Motor Decisions Matter SM

MDM Webinar:
Motor System Management

Thursday, October 29 , 2015

Presented by Gil McCoy, Washington State University Energy Program

Motor Decisions Matter

www.motorsmatter.org

Agenda

1. Introduction
2. Motor System Management Training
3. Q&A

Ground Rules

- All attendees are in listen only mode using their computer audio.

- Please type your questions into the Question Box. We will answer as many questions as possible after the presentations.

Consortium for Energy Efficiency

CEE Members

www.cee1.org

Motor Decisions Matter[SM]

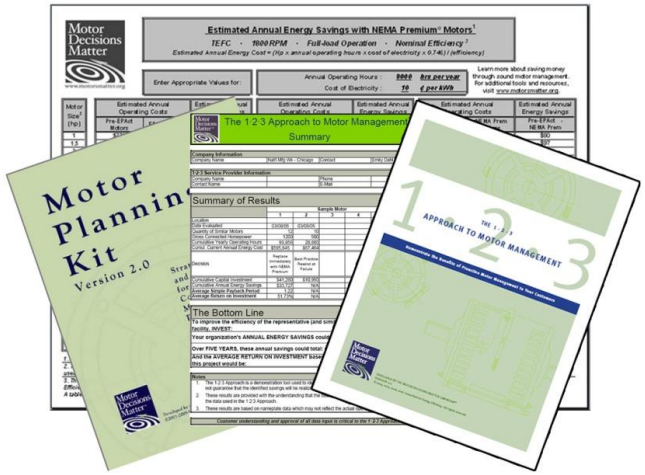
A binational (USA & Canada) campaign to:

- Promote motor system management based on lifecycle cost and proactive planning
  - Highlight financial and performance benefits
  - Improve replace/repair decision making
  - Promote high efficiency equipment and best practice repair
- Collaborate binationally to enhance effectiveness locally

MDM Sponsors make webinars like this possible

Thank you!

MDM Tools



Calculations

- *1*2*3* Spreadsheet
- *1*2*3* User's Guide
- Simple Savings Chart
- MotorSlide Calculator

Concepts

- Motor Planning Kit
- Case Studies
- MDM e-Newsletter

www.motorsmatter.org

WASHINGTON STATE UNIVERSITY
EXTENSION ENERGY PROGRAM

Motor System Energy Management Best Practices

A Webinar Sponsored by:

Consortium for Energy Efficiency

Motor Decisions Matter

October 29th, 2015

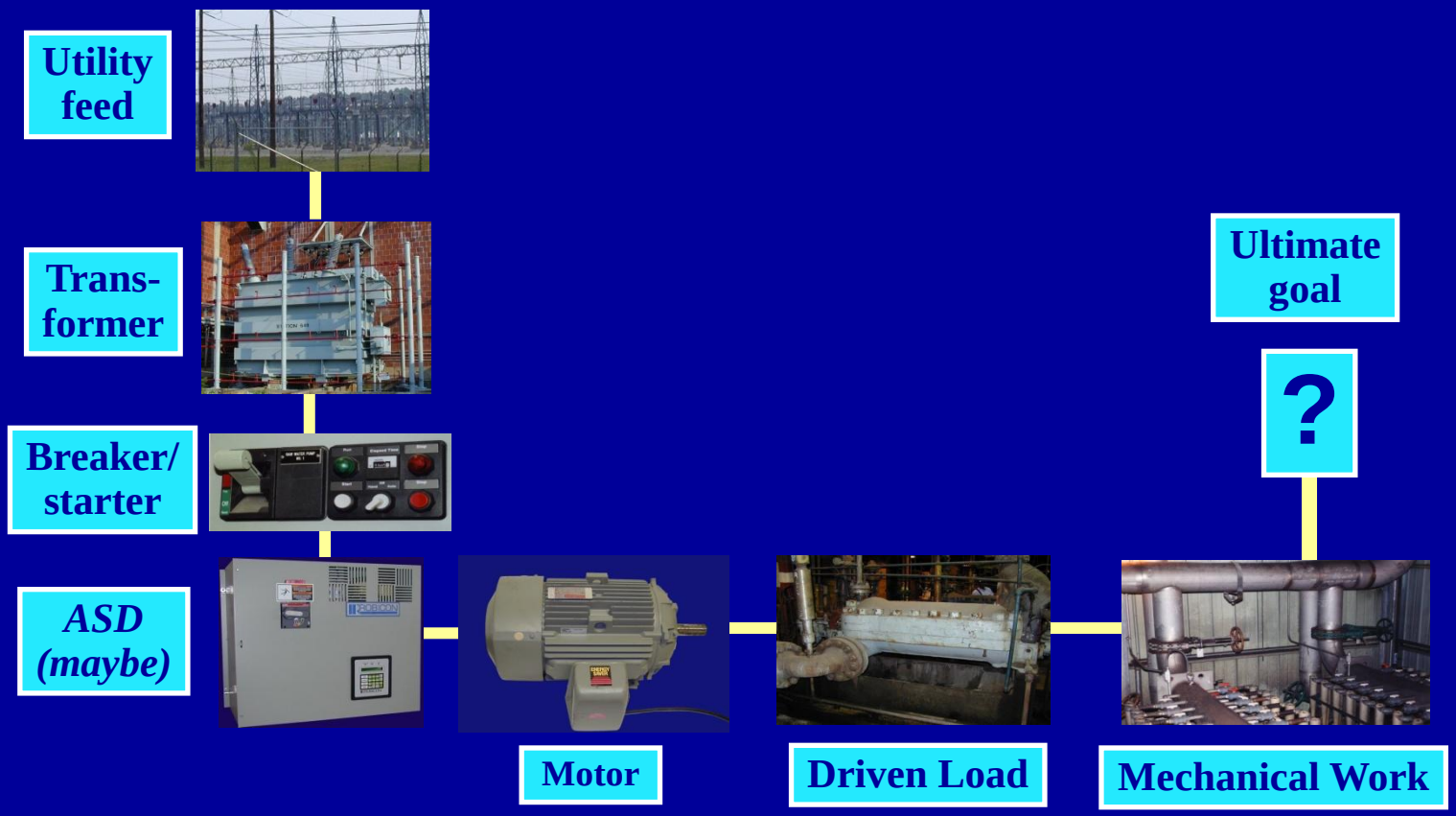
by: Gilbert McCoy, PE
WSU Energy Program

Big Picture Perspective: Motor Systems Energy Use

Motor systems:

- **Are the *single largest electrical end use* category in the North American economy**
- **Account for 38.4% of total U.S. electrical energy use (EIA, 2011)**

A motor SYSTEM is the entire energy delivery process, from electric feed to finished product



What is efficiency?

Efficiency = Output / Input

Efficiency = (Input - Losses) / Input

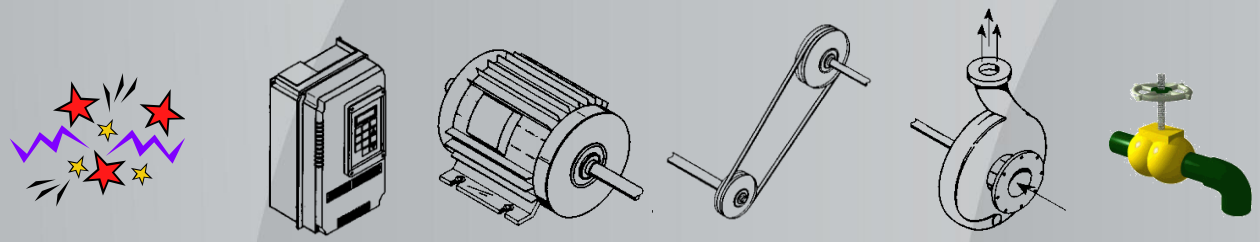
Efficiency = Output / (Output + Losses)

They're all mathematically equivalent.

System Efficiency

$$\eta_{system} = \eta_{eqpt} \times \eta_{Gear/Belt} \times \eta_{Motor} \times \eta_{VFD} \times \eta_{In\text{-}plant\ distribution\ system} \times \eta_{Transformer}$$

Typical Motor System Losses



Useful Work

Load modulation devices
0 to 50%

Coupling device losses
<1 to >10% for large speed reduction

Controller losses
<1 to ~5% for ASD

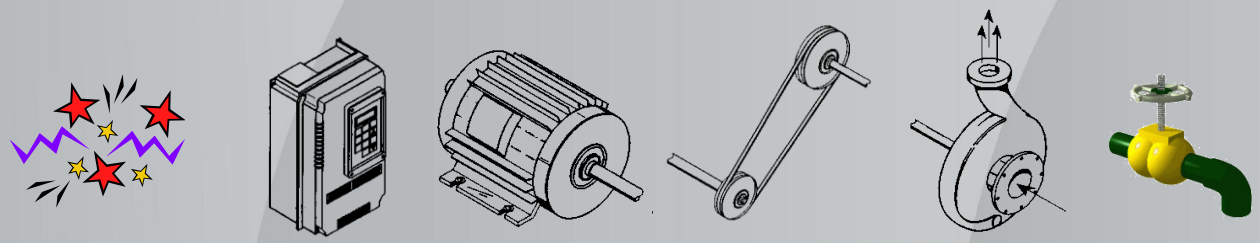
Electrical distribution system losses
<1 to 5%

Motor losses
3.5 to >10%

Driven load losses
30 to 50%
for pumps and fans

Basic Motor Improvements (Component Substitution)

Typical Motor System Losses



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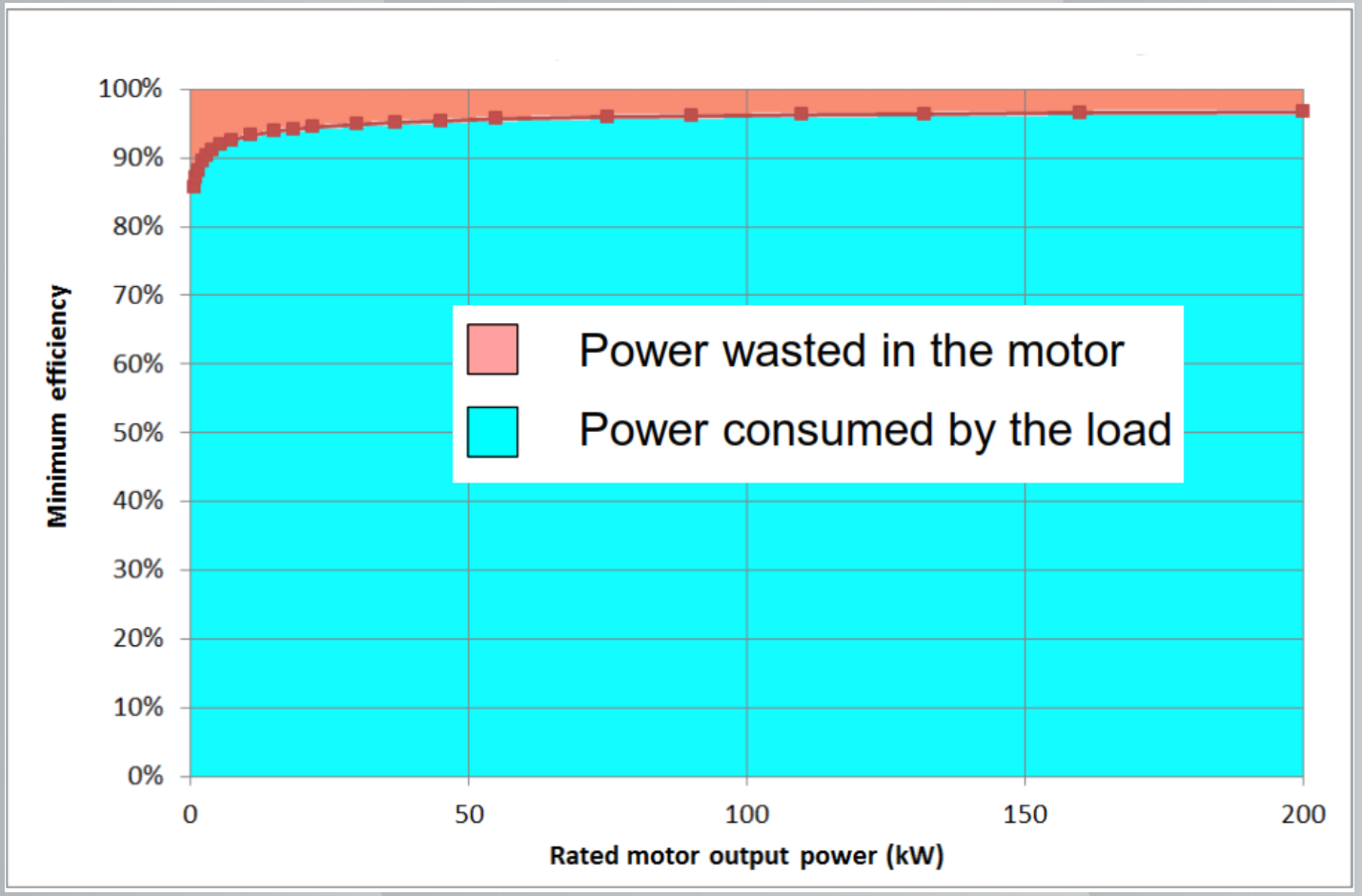
Advanced Motor Improvements (Systems Optimization)

Extended Product Labeling



Source: Nidec Motor Corporation

Motor Efficiency Regulations

Motor Efficiency Definitions

Energy Efficient

- This standard covers 3-phase induction motors with efficiencies equal to or exceeding that in table 12-11 of NEMA's MG 1 standard. It pertains to low voltage (<600V) motors from 2-poles to 8-poles and 1-500 HP.

Premium Efficiency

- This standard covers 3-phase induction motors from 2-poles to 8-poles. It pertains to low voltage motors from 1-500 HP and medium voltage motors (>600 & <5000V) from 250 HP to 500 HP. See http://www.nema.org/premiummotors

Super Premium Efficiency (IEC 60 Hz IE4)

- This standard covers 2-pole to 8-pole motors ranging from 0.12 kW up to 1,000 kW. See table 10 of IEC 60034-30-1 (2014).

