A Best Practices Training Presentation

U.S. Department of Energy

Motor Systems Assessment Training, Including Use of the Motor Systems Tool Suite
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U.S. DOE Industrial Technologies Program (ITP) BestPractices Website

www.eere.energy.gov/industry/bestpractices
EERE Information Center (877) 337-3463
Or www.eere.energy.gov/informationcenter
Big Picture Perspectives: Industrial Motor Systems

Industrial motor systems:

- Are the *single largest electrical end use* category in the American economy
- Account for 23% of U.S. electrical sales.
A motor SYSTEM is the entire energy delivery process, from electric feed to finished product.

- **Utility feed**
- **Transformer**
- **Breaker/starter**
- **ASD (maybe)**
- **Motor**
- **Driven Load**
- **Mechanical Work**
- **Ultimate goal**

**Motor Systems Assessment Training**
Typical Motor System Losses

- **Controller losses**: <1 to ~5% for ASD
- **Coupling device losses**: <1 to >10% for large speed reduction
- **Load modulation devices**: 0 to >50%
- **Driven load losses**: 30 to 50% for pumps and fans
- **Motor losses**: 3.5 to >10%
- **Electrical distribution system losses**: <1 to 5%

Useful Work
Industrial Motor System Savings Potential

Industrial motor system energy use can be decreased by 11% to 18% if industries deploy all mature/proven and cost-effective energy efficiency technologies.

The total savings potential is 75 to 122 billion kWh/year....Valued at $3.6 to $5.8 billion per year at current industrial rates.

Source: 1999 Xenergy Study
What is efficiency?

Efficiency = Output / Input
Efficiency = (Input - Losses) / Input
Efficiency = Output / (Output + Losses)

They’re all mathematically equivalent.
"Energy Efficient"

- This 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.

"NEMA Premium™ Efficient"

- This covers 3-phase induction motors from 2-poles to 6-poles. It pertains to low voltage motors from 1-500 HP and medium voltage (>600 & <5000V). See http://www.nema.org/premiummotors

To Compare all the motor efficiency standards, see http://www.energy.wsu.edu/ftp-ep/pubs/engineering/motors/EfficiencyStandards.pdf
WHAT MAKES AN ELECTRIC MOTOR ENERGY EFFICIENT?

More copper wire of larger diameter in the stator saves energy by reducing the resistance of the stator winding.

Thinner steel laminations decrease eddy current losses.

Larger conductive bars and end rings reduce rotor resistance losses.

Efficient cooling fan design improves air flow and reduces power required to drive the fan.

Modified stator slot design helps to decrease magnetic losses and makes room for larger diameter wire.

Longer stator lowers magnetic density and increases cooling capacity. As a result, both magnetic and load losses are reduced.

Premium grade steel core reduces hysteresis power losses.
Standard, EE, PE Motors – Amount of Copper, Size of Rotor

Courtesy: Toshiba
Replacement Results in Big Savings

- Efficiency (TEFC 4-pole Motors) (percent)
- Horsepower

- Orange dots: Average Old Motor
- Green stars: NEMA EE/EPACT
- Yellow squares: NEMA Premium
- Blue triangles: Prior NEMA EE Standard

Motor Systems Assessment Training
Motor Part Load Performance

### Motor Systems Assessment Training

#### Motor Part Load Performance

- **Nameplate hp**: 150
- **Synch. rpm**: 1600
- **Rated voltage**: 460
- **Motor class**: Average
- **Energy efficiency standards** (NEMA MG1 Table 12-10):
  - ODP: 95.00
  - TEFC: 95.00
- **Full load amps**: 172.61

#### Current, power factor, efficiency

<table>
<thead>
<tr>
<th>% load</th>
<th>% FLA amps</th>
<th>pf%</th>
<th>eff%</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>36.58</td>
<td>60.15</td>
<td>92.48</td>
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<td>100.00</td>
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<td>94.47</td>
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</tbody>
</table>

#### Graphical Representation

Current (% of full load), pf (%), and eff (%) vs load (%)

- **kW**
- **KW**

Load % from 0 to 125
Efficiency versus full-load speed
Motor Management Planning--
Motor Survey and Screening Techniques

Motor Systems Assessment Training
Motor Management Planning

Goals and Benefits:

- Provide dollar savings through reduced energy costs
- Minimize energy consumption (energy use per unit of product)
- Maximize efficiency while reducing downtime
- Improve system reliability and productivity
Rule of Thumb for Energy Management

One person-year of effort should be allocated for energy management activities for every $1 million spent on energy bills annually.

