Electric Motor Energy and Reliability Analysis Using the US Department of Energy's MotorMaster+

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Introduction

Energy efficiency in electric motor systems presents significant opportunities within industry. In a US Department of Energy report provided by Xenergy[1], "In 1994, electric motor-driven systems used in industrial processes consumed 679 billion kWh – 23 percent of all electricity sold in the United States…. Implementation of all well-established motor system energy efficiency measures and practices that meet reasonable investment criteria will yield annual energy savings of 75 to 122 billion kWh, with a value of $3.6 to $5.8 billion…" Reliability and maintenance practices on electric motor systems also provide an excellent opportunity for both energy efficiency and production cost avoidance[2], "Drivepower users and utilities have made significant investments in recent years to improve the efficiency of motor-driven systems. The longevity of these measures – as well as the amount of energy they save – depends heavily on the quality of the maintenance they receive. Although it is usual to think of motor system maintenance as an activity that follows other drivepower decisions, it is actually the first step for most facilities in moving towards more efficient motor systems… The efficiencies of mechanical equipment, in general, can be increased typically 10 to 15 percent by proper maintenance."

Keeping these statements in mind, a number of organizations, including electric motor service centers, equipment manufacturers and utilities have been developing electric motor system *maintenance and management* programs starting as early as 1993 to the present. The concepts, in general, have been to include both energy and condition analysis to provide electric motor users with reliable and energy efficient motor systems. The planned result has been to provide a win-win solution for end-users to improve costs and cost avoidance, reduce power demands on utilities and expanded service capabilities for service companies. In recognition of these efforts, and to support new efforts within industry, the US Department of Energy (US DOE), the Electric Power Research Institute (EPRI), utilities, trade associations, and others have funded and supported a variety of informative materials, support lines and software tools. The US Department of Energy

[1] United States Industrial Electric Motor Systems Market Opportunities Assessment, US DOE, December, 1998.
[2] DrivePower, Ch. 12, "Motor System Maintenance," E-Source, Boulder, CO, 1996.

Office of Industrial Technologies, Best Practices program offers a wide variety of information, tools, and support to assist industrial plants in identifying opportunities for energy efficiency in common systems such as compressed air, motor, steam and pumping systems; and in evaluating opportunities for application of new technologies[3].

The focus of this article is to outline the development of a motor maintenance and management program using MotorMaster+ and simple tools available within industry. We shall also discuss an industry-funded modification to MotorMaster+ designed to allow for a reliability assessment of electric motors combined with an economic analysis. The new version of MotorMaster+ (MM+) which included the recent changes for reliability assessment, is presently in use within industry on a number of projects implemented through companies and utilities such as: Pacific Gas and Electric (PG&E); Dreisilker Electric Motors, Inc.; Nicor Gas; Fermi Lab; BJM CORP; Pruftechnik, Inc.; and others. The new version of MM+ is also available to anyone for download at the OIT, BestPractices website referenced earlier.

Considerations for the Development of the Energy and Reliability Program

The purpose of an energy and reliability program for electric motor systems is to decrease the cost of energy, production and maintenance overheads associated with the production of a product. In effect, reducing the cost per production unit as effectively as possible. "Motor maintenance is more than making sure the motor itself is operating correctly. It also involves ensuring that power supplied to the motor is within acceptable tolerances, that the motor's output power is efficiently transmitted to the load and that the load itself is properly maintained so as not to make the motor work harder than necessary."[4]

The key components of a motor maintenance and management program include:

- Control of the electric motor system inventory in software.
- Pre-made repair versus replace and retrofit decisions.
- Predictive and preventive maintenance program implementation with a continuous improvement component.
- Include top management commitment.
- Usually have an in-house energy coordinator.
- Have obtained employee buy-in.
- Have pre-set energy conservation goals.
- Partnerships between vendors and owners implemented with pre-planned decisions and shared information.

The results of such a program can be immensely effective, resulting in improvements of 10 – 15%, or more.[5] These opportunities result from such simple improvements as:

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[3] Note: Many of these software tools and other information are available for download from the US Department of Energy's Best Practices website: www.oit.doe.gov/bestpractices

[4] Efficiency Opportunities through Motor Maintenance, Application Note, Pacific Gas & Electric, April 25, 1997.