Continuous Evolution of Mandatory Minimum Motor Efficiency Standards

- **Energy Policy Act of 1992** General Purpose Motors 1-200 hp, NEMA Table 12-11 Energy Efficient by October **1997**
- **Energy Independence and Security Act of 2007** General Purpose Motors 1-200 hp, NEMA Table 12-12, Premium Efficiency. 201-500 hp Motors at Table 12-11, Energy Efficient by December of **2010**
- **Amended Integral Horsepower Rule of 2014** Almost all integral hp motors 1-500 hp covered at Premium Efficiency level by June 1, **2016**.
- **Small Motor Rule of 2010** New standards for ¼-3 hp single and three phase 2-pole to 6-pole Open Drip Proof motors by March 9th, 2015

Premium Efficiency Motors Required

All General Purpose 1-500 hp new motor sales and imports must attain NEMA Premium minimum full-load efficiency requirements as of June 1st, 2016

Applies to many special and definite purpose motors, including:

--- C-Face and D-Flange motors

--- Close-coupled pump motors

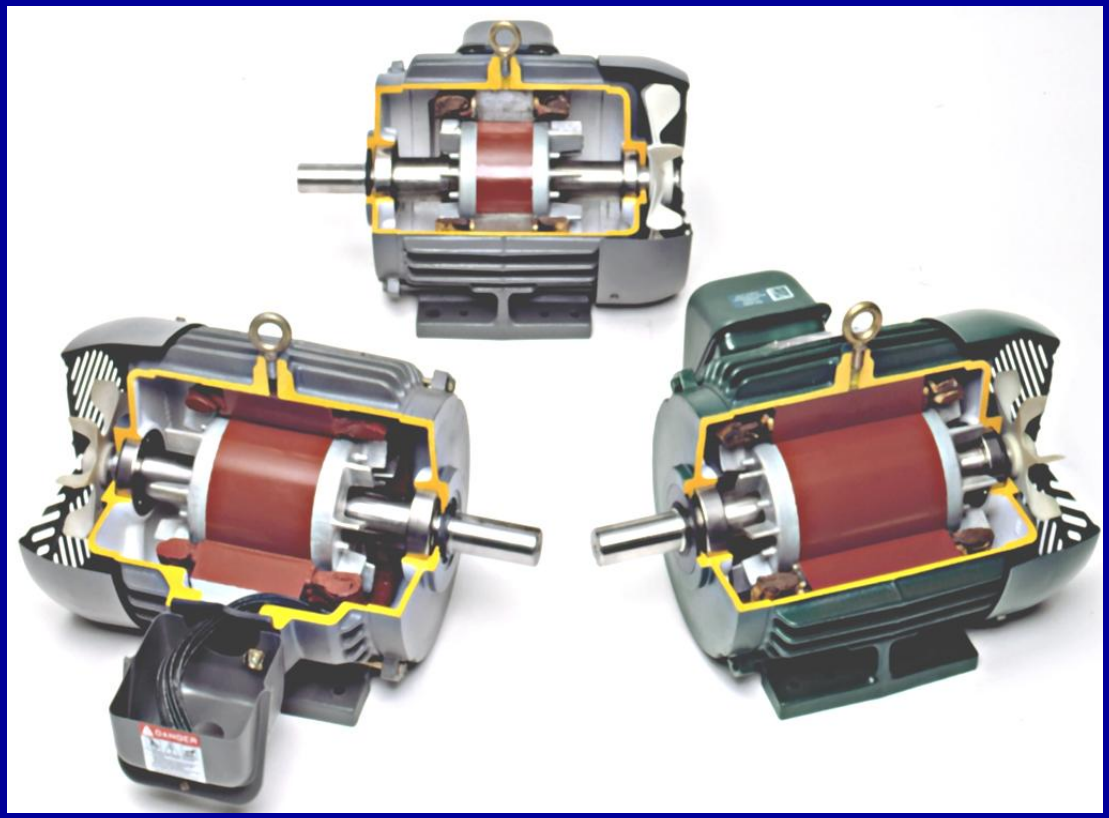
--- Totally enclosed non-ventilated (TENV) motors

--- U-Frame motors

--- Design C (high locked rotor torque) motors

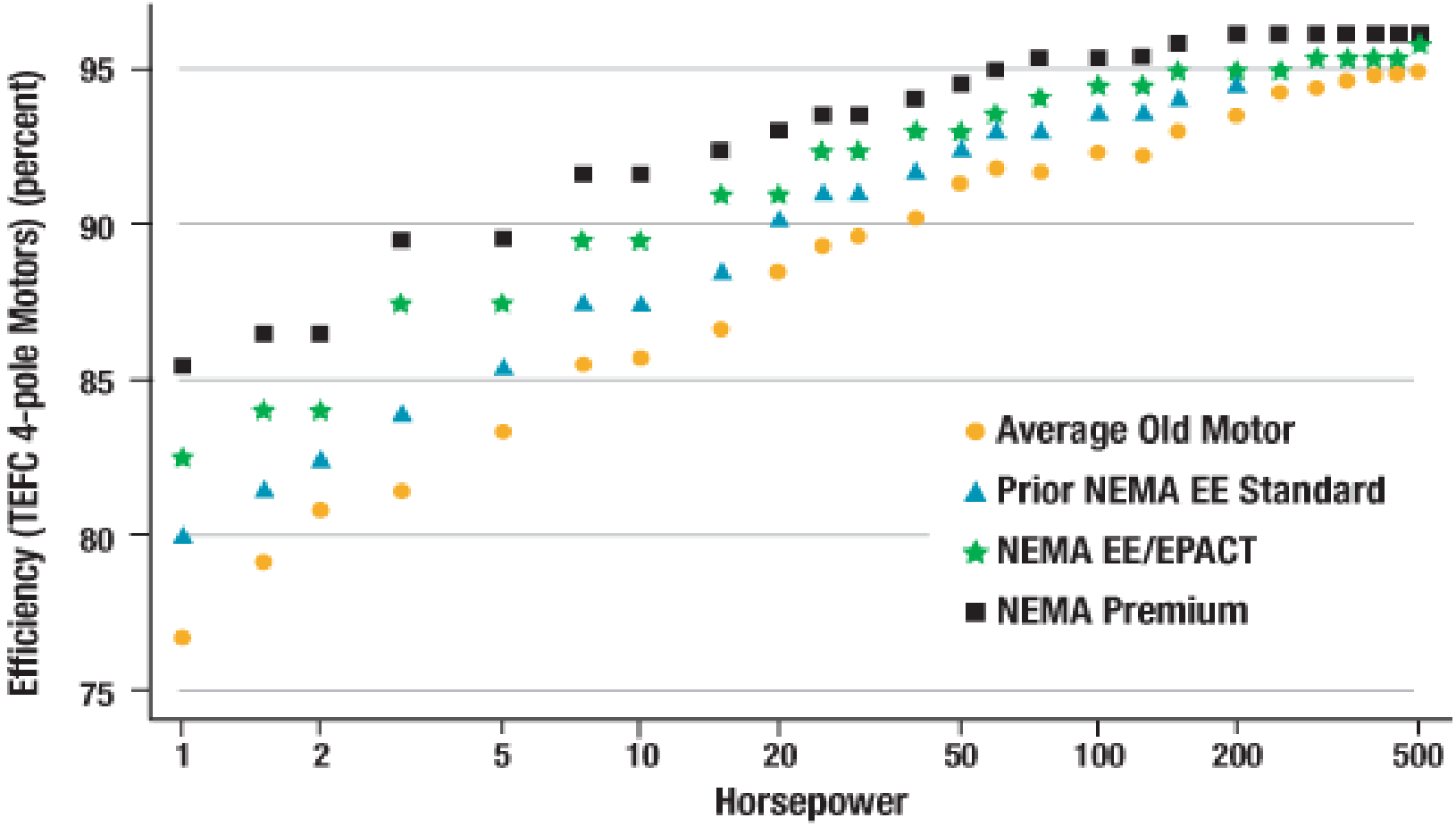
--- Vertical hollow shaft and solid shaft motors

Standard, EE, PE Motors – Amount of Copper, Size of Rotor



Courtesy: Toshiba

Replacement Results in Big Savings



Advanced Super Premium Efficiency Motor Designs

Permanent Magnet and Switched Reluctance Motors:

---Require an electronic power converter or controller to control both torque and speed (inherent variable speed capability)

---Compact/high power density (now available in NEMA T-Frame sizes so can use as retrofits)

---Above Premium Efficiency performance but with high cost. Suitable for niche applications.

Basic Motor Management Planning
Motor Survey and Savings Opportunities

Motor Management Planning

Goals and Benefits:

Provide dollar savings through reduced energy costs Efficiency = More Profit

Minimize energy consumption (energy cost per unit of product)

Maximize efficiency while reducing downtime

Improve system reliability and productivity

Motor Management Planning Actions

- Develop a motor inventory and tracking system
- Replace critical motors with histories of frequent failures immediately
- Develop a new motor purchase policy
- Identify which motors should be replaced with Premium Efficiency units when they fail
- Establish a PEM-Ready spares inventory
- Adopt model motor repair standards
- Consider Life Cycle Cost Analysis

Information Requirements for Motor Management Planning

- Understand Utility Rates and Incentives
- Gather Motor Nameplate Data
- Establish Motor Operating Profiles
- Tune Your Electrical Distribution System
- Obtain Measurements at Connected Loads
- Know Your Load Requirements

Understand your Utility Rate Schedule

Example Utility

General Power Rate

Demand Charge = $10.45/kW-month

Energy Charge = $0.06028/kWh

	Single Shift	Two Shifts	Three Shifts
DC	$12,540	$12,540	$12,540
EC	$14,105	$26,644	$52,805
DC%	47.1%	32.0%	19.2%

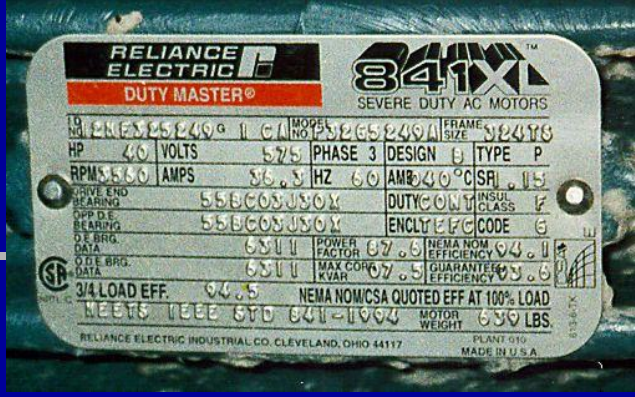
Assumes: Annual energy costs for a 100 kW load

Develop Inventory of Significant Motor-Driven Systems

Include Nameplate Data on:

