but pressure control is affected, avoidance of lower efficiency not possible



Simple modified local control strategy

- Example profile with overlapping pressure bands

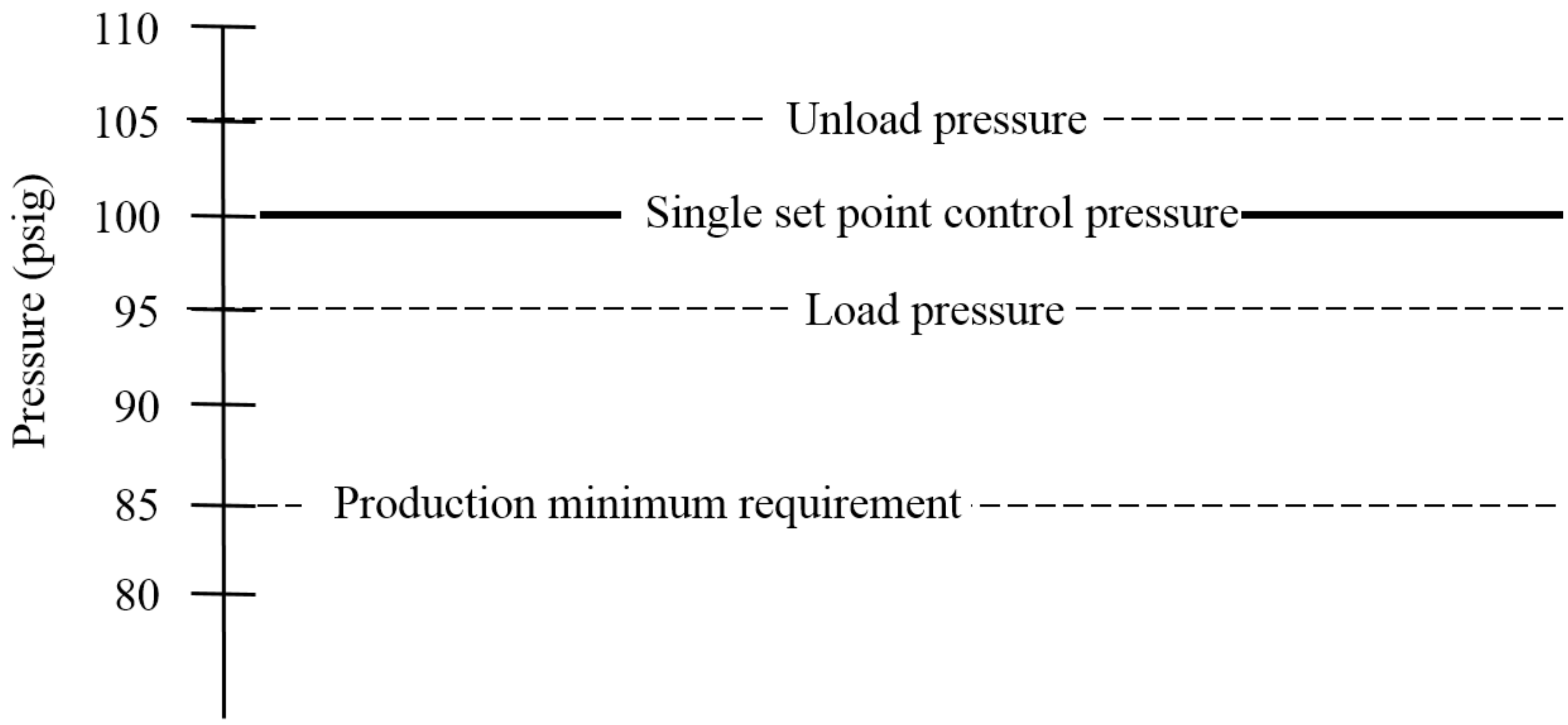


Simple modified local control strategy

- Stacking VFD pressure causes variable pressure
- Pressure level during low loads too high, increased artificial demand
- VFD setpoint band too narrow, problems controlling
- Control points at local control, sag across dryer and filters
- Compressors run in a specific order, not possible to optimize using best unit
- VFD's must start stop for control, not desirable
- VFD might run at minimum speed all the time
- VFD running on inefficient part of the curve

Intelligent single pressure band strategy

- Using central controller improves situation



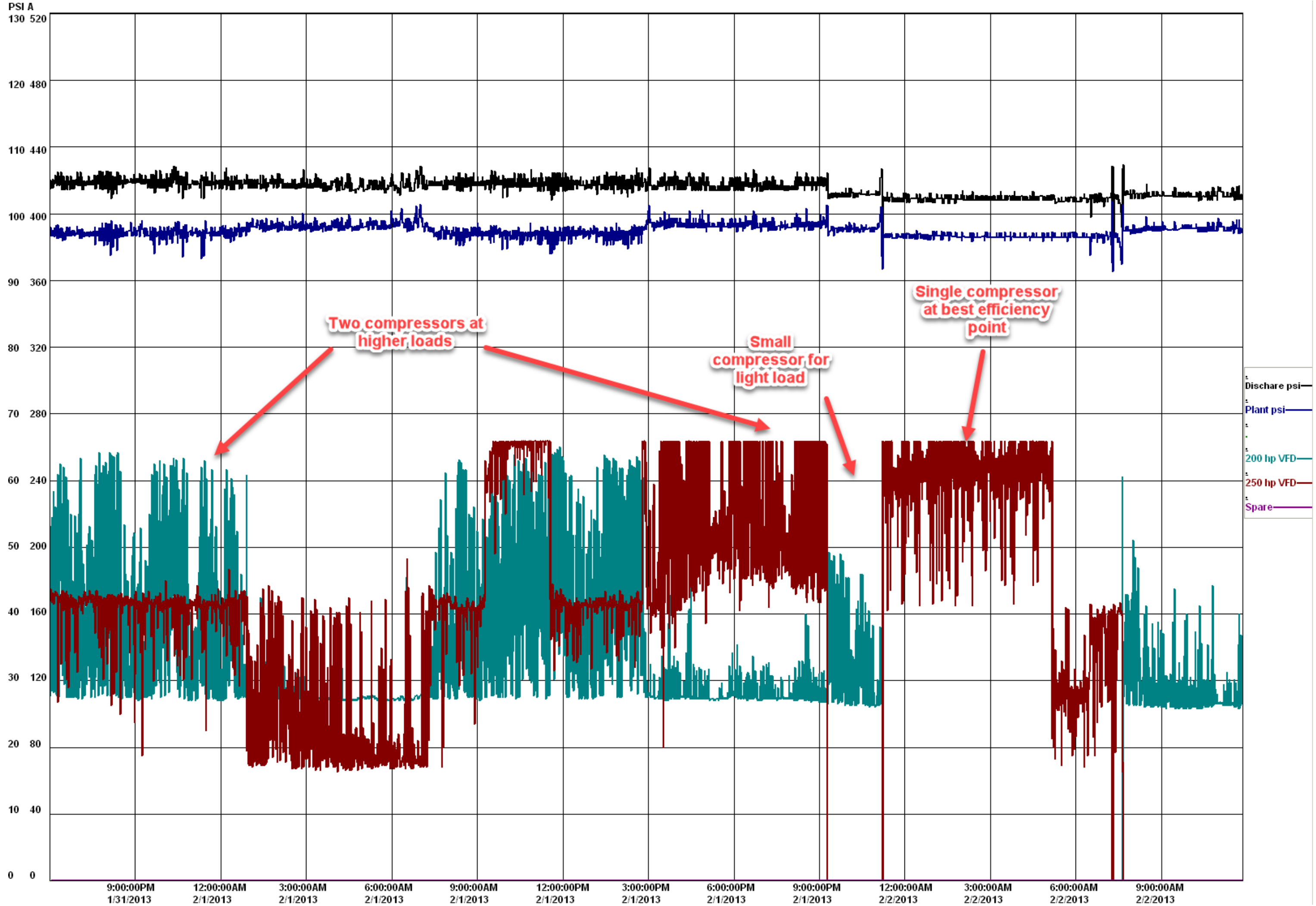
Source: Compressed Air Challenge

Intelligent single pressure band strategy

With intelligent controllers:

