Electric Motors, Motor Management, and Variable Speed Drives

Section M

Electric Motor Management

- Why bother?
- Electric motor basics
- Electricity and electric motors
- Energy efficient electric motors
- Electric motor inventories and rewind policies
- Motor drives
  - VFDs
  - Eddy current clutches
  - Permanent magnetic drives
  - Hydraulic drives, etc.
- Electricity basics review

Electric Motor Management
Why Bother?

- A heavily used motor can cost 10 times its first cost to run for one year!
- US motor use statistics
  - Electric motors use over ½ all U.S. electricity
  - Motor driven systems use over 70% electric energy for many plants
  - Motor driven systems cost about $90 billion to operate per year

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Electric Motor Management
Why So Difficult?

- Load on most driven systems is unknown at least on retrofits
- Very difficult to determine load accurately through measurements
- Electric motor management is FULL of surprises
- Yet, savings can be large (small percentage of a big number is a big number)
- Important note: Often oversized wiring (above code) is cost effective in heavily used systems as it reduces I^2R losses. (CDA and Southwire Corp.)

Section M - 4

Electric Motor Management
Types of Motors

- AC Synchronous motors
  - One to two percent or so (but large motors)
  - Large kW and slow speed applications typical
  - Similar in construction to induction motors, but more expensive
  - More efficient, can be run at leading PF (Cos phi)
  - Can generate or absorb reactive power

Electric Motor Management
Types of Motors

- DC Motors
  - Good for precise speed control and strong torque properties
  - Not efficient, (historically) high maintenance, and higher down time (commutator and brushes need inspection and maintenance)
  - Newer brushless motors much better
  - Less than 5% of the motors today are DC (US)
  - Replacing with a VFD driven AC motor may be cost effective especially if down time is reduced

New Technology DC Motors

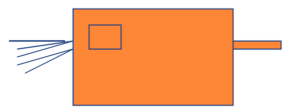
- New Brushless, Electronically Commutated DC motors are much more efficient in smaller sizes, and provide variable speed control. And are higher efficiency at low load than small AC motors.
  - The stepper motor type may have more poles on the stator.
  - The reluctance motor.
    - Switched reluctance motor
    - Variable reluctance motor

Electric Motor Management Motor Types Cont.

- AC Induction motors
  - AC induction motors don’t need commutators or separately excited field windings
  - Lagging power factor (lagging Cos phi)
  - Many different types (ODP, TEFC, etc.)
  - Approximately 95% of US motors today are induction
  - Concentration for this discussion
  - Run on single, - or three- phase power (most)

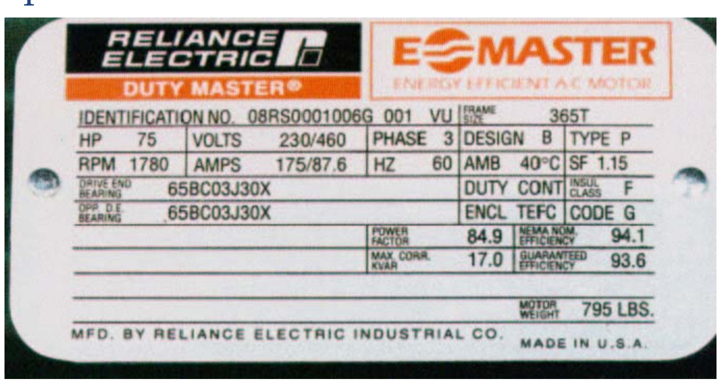
Electric Motor Basics
Name Plates

- kW ____ (shaft power design- output)
- NLRPM (synchronous speed)
- FLRPM (running RPM at design load)
- LRA (starting amps – 1 sec?)
- FLA (amps at design load and voltage)
- Volts (design voltage)
- Max. capacitor
- Efficiency (test vs. guaranteed)
- Service factor



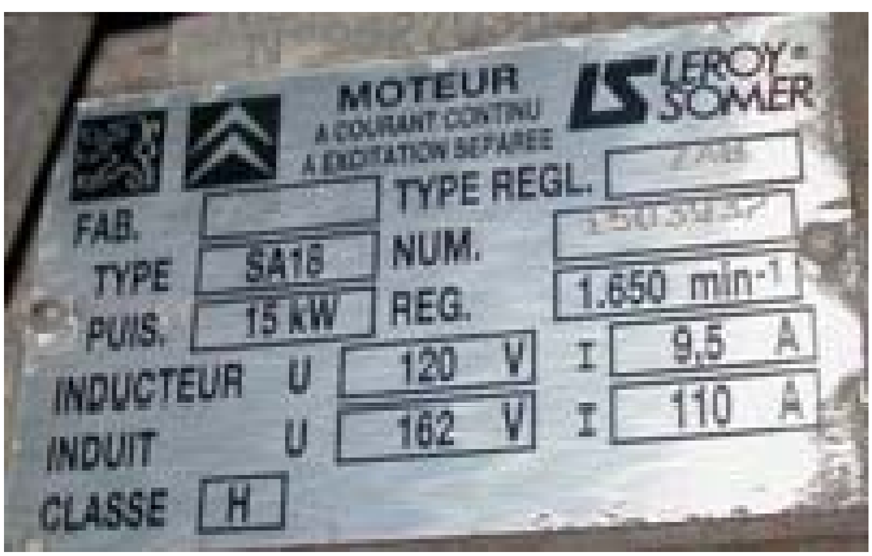
Motor Nameplate Data

- Every motor has a nameplate which lists critical information about the operation of the motor.



Motors M1 - 11

Section M - 11



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Generic Terminology

- Standard efficiency motor
- High efficiency motor
- Premium efficiency motor
  - Or Ultra high efficiency motor

Electric Motor Basics
Motor Speeds

- Alternating current, thus speed will vary with pole pairs (inside motor, pole pairs between stator and rotor)
- One pole pair (2 poles) - one RPM per cycle (50 cps or Hertz); two pole pairs – ½ rpm per cycle, etc.
- Thus

$$\text{SPEED} = \frac{50\,\frac{\text{cycles}}{\text{sec}} \times 60\,\frac{\text{sec}}{\text{min}}}{\text{number of pole pairs}}$$

- SPEED = 3000, 1500, 1000, 750, 600, 500, etc. (no other choices) for 50 Hz power to motor

Electric Motor Basics
Slip

- Design (Full Load) Slip = (NLRPM – FLRPM)
- True (Actual) Slip = (NLRPM – RPM measured)
- % Load = (True Slip)/(Design Slip)
- Perfect indicator but very difficult to measure accurately (+/- 1% typical)
- Many don't use this - why?
  - Difficult to measure accurately
  - Large motors are more efficient than small motors (more later)

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Electric Motor Basics
Slip Example

- FLRPM = 1460 (off name plate)
- Design kW = 50 (off name plate)
- Measured RPM = 1476
- NLRPM = ? (obviously 1500)
- Design slip = 1500 – 1460 = 40
- True slip = 1500 – 1476 = 24
- % load = 24/40 = 0.6 or 60%
- True load = 50 kW x (0.6) = 30 kW
- See plot next slide, motors run very well at 60% load
- This motor will run very cool, is not causing a problem, why bother!!