- Motor
- Coupling
- Driven Equipment
- Load Requirements

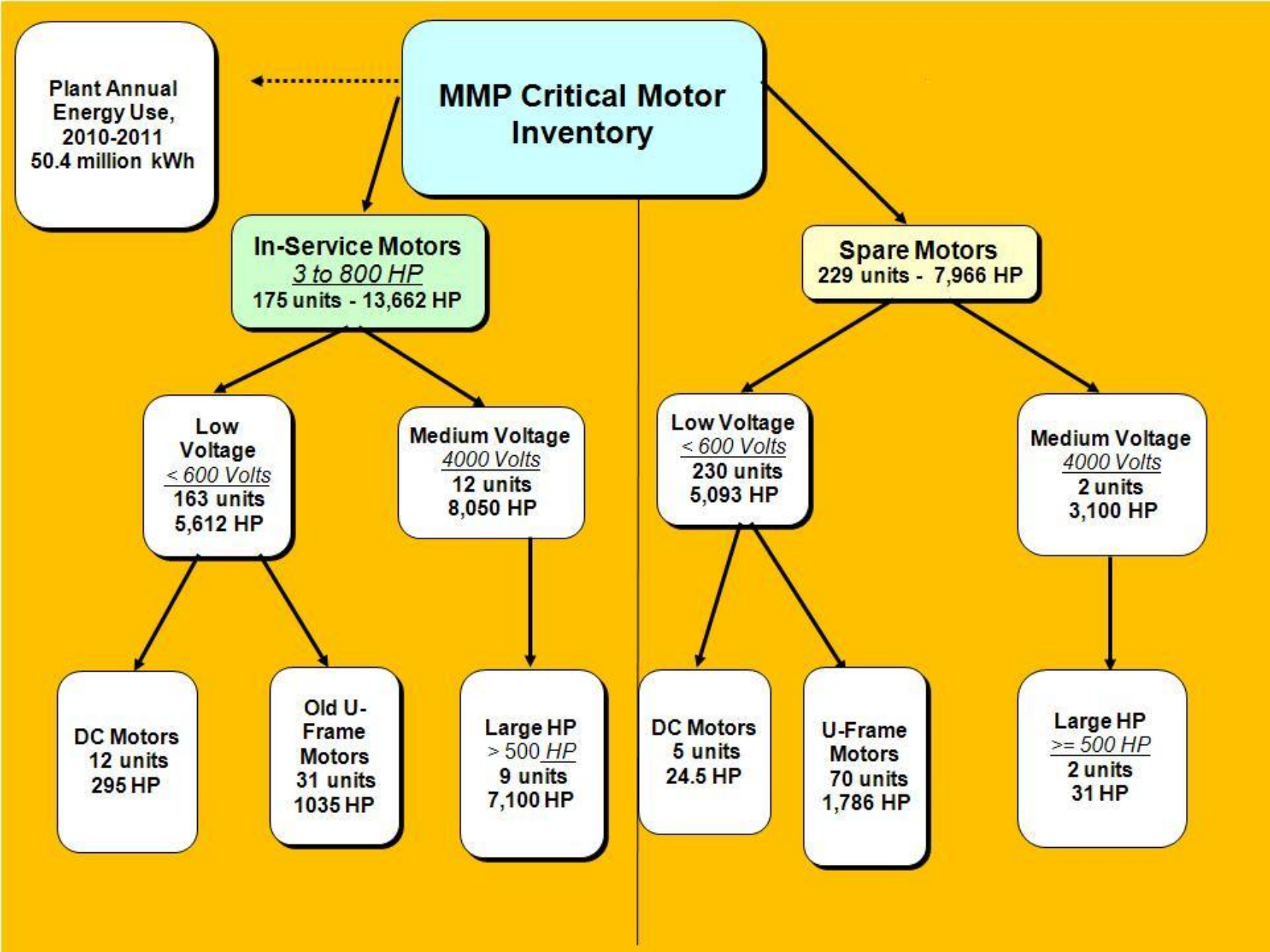
Gather Nameplate Information



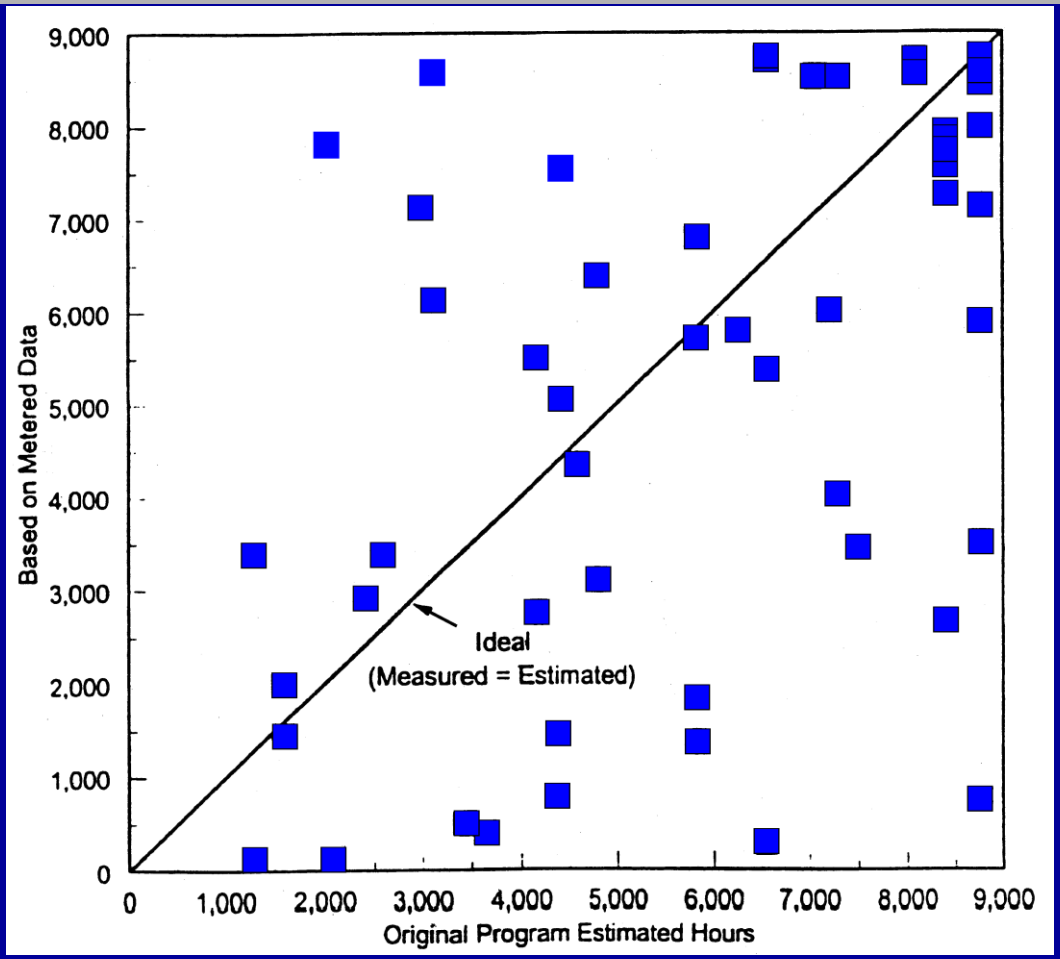
- Frame Type/Size
- Voltage
- Rated Horsepower
- Amps, Rated Load
- Time Rating, i.e. Duty
- Maximum ambient Temperature
- RPM at Rated Load
- Insulation Class
- Design Letter
- Service Factor
- Frequency
- Number of Phases
- Locked Rotor Code, MG1 Part 10.37 (kVA/hp)
- Efficiency, Rated Load
- Other Optional Information

Focus on High Priority Motors

- Larger motors (60 hp and above)
- Motors driving centrifugal loads
- Production critical process (reliability issue)
- “Bad Actor” systems
- Over 2000 hours per year utilization
- Implement predictive and preventive maintenance.
- Non special purpose motors
- Include spares


Plant Annual Energy Use, 2010-2011 50.4 million kWh
MMP Critical Motor Inventory
In-Service Motors
3 to 800 HP
175 units - 13,662 HP
Spare Motors
229 units - 7,966 HP
Low Voltage
< 600 Volts
163 units
5,612 HP
Medium Voltage
4000 Volts
12 units
8,050 HP
Low Voltage
< 600 Volts
230 units
5,093 HP
Medium Voltage
4000 Volts
2 units
3,100 HP
DC Motors
12 units
295 HP
Old U-Frame Motors
31 units
1035 HP
Large HP
> 500 HP
9 units
7,100 HP
DC Motors
5 units
24.5 HP
U-Frame Motors
70 units
1,786 HP
Large HP
>= 500 HP
2 units
31 HP

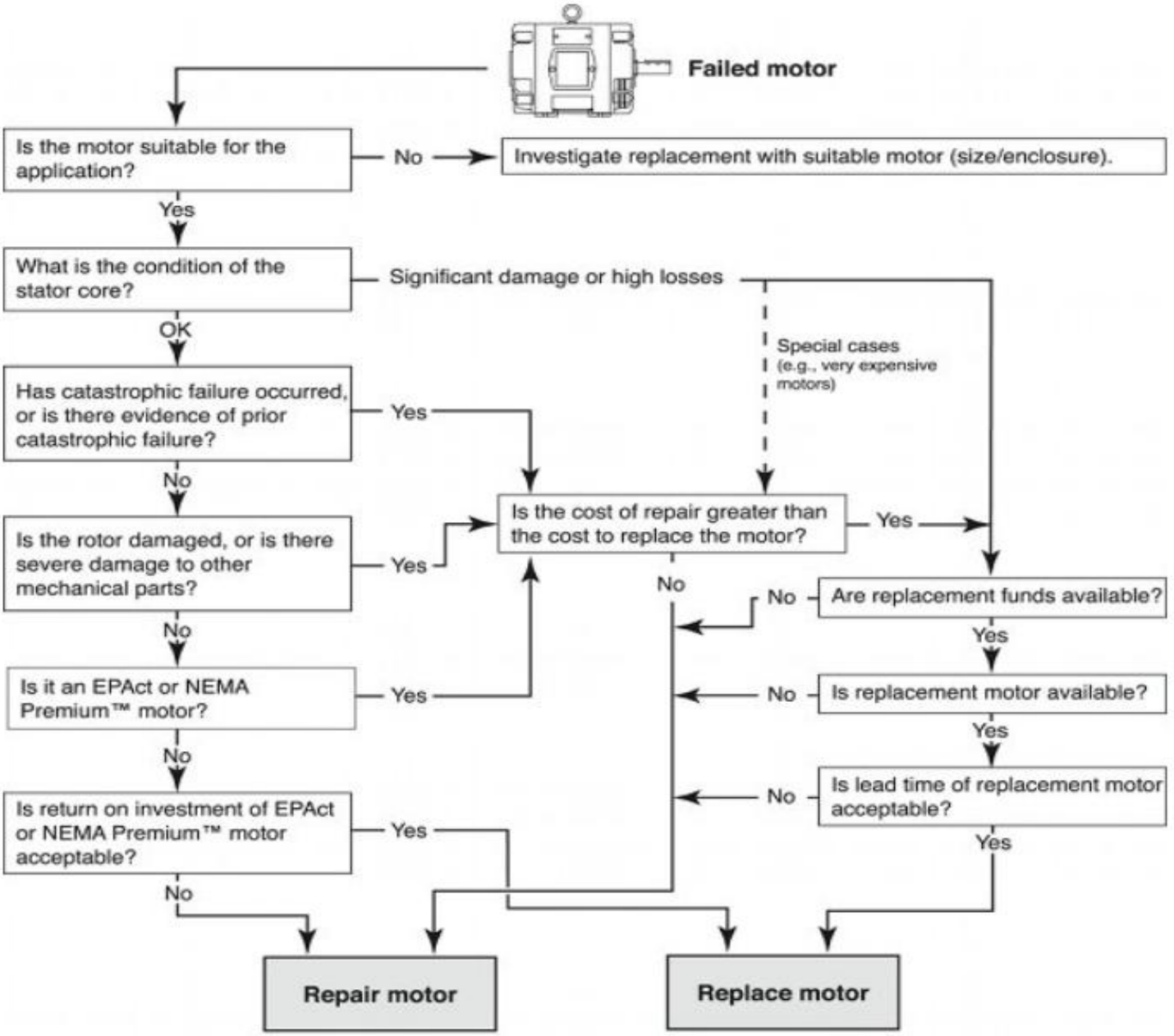
Estimating Operating Hours



Repair versus Replace: You Need to Consider...

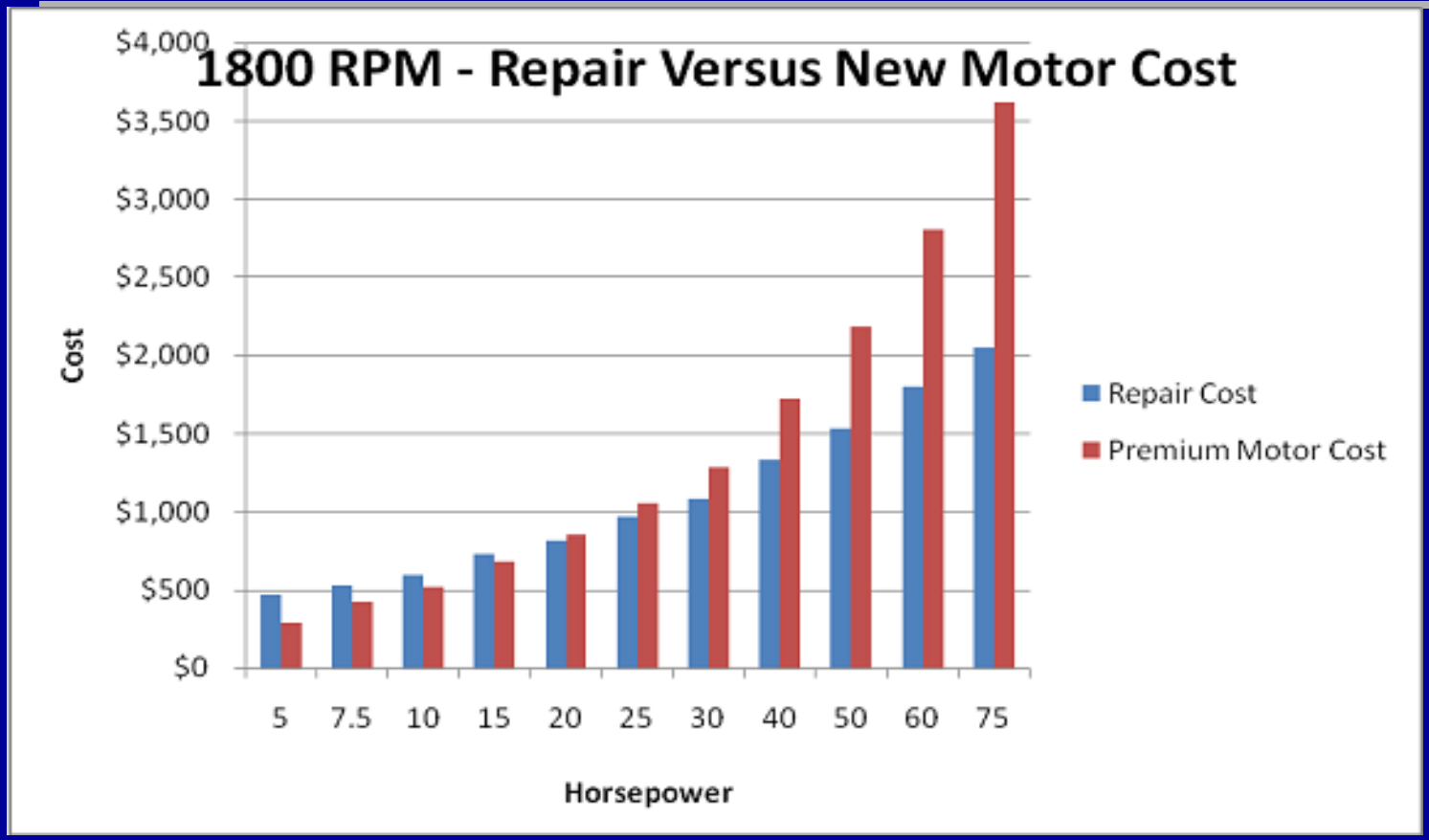
- First cost of repair and new motor purchase.
- Efficiency of existing and proposed new motor at their operating points.
- Urgency and availability of each alternative.
- Possible modifications to the mounting.
- Annual hours of operation.
- Cost of down time.
- Utility incentives
- Available Warranties

