Energy Efficient Motors

Why High Efficiency Motors?

- Electric motors responsible for 40% of global electricity usage
  - Drive pumps, fans, compressors, and many other mechanical traction equipment
- International Energy Agency estimates 7% of global electricity demand could be saved by higher energy efficiency motors
- HEMs are cost effective solutions

Electric Motor Management

- Why is electric motor management important?
  - save energy
  - reduce operating costs
  - minimize downtime
  - increase productivity

Candidates for Audit

- Three-phase induction motors
- Non-specialty motor
- 10 hp to 600 hp
- >3,500 hours per year of operation
- Constant load (not intermittent, not cyclic, or not fluctuating)
  - Pumps
  - Fans

Candidates for Audit

- Underloaded motors
- For Replacement (retrofit, failed)
- Older or rewound standard efficiency motors

Motor Efficiency

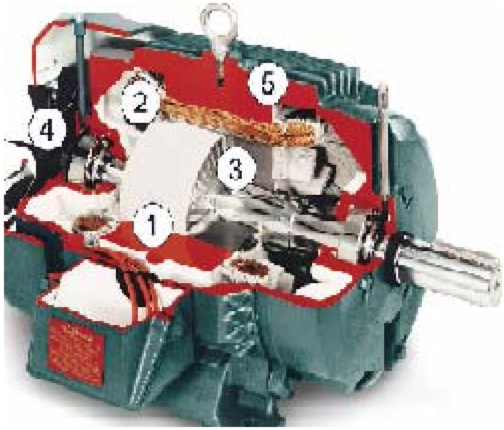
Motor Losses

No Load loss

- Magnetic core
- Friction and windage loss

Load loss

  - stator copper loss
  - rotor copper loss
- Stray Loss



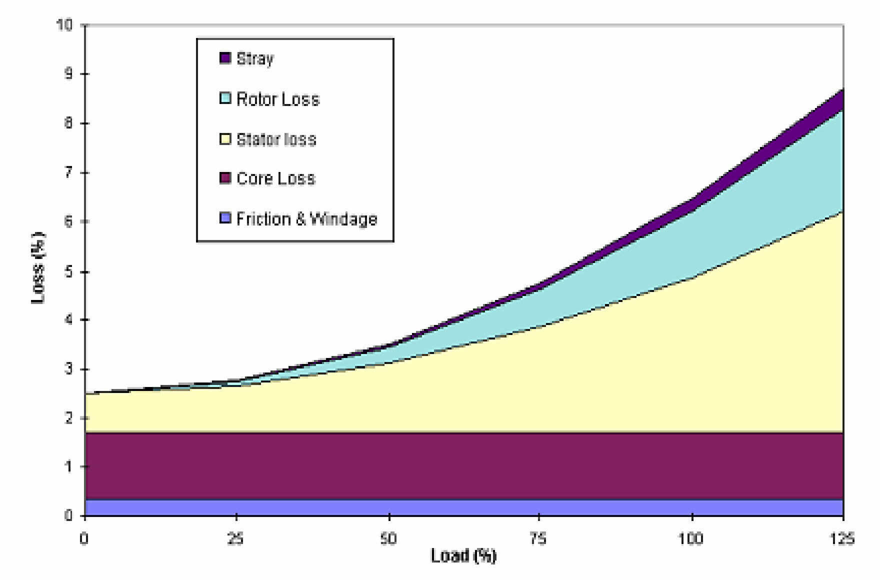
1- iron

2- stator

3- rotor

4- friction & windage

5- stray



Efficiency

$$\text{Efficiency} = \frac{P_{\text{output}}}{P_{\text{input}}} \times 100\%$$

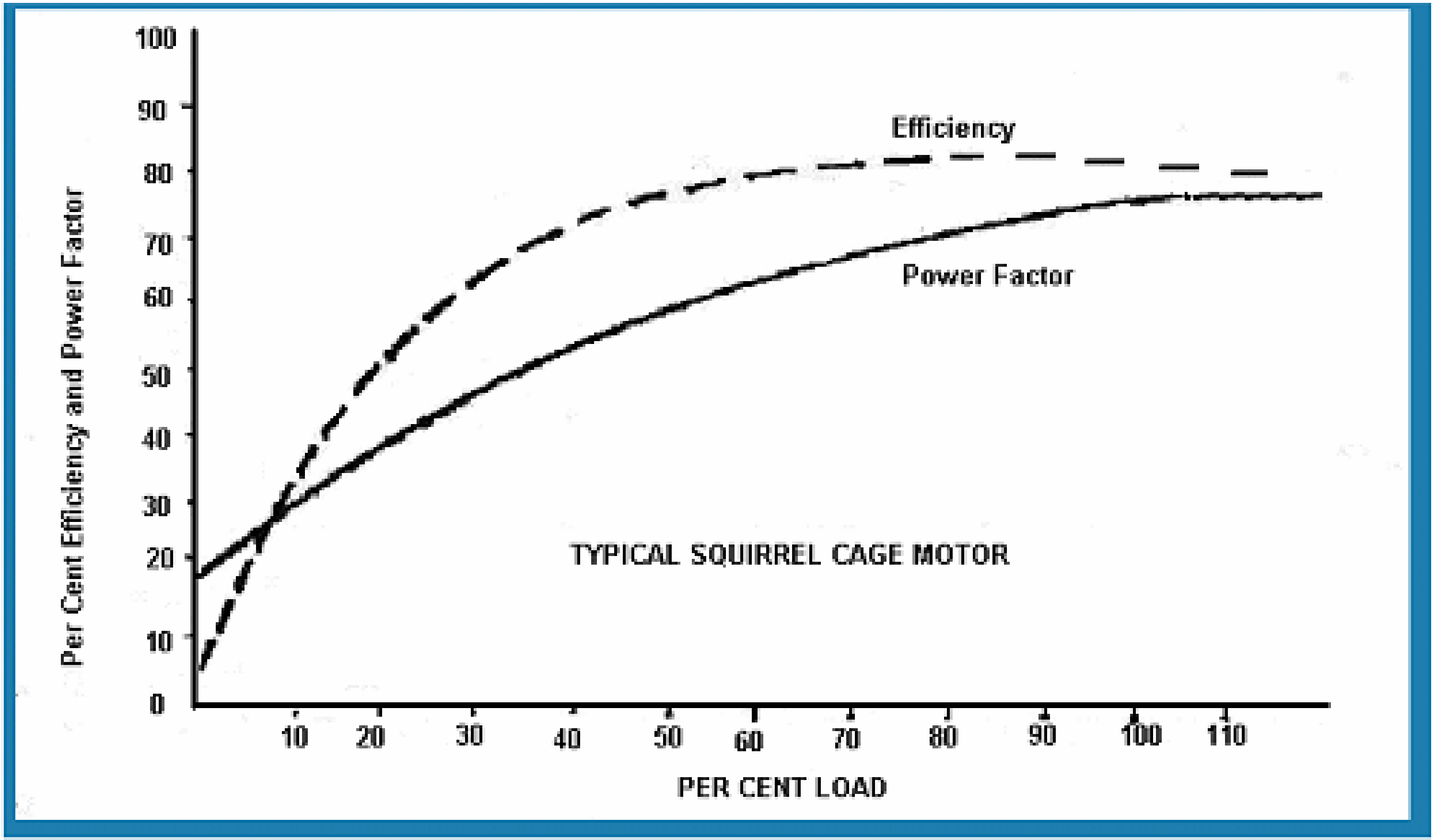
HP??