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Motor Performance and Efficiency Data

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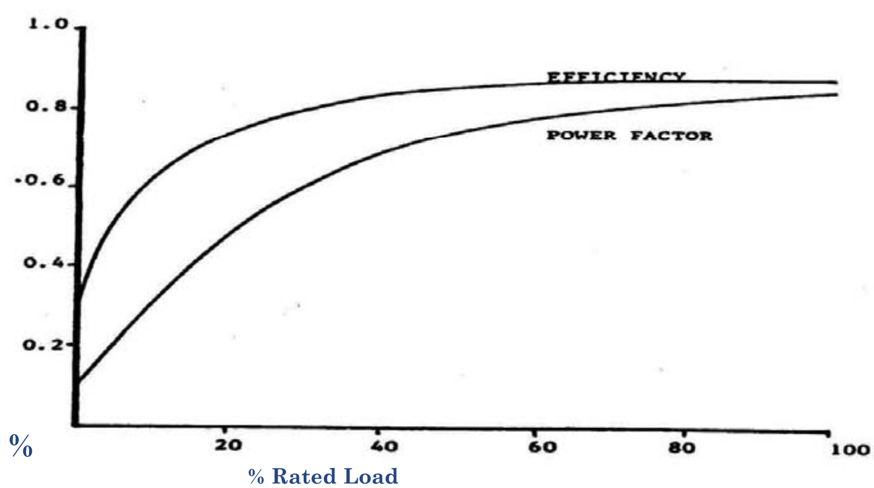
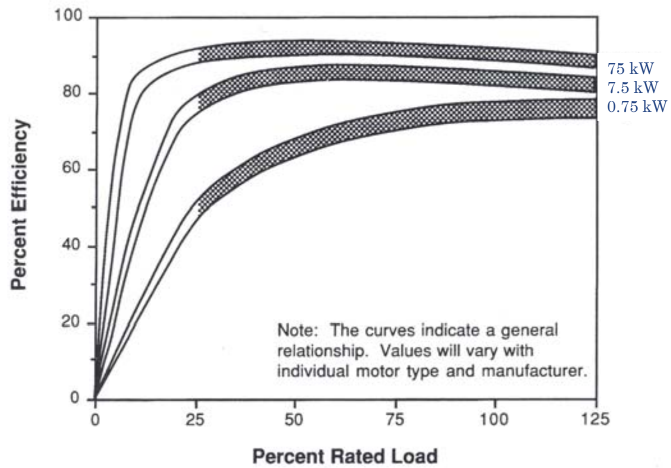
Efficiency and PF vs. Load:



Source: Electrical and Energy Management, IEES, Ga,Tech., Atlanta, GA.

Section M - 18

Typical Efficiency vs. Load Curves for 1,800 rpm, Three-Phase, 60 Hz, Design B Squirrel-Cage Induction Motors



Source: NEMA 1999

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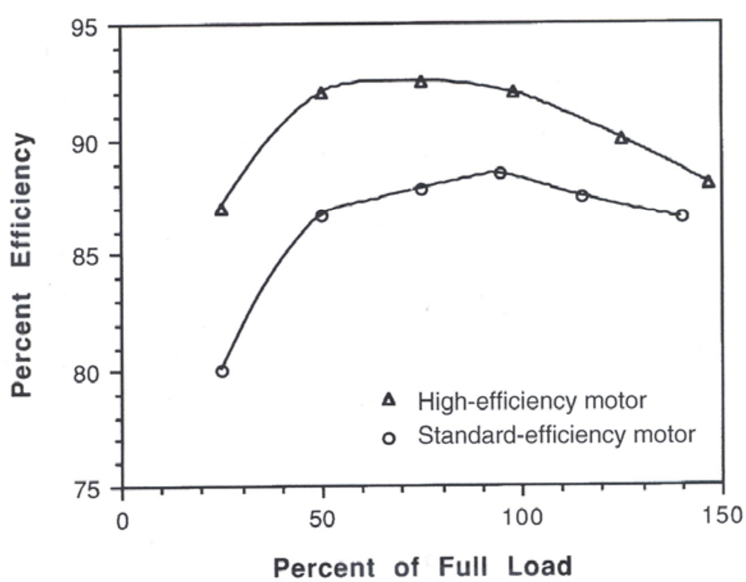
Motors M1 - 19



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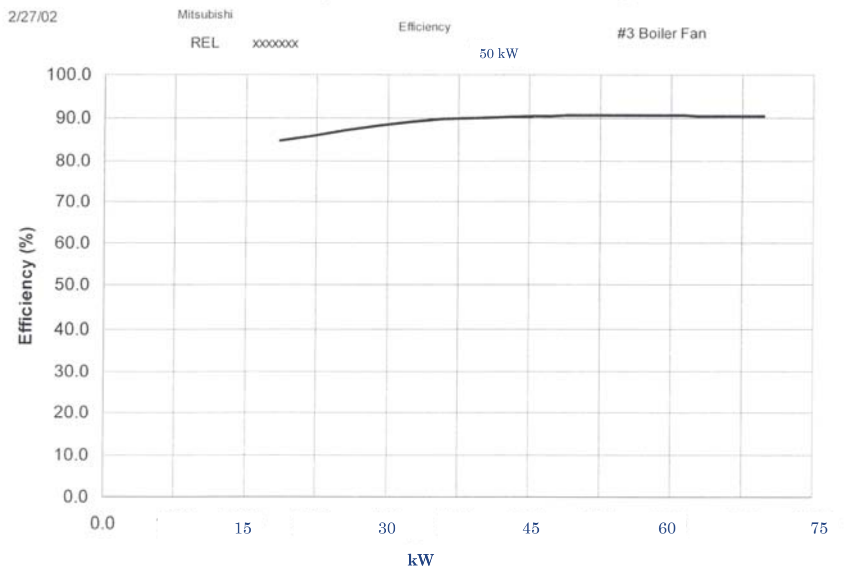
Motor Efficiency Versus Output Power



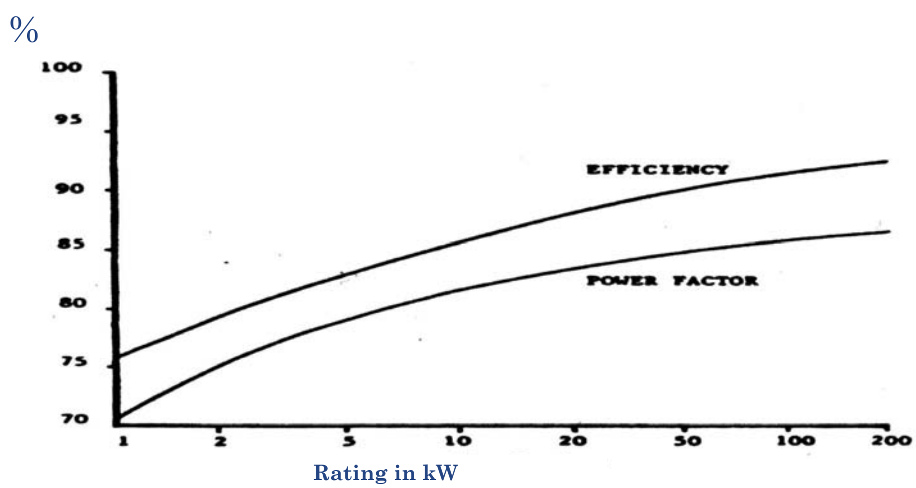
RELIANCE ELECTRIC

In-field electric motor efficiency measurement

Rockwell Automation

Section M - 21

EFFICIENCY AND PF (COS PHI) VS. SIZE



Source: Electrical and Energy Management, IEES, Ga,Tech., Atlanta, GA.