Repair versus Replace



Source EASA

Replace Motors Less than 25 hp

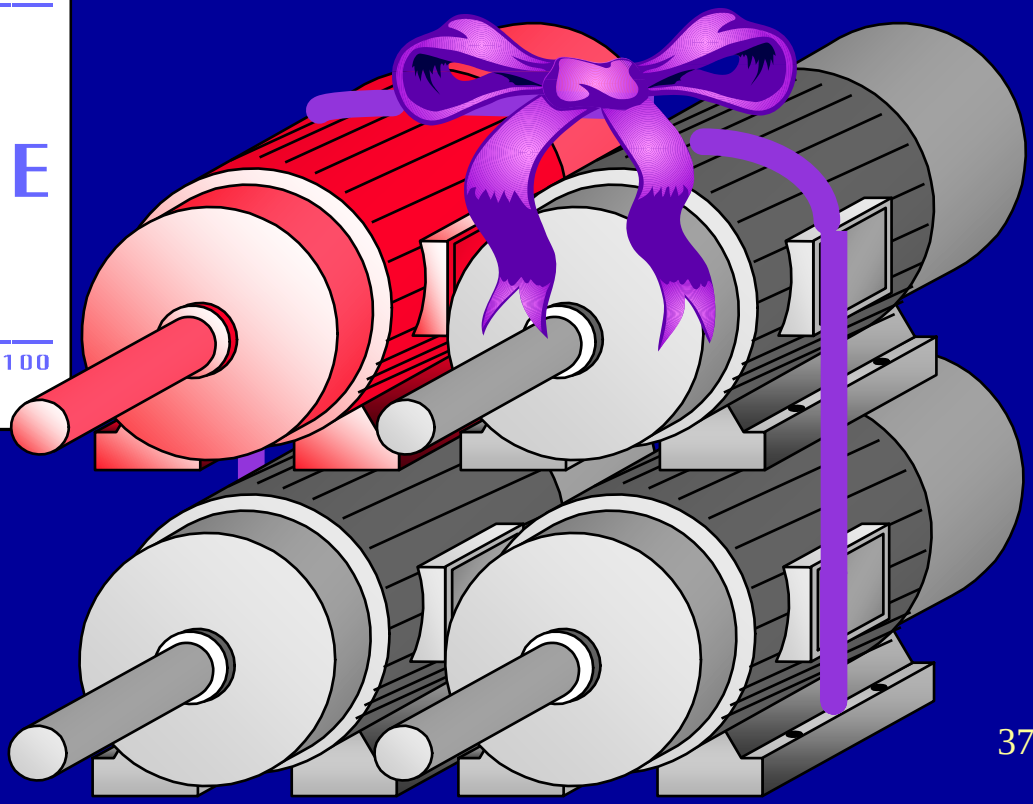


Replace versus Repair Existing Standard Efficiency Motors

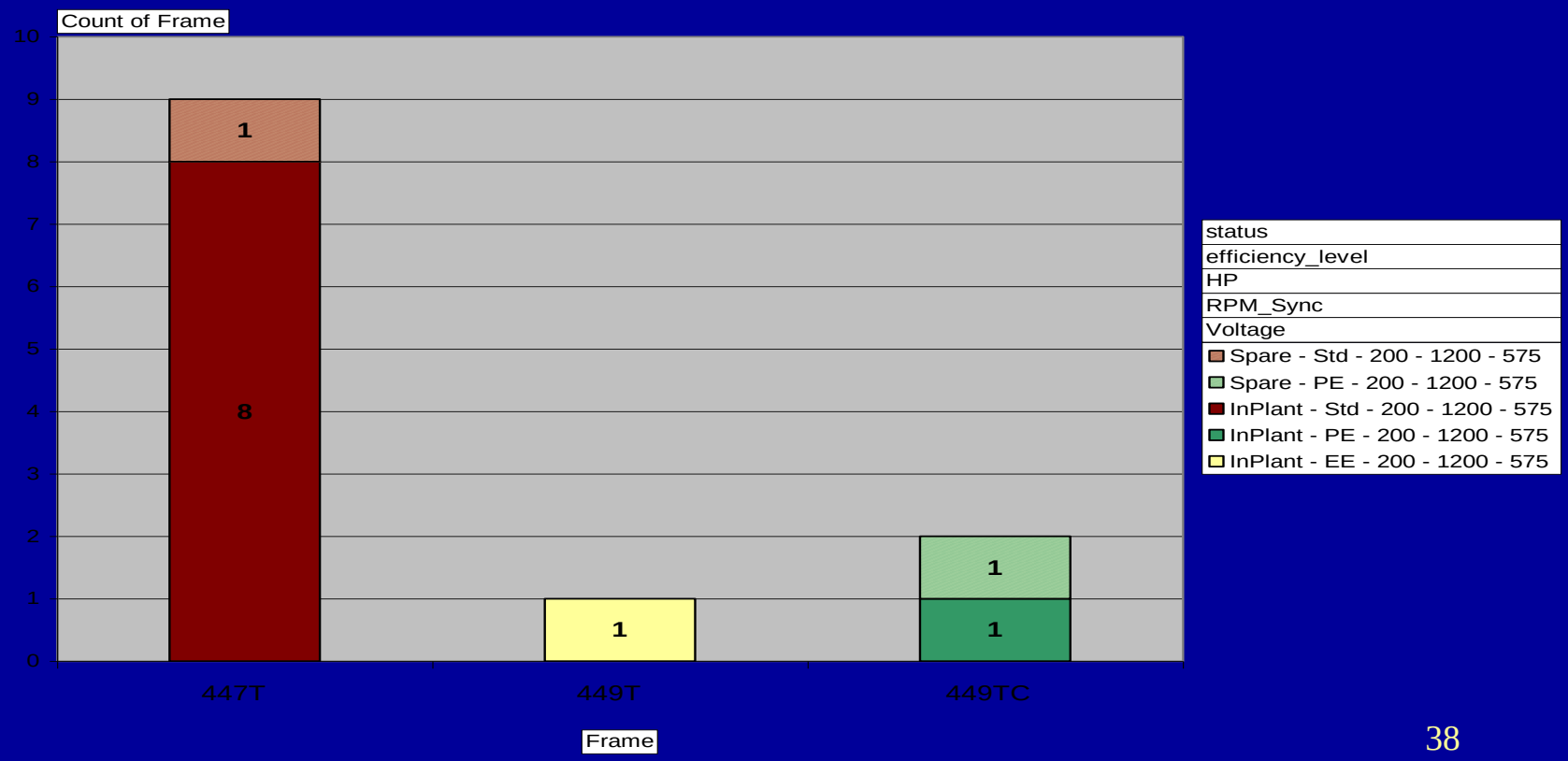
	75%-load Motor Efficiency (%)		Annual Savings from Use of a NEMA Premium™ Efficiency Motor	
Horsepower	Standard Efficiency Motor	NEMA Premium™ Efficiency Motor	Annual Energy Savings, kWh/year	Annual Dollar Savings, $/year
10	85.7	92.2	3,710	$282
25	88.9	93.8	6,560	$498
50	91.1	95.0	9,970	$757
100	91.7	95.3	18,330	$1,392
200	92.8	96.2	34,520	$2,622

Note: Based on replacement of an 1,800 RPM, Totally Enclosed Fan-Cooled motor with 8,000 hours per year of operation, 75% load, and an electrical rate of $0.06028/kWh and $10.45/kW-mo.

Over a 20-year life, the energy savings from a PEM are enough to buy OVER THREE more motors

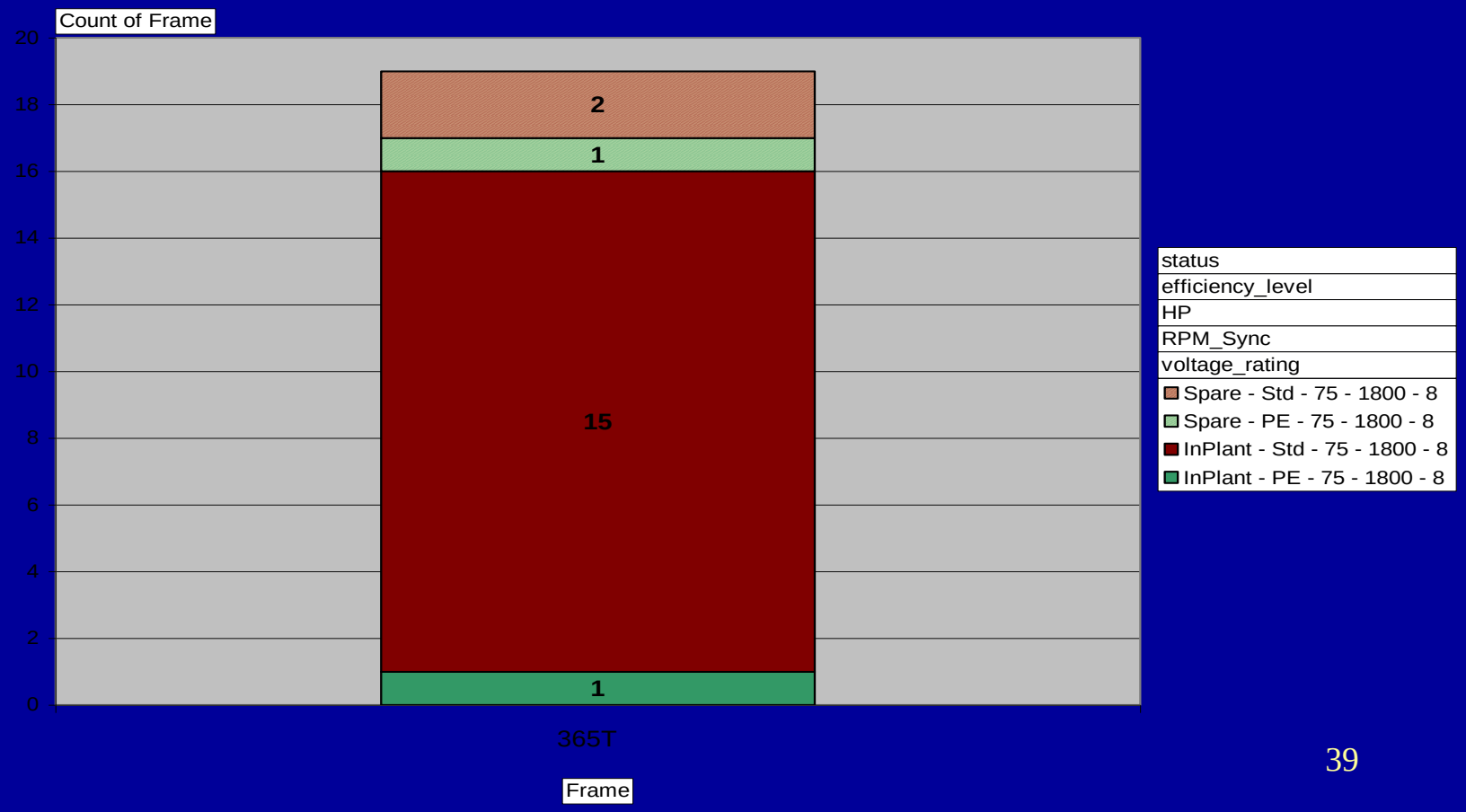


Coverage Charts tell a Story
(for 200 hp 1200 RPM Motors)



A Strategic Spares Inventory

(for 75 hp 1800 RPM Motors)

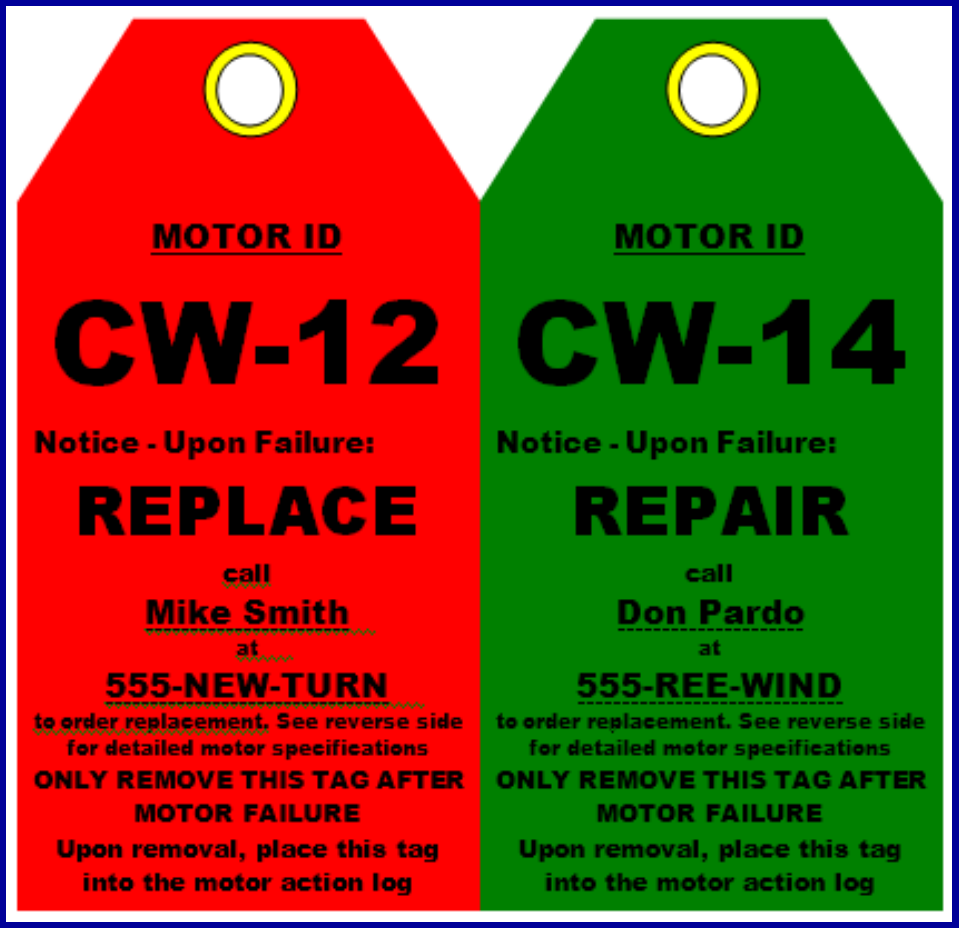


Motor Action Plan

Old Motor	New Motor
Motor # 1	Replace W / EE When Failed
Motor # 2	Downsize / Replace W / EE When Failed
Motor # 3	Immediate Replacement W / EE
Motor # 4	Replace W/Standard or Repair When Failed
Motor # 5	Investigate ASD Potential