After your program has been launched, the level can be set at one person-year for every $2-$5 million spent annually.
Motor Management Program
Building Blocks

- Accurate Motor Inventory Tracking System (or, conduct Motor Survey)
- New Motor Purchasing Policy: Specify Premium Efficiency
- Proactive Repair/Replace Policy
- Strategic Spares Inventory (PEM- Ready)
- Adopt Best Practices Repair Standards
- Predictive and Preventive Maintenance Planning
Information Requirements for Motor Management Planning

- Understand Utility Rates
- Gather Motor Nameplate Data
- Establish Motor Operating Profiles
- Tune your Electrical Distribution System
- Obtain Measurements at Connected Loads
- Know Your Load Requirements
Key Energy Management Activities

Analysis

- Identify Energy Conservation Opportunities
- Evaluate Cost-effectiveness of Capital Improvements
- Prepare a Motor and Motor-Driven Systems Improvement Plan

Implement Measurements and Verify Results

MotorMaster+ Analysis Capabilities

MotorMaster+ Savings Tracker
Specifying a Motor

- Horsepower rating (integral hp, 1-500)
- NEMA Design, Metric, Two-speed
- Enclosure type (ODP, TEFC, EXPL)
- Voltage rating
- Synchronous speed
- Special or Definite Purpose
- Frame Size
- Efficiency class
A small fraction of the motor population is responsible for most energy consumption.

Note the descending order (left to right).

10% Population uses 80% energy.
Additional Inventory Filters

Focus On:

- Non special or definite purpose motors
- Motors with accessible and readable nameplates
- Include spares

Include information on the coupling, driven equipment, and load requirements
Motor 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
### Motor Efficiency Data

#### Company Database

- TMP Mill

#### Motor Efficiency Data

<table>
<thead>
<tr>
<th>Horsepower</th>
<th>1-3</th>
<th>5</th>
<th>7.5</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
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<td>0</td>
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<table>
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<tr>
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<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>15</td>
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<tr>
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<td>0</td>
<td>1</td>
<td>6</td>
<td>3</td>
<td>1</td>
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#### Energy Efficiency and Premium Efficiency

- **Energy Efficient**: 8.6 % by number, 8.7 % by horsepower
- **Premium Efficiency**: 7.1 % by number, 7.3 % by horsepower
- % by load served: Incomplete
### Motor Efficiency Data

#### Company Database
Kraft Pulp Mill

#### Company Information

<table>
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<tr>
<th>Horsepower</th>
<th>1-3</th>
<th>5</th>
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<th>10</th>
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<th>400</th>
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<tbody>
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<td>14</td>
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<td>10</td>
<td>13</td>
<td>2</td>
<td>7</td>
<td>227</td>
</tr>
</tbody>
</table>

#### Energy efficient

- % by number: 13.0
- % by horsepower: 10.2
- % by load served: (Incomplete)

#### Premium efficiency

- % by number: 33.2
- % by horsepower: 26.4
- % by load served: 0.0
An evaluation of customer-supplied operating hour assumptions in PGE’s Drive-Power program found widespread scatter. Measured or true values ranged from 0 to 8,000 hours for an assumed value of 2,000 hours; and from 500 to 8,760 hours for estimates of 6,500 hours.
Operator Operating Hour Estimates

![Diagram](image)

- Ideal (Measured = Estimated)
- Based on Metered Data
- Original Program Estimated Hours
Motor Improvement Planning
Action Items

Replace critical motors with histories of frequent failures immediately

Develop a new motor purchase policy

Determine which operable motors should be immediately replaced based on cost-effectiveness criteria

Identify which motors should be replaced with Premium Efficiency units when they fail

Establish a PEM-Ready spares inventory
Forget First Cost!

100 HP TEFC EPACT motor costs ~ $6,256
It costs $38,985 to operate per year!
(or 623% of first cost)

@ $.054/kWh & $4.87/kW, 8150 hrs/yr, 100% load

Now consider a car: First cost ~ $25,000
Even at $3.00/gal, annual fuel costs are only about $1,500 or 6% of first costs
@ 12,500 miles/year, 25 mpg
Equivalent Rates of Use

If the new car used energy at the same ratio of first cost to annual operating cost as the motor:

--- It would have to be driven about 216,375 miles or 348,220 km every two months, or

--- Gasoline would have to be priced at $311.58/gal (or $82.30/liter)
# Annual Savings from Specifying New NEMA Premium™ Efficiency Motors

<table>
<thead>
<tr>
<th>Horsepower</th>
<th>Full-load Motor Efficiency (%)</th>
<th>Annual Savings from Use of a NEMA Premium™ Efficiency Motor</th>
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<tbody>
<tr>
<td></td>
<td>Energy Efficient Motor</td>
<td>NEMA Premium™ Efficiency Motor</td>
</tr>
<tr>
<td>10</td>
<td>89.5</td>
<td>91.7</td>
</tr>
<tr>
<td>25</td>
<td>92.4</td>
<td>93.6</td>
</tr>
<tr>
<td>50</td>
<td>93.0</td>
<td>94.5</td>
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<tr>
<td>100</td>
<td>94.5</td>
<td>95.4</td>
</tr>
<tr>
<td>200</td>
<td>95.0</td>
<td>96.2</td>
</tr>
</tbody>
</table>

Note: Based on purchase 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 $0.05/kWh.
Contingency planning - making the change when a failure occurs

The alternatives evaluation picture changes dramatically when failures occur.