- The system is capable of controlling both fixed speed and VFD compressors in a single target setpoint,
- The various compressor efficiency, flow and power characteristics are programmed into the controller,
- The controller calculates total system flows based on compressor status,
- The controller compares system flows and finds the optimum combination of compressors to best satisfy the flow,
- Some machine learning may be available where the controller recognizes repeating conditions, for example at a certain time each weekday, and anticipates the need for a certain combination of compressors to avoid large pressure peaks or valleys.
- The best controllers of this type have monitoring systems that allow the operators to track system KPI's to ensure optimal efficiency is being achieved.

Example of intelligent control



Summary

- In most systems the presence of one of more VFD's improves efficiency
- All VFD curves are not alike
- Cascaded pressure bands causes challenges
- Stacking pressure settings causes variable pressure, hard to control
- Best control is through with single setpoint intelligent central control with automatic selection of best compressors and best operating point
- Good system minimizes pressure swings, improves efficiency
- Good system communicates with user to track KPI's

About the Speaker

Werner Rauer
Kaeser Compressors, Inc.

- Product Manager for oil-injected screw compressors at Kaeser Compressors, Inc.
- Over 30 years of industry experience
- Active leader in the Compressed Air and Gas Institute (CAGI), developing the widely used CAGI compressor performance datasheets
- Chairs CAGI's Engineering Committee for rotary/positive displacement compressors
- Completed the DOE Compressed Air Challenge I and II, is a CAGI Certified Compressed Air System Specialist, and is a Master Certified System Specialist through Kaeser's Factory Training Program

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Control Strategies for Multiple VFD Air Compressors Part 2

Werner Rauer
Rotary Screw Compressors Product Manager
Kaeser Compressors, Inc.

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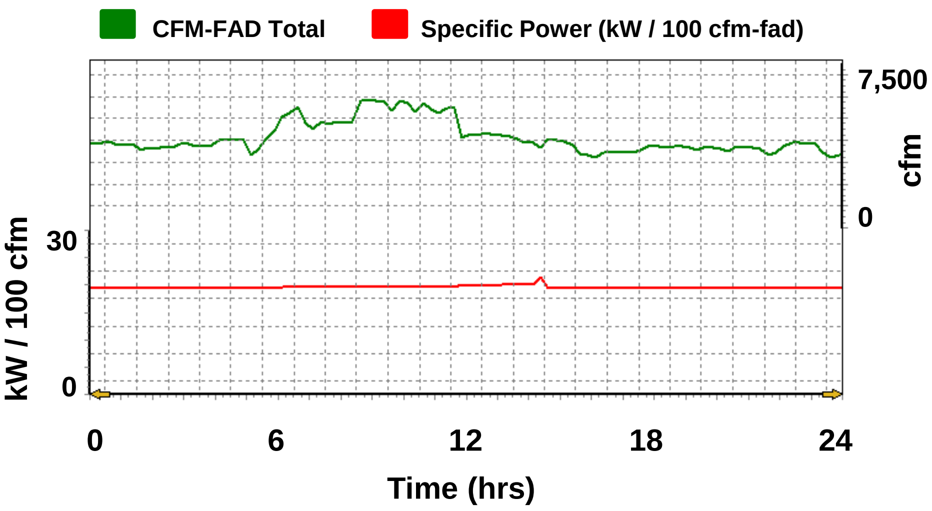
Balancing Expectations

Characteristics of Well Optimized Systems

- Maintain lowest stable operating pressure regardless of demand
- Maintain specific power regardless of demand
- Properly select compressors based on demand
- Realize close to 100% duty cycle for all units within system minimizing energy consumption

System Optimization in Practice



Review

Pros *(when properly applied)*

- Good part-load efficiency
- Steady pressure
  - Operates at lower pressure
- Low inrush currents
- Improved power factor
- Provides load/demand profile
  - With modern controllers
- May qualify for energy rebates
- Smaller receiver tank

Cons *(when misapplied)*

- Inefficient operation
- Higher purchase cost
- Reliability
- Complexity
- Maintenance cost
- Sensitivity to environment

Reasons to operate multiple VFD compressors

- Rebates for VFD equipment
- System efficiency (if done right)
- Frequent and large changes in demand
- Little or no air receiver tank ("no storage")
- To fill/fix a control gap
- Hugely different shift demands
- Operating at close to system pressure
- Because "I can…"

Reasons NOT to operate multiple VFD compressors

- Initial cost of purchasing and installation of VFD and controls
- Reliability / Complexity
- System efficiency (if not done right)
- How to control them?
- Complex control system

How to operate multiple VFD compressors

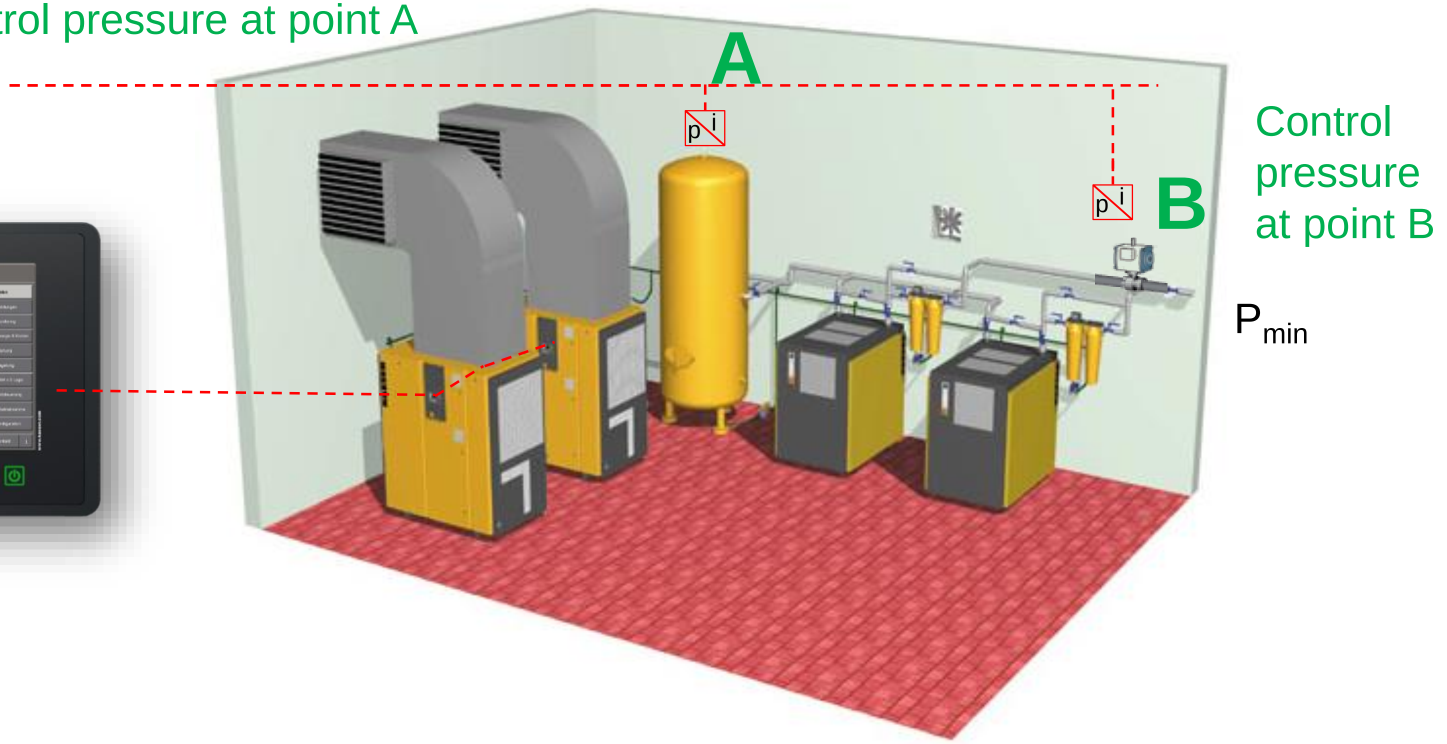
- With or without system master controller
  - manual – sequential – parallel
- “digitally networked” or analog controls
- Provide target speed/flow
- Provide target pressure
- Provide target pressure with cascade
- ……..