$$\text{Efficiency} = \frac{746 \times \text{HP output}}{\text{Watts input}} \times 100\%$$

$$\text{Efficiency} = \frac{\text{Watts output} \times 100\%}{\text{Watts output} + \text{Watts losses}}$$

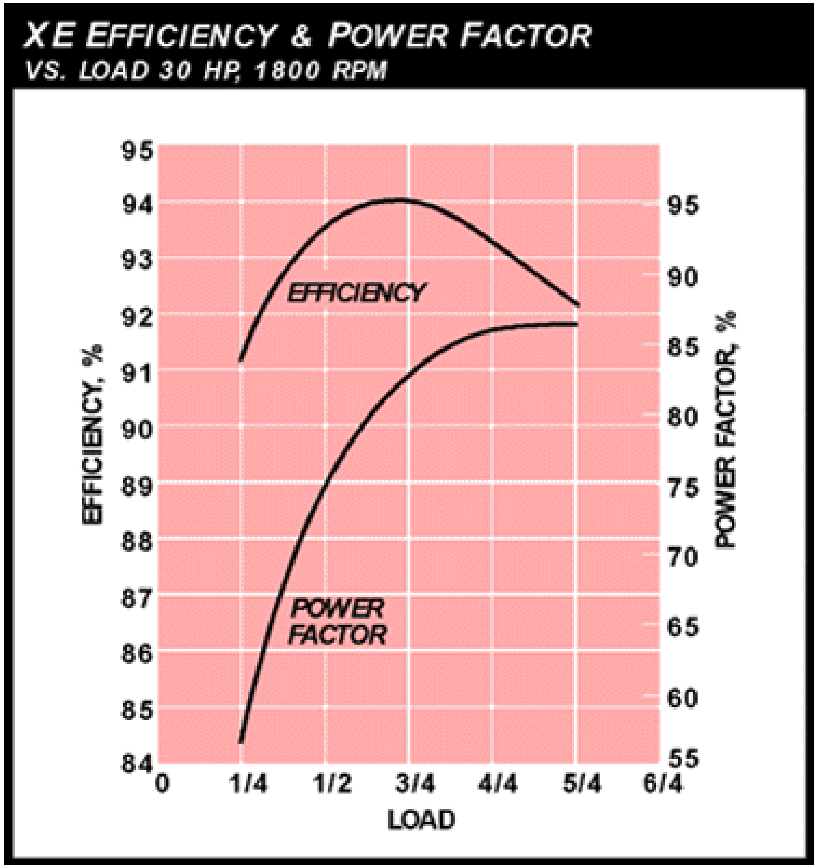
$$\text{Efficiency} = \frac{\text{Watts input} - \text{Watts losses} \times 100\%}{\text{Watts input}}$$

Effect of Loading on Efficiency & PF



Optimum loading = 60 to 80%, or near 75%

Effect of Loading on Efficiency & PF



Source: http://www.reliance.com/mtr/b7087_5/b7087_5_7.htm

How Improving Efficiency Can Reduce Costs

- 1% improvement in efficiency will significantly affect kW savings

For a 373 kW motor (500 hp) with 94% efficiency at 80% loading

required input kW = 373kW x 0.80/0.94 = **317.45 kW**

For a 373 kW motor (500 hp) with 95% efficiency at 80% loading
required input kW = 373kW x 0.80/0.95 = **314.11 kW**

kW Savings = 3.34

Source: CDA: Understanding High Eff. Motors

Determining Motor Loads

Motor % Loading

Input Power

- Line Current
- Slip Method

•**Input power method is preferred**

•Both Line Current and Slip Methods apply only at rated input voltage, hence measurements must be corrected.

•Current at low load is not good load indicator.

•Nameplate speed has some % tolerance.

Motor % Loading

Input Power

$$\text{Motor Load} = \frac{P_{im}}{P_{ir}} \times 100\%$$

$$= \frac{\text{Measured kW}}{\text{Rated kW / Efficiency}} \times 100\%$$

P_{im} = Measured power input in kW

P_{ir} = Input power at full-rated load in kW

Motor % Loading

Line Current

$$\text{Load} = \frac{Im}{Ir} \times \frac{Vm}{Vr} \times 100\%$$

Im = measured input current, amperes
Ir = Nameplate rated current, amperes
Vm = measured line-to-line
Vr = Nameplate rated voltage

Motor % Loading

The Slip Method

$$\text{Load} = \frac{\text{Slip} \times 100\%}{(S_s - S_r)(V_r/V^2)}$$

Slip = Synchronous speed - Measured speed in rpm

Ss = Synchronous speed in rpm

Sr = Nameplate rated full-load speed

Vr = Rated full load volts

V= measured volts

Ss = 120 x f/p

Motor % Loading (Standard Motor)

Example: 15hp or 11.25 kW standard motor with efficiency of 88% and a measured kW of 5.62