Changes that couldn't be justified when the system was functional may very well be after failure.

The alternative may actually be less costly than simple repair/replacement of the existing component.
Turn Misfortune to Advantage

A motor failure can provide a good opportunity to tune up other aspects of the system:

Downsize motor where appropriate.

- Evaluate driven load speed with respect to new motor; change sheaves size if warranted. Remember pump and fan drive power can vary at the cube of speed or even greater.
- Consider upgrade to an ASD and inverter duty motor.
Repair versus Replace: You Need to Consider...

First cost of repair and new purchase.
Efficiency of existing and proposed new motor.
Urgency and availability of each alternative.
Possible modifications to the mounting.
Annual hours of operation.
Cost of down time and repairs from a possible early failure in either scenario.
Utility incentives
# Replace versus Repair Existing Standard Efficiency Motors

<table>
<thead>
<tr>
<th>Horsepower</th>
<th>Motor efficiency (%)</th>
<th>Annual Savings from Use of a NEMA Premium™ Efficiency Motor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standard Efficiency Motor</td>
<td>NEMA Premium™ Efficiency Motor</td>
</tr>
<tr>
<td>10</td>
<td>85.7</td>
<td>91.7</td>
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<td>25</td>
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<td>200</td>
<td>92.8</td>
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</table>

Note: Based on purchase 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 $0.05/kWh.
Breakpoint HP Replacement with TEFC Nema Premium Efficiency Motor
Coverage Charts tell a Story
(for 200 hp 1200 RPM Motors)
Excess Number of Spares?
(125 hp 1800 RPM)
Accelerated Motor Replacement

Cumulative Energy Savings

- 2.23 Million kWh/year
- Savings Increase

Time (years)

% Total Savings

Accelerated Replacement
Baseline
## Motor Improvement Plan

<table>
<thead>
<tr>
<th>Old Motor</th>
<th>New Motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor # 1</td>
<td>Replace W / EE When Failed</td>
</tr>
<tr>
<td>Motor # 2</td>
<td>Downsize / Replace W / EE When Failed</td>
</tr>
<tr>
<td>Motor # 3</td>
<td>Immediate Replacement W / EE</td>
</tr>
<tr>
<td>Motor # 4</td>
<td>Replace W/Standard or Repair When Failed</td>
</tr>
<tr>
<td>Motor # 5</td>
<td>Investigate ASD Potential</td>
</tr>
</tbody>
</table>
Summary

- Motor nameplate
- Type of load
- Operating hours
- Field data (Amps, Volts, Watts, PF, RPM)
- Utility rates
- Utility rebates
- Repair or replace?
- Savings Tracking
- Batch Analysis

MotorMaster +

Motor Energy Management Plan

Motor Master +
Version 3.0
**What is MotorMaster+?**

**Decision Support Software**

<table>
<thead>
<tr>
<th>Motor Price and Performance Database</th>
<th>Energy Management</th>
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</thead>
<tbody>
<tr>
<td>Motor Selection Tool</td>
<td>Energy Accounting</td>
</tr>
<tr>
<td>Energy Savings Analysis</td>
<td>Utility Motor Rebate Support</td>
</tr>
<tr>
<td>Inventory Management</td>
<td>Life Cycle Costing</td>
</tr>
<tr>
<td>Maintenance Logs</td>
<td>Tracks Energy Savings and Emissions Reductions</td>
</tr>
</tbody>
</table>
Motor Manufacturers’ Price and Performance Database

Electronic catalog with data for over 27,000 motors

NEMA A-D, IEC (Metric), Two-Speed
General and Definite Purpose (U-Frame, IEEE 841, Washdown, Severe-Duty, Inverter-Duty, Close-Coupled Pump)
Updated approximately every two years
Inventory Management Capabilities

Motor Inventory

Location Searches

**List:** All Motors in descending order of hp or annual energy consumption.
- All Motor
- By Facility
- By Department
- By Process
- By Serving Utility

Descriptor Searches/Selective Reports

- Motors with power supply problem (phase unbalance >=3%, 2%, 1%, etc..)
- Indicate all motors with power factor <=stated value
- Identify rewound motors
- List Motors >=specified age
- List motors by process equipment type
- Identify motors >=or <= stated hp value
- List all spares
- List all oversized motors (load <=40%, 50%)
- Show motors with annual energy use > stated value.
Inventory Management

Track spare and in-service motors.