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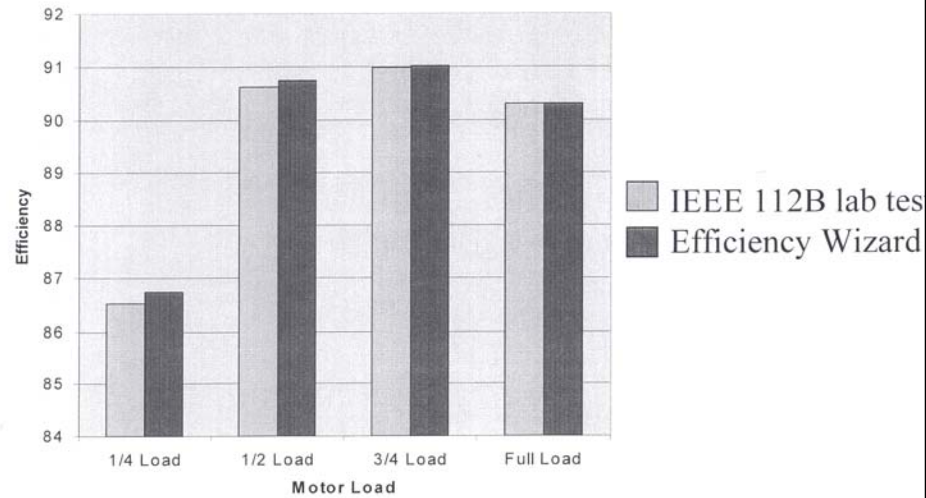
Efficiency Calculation Accuracy

7.5 kW Motor



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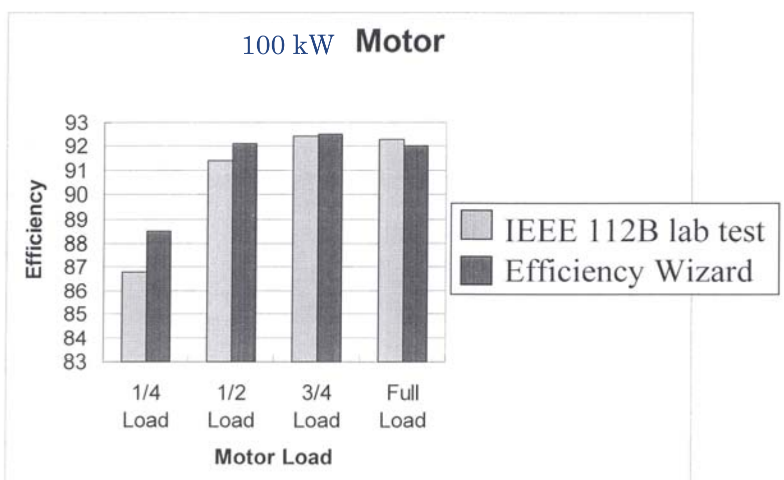
Efficiency Calculation Accuracy



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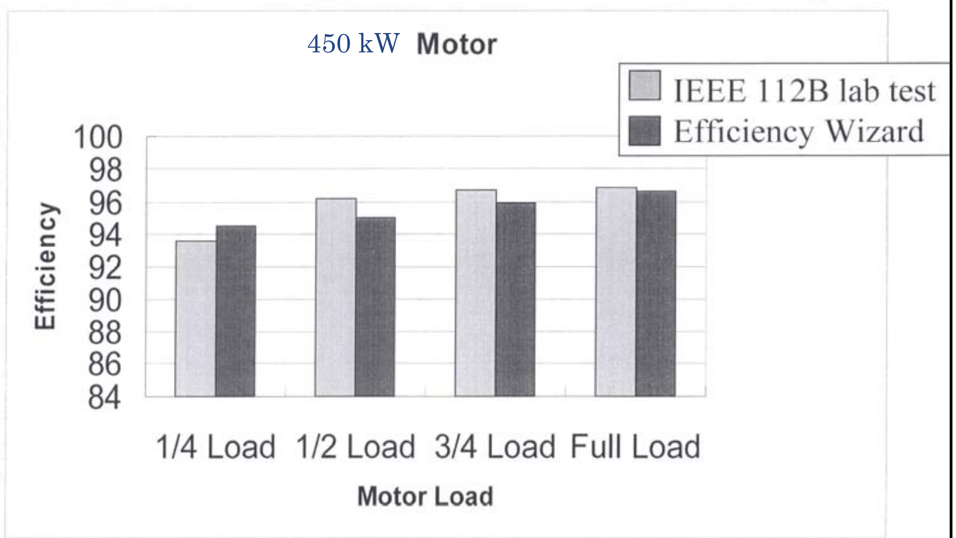
Efficiency Calculation Accuracy



RELIANCE ELECTRIC In-field electric motor efficiency measurement Rockwell Automation

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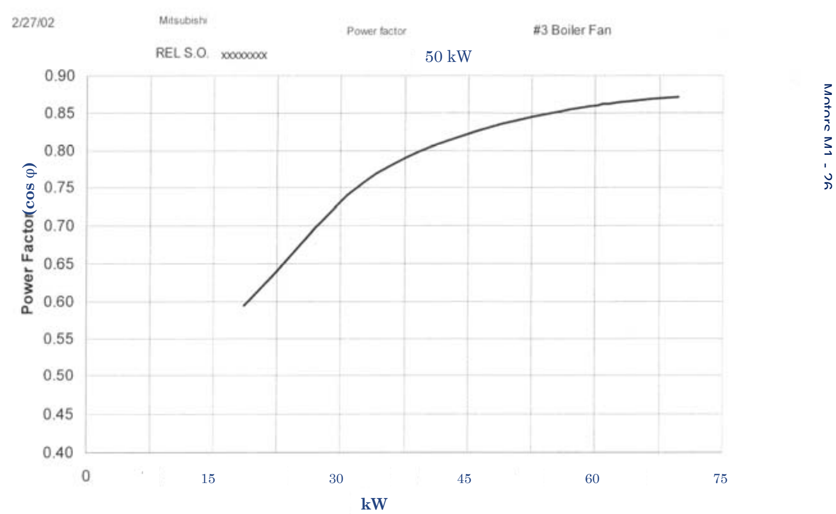
Power Factor (cos φ) vs Output Power



RELIANCE ELECTRIC In-field electric motor efficiency measurement Rockwell Automation 16