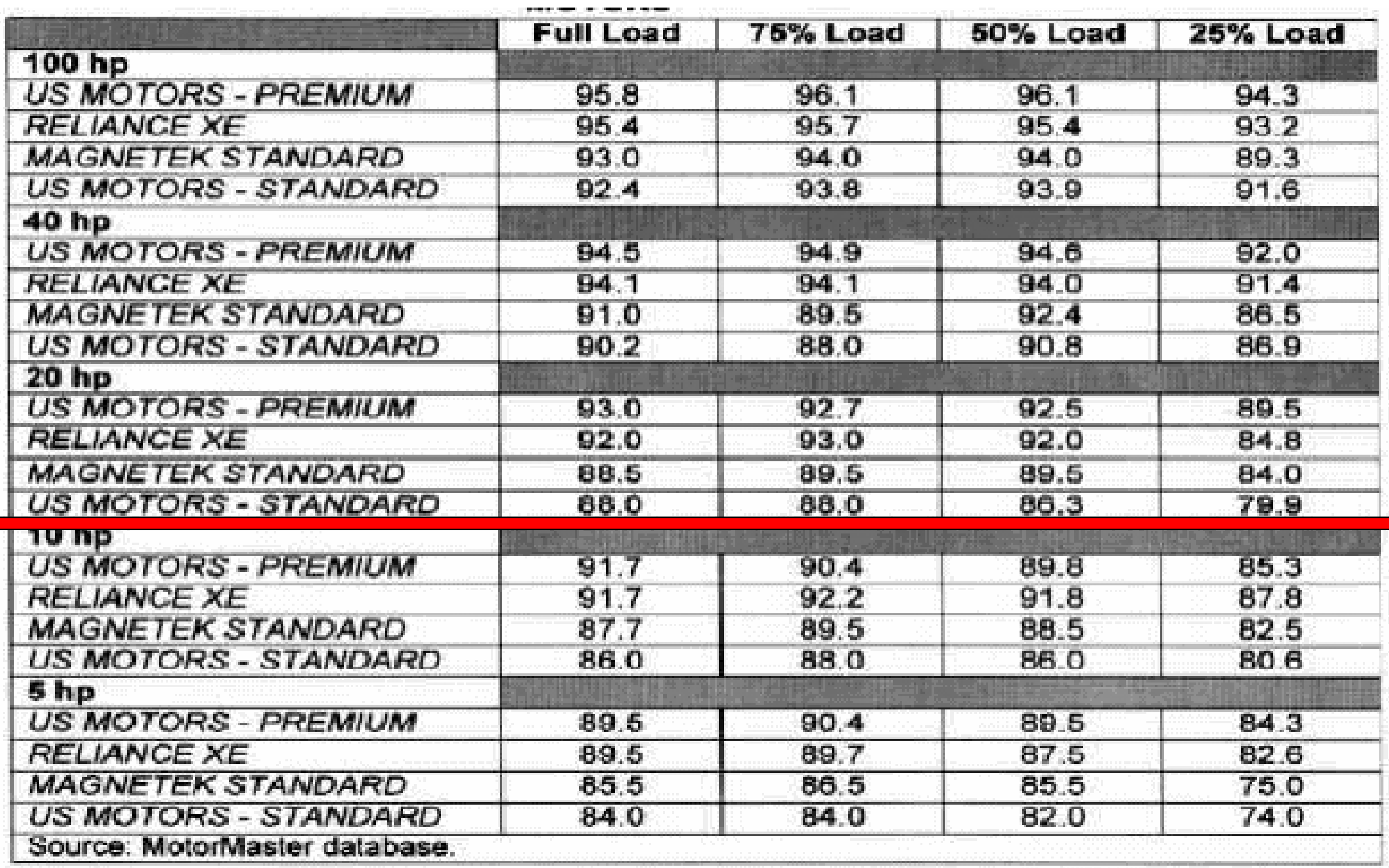
<u>Input Power Method</u>

$$\% \text{ Loading} = \frac{\text{Input kW}}{\text{Rated kW / Rated Efficiency}} \text{ X } 100\%$$

$$\frac{5.62}{11.25 / 88.0} \text{ X } 100\%$$

$$= 43.96 \ \%$$

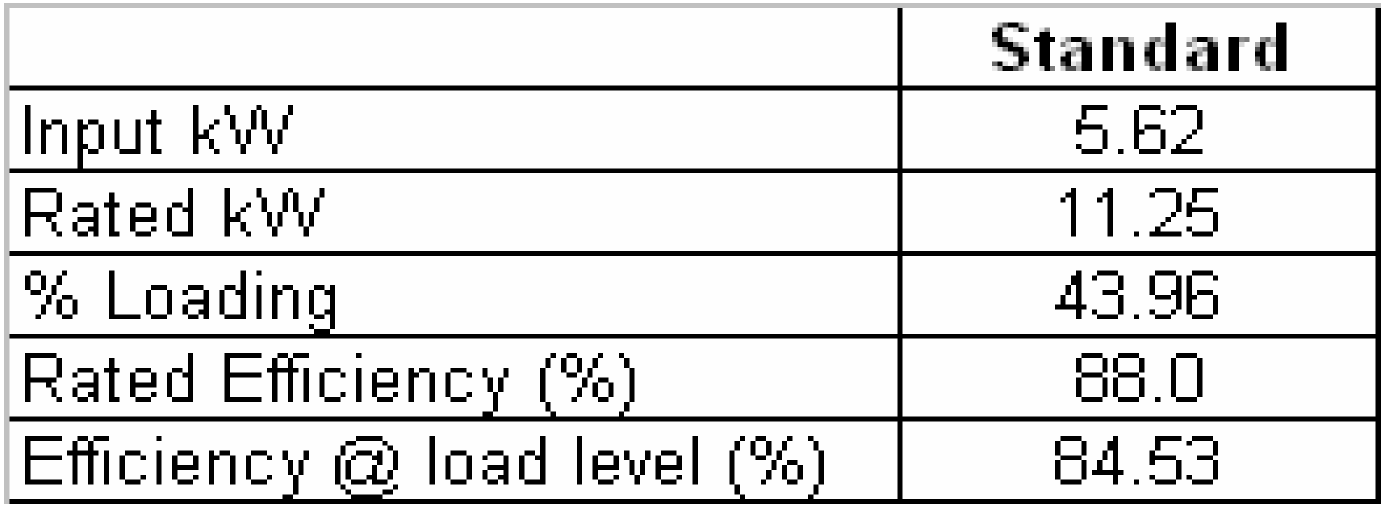
Motor Efficiency at Different Loading Conditions



	Full Load	75% Load	50% Load	25% Load
100 hp				
US MOTORS - PREMIUM	95.8	96.1	96.1	94.3
RELIANCE XE	95.4	95.7	95.4	93.2
MAGNETEK STANDARD	93.0	94.0	94.0	89.3
US MOTORS - STANDARD	92.4	93.8	93.9	91.6
40 hp				
US MOTORS - PREMIUM	94.5	94.9	94.6	92.0
RELIANCE XE	94.1	94.1	94.0	91.4
MAGNETEK STANDARD	91.0	89.5	92.4	86.5
US MOTORS - STANDARD	90.2	88.0	90.8	86.9
20 hp				
US MOTORS - PREMIUM	93.0	92.7	92.5	89.5
RELIANCE XE	92.0	93.0	92.0	84.8
MAGNETEK STANDARD	88.5	89.5	89.5	84.0
US MOTORS - STANDARD	88.0	88.0	86.3	79.9
10 hp				
US MOTORS - PREMIUM	91.7	90.4	89.8	85.3
RELIANCE XE	91.7	92.2	91.8	87.8
MAGNETEK STANDARD	87.7	89.5	88.5	82.5
US MOTORS - STANDARD	86.0	88.0	86.0	80.6
5 hp				
US MOTORS - PREMIUM	89.5	90.4	89.5	84.3
RELIANCE XE	89.5	89.7	87.5	82.6
MAGNETEK STANDARD	85.5	86.5	85.5	75.0
US MOTORS - STANDARD	84.0	84.0	82.0	74.0

Source: MotorMaster database.