Energy savings in compressed air systems

By correctly positioning the pressure transducer

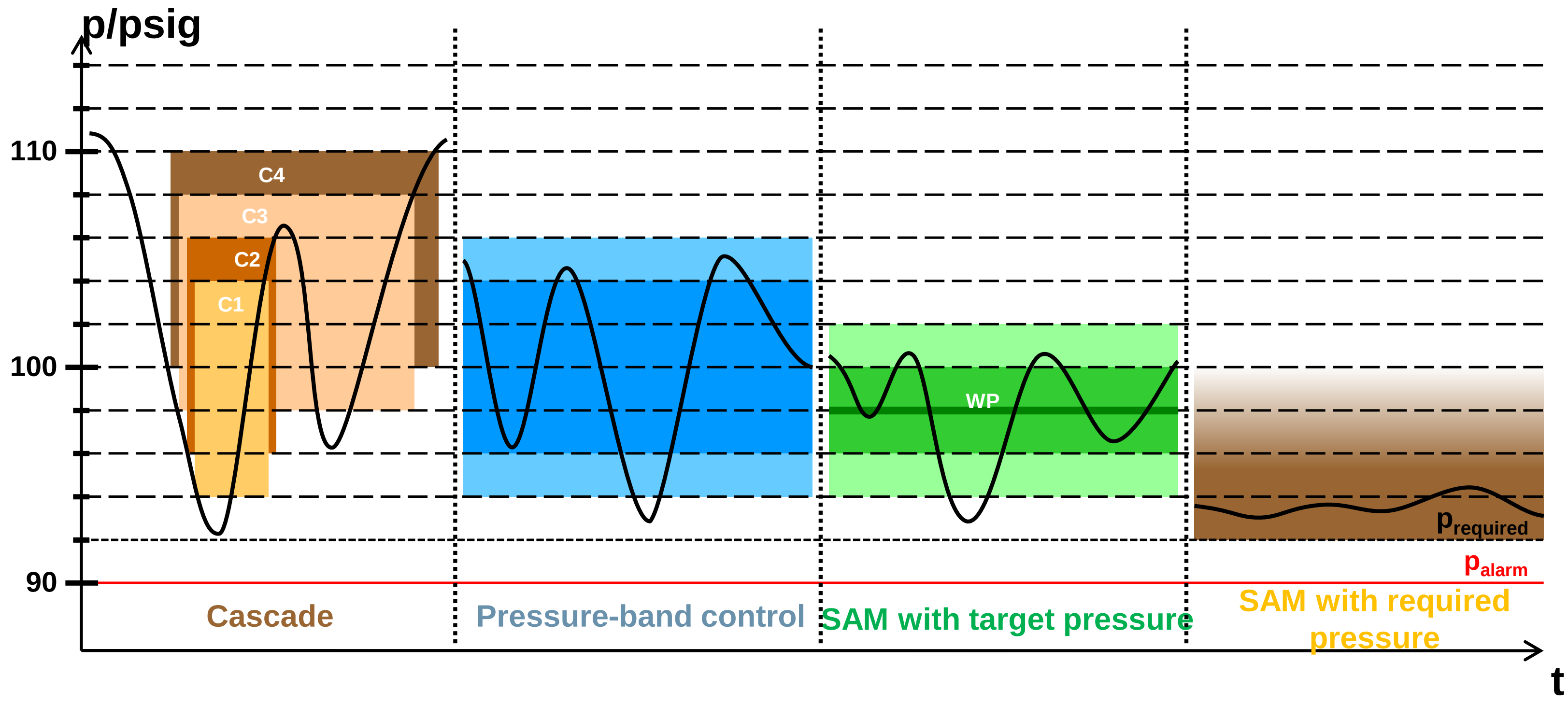
Control pressure at point A

Settings:
$P_{required}$ = 100 psig
P_{low} = 98 psig



External control unit

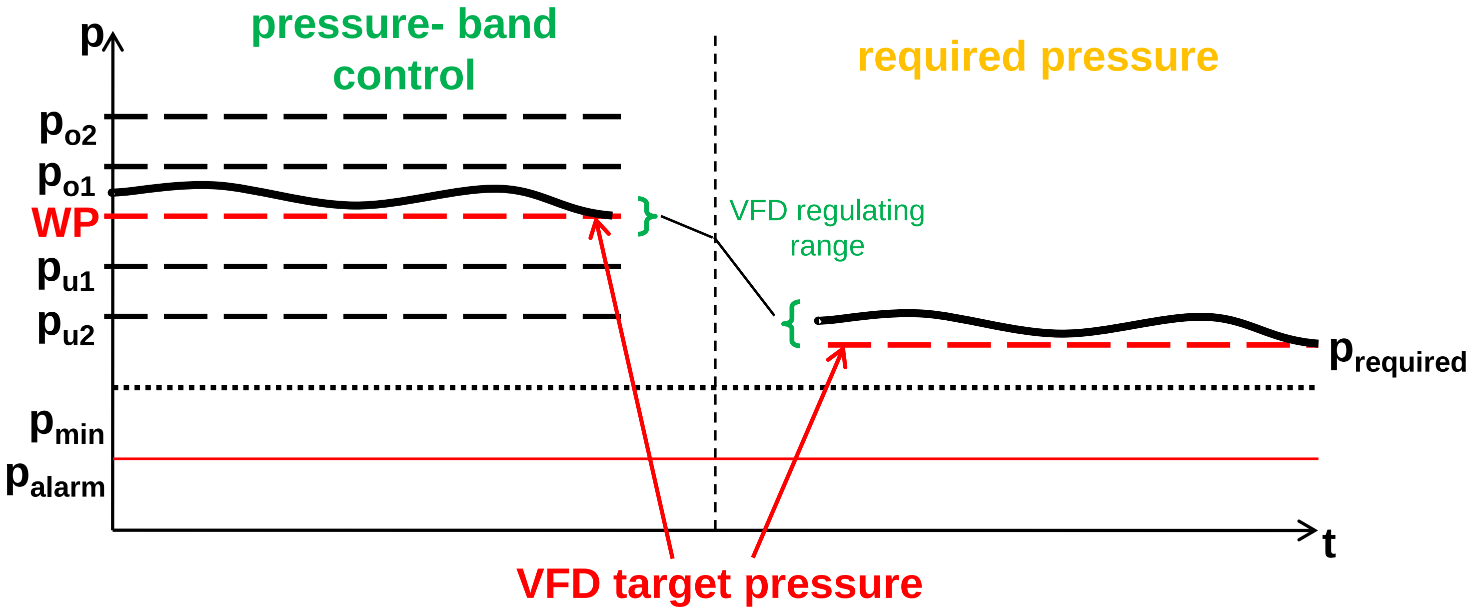
Various control modes in comparison