Store nameplate, operating profile, field measurement, and load-related information.

Automatic motor load and efficiency estimation features.

Can copy catalog or inventory motors.

Possible to import existing motor databases into the Inventory module.
Motor Efficiency Determination

Laboratory: IEEE 112B Basis for NEMA Nominal Efficiency; Nameplate per MG1 Table 12-10

MotorMaster+ Methods

- ORMEL96 - Calculates Part Load Efficiency from Measured Slip plus Nameplate Data
- kW - Calculates Load; Looks up Part-load Efficiency
- Slip - Calculates Load; Looks up Part-load Efficiency
- Amp - Calculates Load; Looks up Part-load Efficiency
Failed Motor Efficiency Upgrade

From user-editable default table.
## Functional Motor Efficiency Upgrade

### Motor Comparison

**Existing** (Avg S/or Efficiency)

<table>
<thead>
<tr>
<th>Size/Speed</th>
<th>HP</th>
<th>1200</th>
<th>RPM</th>
<th>Efficiency (%)</th>
<th>Full load RPM</th>
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<td>1200</td>
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</table>

**Energy-Efficient** (Avg Energy Efficiency)

<table>
<thead>
<tr>
<th>Size/Speed</th>
<th>HP</th>
<th>1200</th>
<th>RPM</th>
<th>Volts</th>
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<tbody>
<tr>
<td>New Motor</td>
<td>800</td>
<td>1200</td>
<td>460</td>
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</tr>
</tbody>
</table>

- **Utility**: Foot Power
- **Rate Schedule**: Schedule 24 - General
- **Facility**: Consolidated Power
- **Energy price ($/kWh)**: 0.06687
- **Demand charge ($/kW)**: 8.750

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*Motor Systems Assessment Training*
Consider discounts, rebates, and other economic factors

LifeCycle lets you apply IRR or make other more precise life cycle economic considerations.
Adding Utility Rate Schedules

Can accommodate two seasons (generally Summer and Winter)

Enter demand charges ($/kW-mo) for each season

Enter energy charges for each season.

Can handle up to three energy charge "tailblocks".

Enter any number of utilities and rate schedules.

Assign at Facility Level.
Life Cycle Cost Analysis

Computes the after-tax return-on-investment in an energy efficiency measure.

Displays cash flows, net present value, and the benefit-to-cost ratio.

Linked to Compare and Batch Analysis modules.
Maintenance Logs
Savings Tracker

Uses “before” and “after” measured values to validate energy and dollar savings from conservation and efficiency improvements.

Motor and driven-equipment Energy Action records are aggregated with total savings indicated.

May create a Greenhouse Gas Emissions Reduction report (EIA 1605 EZ).
Use Batch Analysis to determine which in-plant motors are candidates for immediate replacement with a new Premium Efficiency motor.

Identify which motors should be replaced at their time of failure.

Know which motors should be repaired and returned to service when they fail.
Batch Analysis Capability

Replacing Groups of Inefficient Motors

- MotorMaster+’s Batch Analysis can accept inputs from the Inventory module, automatically conduct analyses, and then summarizes dollar and energy savings due to changing out all motors (in a given plant, department, etc.) or only those motors with simple paybacks below a target value.
Batch Analysis Choices

**Motor Changeout Choices.** The analyst can replace existing motors with a particular brand of motor or identify the “best available” replacement motor. This motor yields the most rapid simple payback on investment.

**Batch Upgrade Capability.** This feature allows the user to specify only severe-duty, NEMA Premium or IEEE 841 replacement motors.
Optimization and Auto Sizing Routine

Identify the “best available” motor. The MotorMaster+ batch analysis will select the “best” replacement motor based on:

- full and part-load efficiency values (bin)
- discounted list price
- centrifugal load speed/slip relationships.

The package of “best” replacement motors provides the quickest overall payback on investment.
Underloaded Motors

Consideration of Oversized and Underloaded Motors. A motor is considered oversized if it constantly operates at less than 40% of full load. Compares’ Auto Downsizing analysis will automatically consider replacement motors of the same size as well as smaller motors.

MotorMaster+ will not allow loads on potential replacement motors to exceed 85%.
How to obtain MotorMaster+

Download from the U.S. Dept. of Energy’s ITP website at:
http://www1.eere.energy.gov/industry/bestpractices/software.html#mm

Additional industrial efficiency resources are available at:
http://www1.eere.energy.gov/industry/