Efficiency at Load Level

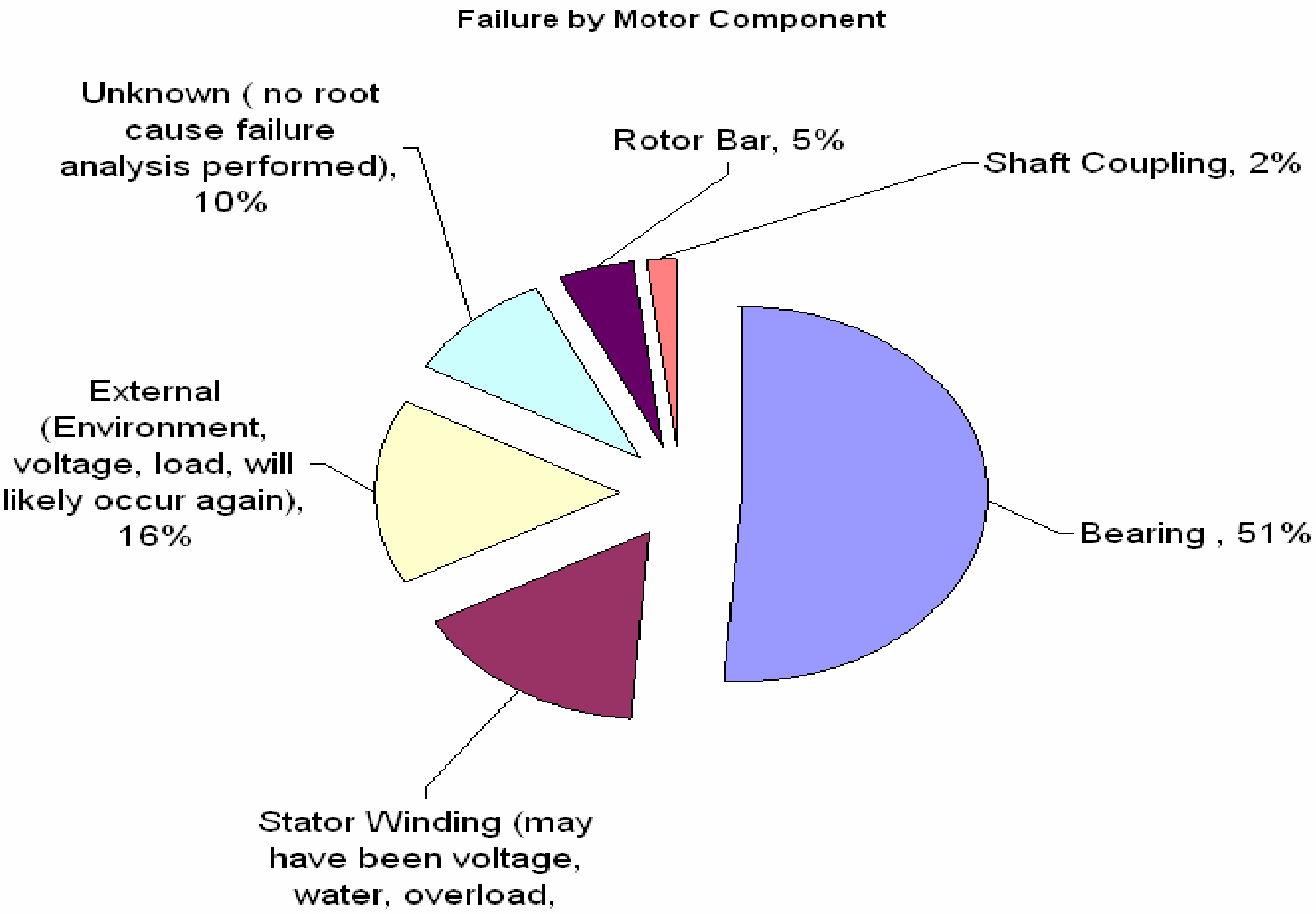


	Standard
Input kW	5.62
Rated kW	11.25
% Loading	43.96
Rated Efficiency (%)	88.0
Efficiency @ load level (%)	84.53

Note: Efficiency at load level was computed by interpolation using the previous slide, table of efficiency at diff. loading conditions

Motor Replacement

Failure by Motor Component



Source: Effect of Repair/Rewinding on Motor Efficiency

When Motor Fails?

- Replace with same standard type
- Replace with proper size and type
- Replace with high efficiency type
- Rewind

Rewind a Failed Motor?

Rewound Motors

- *Study indicates that losses of rewound motors increased by 18% or approx. 1.5 to 2.5% decrease in efficiency*

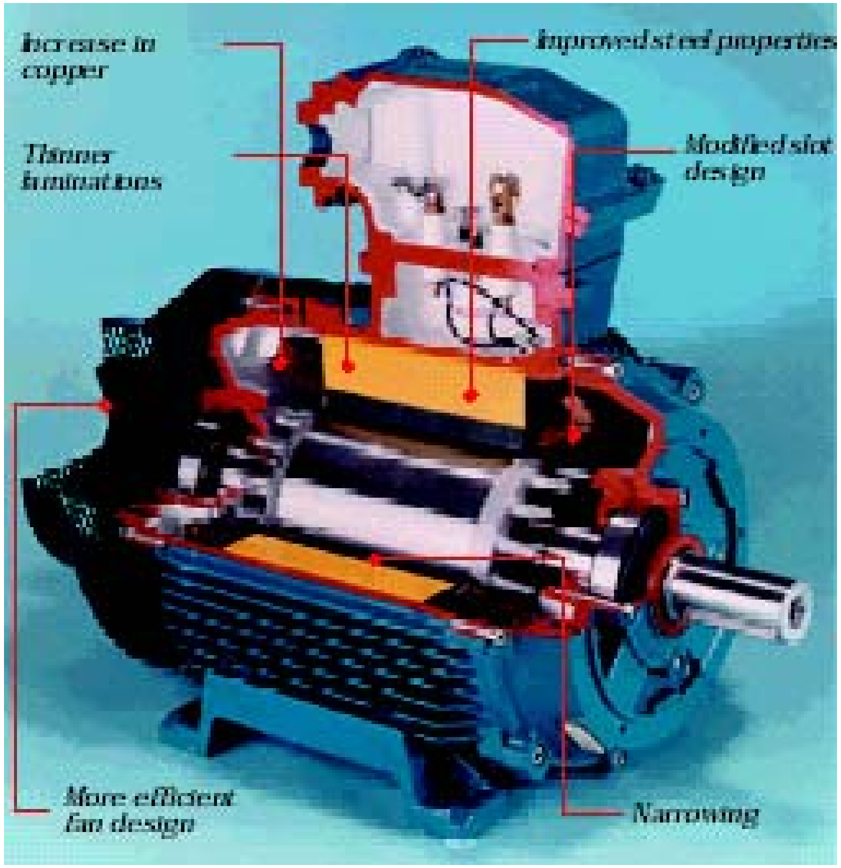
- *Motors <40HP and >15 years old (or prev. rewound) have significantly lower efficiencies, hence it is best to replace them*

- *If the rewind cost exceeds 50% to 65% of a new HEM price, buy a new HEM. Increased reliability and efficiency should quickly recover price premium*