Master control with required pressure control

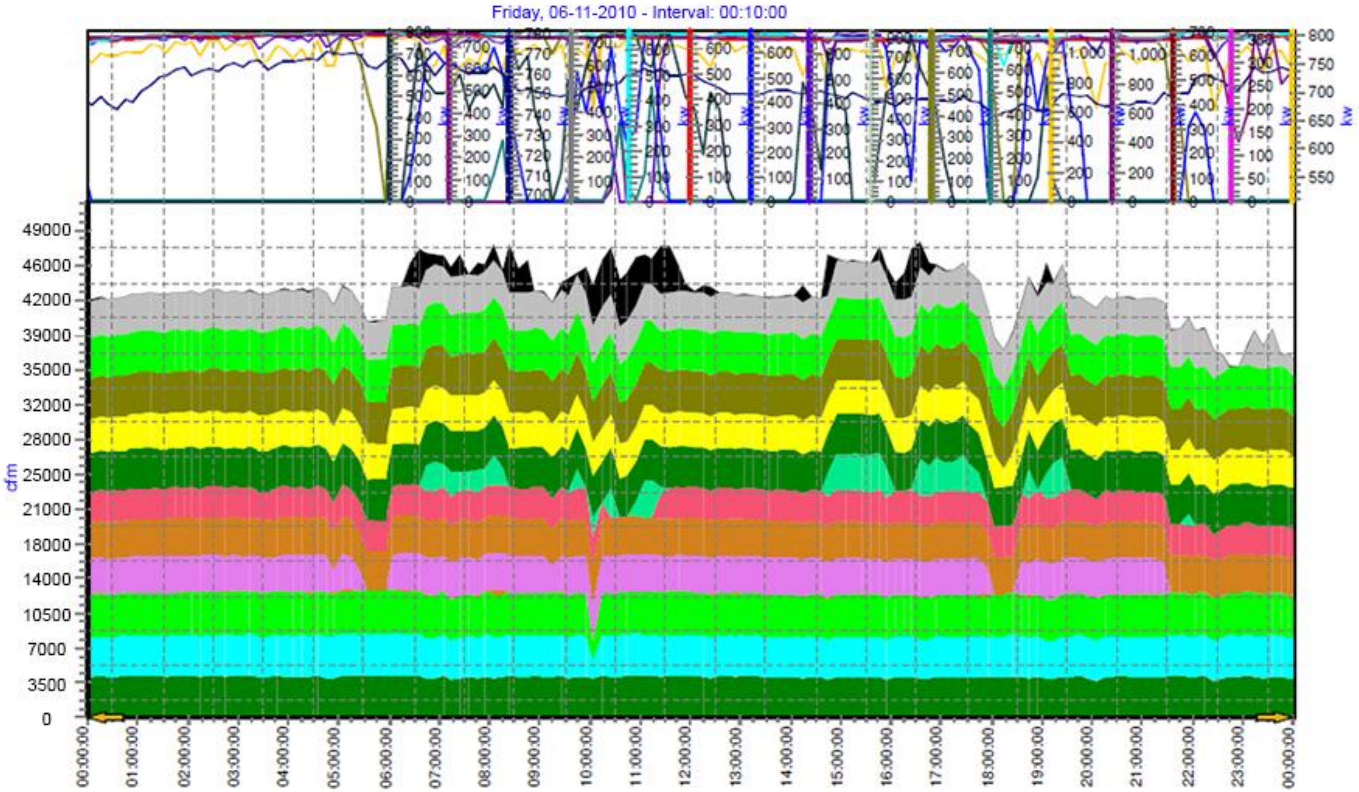
Lowers the VFD control pressure to the lower limit

The VFD setting regulates the pressure as long as this is possible efficiently



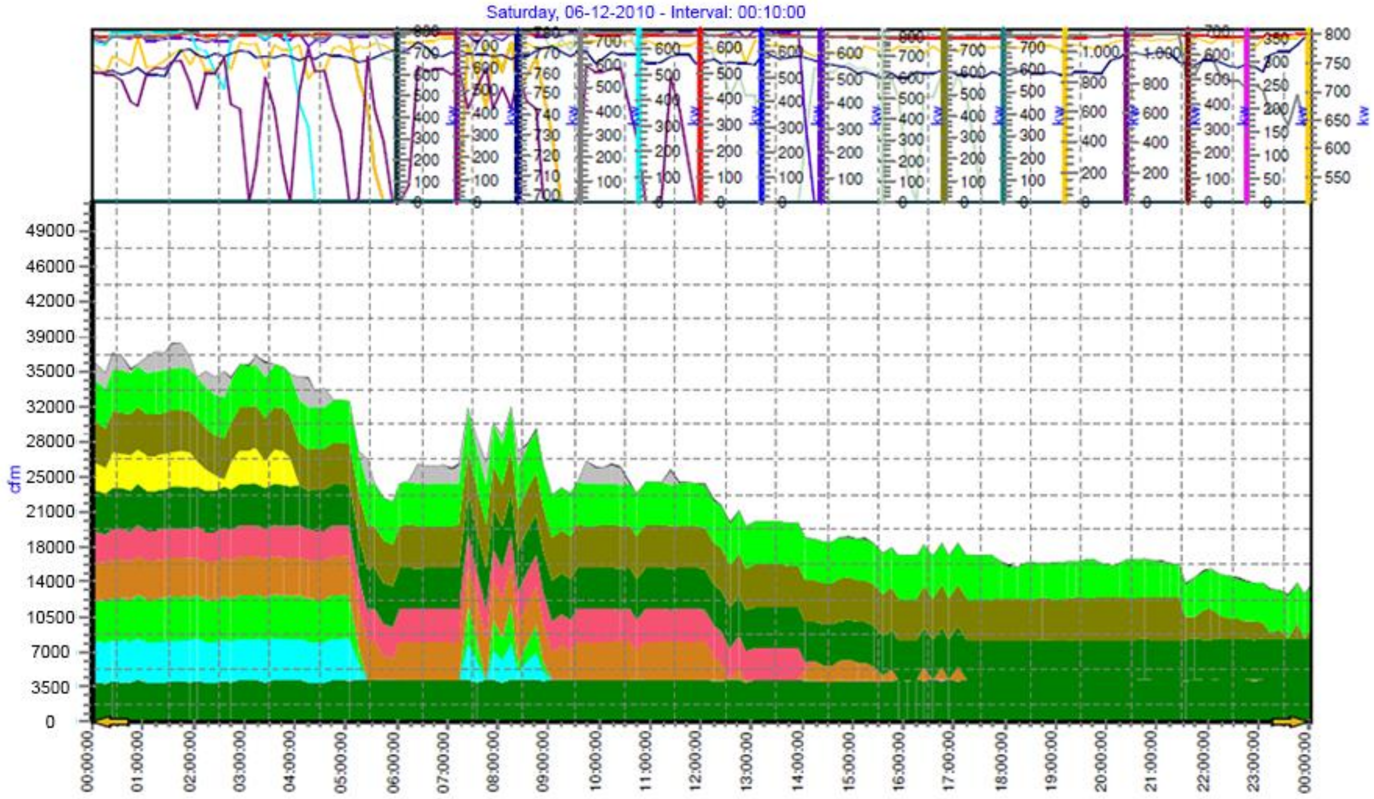
First step is the air system analysis of the existing system