[5] Efficiency Opportunities through Motor Maintenance, PG&E

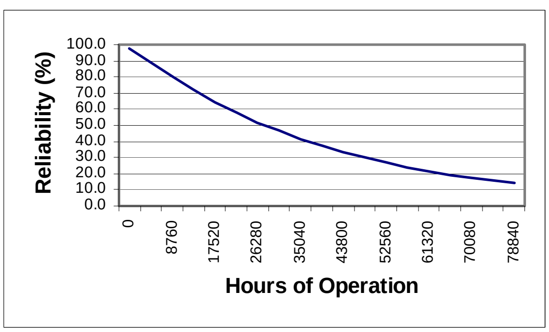
Replacing failed electric motors with energy efficient or premium efficient electric motors; Scheduled and proper greasing of electric motor bearings, reducing electric motor system friction losses; correcting impedance unbalance in motor windings and electrical systems; correct belt tension and alignment; properly sizing electric motors to the load; testing questionable equipment before and after repair; and other measures that can be immediately implemented or implementation planned for outages. These examples and other related benefits can have energy, reliability, waste stream and production financial impacts that more than justify the combined energy and reliability effort.

Reliability

In all dynamic systems, the chance that the system will operate as designed decreases over time. Electric motors are made up of a number of dynamic systems in which each has a reliability function that decreases as the motor ages. The purpose of a reliability based motor program is to optimize the costs of operating the electric motor and equipment. Measuring the reliability of electric motor systems by quantifying the costs associated with unreliability places the reliability portion of the motor management program in the arena of business impact.[6]

The reliability of the system, as defined within this article, is the measure of the chance that the equipment will operate over a period of time. One of the keys to understanding reliability is knowing the Mean Time Between Failures (MTBF). For instance, if an electric motor has a failure rate of one in 40,000 hours, the MTBF would be 40,000 hours. The failure rate for that motor would be 1/MTBF, or 2.5×10^{-5} (identified as λ).

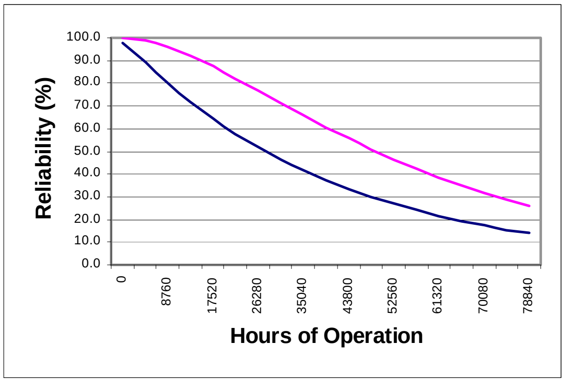
Figure 1: Reliability Over Time



Knowing the failure rate, the information can be applied to the reliability function ($R = e^{-t\lambda}$). Therefore, the chance that the motor system will operate for 50,000 hours would be: $R = e^{-(50{,}000)*(.000025)} = 0.287$, or 28.7%. In a redundant (parallel) system, the overall system reliability increases. The result of a single parallel system is $R = R_a + R_b - (R_a)(R_b)$. Using the previous example, the parallel system has a 49.2% chance of operating through 50,000 hours.

[6] A Novel Approach to Industrial Assessments for Improved Energy, Waste Stream, Process and Reliability, Howard W. Penrose, Ph.D, Kennedy-Western University, 1999.

Figure 2: Parallel Reliability



In an electric motor maintenance and management program, there are several points in which the system reliability can be influenced. These points include:

1. Acceptance of new electric motors
2. Acceptance of motor vendors
3. Acceptance of repaired electric motors
4. Acceptance of motor repair centers
5. Tracking and correction of minor defects during the life cycle of the system (Predictive and preventive maintenance, Root-Cause-Analysis, Reliability Based Maintenance, etc.).

It is important to note that the reliability of a vendor should be measured over time and not based upon singular visits and measurements. In particular, a series of specifications should be provided and the vendor measured against that specification over time.