Source: Buying an Energy-Efficient Electric Motor, Motor Challenge

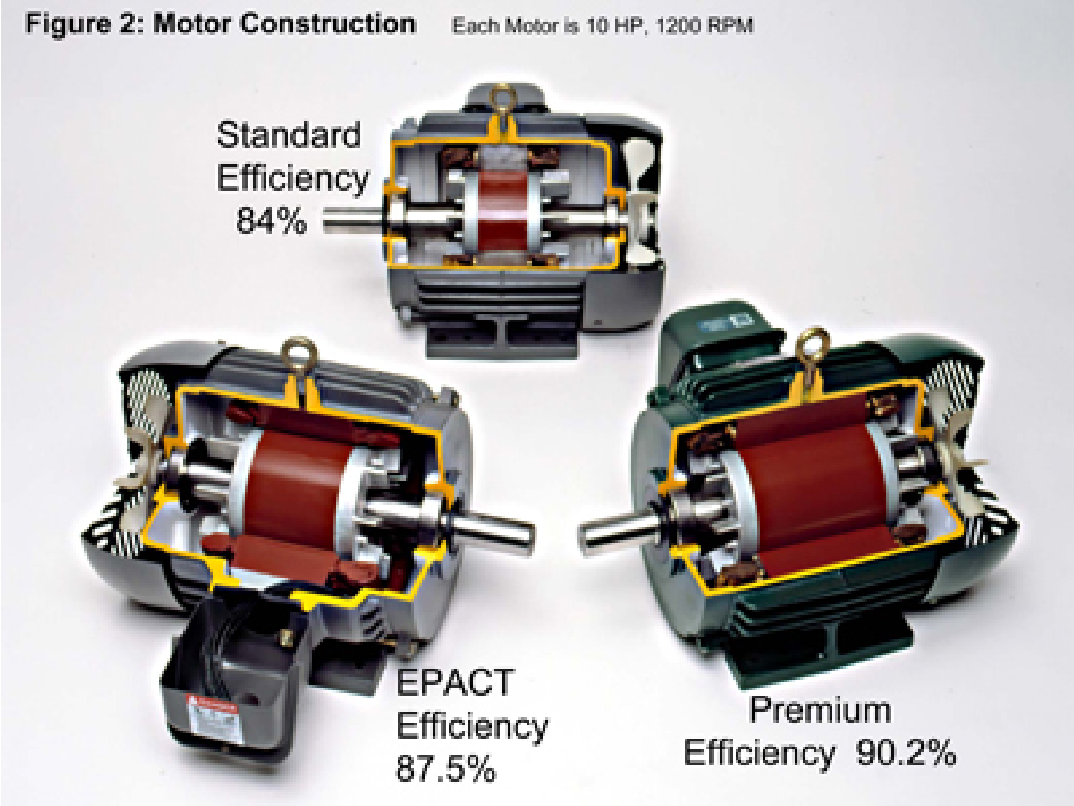
High Efficiency Motors

- Improved steel properties
- Thinner laminations
- Increase conductors volume
- Modified slot design
- More efficient fan design



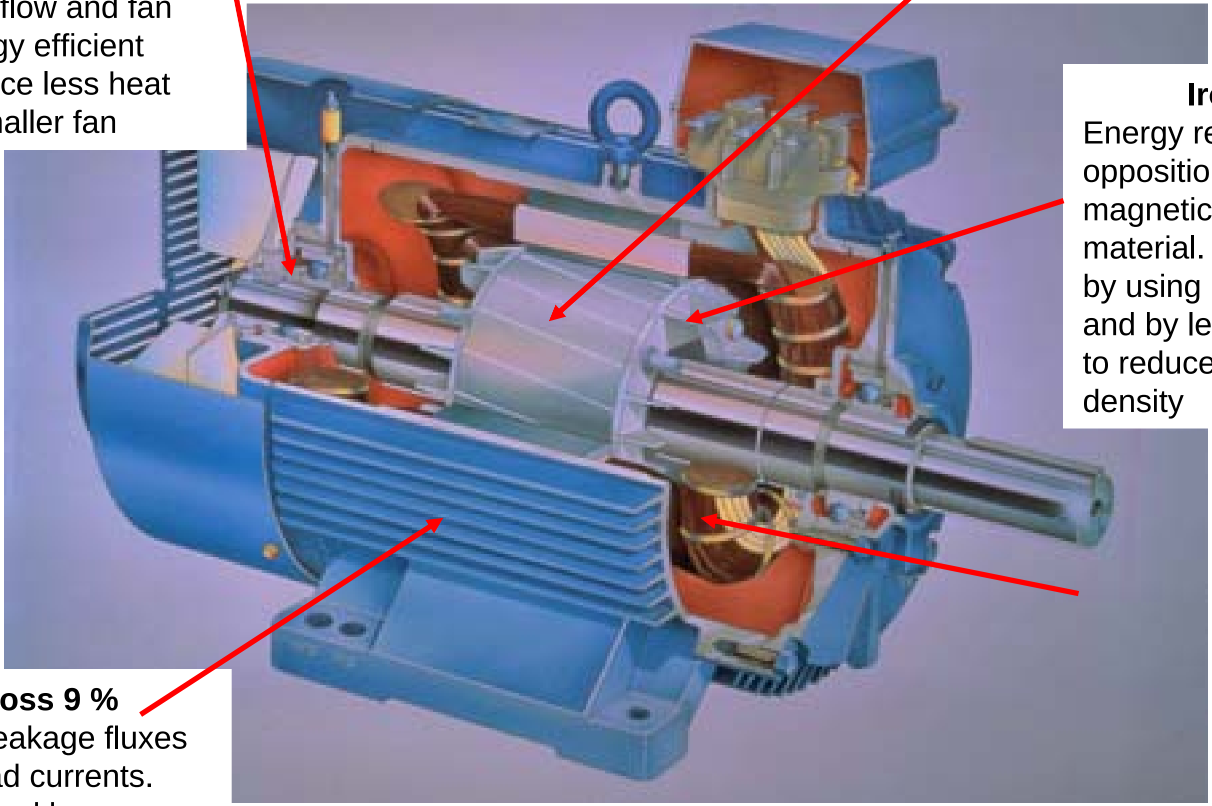
Courtesy of Copper Dev. Centre

Comparison of HEM vs Standard Motors



Source: www.pump-zone.com\how much do electric motors cost?

Energy Losses



Windage + Friction 13 %
Air resistance and bearing friction are essentially independent of motor load. Can be reduced by improving bearing and seal selection, air flow and fan design. Energy efficient motors produce less heat and use a smaller fan

Rotor losses 20%
Heating in the rotor winding can be reduce by increasing the size of the conductive bars and end rings to produce lower resistance

Iron loss 23%
Energy required to overcome opposition to changing magnetic fields in the core material. Can be decreased by using better quality steel and by lengthening the core to reduce magnetic flux density

Stray Loss 9 %
The result of leakage fluxes induced by load currents. Can be improved by improving slot geometry

Motor Efficiencies

- To summarise we can state that higher efficiency is reached by:
  - Smaller joule losses in stator and rotor by using more copper;
  - Smaller iron losses because of better iron core;
  - Smaller mechanical losses because of better ventilation fans and bearings.

Source: Leonardo Energy – Power quality and Utilisation Guide

Motor Efficiencies

- Apart from that the efficiency depends on the following factors:
  - The capacity: larger motors have a higher efficiency;
  - The number of pair of poles: the more pair of poles, the lower the efficiency;
  - The load: the lower the load, the lower the efficiency.