Example: air demand and power consumption during a **weekday**



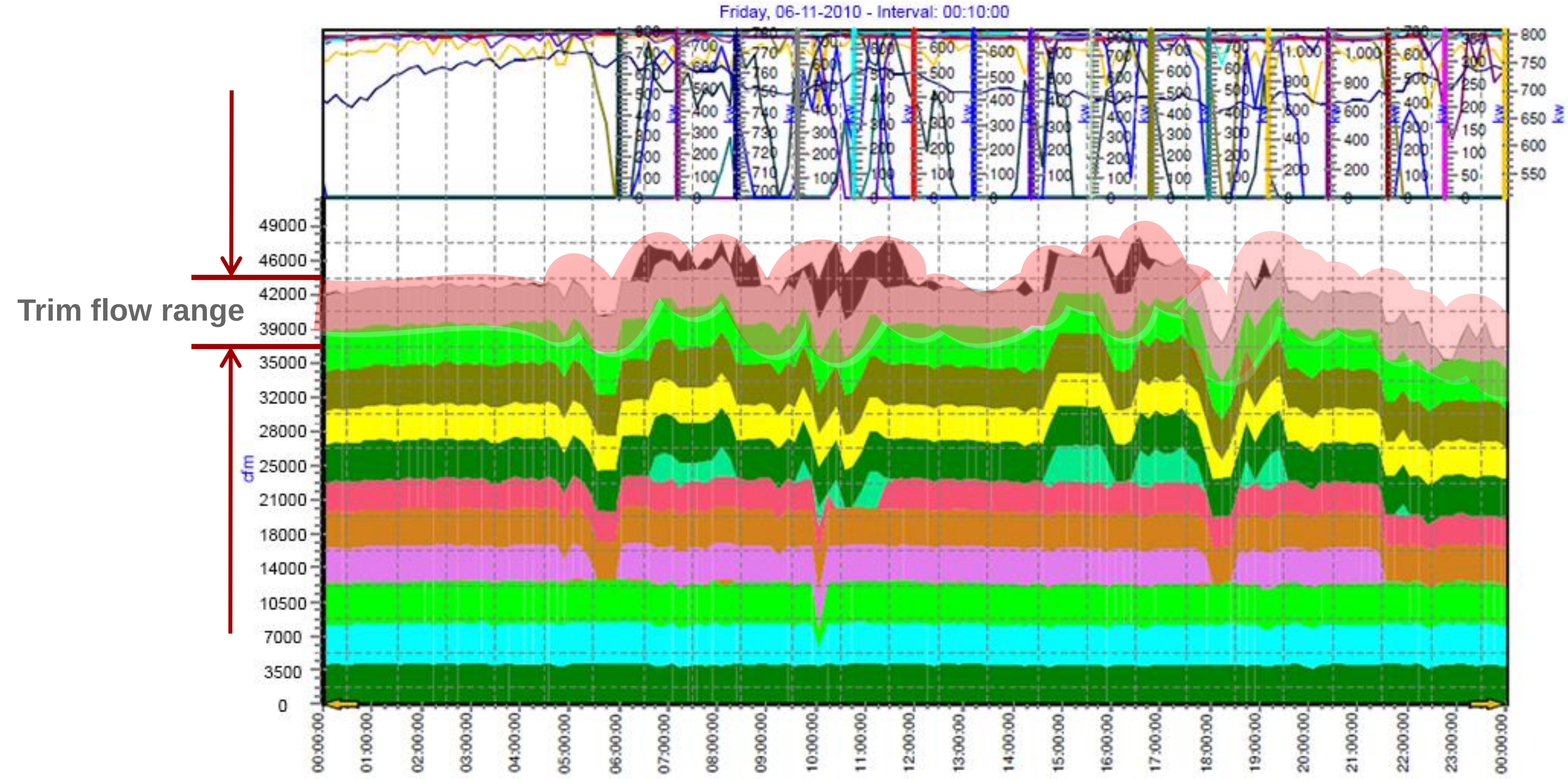
First step is the air system analysis of the existing system

Example: air demand and power consumption during a **weekend**



Analysis of existing and ideas/suggestions for future compressed air system

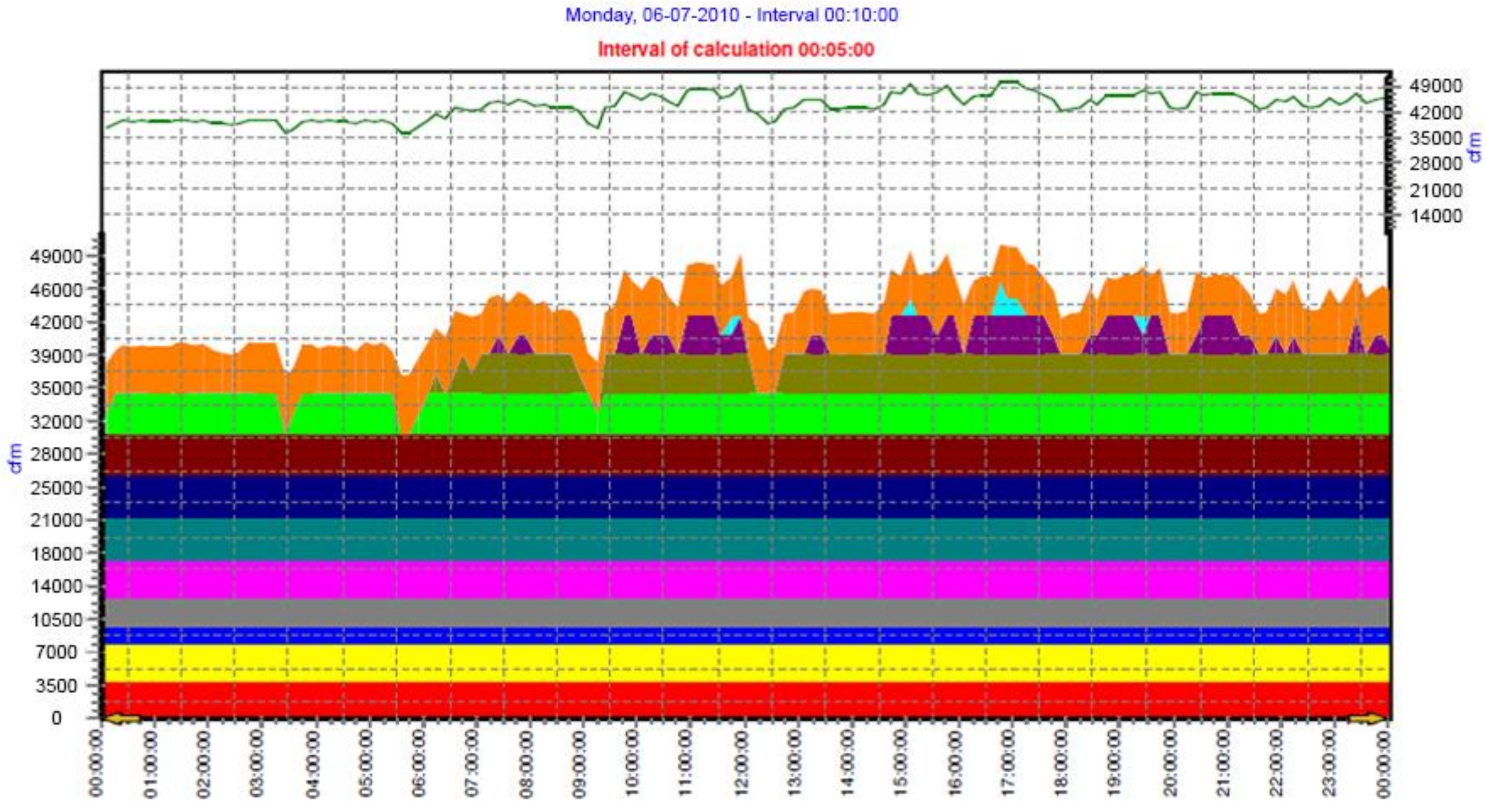
Quick view of the planned and simulated control range for the future trim units