The reliability costs of a motor system can be calculated. In the following example, a motor fails twice per 50,000 hours, it takes 6 hours to repair the system upon each failure, the system operates 8,760 hours per year, production costs are $10,000 per hour and maintenance costs are $100/ hour (energy, motor repair / replacement and waste costs not considered):

Table 1: Reliability Cost Example

	Lifecycle	Annual
Interval (hours)	50,000	8,760 / year
Failures	2	0.351/yr
MTBF (hours)	25,000	25,000
Failure Rate (10^{-6}), λ	40	40/hr
Repair Time (hours)	12	2.1
Production Cost	$10,000 / hour	$21,000 / year
Maintenance Cost	$100/hour	$210 / year
Availability	13.5% over 50,000 hours	70.4%/year
Costs	$121,060 over 50,000 hours	$21,210 / year

Should a maintenance and reliability program (for this one system of many) reduce the failures by half, the impact would be a cost of $58,300 over 50,000 hours, a reduction of $62,760 (52%).

Energy

There are two basic energy costs that must be observed in an energy and reliability program: life cycle or annual energy costs; and, energy costs due to motor condition. In the first instance, the annual operating costs are based upon motor load, energy usage and demand charges, operating hours, motor size and efficiency. When viewing energy costs due to condition, the increased losses due to phase unbalances or increased friction and windage (bearing failure, for instance) are taken into account.

Equation 1: Energy Demand

$$\text{kW usage} = \%\text{Load} \times 0.746 \times (\text{horsepower} / \text{Efficiency})$$

Equation 2: Energy Demand Between Electric Motors

$$\text{kW} = 0.746 \times \text{hp} \times \%\text{L} \times (100/\text{Lower Eff.} - 100/\text{Higher Eff.})$$

When considering the previous (reliability) example as an 1800-RPM, 50 horsepower electric motor, 75% loaded, 92% efficient, operating 8,760 hours per year, the operating demand would be 30.4kW. The annual usage would be 266,304kWh. If the energy charges are an average of $14 per kW demand and $0.06 per kWh usage, the associated costs would be (30.4kW x $14/kW x 12 months) $5,107.20 demand and $15,978.24 usage per year for an annual energy bill of $21,085.44 or $120,397.86 over the 50,000 hour life cycle (5.7 years).

If the 50 horsepower electric motor is compared to a new, 95% energy efficient, electric motor with a purchase price of $2,400 and installation cost of $600, the annual cost savings would be $161.32 demand and $756.86 usage per year, or $918.18 total per year. This would yield a simple payback of ($3,000 cost + installation / $918.18 annual savings) 3.3 years. In many cases, companies will set a two-year payback as the minimum before performing a motor retrofit (replacing a working motor with a new energy efficient motor). However, when performing an economic (lifecycle) analysis, the before tax Benefit-to-cost ratio would be 1.62 and the after tax return on investment would be 32.6%, which is normally an acceptable rate for a retrofit.

Should the 50 horsepower electric motor fail in operation, a repair versus replace scenario may be performed. The difference between the new motor cost and the repair cost are used to determine the simple payback. In this case, the repair costs $1,250, resulting in a difference of $1,150. The simple payback is ($1,150 cost / $918.18 energy savings) 1.25 years, with a 5.53 after tax benefit-to-cost ratio and 212.7% after tax return on investment. Thus the motor should be replaced versus repaired.

The preceding examples assumed that only efficiency would be the appropriate evaluation. When considering condition, these numbers begin to change drastically. For the following example, a motor circuit analysis evaluation of impedance shall be reviewed. Impedance unbalance and voltage unbalance are similar as, per Ohm's Law: Current = Voltage / Impedance, resulting in the following examples being applicable to both voltage and impedance unbalance.

The purpose of an electric motor is to convert electrical energy to mechanical torque. It operates best when all three phases, of a three-phase motor, are 120 electrical degrees from each other and other stator, rotor and friction losses are controlled. As the phases vary from 120 degrees from each other, the efficiency of the electric motor decreases because it becomes harder for the magnetic fields within the stator to turn the rotor, and, when far enough off, they interfere with each other. This effect is found in both voltage and impedance unbalances, including impacts to efficiency, reliability and production.