Source: Leonardo Energy – Power quality and Utilisation Guide

Comparison of HEM vs Standard Motors

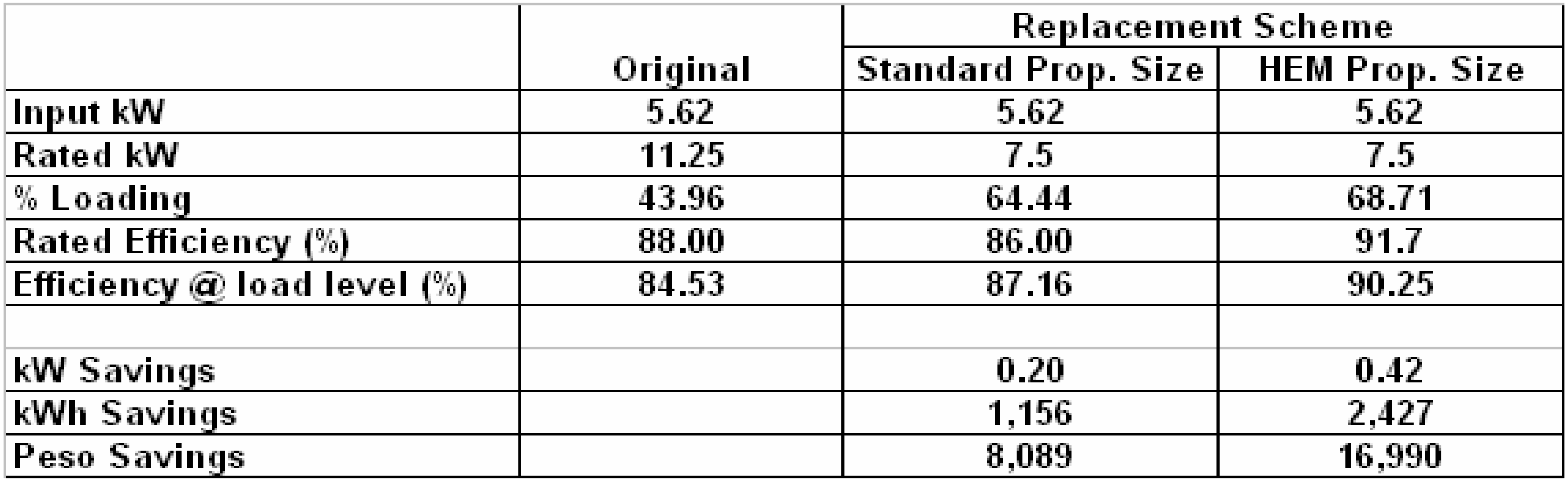
Sample Comparison of Standard Vs HEM

	Typical Losses (Watts)	
Loss Components	Std.	High Eff.
1) Iron	220	104
2) Stator I2 r	530	298
3) Rotor I2 r	218	192
4) Friction & Windage	71	70
5) Stray Loss Load	131	101
Total	1,170	**765**

AC Motor Components of Motor Loss
Typical Design B Motor 10 HP, 1750 RPM, TEFC

High Efficiency vs Standard Motor

Sample Estimated Savings



		Replacement Scheme	
	Original	Standard Prop. Size	HEM Prop. Size
Input kW	5.62	5.62	5.62
Rated kW	11.25	7.5	7.5
% Loading	43.96	64.44	68.71
Rated Efficiency (%)	88.00	86.00	91.7
Efficiency @ load level (%)	84.53	87.16	90.25
kW Savings		0.20	0.42
kWh Savings		1,156	2,427
Peso Savings		8,089	16,990

Note: Efficiency at load level was computed by interpolation using the previous slide, table of efficiency at diff. loading conditions

Estimated Annual Peso Savings

$$\text{kW Saved} = \text{kW} \times \left(\frac{1}{\text{EffSTD}} - \frac{1}{\text{EffHE}} \right)$$

$$= 5.62 \text{ kW } (1/0.8453 - 1/0.9025) = 0.4214 \text{ kW}$$

$$\text{kWh Saved} = \text{kWsaved} \times \text{hours}$$

$$= 0.4214 \times 5{,}760 = 2{,}427 \text{ kWh}$$

Peso Savings = 2,427 x *P7.0/kWh = P16,990

@P9/kWh: Savings = P21,843

*Peso/kWh, may vary depending on applicable rate

operating hours = 20 hours/day, 24 days/month, 12 months/year

Using High Efficiency Motor

Simple Payback Period

$$\text{Payback Period} = \frac{\text{Cost of High Efficiency Motor}}{\text{Peso Savings}}$$

$$\frac{*45{,}000\text{ Php}}{16{,}990\text{Php}}$$

$$= \quad 2.65\text{ years}$$

Only 2 years if electricity rate is P9/kWh

Sample - HVAC Applications

A Library and Archive premises uses a number of chillers and air conditioning units to maintain a constant cool environment for stored films and video tapes. A detailed study was undertaken on four motors so that the performance of high-efficiency motors could be compared directly. Table 2-3 gives details of the motors selected & table 2-4 shows the comparison between Standard and HEM in these 4 applications . The overall payback period on the replacements was 1.1 years

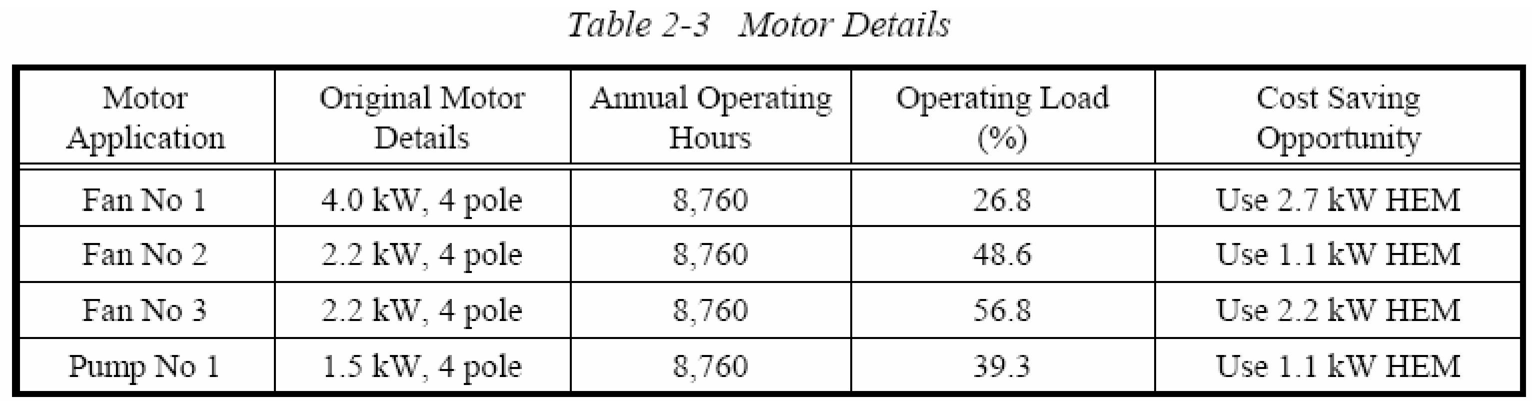


Table 2-3 Motor Details

Motor Application	Original Motor Details	Annual Operating Hours	Operating Load (%)	Cost Saving Opportunity
Fan No 1	4.0 kW, 4 pole	8,760	26.8	Use 2.7 kW HEM
Fan No 2	2.2 kW, 4 pole	8,760	48.6	Use 1.1 kW HEM
Fan No 3	2.2 kW, 4 pole	8,760	56.8	Use 2.2 kW HEM
Pump No 1	1.5 kW, 4 pole	8,760	39.3	Use 1.1 kW HEM