Sample Motor Tags

(Courtesy Advanced Energy)



Advanced Motor Management Planning System Optimization Techniques

Tune Your In-Plant Distribution System

- Over/Under voltage improvement
- Reduce or eliminate voltage unbalance
- Use voltage drop or infrared survey to identify and eliminate hot spots due to loose, pitted, or worn contacts, fuse clips or terminations
- Correct for poor power factor

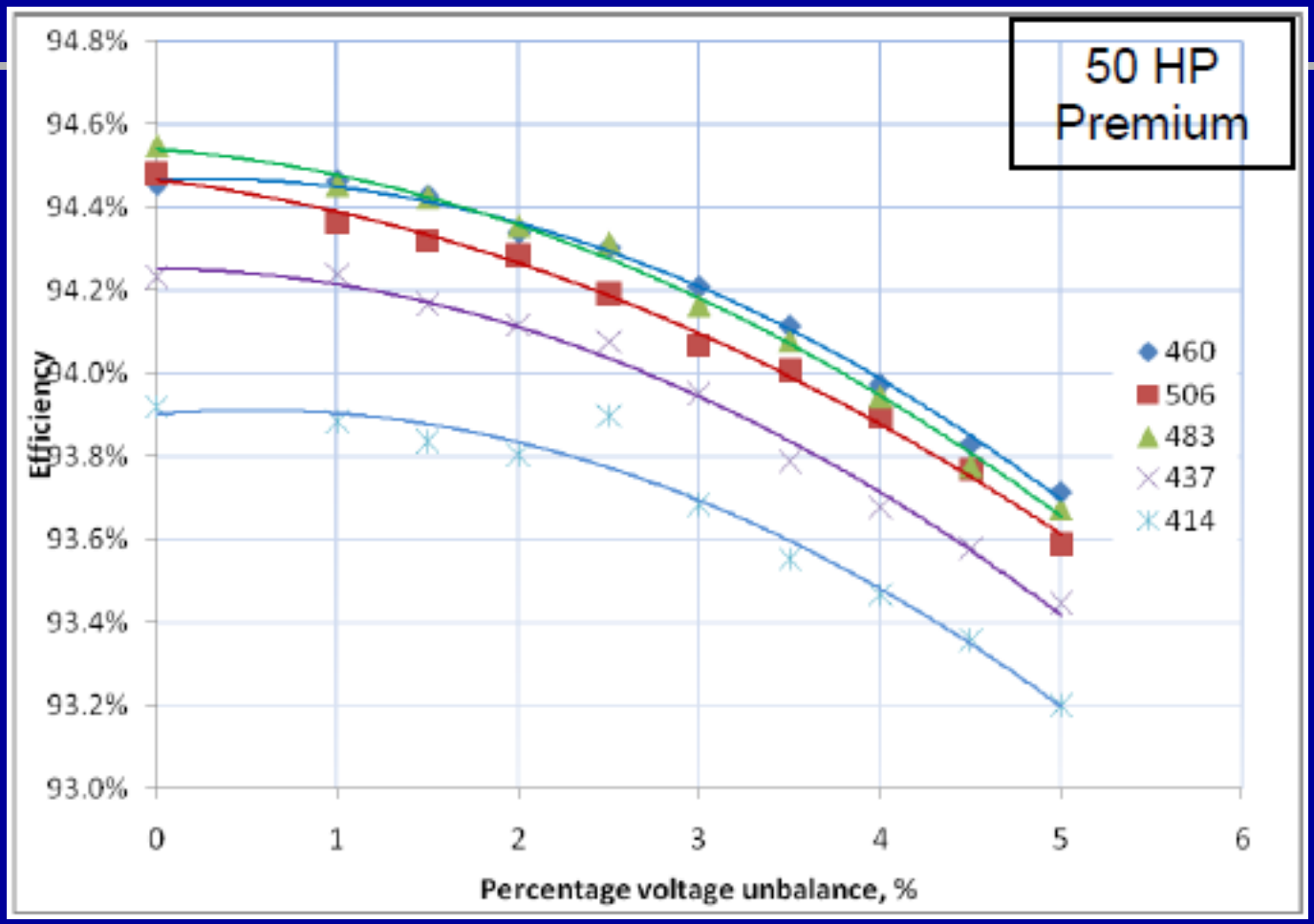
Operation Under Abnormal Conditions

Voltage unbalance shortens the life of a three-phase motor.

Unbalance is defined as 100 times the maximum deviation of the line voltage from the average voltage, divided by the average voltage. For example, if the measured line voltages are 462, 463, and 455 volts, the average is 460 volts. Unbalance is

$$100\% \times (460 - 455)/460 = 1.1\%$$

Undervoltage with Unbalance



Source: Advanced Energy, 2013

Allowable Starts per Hour and Minimum off-time Between Starts

10 hp/1800 RPM	**12.5**	**(46 sec)**
50 hp/1800 RPM	**6.8**	**(72 sec)**
200 hp/1800 RPM	**4.0**	**(300 sec)**

Source: NEMA Standard No MG 10

Oversized Motors: Myth and Reality

Oversized Motors: Myth and Reality				
Motor Horsepower hp	Motor Oversizing 40% Load on a 100 hp Motor (60 Hz Operation)			
	Standard Efficiency		Premium Efficiency	
	Efficiency, %	kW	Efficiency, %	kW
100	89.2	33.45	93.7	31.84
75	91.1	32.75	95.1	31.37
60	91.5	32.60	94.9	31.44
50	91.6	32.57	94.8	31.47
40	90.2	33.08	94.2	31.67

Power Transmission Systems

V-belts have a peak efficiency of 95 to 98% at the time of installation. Efficiency deteriorates by as much as 5% over time if slippage occurs and the belt is not properly tensioned.

Consider Notched Belts

Notched belts have slots that run perpendicular to the belt's length and can be used in the same smooth pulleys as equivalent rated V-belts. Their efficiency is about 2% higher than for a standard V-belt.

….or Synchronous Belts

Synchronous belts (also called cogged, timing or high-torque belts) are toothed and require the installation of toothed drive sprockets. Their efficiency is 98% over a wide load range.

Synchronous belts require less maintenance and re-tensioning, operate in wet and oily environments, and run slip-free. However, they are noisy, transfer vibrations and are unsuitable for shock loads.

Caution

---Some energy managers have reported bearing failures after converting to synchronous belts.

---Make sure that the belt-driven motors are equipped with cylindrical roller bearings rather than deep groove ball bearings. These bearings are designed for heavy radial loads and fast accelerations.

Efficiency Range versus Gear Type

Worm Gear

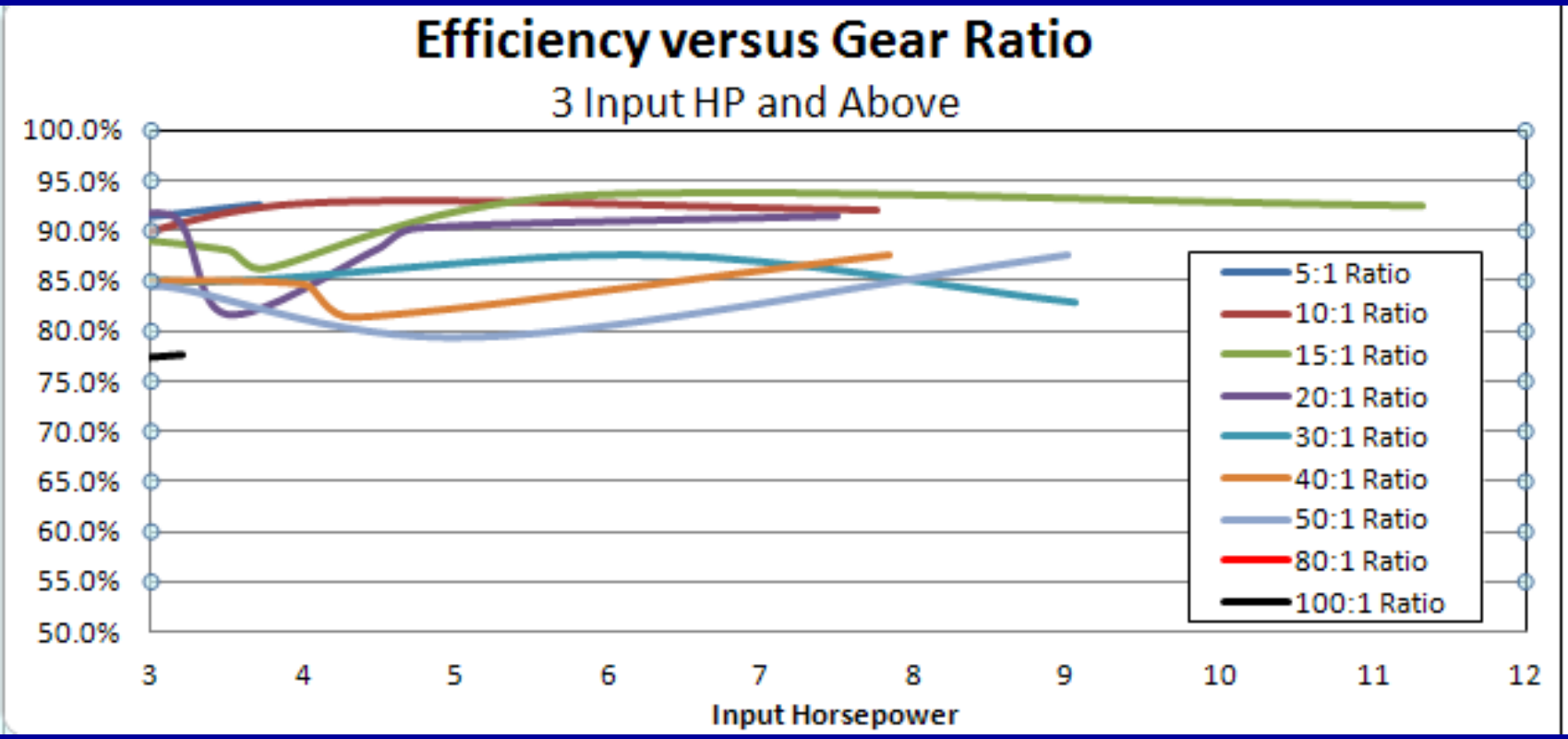
Bevel Gear

Spur Gear

Helical Gear

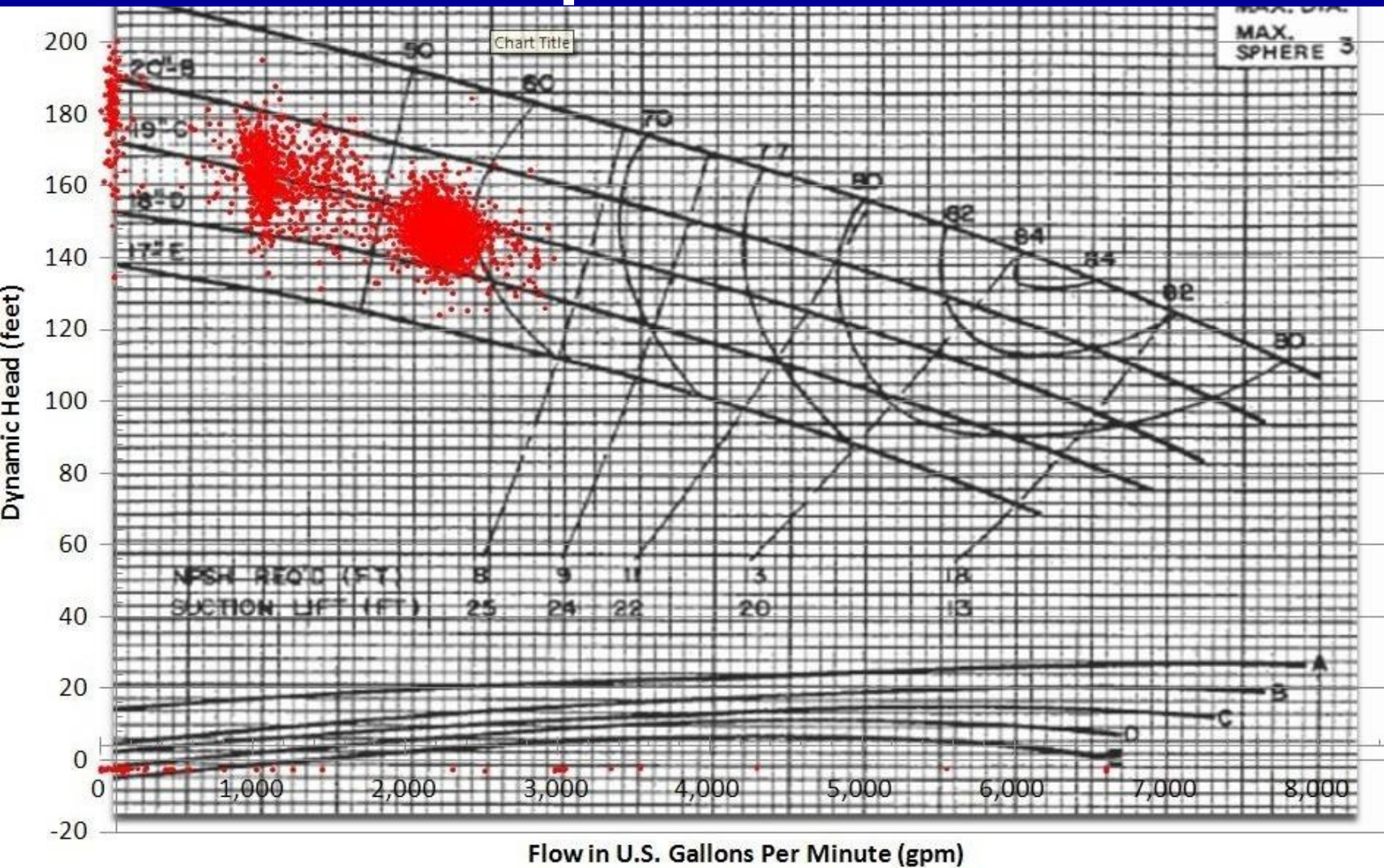
Gear Reducer Type	Gear Ratio Range	Efficiency Range (%)
Spur	1:1 to 6:1	98%-99%
Helical	2:1 to 10:1	92%-98%
Bevel	1:1 to 5:1	97%-99%
Helical/Bevel	5:1 to 200:1	92%-95%
Worm (single stage)	5:1 to 100:1	55%-94%

Worm Gear Efficiency versus Gear Ratio



1800 Input RPM

Match Equipment to Load Requirements



Overall Efficiency (Baseline)

$$\eta_{system} = \eta_{Pump} \times \eta_{Gear/Belt} \times \eta_{Motor} \times \eta_{Line} \times \eta_{Transformer}$$

$$= (0.48) \times (0.95) \times (0.92) \times (0.98) \times (0.99)$$

$$= 0.407 \times 100\% \text{ or } 40.7\%$$

Change motor efficiency to 96.2%, system efficiency improves to only 42.5%

Pump Replacement Results

---250 hp MV motor and pump replaced by 125 hp LV motor-driven pump

---Motor efficiency improves from 91.9% to 96.2%

---Pump efficiency improves from 48.2% to 73.9%

---Annual energy savings of 712,150 kWh, equivalent to 50.8% of baseline energy use.