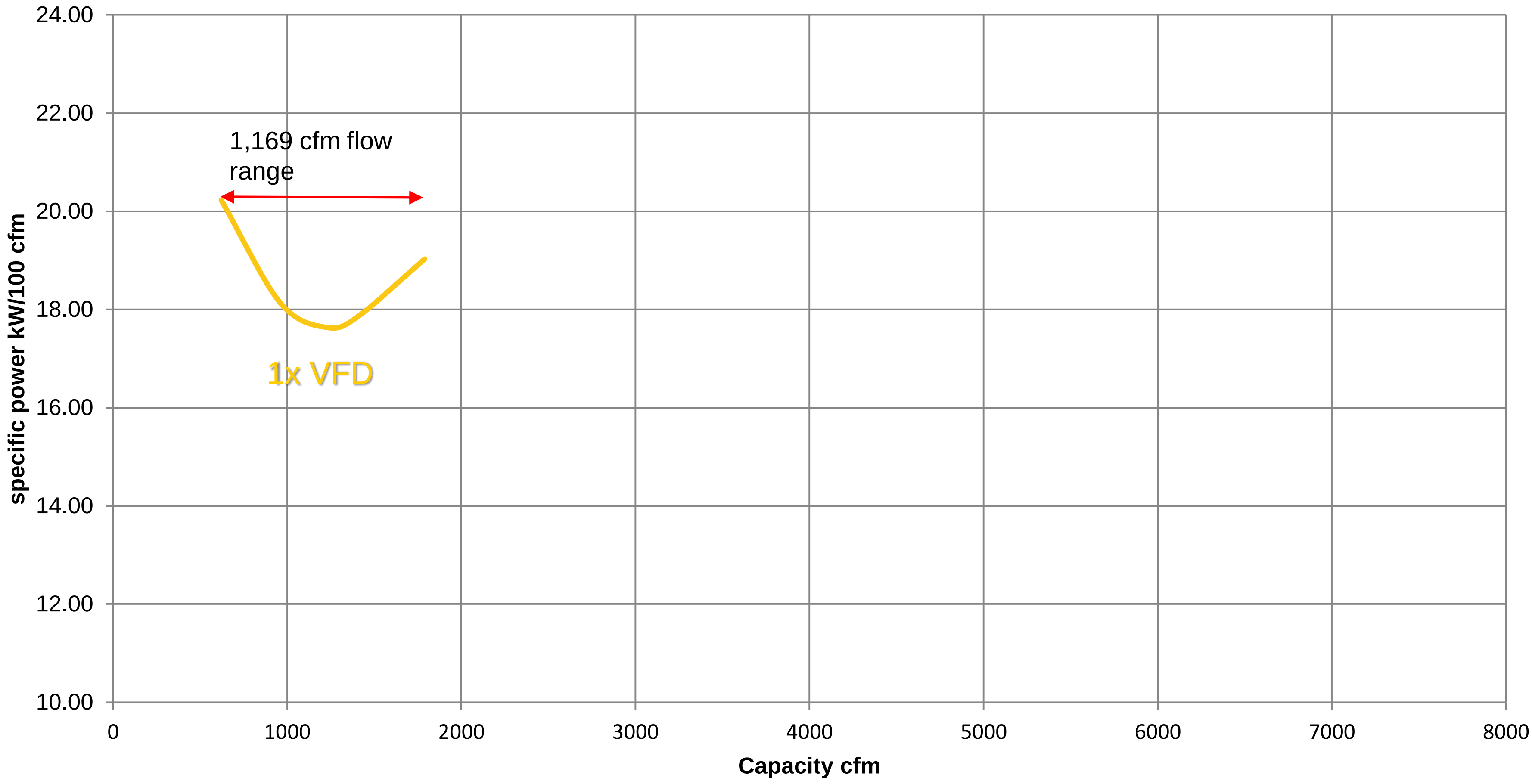
Goal simulation

Trim control using multiple VFD compressors controlled as “one”