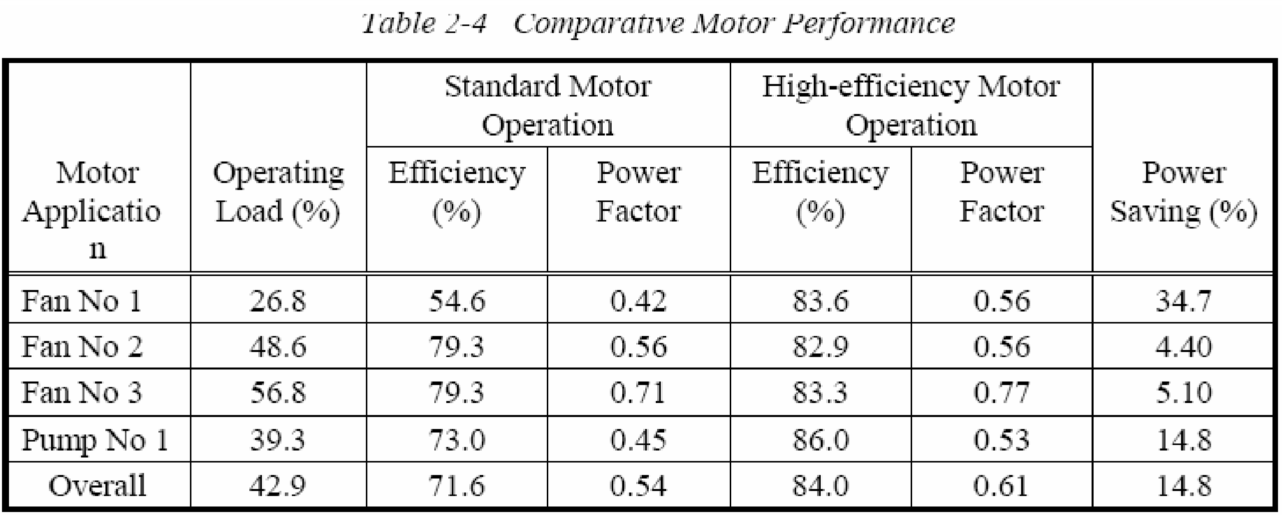


Table 2-4 Comparative Motor Performance

Motor Application	Operating Load (%)	Standard Motor Operation		High-efficiency Motor Operation		Power Saving (%)
		Efficiency (%)	Power Factor	Efficiency (%)	Power Factor	
Fan No 1	26.8	54.6	0.42	83.6	0.56	34.7
Fan No 2	48.6	79.3	0.56	82.9	0.56	4.40
Fan No 3	56.8	79.3	0.71	83.3	0.77	5.10
Pump No 1	39.3	73.0	0.45	86.0	0.53	14.8
Overall	42.9	71.6	0.54	84.0	0.61	14.8

Other Benefits of Good Motor Loading and High Efficiency

- *Improved Power factor*
- *Less kW demand*
- *Reliability*

Energy Savings Through Variable Speed Drives

Variable Speed Drives

- In applications that require flow or pressure, particularly in systems with high friction loss, the most ‘energy effective’ technique is often variable speed control. This is because the consumed power is proportional with **n^3**, n being the number of revolutions.

Suitable Prime Movers for Variable Speed include:

- Electronic Inverter Drive
- Slip ring and commutator type AC electric motors
- Slip coupling
- DC electric motors
- Variable V-belt drives
- Steam turbine and reciprocating motors
- Multi-speed dual wound or pole changing electric motors

Electronic Inverter Drives

- Major advantages of electronic variable frequency drives of speed control over other techniques:
  - Reliable soft start-up and shut-down procedures;
  - Independent torque and speed control;
  - Lots of motor safety controls.

Motor Power Input using Variable Speed Drives

$$\frac{\text{Input Power}_2}{\text{Input Power}_1} = \left(\frac{\text{Fan Speed}_2}{\text{Fan Speed}_1}\right)^3$$

$$\frac{\text{Input Power}_2}{\text{100 watts}} = \left(\frac{\text{650 rpm}}{\text{500 rpm}}\right)^3$$