Section M - 26

Proposed European Union–CEMEP Energy Efficiency Classification Scheme for Two- and Four-Pole Induction Motors

Minimum Nominal Efficiency (as determined by Method IEC 34.2) (%)

	Class 2		Class 1	
Motor Size (kW)	2-pole	4-pole	2-pole	4-pole
1.1	76.2	76.2	82.2	83.8
1.5	78.5	78.5	84.1	85.0
2.2	81.0	81.0	85.6	86.4
3.0	82.6	82.6	86.7	87.4
4.0	84.2	84.2	87.6	88.3
5.5	85.7	85.7	88.5	89.2
7.5	87.0	87.0	89.5	90.1
11.0	88.4	88.4	90.6	91.0
15.0	89.4	89.4	91.3	91.8
18.5	90.0	90.0	91.8	92.2
22.0	90.5	90.5	92.2	92.6
30.0	91.4	91.4	92.9	93.2
37.0	92.0	92.0	93.3	93.6
45.0	92.5	92.5	93.7	93.9
55.0	93.0	93.0	94.0	94.2
75.0	93.6	93.6	94.6	94.7

Source: European Union–CEMEP 1999

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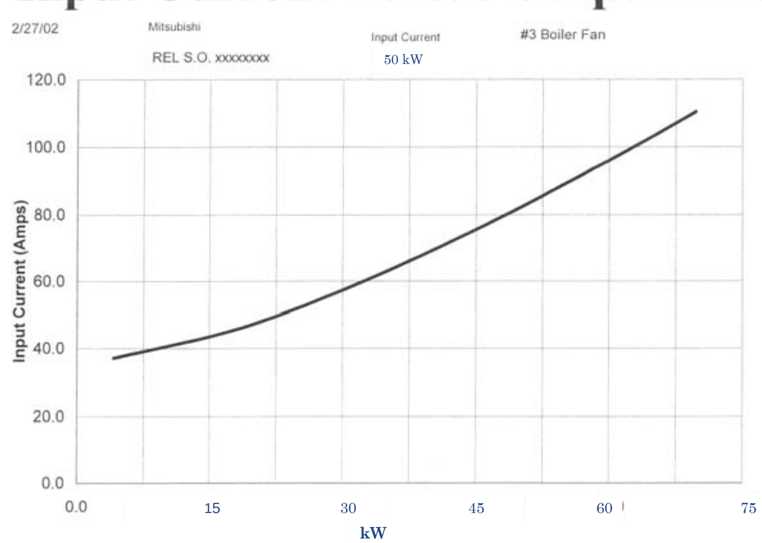
Motors M1 - 27

Input Current Versus Output Power



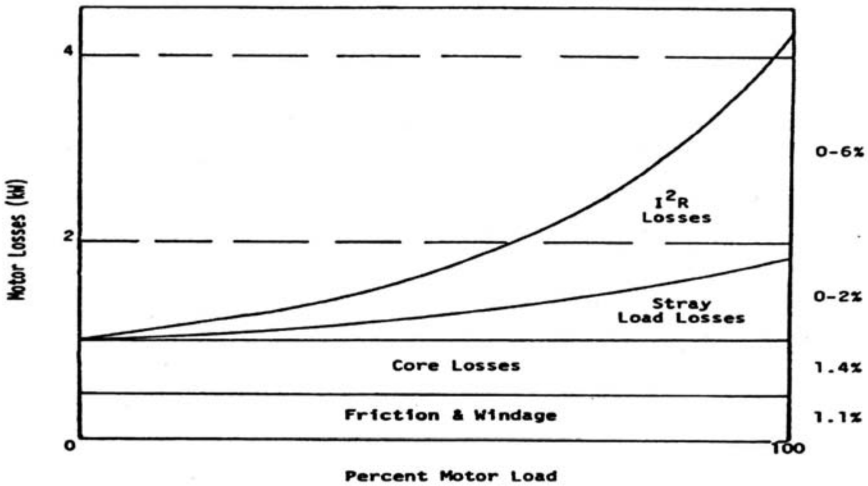
RELIANCE ELECTRIC

In-field electric motor efficiency measurement

Rockwell Automation

Section M - 28

Electric Motor Management—Losses in Motors



Note: This graph explains the efficiency drop off with load reduction

Source: "Electrical Motors and Energy Conservation", Ronald Cota, Specifying Engineer, July, 1978.

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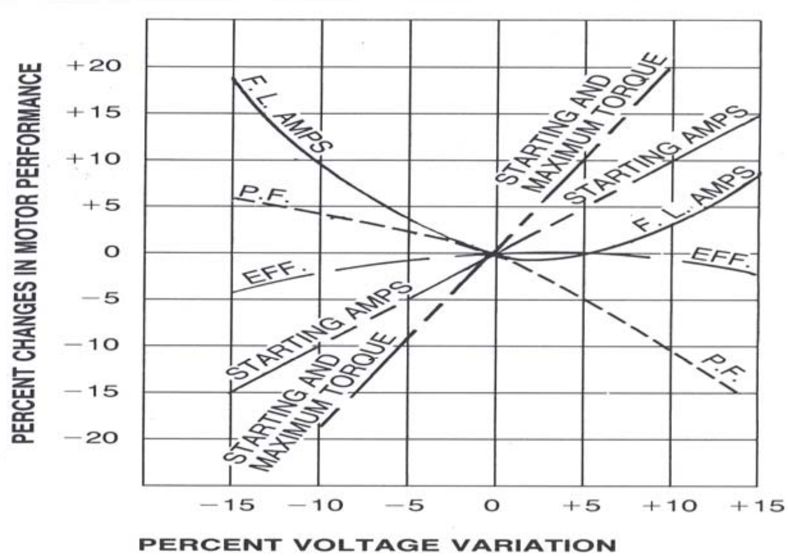
Motor Performance as Supply Voltage Varies



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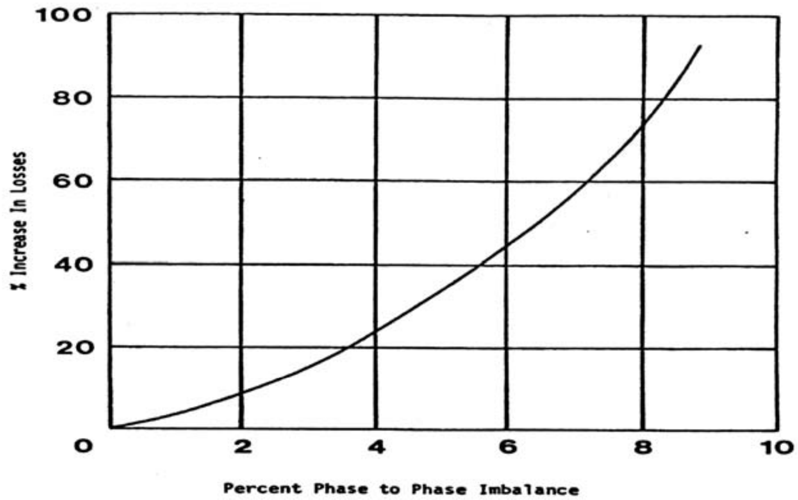
Voltage Imbalance Impact



Source: Electrical and Energy Management, IEES, Ga,Tech., Atlanta, GA.

$$$$

- Energy efficient motors (used 2000 hours or more per year) are almost always cost effective for new purchases
- Energy efficient motors as an alternative to rewinds is almost always cost effective (2000+ hrs) for all except large TEFCs (see earlier discussion)
- Premium efficiency motors are difficult to justify economically without DSM (design-side management program) help unless hours are very high and energy is expensive (bull frog is already close to the pond)

$$$$

- Leave existing motors alone until they fail except:
  - Exceptionally oversized motors (25% loading or so)
  - Sizes that are needed elsewhere (requires inventory)
- When they fail, maybe buy new energy efficient motors (EPACT or Premium) instead of paying for rewind (much more on this later)
- If financial incentives are available, much more may be done
- Premium efficient motors need economic help in much of the country (Utility or motor manufacturers' incentives.)