Original Pump Operating Power = 167.7 kW

Final Pump Operating Power = 82.4 kW

Consider Systems Imbalance

Mark the system for further review if the imbalance between actual and best efficiency point conditions exceeds +/- 15%.

Imbalance (%)

$$= \{(Qm \times Hm)/(Q_{BEP} \times H_{BEP}) - 1\} \times 100$$

<u>Prioritize systems based upon level of imbalance or mismatch.</u>

Electronic Adjustable Speed Drives

Good Candidates for ASDs

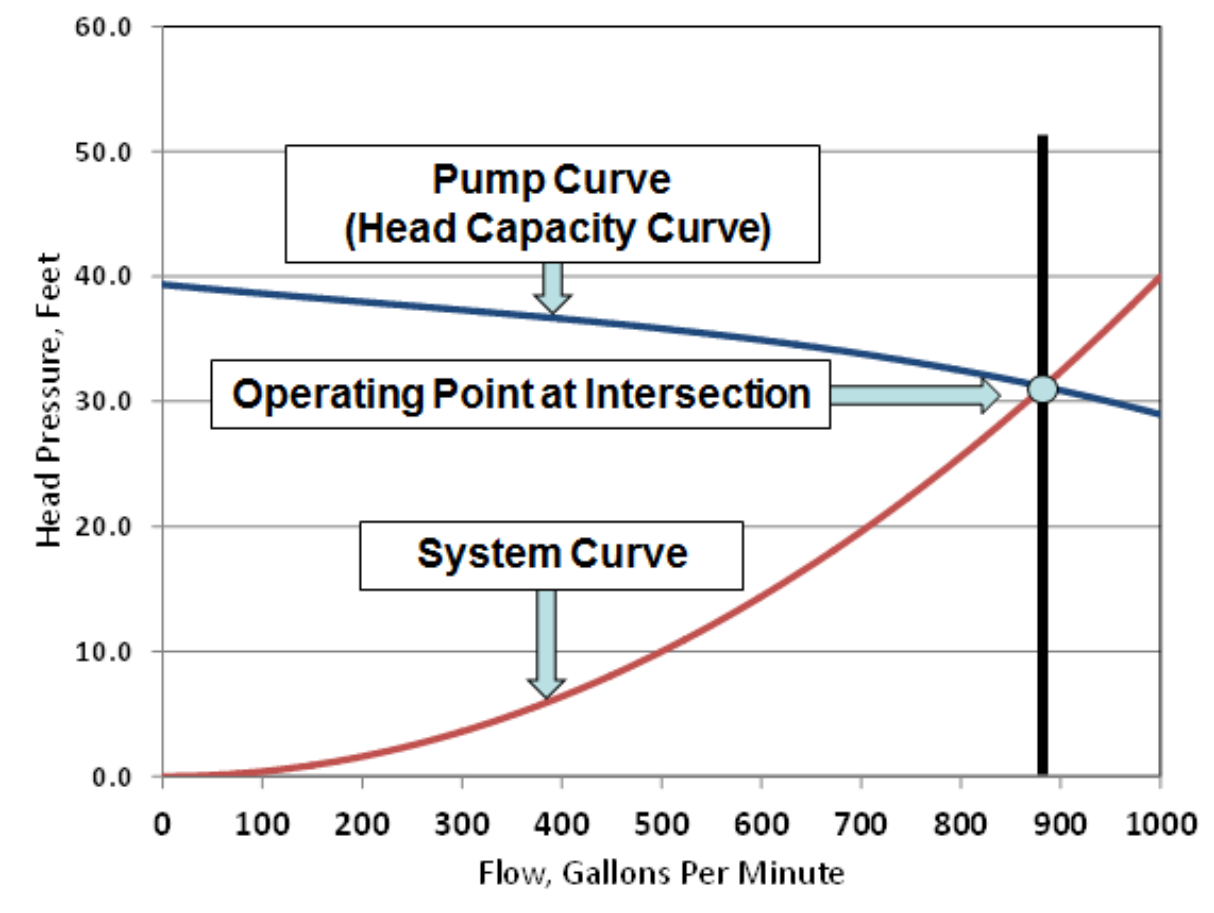
Any fluid mover that is currently controlled by throttling valves, dampers or bypass flows much of the time

Any fixed flow fluid mover that provides greater than needed flow much of the time

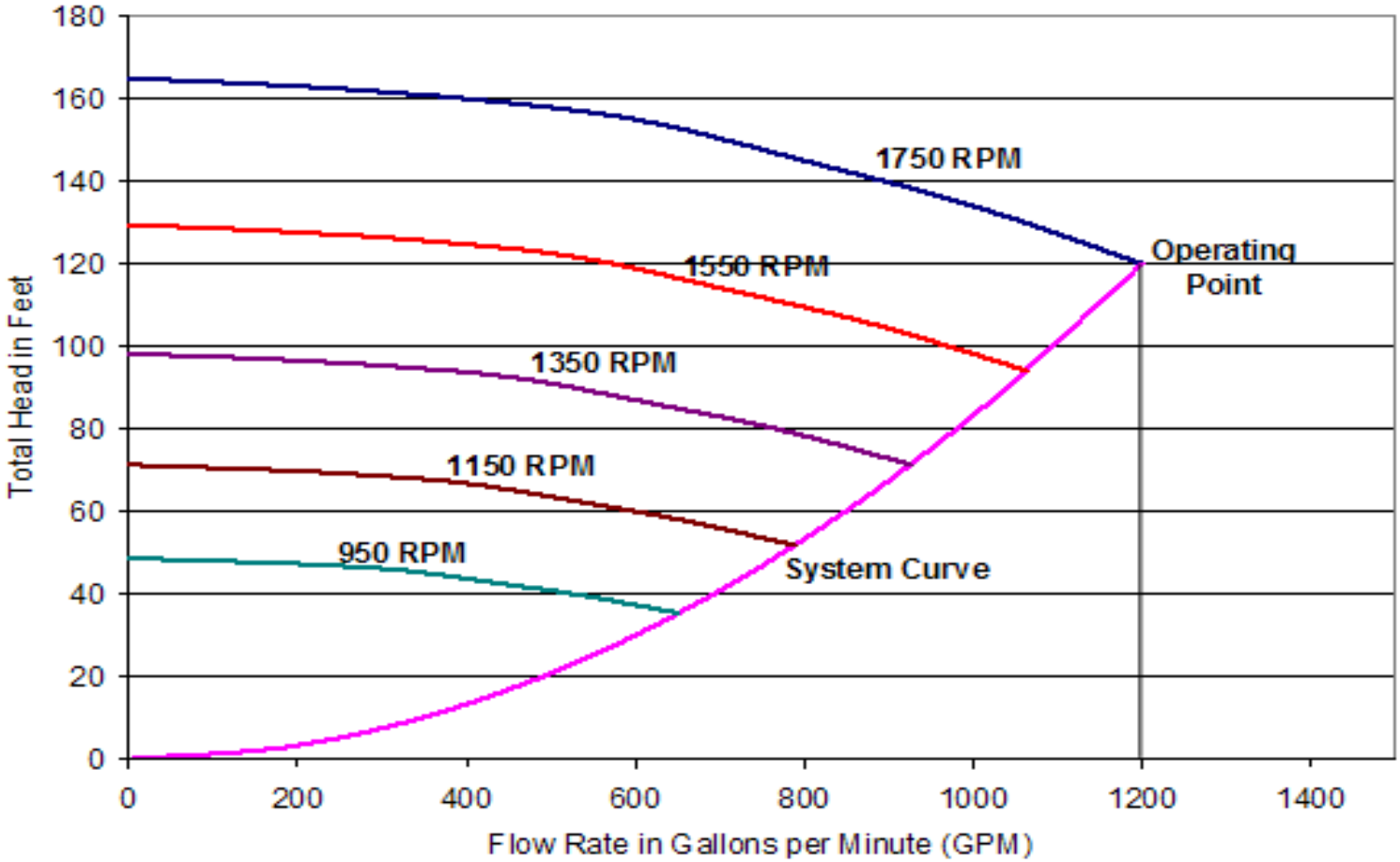
Existing applications with less efficient speed control devices, especially where there is considerable operating time below 90% load or where high to moderate torque is required at reduced speed

Where older less efficient and high maintenance DC drive systems are currently being used