$$\text{Input Power}_2 = \text{220 watts}$$

Sample - Variable Speed Drive Application

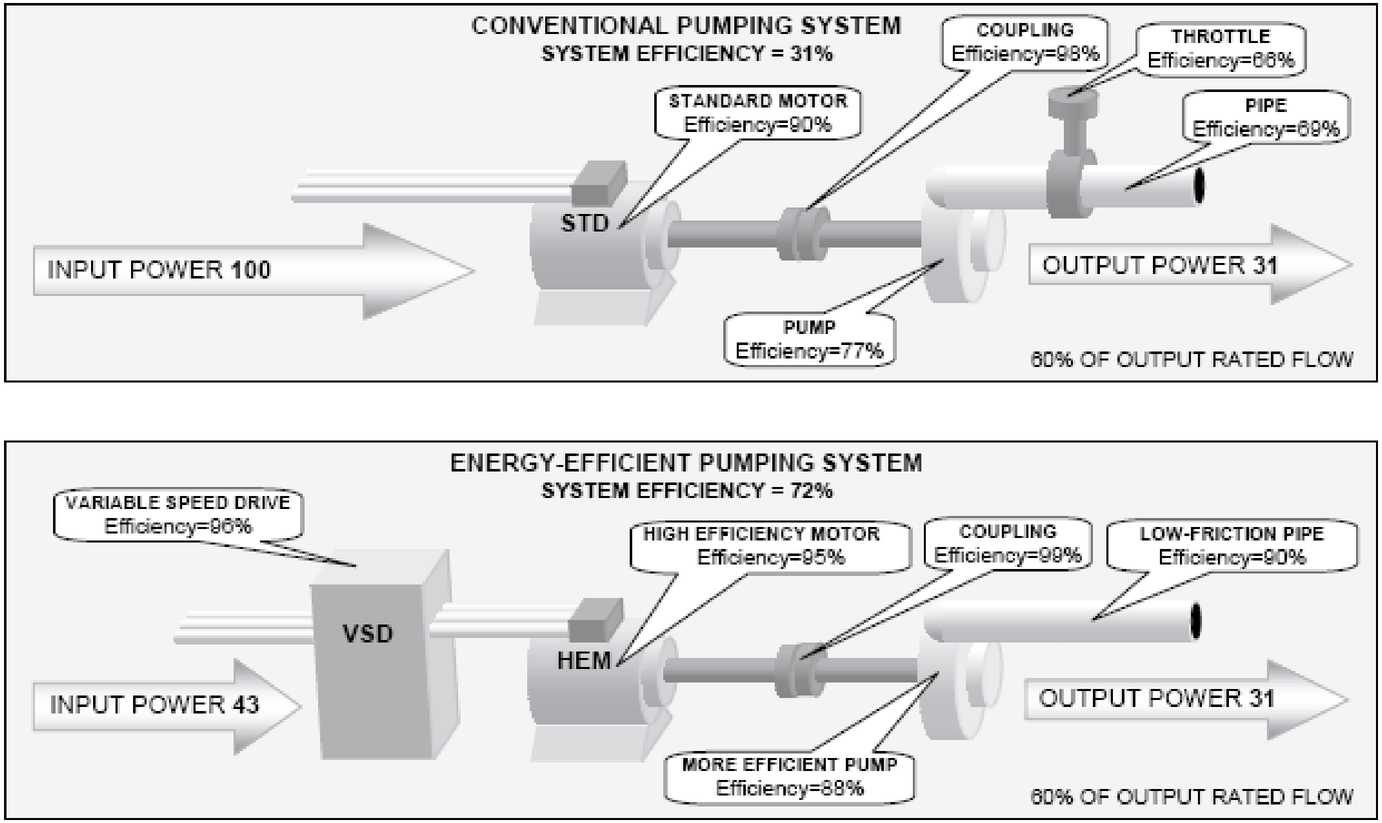
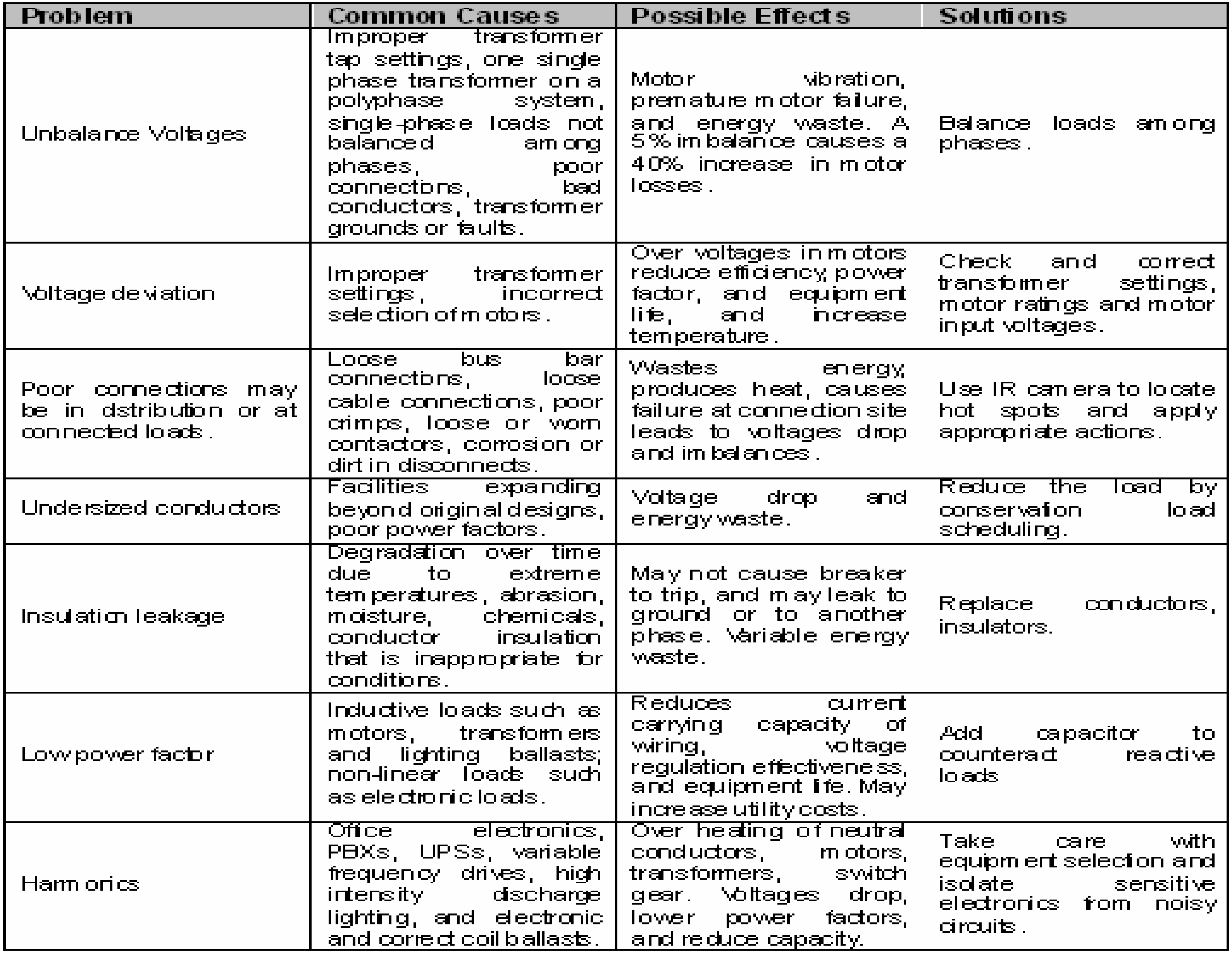


Figure 1 - a) Conventional pumping system (total efficiency = 31%)
b) Energy-efficient pumping system combining efficient technologies (total efficiency = 72%)

Power Quality

Power Quality Issues



Problem	Common Causes	Possible Effects	Solutions
Unbalance Voltages	Improper transformer tap settings, one single phase transformer on a polyphase system, single-phase loads not balanced among phases, poor connections, bad conductors, transformer grounds or faults.	Motor vibration, premature motor failure, and energy waste. A 5% imbalance causes a 40% increase in motor losses.	Balance loads among phases.
Voltage deviation	Improper transformer settings, incorrect selection of motors.	Over voltages in motors reduce efficiency, power factor, and equipment life, and increase temperature.	Check and correct transformer settings, motor ratings and motor input voltages.
Poor connections may be in distribution or at connected loads.	Loose bus bar connections, loose cable connections, poor crimps, loose or worn contactors, corrosion or dirt in disconnects.	Wastes energy, produces heat, causes failure at connection site leads to voltages drop and imbalances.	Use IR camera to locate hot spots and apply appropriate actions.
Undersized conductors	Facilities expanding beyond original designs, poor power factors.	Voltage drop and energy waste.	Reduce the load by conservation load scheduling.
Insulation leakage	Degradation over time due to extreme temperatures, abrasion, moisture, chemicals, conductor insulation that is inappropriate for conditions.	May not cause breaker to trip, and may leak to ground or to another phase. Variable energy waste.	Replace conductors, insulators.
Low power factor	Inductive loads such as motors, transformers and lighting ballasts; non-linear loads such as electronic loads.	Reduces current carrying capacity of wiring, voltage regulation effectiveness, and equipment life. May increase utility costs.	Add capacitor to counteract reactive loads
Harmonics	Office electronics, PBXs, UPSs, variable frequency drives, high intensity discharge lighting, and electronic and correct coil ballasts.	Over heating of neutral conductors, motors, transformers, switch gear. Voltages drop, lower power factors, and reduce capacity.	Take care with equipment selection and isolate sensitive electronics from noisy circuits.

- ***Additional Notes on HEM***

Why Choose High Efficieny Motors

- Three factors to keep in mind whether you’re replacing an old worn out motor or specifying for a new piece:
  - Energy efficient motors only provide savings when they’re running, and the more the motors run, the more energy and money they save.
  - Maximum savings (and the fastest returns on investment) are attained in regions where utility rates are highest. Even so, energy-efficient motors are highly recommended even in low energy-cost areas because they provide savings that justify their initial cost over time.
  - Select motor for its intended application . Every new installation should only be made after conducting a thorough analysis of the economic and technical factors involved.

Energy Efficient Motors

- *“An electric motor can consume electricity to the equivalent of its capital cost within the first 500 hours of operation - a mere three weeks of continuous use, or three months of single shift working.*
- *Every year, the running cost of the motor will be from four to sixteen times its capital cost.*
- *Over its working life, an average of thirteen years, it may consume over 200 times its capital cost in energy.*
- *Clearly, the lowest overall cost will not be achieved unless both capital and running costs are considered together.”*

CDA Publication 116

Barriers to HEM Usage

- Lack of awareness
- Energy expenses are invisible to management – hidden in general overhead
- Low priority among capital investment and operating objectives
- Subsidies on electricity price
- First cost vs. long term operating costs
- Reluctance to change a working process due to lack of experience

Good Day!!

Thank You.

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ENPAP - AEMAS