Motor Basics-Motor Rewinds

- Most rewind motors over ___ kW
- Typical rewinds cost 60+% of a new motor
- New motor could be an energy efficient motor
- Motor efficiency often suffers during rewind. Average drop about 1% according to one study and sometimes significantly more.
- If efficiency drops, losses increases, motor runs hotter and won't last as long

Motor Basics
Motor Rewinds Cont.

- Rewinds can be done well. Use DoE rewind specifications, inspect shop, and periodically requests tests. However, 1% still seems valid
- Why does efficiency drop?
  - Oven temperature of burnout and cure is critical
  - Reassembly can cause more acute problems

Electric Motor Management
Energy Efficient Motors

- Energy efficient motor characteristics
  - More efficient, and often higher power factor
  - Save energy and reduce demand
  - Reduce load on cables, transformers, etc. (note double whammy with higher efficiency and higher PF (Cos phi))
  - Speed is slightly higher (can be critical)
  - Significantly larger inrush (LRA)

$$$$

- Watch carefully energy efficient motor retrofits on centrifugal applications
- Faster speed
  - More volume (work)
  - More power requirement (cube)
- Re-sheave to lower speed?
  - Same (or less) volume
  - Reduced power requirement
  - Watch retrofit applications in other areas also e.g. screw compressors
- Watch LRA and circuit breakers

Energy Efficient Motors Calculating Savings

- Power and energy savings depends of efficiency of standard vs. energy efficient motor

$$\text{Power savings} = kW_e = \left[\frac{KWNP \times LF}{EFF}\right]_{Stan} - \left[\frac{KWNP \times LF}{EFF}\right]_{EE}$$

- Energy savings = Power savings x Time

  = kW_e X Operating hours

Tools to Help

- The following software packages are available free from OIT of DoE. Contact OIT Clearinghouse 800-862-2086 or clearinghouse@ee.doe.gov They are also downloadable from the DoE web site.
  - MotorMaster: An energy-efficient motor selection and management tool. Motor inventory management, maintenance log tracking, efficiency analysis, savings evaluation, energy accounting, and environmental reporting
  - Pump System Assessment Tool (PSAT): Efficiency of pumping system operations. Pump performance and potential energy and other cost savings
  - ASD Master: Adjustable speed drive evaluation methodology and application software. Available from EPRI also.
  - Steam Sourcebook: Guide to improved steam system performance.

Motors and Variable Speed Drives

Electric Motor Management Drives

- Motors are fixed speed devices likely running between NLRPM and FLRPM
- Other speeds on the driven end have to be engineered (which will affect the load on the motor)
- Because of the "fan" laws (pumping or blowing) centrifugal devices are desired applications for varying LPS of air or water

Centrifugal Fan and Pump Laws

- Flow and Speed

$$\frac{LPS_{new}}{LPS_{old}} = \frac{RPM_{new}}{RPM_{old}}$$

- Pressure (Head) and Speed

$$\frac{P_{new}}{P_{old}} = \frac{[RPM_{new}]^2}{[RPM_{old}]^2} = \frac{[LPS_{new}]^2}{[LPS_{old}]^2}$$

- Power and Speed

$$\frac{kW_{new}}{kW_{old}} = \frac{[LPS_{new}]^3}{[LPS_{old}]^3}$$

Electric Motor Management
Fan Laws Example

- A 30 kW centrifugal blower is on a forced draft cooling tower. It is basin temperature controlled but conversion to a variable speed drive is being considered. When the blower is running at ½ speed, what is the impact on the LPS of air flow, and what is the new kW requirement?

Electric Motor Management
Fan Laws Example

- New LPS is __________old LPS
- New kW requirement is:
- These type savings are why variable speed drives are so popular today

Electric Motors Variable Volume Options

- Outlet damper control (see sketch, location 1)
- Inlet vane control (see sketch, location 2)
- Magnetic clutching (see sketch, location 3)
  - Eddy current clutch
  - Permanent magnetic clutch
- Variable Frequency Drives (see sketch, location 4)
- Hydraulic drives, variable sheaves, etc.

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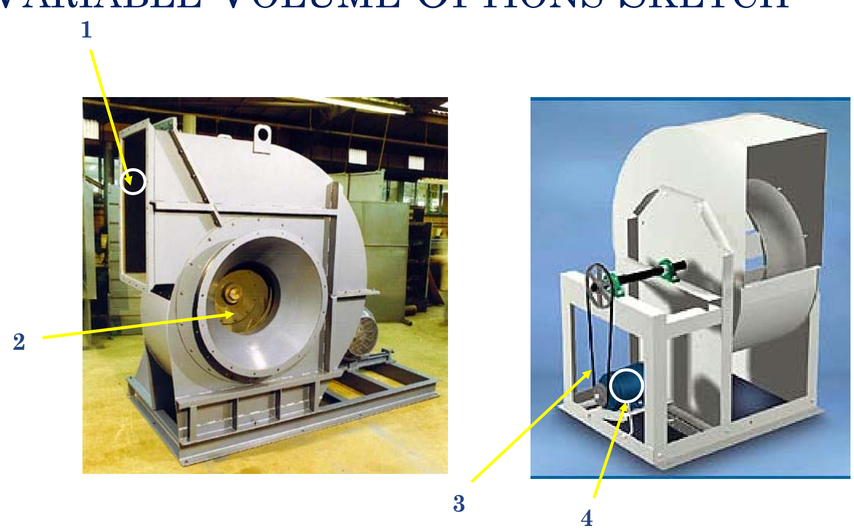
Electric Motors Variable Volume Options Sketch