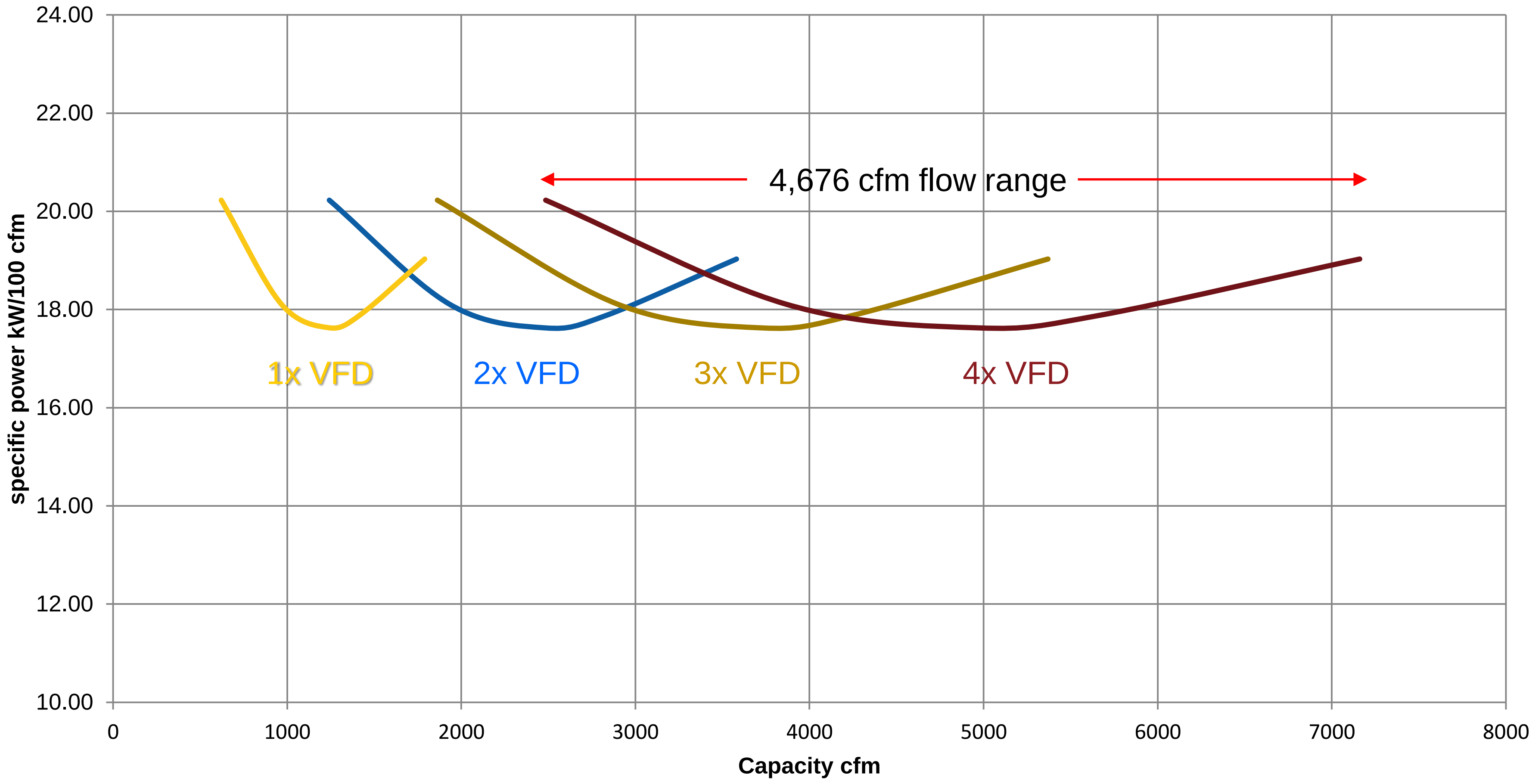
→ Practically no switching looses → consistent overall specific power