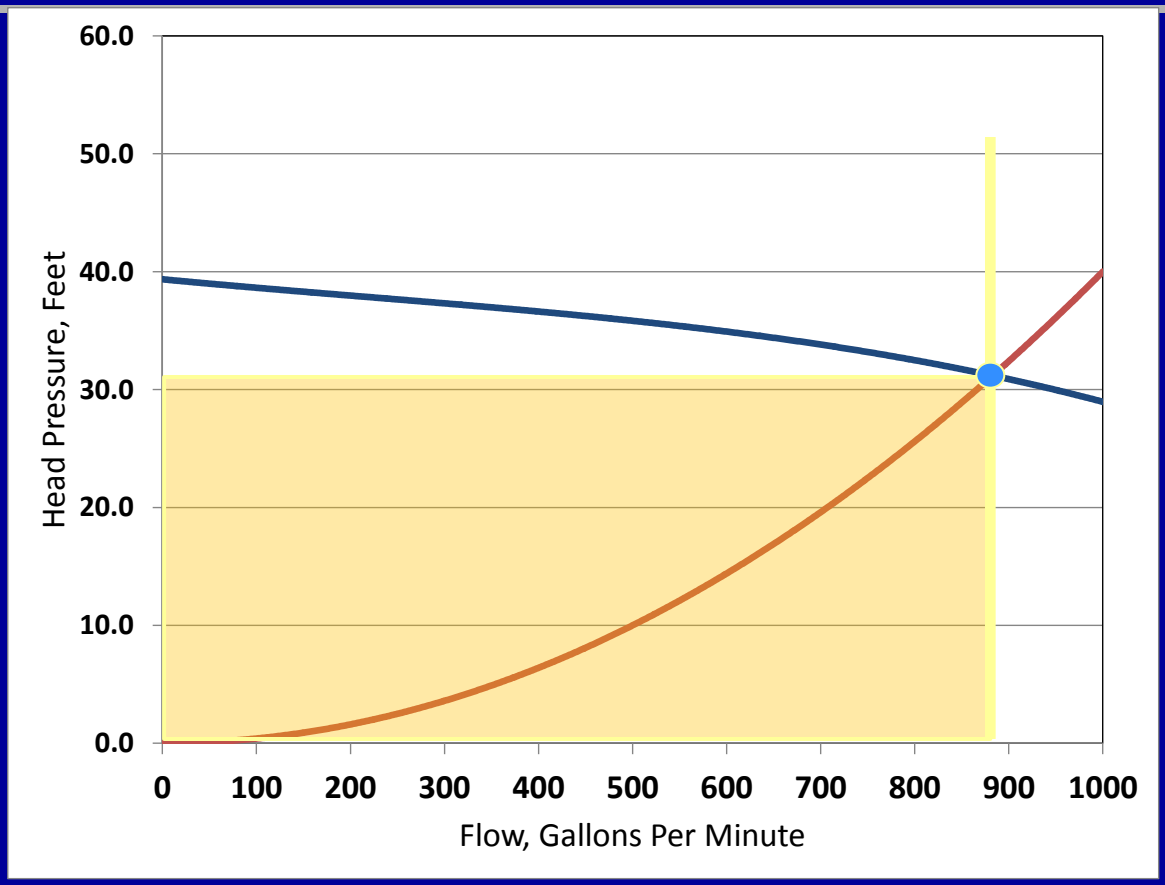
Pump Operating Point



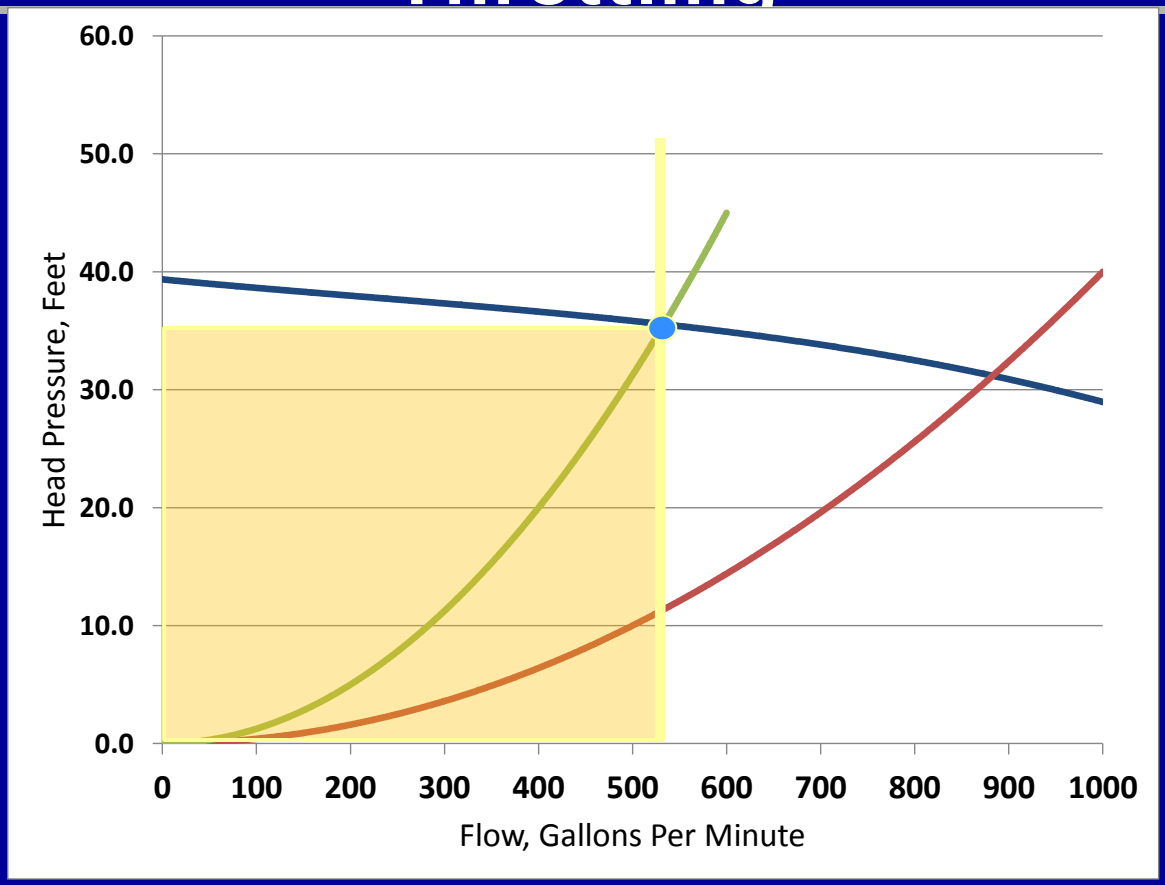
ASD Flow Control



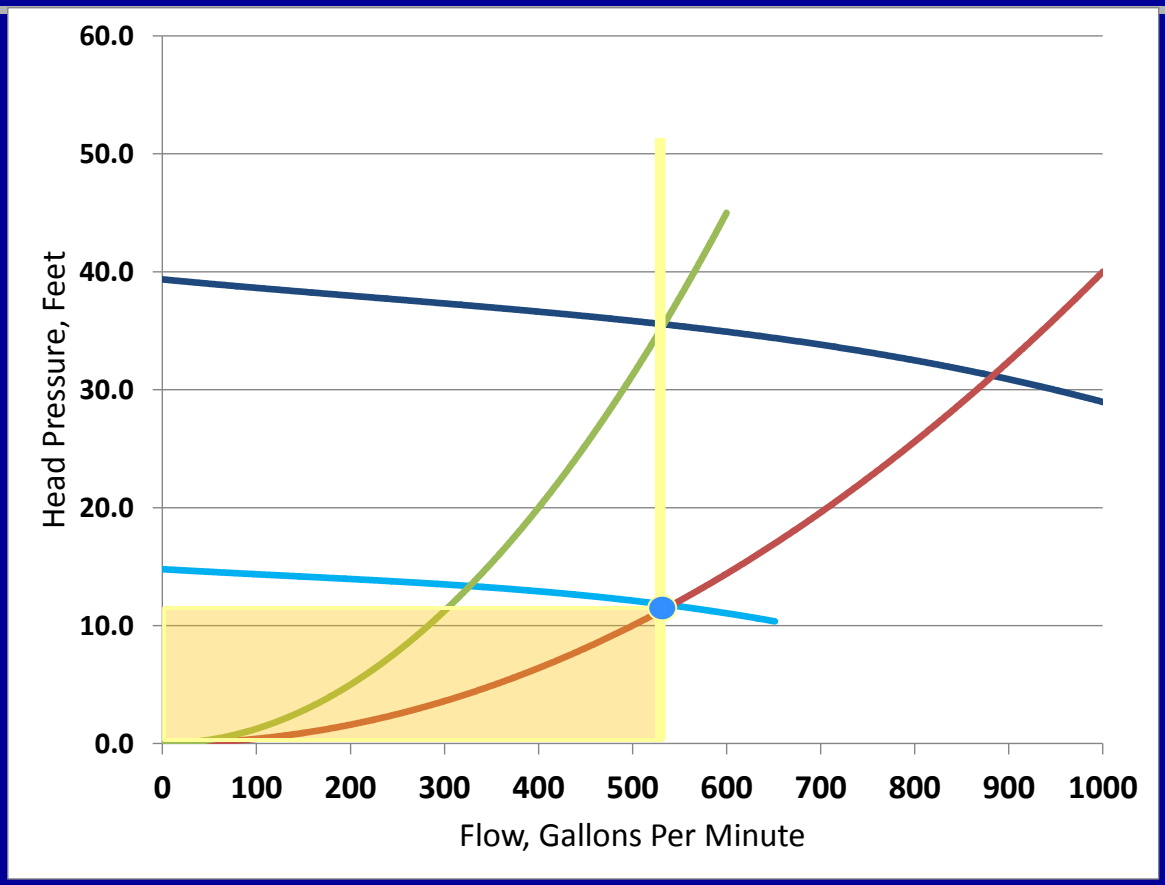
Water Power at Operating Point



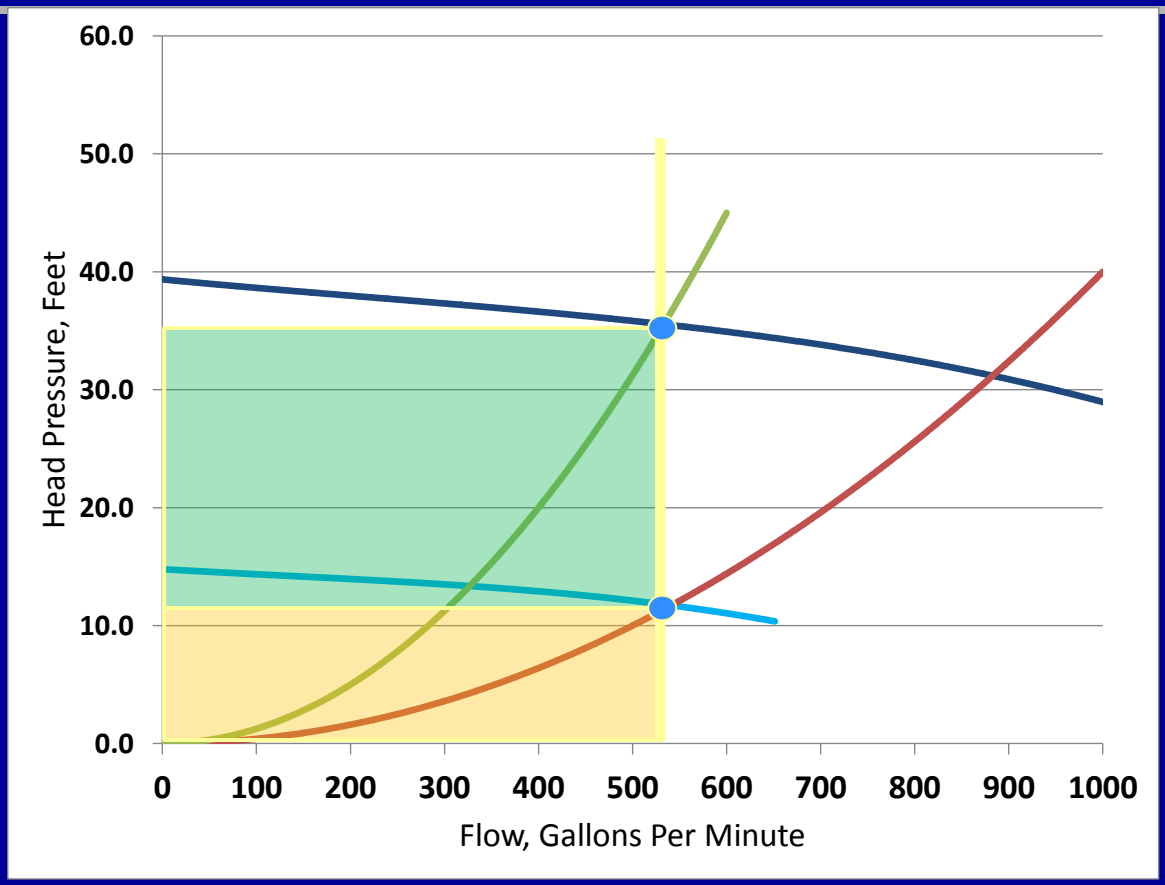
Water Power with Flow Reduced by Throttling



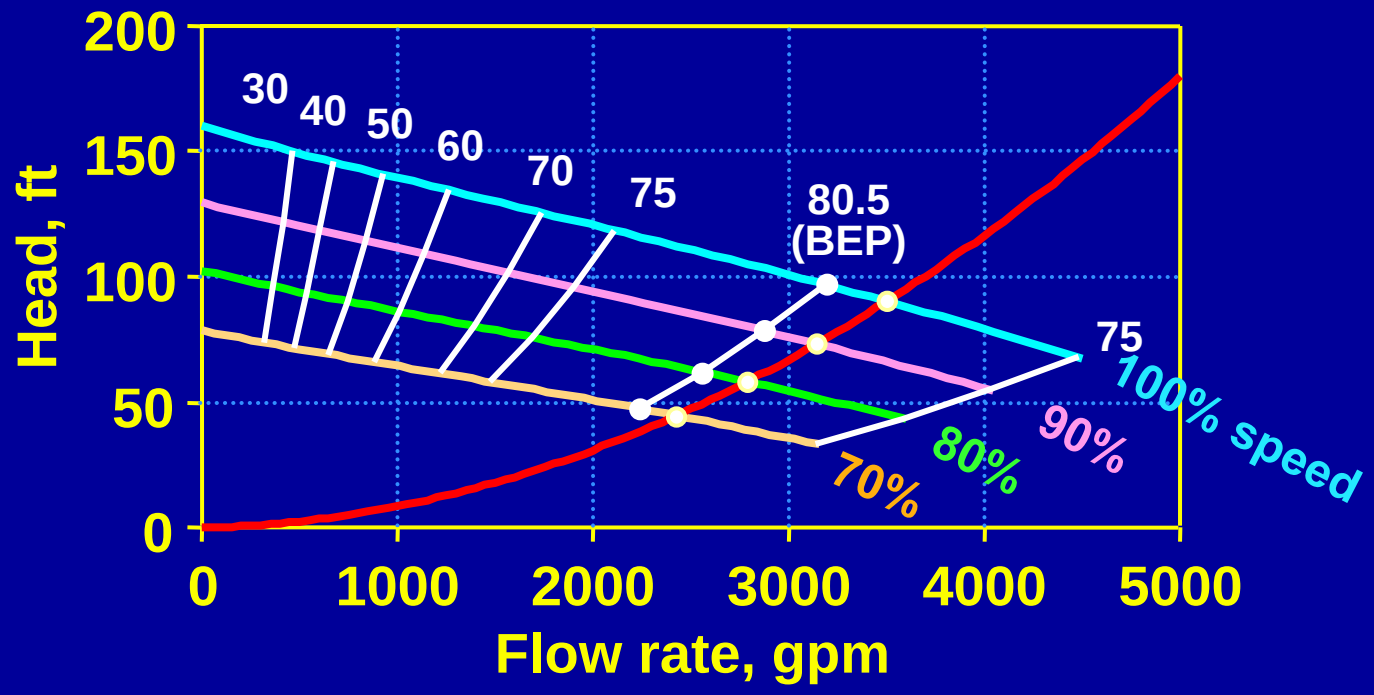
Water Power with Flow Reduced by VSD



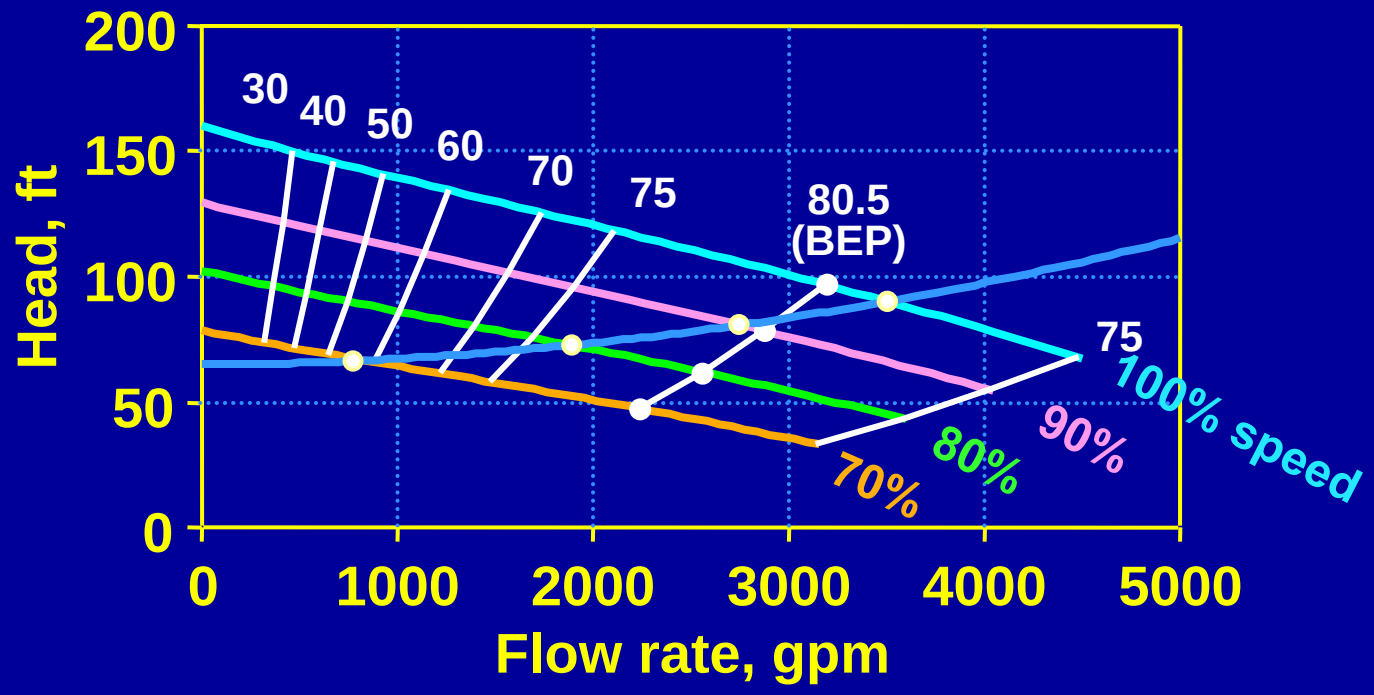
Water Power Reduction with Variable Speed Operation