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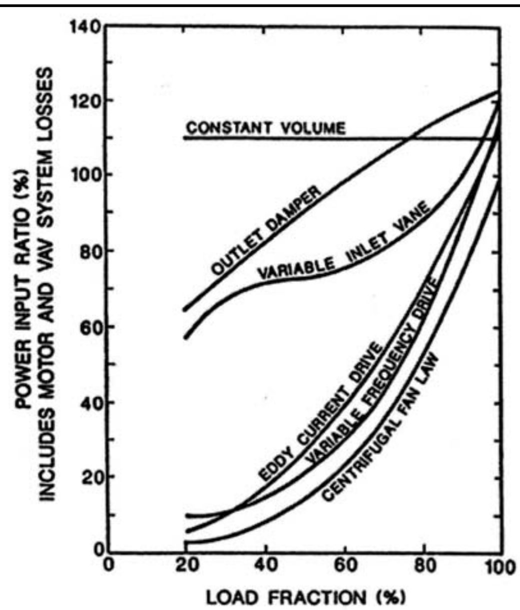
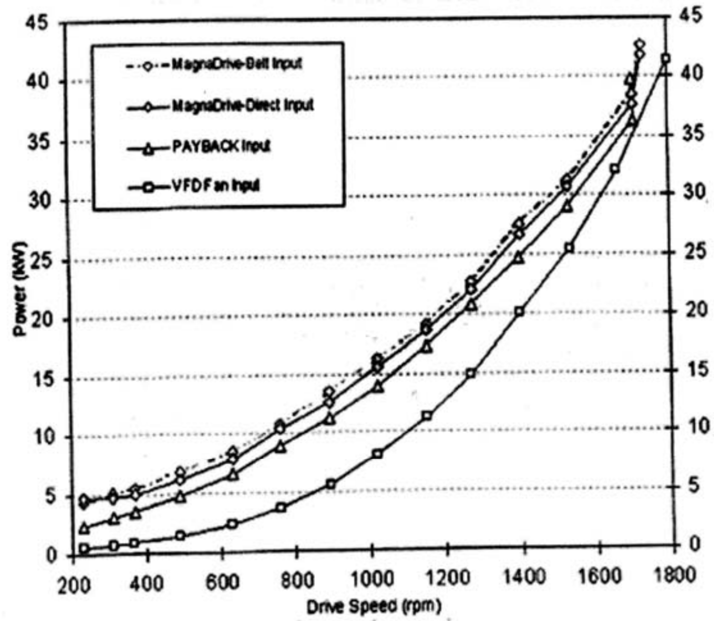
Variable Speed Drive Alternatives Performance

- The next page shows performance expectations from an older EPRI report
- The page after that shows performance from a more recent PNL test
- The third page shows an "average" VAV loading profile. It can be used as a default loading if better figures are not available. Quick Fan from DoE presents another default possibility.



Typical Power Consumption of Various Control Systems



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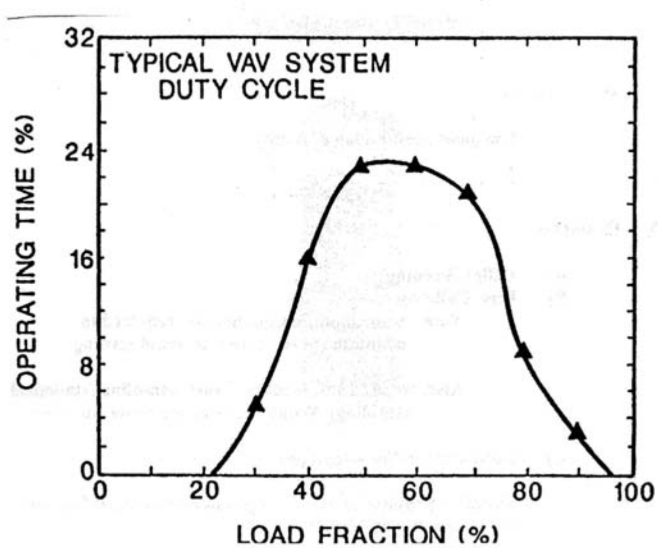
VFD: Default Loading Profile



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$$$$

- Choose the technology that your staff understands and likes to use
- You probably don't want to mix technologies in a given facility (opinion)
- Most efficient is VFD followed closely by magnetic clutching followed (way back) by inlet vane and outlet damper controls

$$$$

- Concentrate on centrifugal devices, not axial or reciprocating devices
  - Chilled water pumps, cooling water pumps, etc.
  - Blowers on cooling towers or VAV (variable-air-volume) HVAC units

$$$$

- For cooling towers, work on air side as opposed to water side
  - Larger motors
  - Doesn't affect operation as much (freeze protection, biological control, etc.)
  - Multiple cell towers may be a good candidate for one drive on multiple motors

Electric Motor Management
Other Drives

- Variable sheaves
  - Very closely approach fan laws
  - Repeatability and maintenance often a problem
  - Many lock blades and install VFDs
- Hydraulics
  - Effective
  - Expensive
  - Not often used as discussed here

Electric Motor Management
Axial and Reciprocating

- Centrifugal laws do not apply
- More difficult to predict savings
- If linear, no "real energy savings" over present on/off operation (certainly improved soft start operations and perhaps control)
- Obviously, savings if converting from constant volume to variable volume

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$$$$
Variable Speed Drive Applications

- Any large centrifugal blower or pump that runs a lot!
  - Constant volume? Convert to var. volume
  - Variable volume with inlet or outlet control
- Chilled water pumps, large campus
- Cooling water pumps
- VAVs using inlet vane
- Forced draft (blower) cooling towers

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NEW TECHNOLOGY OPTIONS

- For variable speed applications in small air handlers and small HVAC systems, there are several new technologies that may be more energy efficient than AC induction motors with VFDs.
- SR motors – switched reluctance motors
- VR motors – variable reluctance motors
- PM motors – permanent magnet motors
- Electronically commutated motors

EXAMPLE PROBLEMS

1. Facility Information

- Facility has a 55 kW pump motor operating at an annual load factor of 70%
- Existing motor is 87% efficient, and operates 4000 hours each year
- Electric cost is $0.10 per kWh
- New 55 kW motor will be 94% efficient
- New high efficiency motor premium is about $1200

Efficiency Evaluation for Yearly Motor Energy Savings

$$S = kWNP \times LF \times C \times N \times \left[\frac{100\%}{Ea} - \frac{100\%}{Eb} \right]$$

- S = Annual savings in dollars on energy use
- kWNP = kW Name Plate Rating
- C = Energy Cost, dollars per kWh
- N = Annual hours per year running time
- Ea = Efficiency of standard motor
- Eb = Efficiency of higher efficient motor
- LF = Load factor of motor

Calculation of Energy Savings

$$S = kWNP \times LF \times C \times N \times \left[\frac{100\%}{Ea} - \frac{100\%}{Eb}\right]$$

$$S = 55 \times 0.7 \times \$0.10 \times 4000 \times \left[\frac{100\%}{87\%} - \frac{100\%}{94\%}\right]$$

$S = 38.5 \times \$0.10 \times 4000 \times 0.0856$

$S = \$1318.24/\text{year}$

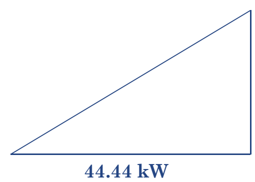
Economic Analysis of Motor EMO

- Savings is $1318.24
- Cost is about $1200
- SPP = $1200/$1318.24 per year
  = 0.9 years