Specific power oil-free VFD's at 100 psig conventional control

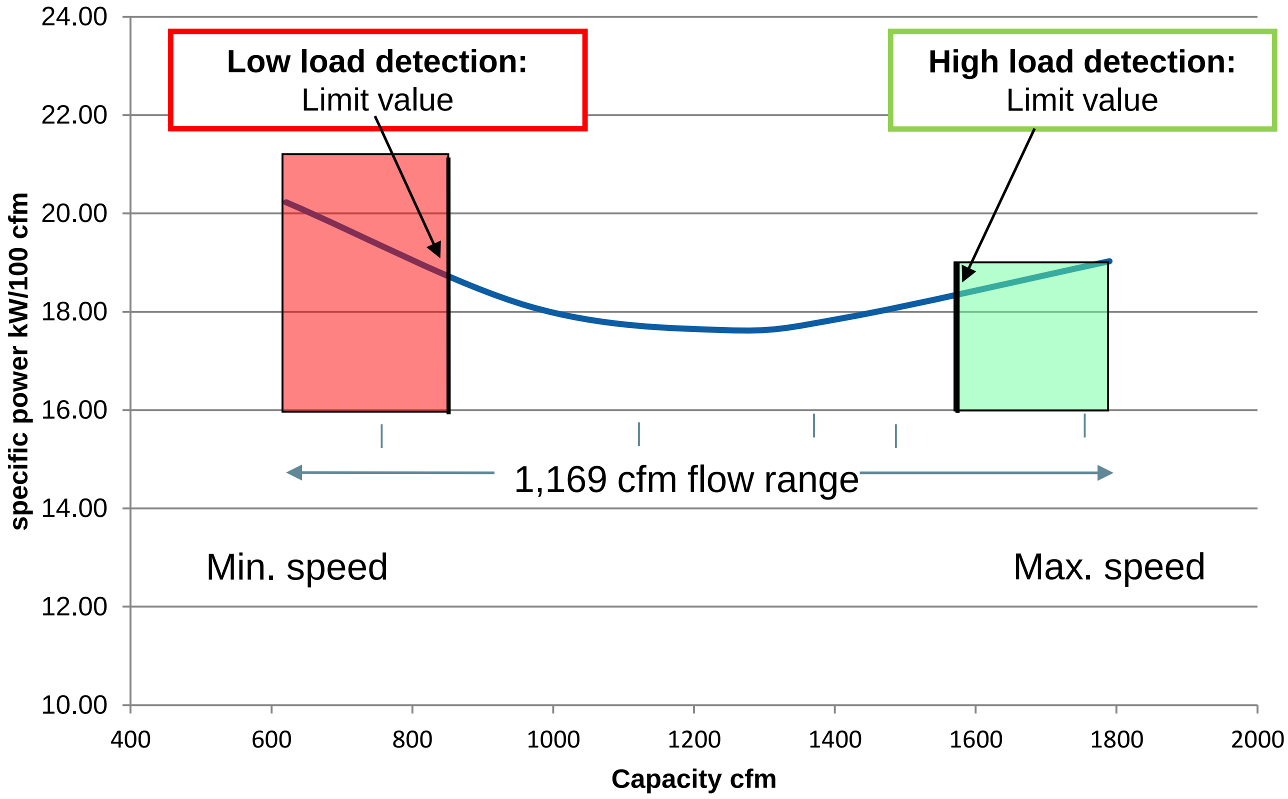


Specific power oil-free VFD's at 100 psig conventional control

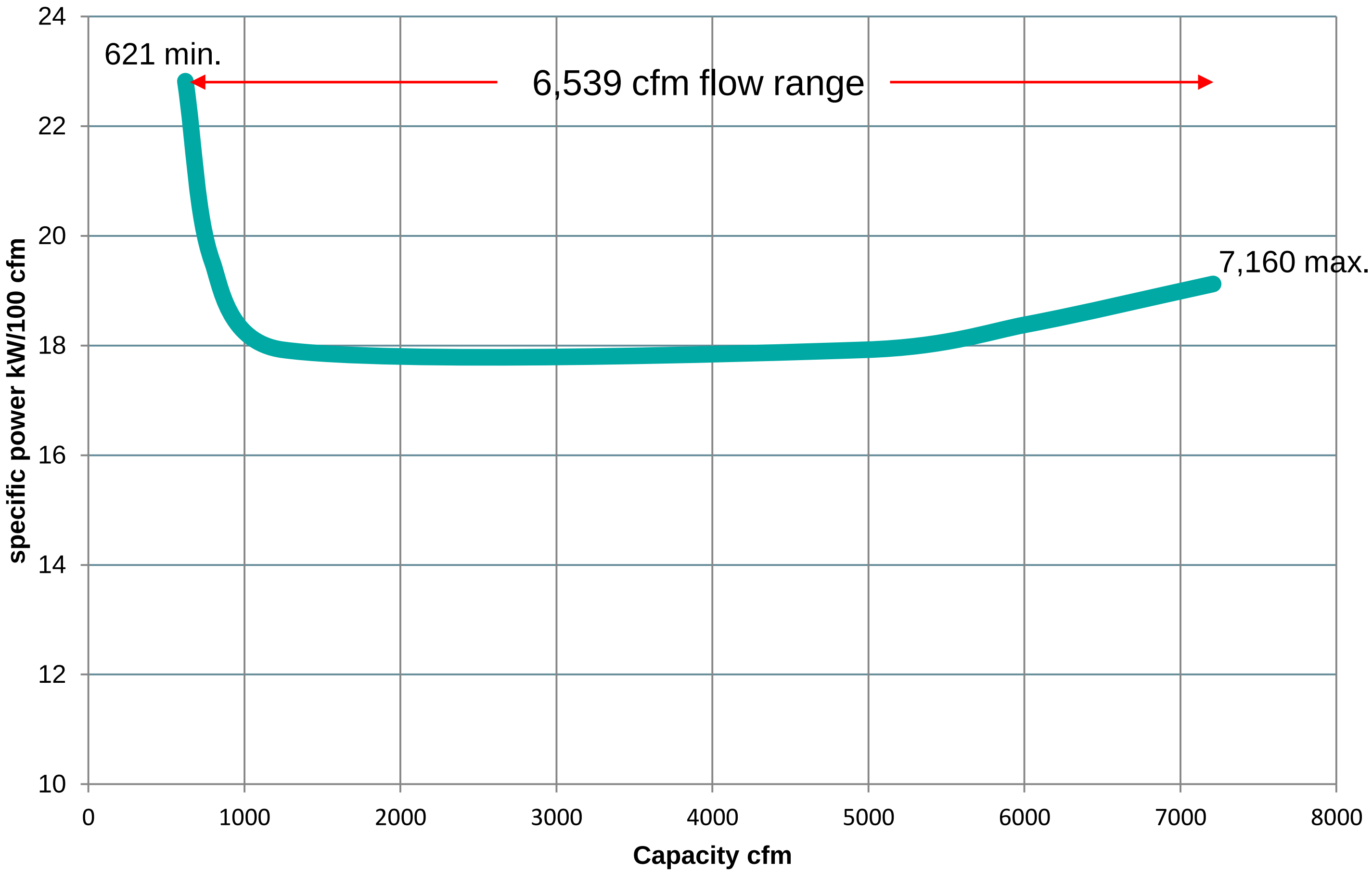


Adding modern master control

Specific power over flow range oil-free VFD w/c at 100 psig - single unit

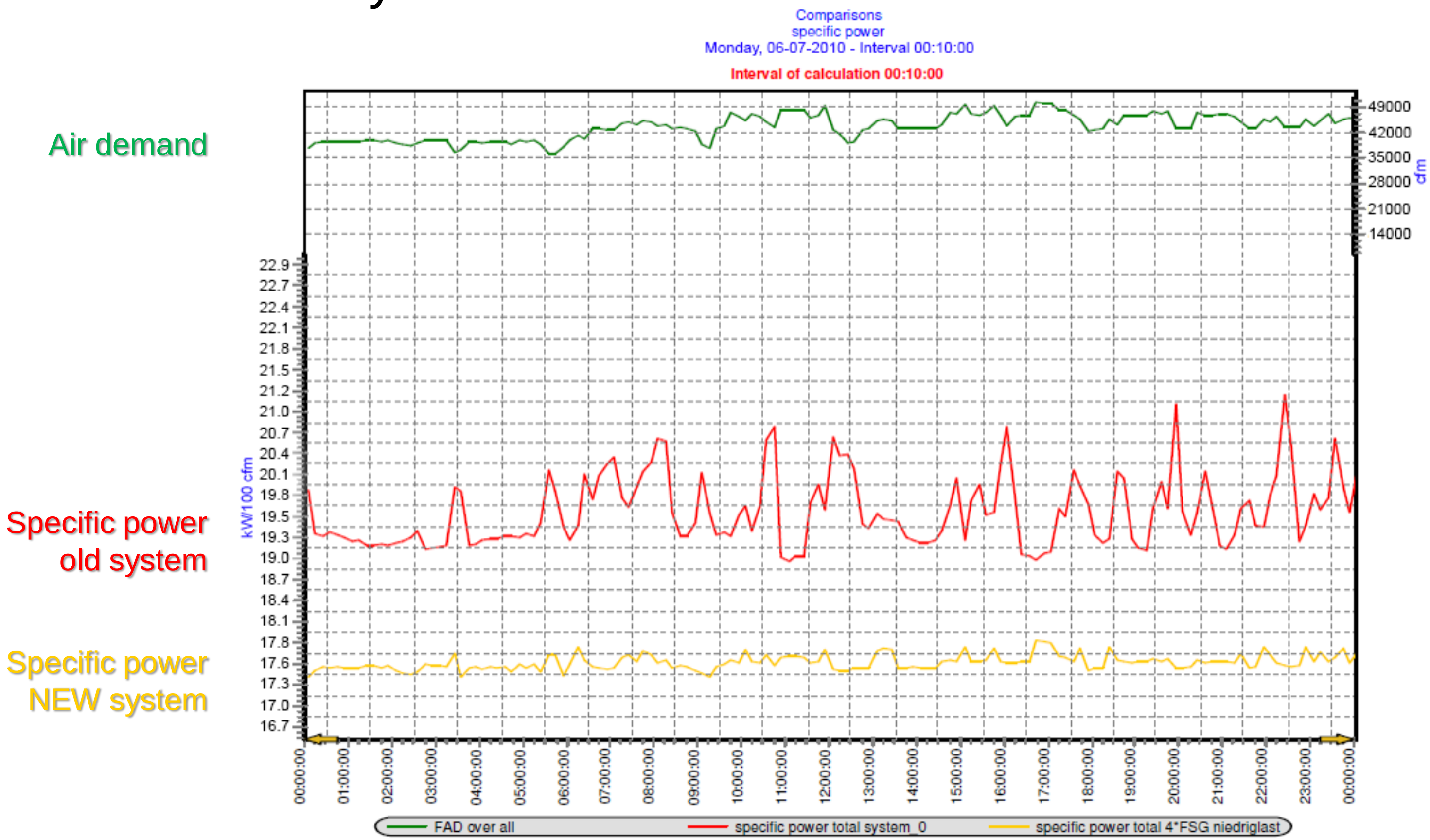


Specific power 4x oil-free VFD at 100 psig using synchronized, intelligent master control



Goal accomplished

Improved KPI specific power for the overall system – absolute value as well as consistency



Operate multiple VFD compressors? Yes….

- Depends on application!
- Requires analysis and proper sizing
- Requires synchronized, intelligent control
- Requires Master controller:
  - All digital control
  - Digital twin of all compressors
  - Specific logic or adapting control algorithm

THANK YOU

For more information, visit:

https://airbestpractices.com/technology/air-compressors/5-tips-optimizing-vsd-air-compressors

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Control Strategies for Multiple VFD Air Compressors

Q&A

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Thank you for attending!

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The next slide will show a statement related to today's topic that needs to be filled in. You will be provided the first letter of the words as a clue. Please submit your answers in your questions box.

Example

When I think of a beach vacation, I think of _______.

T____

T___ B___

S___ S_____

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Example

When I think of a beach vacation, I think of _______.

TOWEL

TIKI BAR

SEA SHELLS

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Based on the clues below, please submit your answers in your questions box.

What are some reasons to install multiple VFD air compressors? _______.

Fix C------ G--

E----- R------

S----- E---------

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Based on the clues below, please submit your answers in your questions box.

What are some reasons to install multiple VFD air compressors? _______.

Fix Control Gap

Energy Rebates

System Efficiency

Thank you for attending!

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Piping and Storage for Compressed Air Systems

Tom Taranto
Data Power Services
Keynote Speaker

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