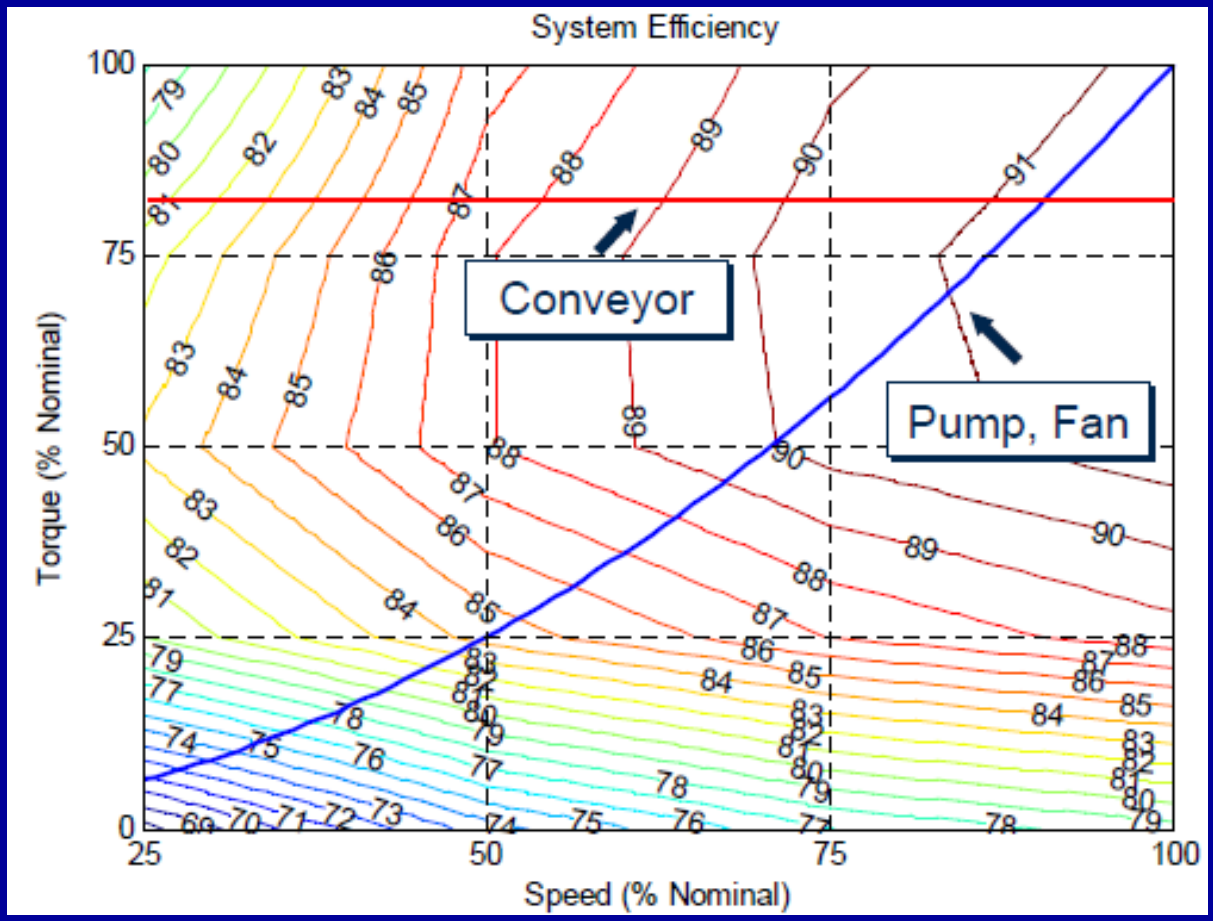
Constant Pump Efficiency is Maintained for Systems Dominated by Friction Losses



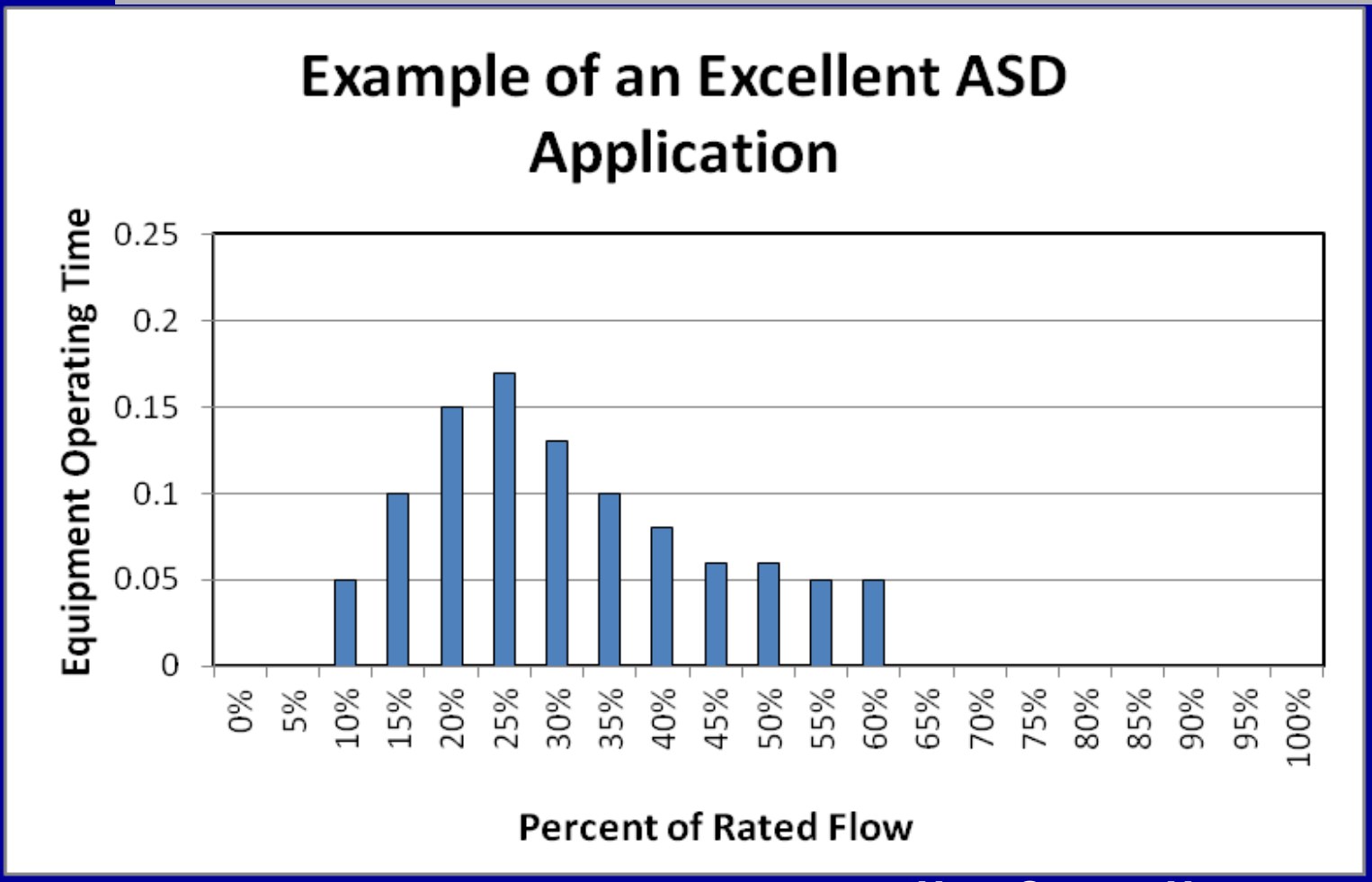
Pump Efficiency does not Remain Constant in a System with Static Head



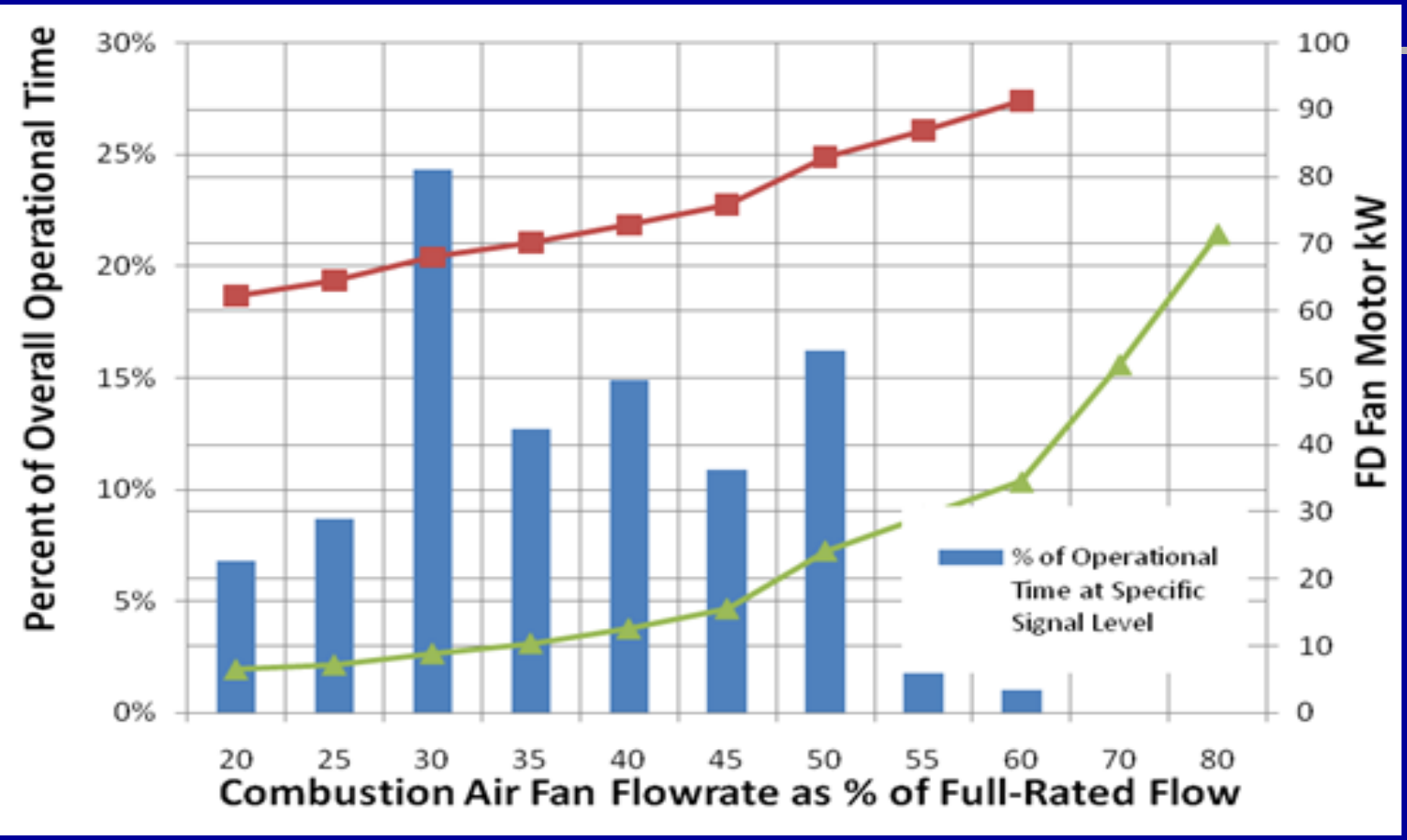
Motor and Drive Efficiency Constant and Variable Torque Loads



Ideal Load Profile for ASDs
High Operating Hours at Low Flows



Conducting a "Bin" Energy Savings Analysis



Inherent ASD Benefits

- Controls speed variations
- Provides process control
- Eliminates startup impacts causing system vibration
- Provides fault tolerance
- Supports low current soft starts
- Restarts spinning load
- Controls speed swings
- Enhances product quality
- Power Factor Improvement
- Conserves more energy than any other option at speed turn-downs below about 90%.

Advanced Beyond Super Premium Efficiency Motor Designs

Permanent Magnet and Switched Reluctance Motors:

---Require an electronic power converter or controller to control both torque and speed (inherent variable speed capability)

---Compact/high power density (now available in NEMA T-Frame sizes so can use as retrofits)

---Above Super Premium Efficiency performance but with high cost. Suitable for niche applications.

For Additional Information

Copper Development Association (CDA) Case Studies on Energy Efficiency:
http://www.copper.org/publications/pub_list/energy_efficiency.html

U.S. DOE Motor Publications:
http://energy.gov/eere/amo/motor-systems

U.S. DOE Motor Energy Tip Sheets:
http://energy.gov/eere/amo/tip-sheets-system

Questions?

Use the Q&A chat box in the upper right corner

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