ELECTRIC MOTOR PRINCIPLES REVIEW

2. A three phase 50 kW motor with a load factor of 0.8 has an efficiency of 90%, what is the kW electrical power input?

$$kWin = \frac{50\ KWx0.80}{0.90} = 44.44\ kW$$



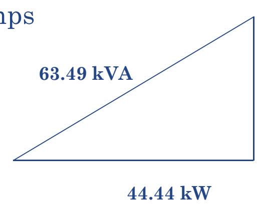
ELECTRIC MOTOR PRINCIPLES REVIEW

3. For the motor in 2, if the PF = cos phi = 0.7 and voltage is 380 V,
what is the kVA and what is the amp draw?

PF = 0.7 = kW/kVA

0.7 = 44.44/kVA or kVA = 44.44/0.7 = 63.49 kVA
Also kVA = $\sqrt{3}$ x (kV) x I = ($\sqrt{3}$)(0.380) I = 63.49 kVA

I = 63.49 / ($\sqrt{3}$ x 0.380) = 96.47 amps



Electric Motor Principles Review

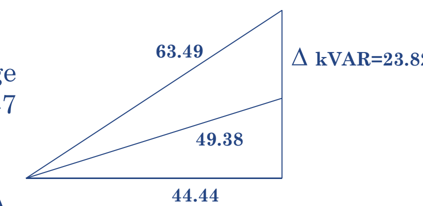
4. Next, we want to correct the PF (cos phi) to 0.90. What size capacitor is needed and what is the impact on the amperage?

ΔkVAR = 44.44 (tan $\cos^{-1}$ 0.7 – tan $\cos^{-1}$ 0.9) = 23.82 kVAR
You will find the value for ( ) above in PF table (see Section K) (.536)

New kVA = 44.44/0.9 = 49.38   kVA = 49.38 = (kV)I$\sqrt{3}$

I = 49.38/(0.380$\sqrt{3}$) = 75.03 amps

Thus, PF correction dropped amperage (upstream of the capacitor) from 96.47 to 75.03 amps or 22%



Also, new kVA = $\sqrt{3}$ kV I = 49.38 kVA

Table 11.7 Power-Factor Improvement[a]

Original Power Factor (%)	Desired Power Factor (%) 80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	
50	0.982	1.008	1.034	1.060	1.086	1.112	1.139	1.165	1.192	1.220	1.248	1.276	1.306	1.337	1.369	1.403	1.442	1.481	1.529	1
51	0.937	0.962	0.989	1.015	1.041	1.067	1.094	1.120	1.147	1.175	1.203	1.231	1.261	1.292	1.324	1.358	1.395	1.436	1.484	1
52	0.893	0.919	0.945	0.971	0.997	1.023	1.050	1.076	1.103	1.131	1.159	1.187	1.217	1.248	1.280	1:314	1.351	1.392	1.440	1
53	0.850	0.876	0.902	0.928	0.954	0.980	1.007	1.033	1.060	1.088	1.116	1.144	1.174	1.205	1.237	1.271	1.308	1.349	1.397	1
54	0.809	0.835	0.861	0.887	0.913	0.939	0.966	0.992	1.019	1.047	1.075	1.103	1.133	1.164	1.196	1.230	1.267	1.308	1.356	1
55	0.769	0.795	0.821	0.847	0.873	0.899	0.926	0.952	0.979	1.007	1.035	1.063	1.090	1.124	1.156	1.190	1.228	1.268	1.316	1
56	0.730	0.756	0.782	0.808	0.834	0.860	0.887	0.913	0.940	0.968	0.996	1.024	1.051	1.085	1.117	1.151	1.189	1.229	1.277	1
57	0.692	0.718	0.744	0.770	0.796	0.822	0.849	0.875	0.902	0.930	0.958	0.986	1.013	1.047	1.079	1.113	1.151	1.191	1.239	1
58	0.655	0.681	0.707	0.733	0.759	0.785	0.812	0.838	0.865	0.893	0.921	0.949	0.976	1.010	1.042	1.076	1.114	1.154	1.202	1
59	0.618	0.644	0.670	0.696	0.722	0.748	0.775	0.801	0.828	0.856	0.884	0.912	0.939	0.973	1.005	1.039	1.077	1.117	1.165	1
60	0.584	0.610	0.636	0.662	0.688	0.714	0.741	0.767	0.794	0.822	0.850	0.878	0.905	0.939	0.971	1.005	1.043	1.083	1.131	1
61	0.549	0.575	0.601	0.627	0.653	0.679	0.706	0.732	0.759	0.787	0.815	0.843	0.870	0.904	0.936	0.970	1.008	1.048	1.096	1
62	0.515	0.541	0.567	0.593	0.619	0.645	0.672	0.698	0.725	0.753	0.781	0.809	0.836	0.870	0.902	0.936	0.974	1.014	1.062	1
63	0.483	0.509	0.535	0.561	0.587	0.613	0.640	0.666	0.693	0.721	0.749	0.777	0.804	0.838	0.870	0.904	0.942	0.982	1.030	1
64	0.450	0.476	0.502	0.528	0.554	0.580	0.607	0.633	0.660	0.688	0.715	0.744	0.771	0.805	0.837	0.871	0.909	0.949	0.997	1
65	0.419	0.445	0.471	0.497	0.523	0.549	0.576	0.602	0.629	0.657	0.685	0.713	0.740	0.774	0.806	0.840	0.878	0.918	0.966	1
66	0.388	0.414	0.440	0.466	0.492	0.518	0.545	0.571	0.598	0.626	0.554	0.682	0.709	0.743	0.775	0.809	0.847	0.887	0.935	0
67	0.358	0.384	0.410	0.436	0.462	0.488	0.515	0.541	0.568	0.596	0.624	0.652	0.679	0.713	0.745	0.779	0.817	0.857	0.905	0
68	0.329	0.355	0.381	0.407	0.433	0.459	0.486	0.512	0.539	0.567	0.595	0.623	0.650	0.684	0.716	0.750	0.788	0.828	0.876	0
69	0.299	0.325	0.351	0.377	0.403	0.429	0.456	0.482	0.509	0.537	0.565	0.593	0.620	0.654	0.866	0.720	0.758	0.798	0.840	0
70	0.270	0.296	0.322	0.348	0.374	0.400	0.427	0.453	0.480	0.508	0.536	0.564	0.591	0.625	0.657	0.691	0.729	0.769	0.811	0

Table K: Power-Factor Improvement

71	0.242	0.268	0.294	0.320	0.346	0.372	0.399	0.425	0.452	0.480	0.508	0.536	0.563	0.597	0.629	0.663	0.701	0.741	0.783	0
72	0.213	0.239	0.265	0.291	0.317	0.343	0.370	0.396	0.423	0.451	0.479	0.507	0.534	0.568	0.600	0.634	0.672	0.712	0.754	0
73	0.186	0.212	0.238	0.264	0.290	0.316	0.343	0.369	0.396	0.424	0.452	0.480	0.507	0.541	0.573	0.607	0.645	0.685	0.727	0
74	0.159	0.185	0.211	0.237	0.263	0.289	0.316	0.342	0.369	0.397	0.425	0.453	0.480	0.514	-3.546	0.580	0.618	0.658	0.700	0
75	0.132	0.158	0.184	0.210	0.236	0.262	0.289	0.315	0.342	0.370	0.398	0.426	0.453	0.487	0.519	0.553	0.591	0.631	0.673	0
76	0.105	0.131	0.157	0.183	0.209	0.235	0.262	0.288	0.315	0.343	0.371	0.399	0.426	0.460	0.492	0.526	0.564	0.604	0.652	0
77	0.079	0.105	0.131	0.157	0.183	0.209	0.236	0.262	0.289	0.317	0.345	0.373	0.400	0.434	0.466	0.500	0.538	0.578	0.620	0
78	0.053	0.079	0.105	0.131	0.157	0.183	0.210	0.236	0.263	0.291	0.319	0.347	0.374	0.408	0.440	0.474	0.512	0.552	0.594	0
79	0.026	0.052	0.078	0.104	0.130	0.156	0.183	0.209	0.236	0.264	0.292	0.320	0.347	0.381	0.413	0.447	0.485	0.525	0.567	0
80	0.000	0.026	0.052	0.078	0.104	0.130	0.157	0.183	0.210	0.238	0.266	0.294	0.321	0.355	0.387	0.421	0.459	0.499	0.541	0
81		0.000	0.026	0.052	0.078	0.104	0.131	0.157	0.184	0.212	0.240	0.268	0.295	0.329	0.361	0.395	0.433.	0.473	0.515	0
82			0.000	0.026	0.052	0.078	0.105	0.131	0.158	0.186	0.214	0.242	0.269	0.303	0.335.	0.369	0.407	0.447	0.489	0
83				0.000	0.026	0.052	0.079	0.105	0.132	0.160	0.188	0.216	0.243	0.277	0.309	0.343	0.381	0.421	0.463	0.
84					0.000	0.026	0.053	0.079	0.106	0.134	0.162	0.190	0.217	0.251	0.283	0.317	0.355	0.395	0.437	0.
85						0.000	0.027	0.053	0.080	0.108	0.136	0.164	0.191	0.225	0.257	0.291	0.329	0.369	0.417	0.
86								0.026	0.053	0.081	0.109	0.137	0.167	0.198	0.230	0.265	0.301	0.343	0.390	0.
87									0.027	0.055	0.082	0.111	0.141	0.172	0.204	0.238	0.275	0.317	0.364	0.
88										0.028	0.056	0.084	0.114	0.145	0.177	0.211	0.248	0.290	0.337	0.
89											0.028	0.056	0.086	0.117	0.149	0.183	0.220	0.262	0.309	0.
90												0.028	0.058	0.089	0.121	0.155	0.192	0.234	0.281	0.
91													0.030	0.061	0.093	0.127	0.164	0.206	0.253	0.
92														0.031	0.063	0.097	0.134	0.176	0.223	0.
93															0.032	0.066	0.103	0.145	0.192	0.
94																0.034	0.071	0.113	0.160	0.
95																	0.037	0.079	0.126	0.
96																		0.042	0.089	0.
97																			0.047	0.
98																				0.
99																				

Table K: Power-Factor Improvement

Motor Practice Problem

- A recent advertisement said a premium efficiency 50 kW motor is available at 94.5%. It would replace a motor that presently runs at 90.7%. Given the parameters below, calculate the cost of operating both motors and the savings for conversion:
  - Motor runs 8760 hours/year
  - Demand cost is $10 per kW month
  - Energy cost is $0.06/kWh
  - Motor runs at 80% load all the time

Motor Practice Problem

- Cost to operate existing motor
  - Demand
  - Energy
  - Total

Motor Practice Problem

- Cost to operate premium efficiency motor
  - Demand
  - Energy
  - Total
- Savings

Appendix

Electric Motor Management
Single Phasing

- Single phasing is the loss of one phase in a 3 phase system
- Worst case scenario of voltage imbalance (see slide M-36)
- Causes
  - In plant
  - Pole hits
  - Tree limbs
  - Animals
  - Lightning
  - In other words, this does happen

Single Phasing (Cont.)

- ***Each*** 10^0 C rise in temp. reduces motor life 50%
- Single phasing is the ultimate in voltage imbalance, so dramatic heat rise occurs (large amperage flows on the other 2 phases)
- NEC 430.36 states that if fused, all 3 phases should be fused. Similar statements for thermal overload devices
- Further, these overload protections should be sized on "actual loads" rather than name plate (i.e. devices will trip more quickly)
- Phase current increases by $\sqrt{3}$ in single phasing (remember the temp. increase rule)

Electric Motor Management Selection of Best Option

- Outlet damper control
  - Simple and effective
  - Not efficient, infrequently used
  - Great candidate for conversion to others
- Inlet vane control
  - Simple and effective
  - More efficient than outlet damper, but significantly less than other options, fairly frequently used
  - Great candidate for conversion to others

Electric Motor Management
Selection of Best Option

- Variable Frequency Drive (VFD)
  - Probably most efficient
  - Competitive cost
  - Harmonic concerns (input and output)
    - Worst drives are old 6 pulse drives, where most intense harmonics are the 5^{th} and 7^{th}.
    - In general, worst harmonics are n (+/-) 1, where n is the number of pulses.
    - And, higher order harmonics are less intense than lower order ones.

VFDs (cont.)

- Remote (clean area) installation
- Multiple motors may be connected to one drive providing higher savings, but sizing is critical
- Motors and load must be agreeable to VFDs

Variable Frequency Drive Example

- A large 50 HP (37 kW) blower with inlet vane control drives a VAV system operating 6500 hours per year. Energy costs $0.04/kWh. What is the total savings per year for removing the inlet vane control and replacing it with a VFD?
  - Assume the performance figures in slide M-75 apply
  - Assume the loading figures in slide M-77 apply.
  - Construct an Excel spread sheet to do the calculations (will be done for you on next page)

Variable Frequency Drive Example

Profit Improvement With Variable Frequency Drives

1 Load Ratio	2 Power Input Ratio (Old)	3 Power Input Ratio (VFD)	4 Duty Cycle Fraction	5 kWh Saved	6 Dollar Savings
0.20	0.57	0.09	0.00	0	0
0.30	0.67	0.11	0.05	6786	271
0.40	0.71	0.14	0.16	22103	884
0.50	0.72	0.2[illegible]	0.23	28985	1159.
0.60	0.75	0.29	0.23	25641	1026
0.70	0.80	0.43	0.20	17934	717
0.80	0.88	0.62	0.09	5671	227
0.90	0.99	0.85	0.03	1018	41
1.00	1.20	1.16	0.01	97	4

Total Annual Electricity Savings . . . . 108,235 kWh
Total Annual Dollar Savings $4,329

Annual Savings for a Large Air Handler

Variable Frequency Drive Example

- Calculation for 50% load row in Spread Sheet:

(50HP)(0.746kW/HP)(0.72-0.20)(0.23)(6500hr/yr)($0.04/kWH) = $1159

Spread Sheet repeats this for all rows

Electric Motor Management Selection of Best Option

- Magnetic clutches (permanent magnet or eddy current)
  - Bulky and heavy on motor shaft
  - No harmonics
  - Close to same savings as VFDs, but less

END OF SECTION M