Figure 3: Impedance Unbalance and Efficiency

A 50 horsepower electric motor, as shown in the previous examples, with a 3.5% impedance unbalance would have a resulting efficiency of 89% (3% reduction due to heating). The resulting energy costs would be $5,275.20 demand and $16,503.84 annual energy usage, totaling $21,779.00 per year, an increase of $689.64 per year.

<u>Combined Energy and Reliability</u>

When considering both energy and reliability, production losses can be incorporated as part of the costs. The following information is gathered for evaluation based upon the preceding examples:

- Electric Motor: 50 hp, 1800 RPM, 75% loaded, 8,760 hours per year, 92% efficient with a 3.5% impedance unbalance (89% resulting efficiency).
- Electrical Costs: $14/kW demand and $0.06/kWh.
- Reliability: 2 failures every 50,000 hours.
- Lifecycle: For the purpose of this example, the lifecycle is 50,000 hours.
- Replacement motor: 50 hp, 1800 RPM, premium efficient motor (95%), balanced phases that will reduce the failures to one in 50,000 hours.

Table 2: Combined Energy, Reliability and Production Costs

	Leave As Is	Replace Motor
Reliability Costs	$121,060.00	$58,300.00
Lifecycle Energy	$124,358.09	$116,437.41
Production Costs	$120,000.00	$60,000.00
Corrective Maintenance	$1,200.00	$600.00
Total	**$366,618.09**	**$235,337.41**
Annual Costs	**$64,206.32**	**$41,214.96**

Savings incurred will be at least $22,991.36 with an investment of $3,000 resulting in a simple payback of 1.6 months.

Selection of Tools for an Electric Motor Energy and Reliability Program

As part of each successful electric motor energy and reliability program, a series of tools and software have to be selected in order to monitor and maintain the program. Based upon a series of market transformation and industrial assessment projects[7,8], several considerations must be made when putting together an energy and reliability toolkit: Initial cost; training requirements; ergonomics; accuracy; and least invasive to the process.

These concepts were incorporated in a recent PG&E study, which focused on electric motor energy and condition issues only. The purpose was to assemble a "tool kit" based upon independent research into a number of data logging, efficiency and condition analysis tools to determine energy and condition opportunities and how they interrelate. The initial areas of study were software, data loggers, motor circuit analysis, vibration analysis, and infrared analysis. The results were to be developed into an Electric Motor Performance Analysis Tool (PAT) which would be used as part of a market transformation strategy[9]. The tools that resulted from this study included: the US Department of Energy's MotorMaster+; the Fluke 41B; the Summit Technology PowerSight 3000 datalogger; the BJM CORP ALL-TEST IV PRO motor circuit analyzer; and, the Pruftechnik Vibratip. Infrared analysis was determined not to play a part in the motor only analysis, but would be an effective tool in a motor system analysis.

MotorMaster+

MotorMaster+ (MM+) is used as a motor management support tool for commercial and industrial sites. It is designed for auditors, industrial energy coordinators, and plant or consulting engineers to provide the most efficient and cost effective decisions for electric motor and system planning. MM+ is used to identify inefficient, undersized and

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[7] Electric Motor Performance Analysis Tool (PAT): Market Transformation Plan, Howard W. Penrose, Ph.D, Flowcare Engineering and PG&E, PG&E, 1999.

[8] A Novel Approach to Industrial Assessments for Improved Energy, Waste Stream, Process and Reliability, Howard W. Penrose, Ph.D, Kennedy-Western University, 1999.

[9] Electric Motor Performance Analysis Tool (PAT): Market Transformation Plan, Howard W. Penrose, Ph.D, Flowcare Engineering and PG&E, PG&E, 1999.

oversized electric motors then calculate the energy and demand savings associated with the selection of energy efficient or premium efficient replacements.

Figure 4: MotorMaster+

The software tool contains a hierarchy of each plant being analyzed, a field data module, a motor price and performance database on over 20,000 new motors, energy conservation analysis, life cycle analysis, energy accounting capabilities and even an environmental conservation capability.

The field data module serves as a motor inventory and field measurement storage repository. The module houses motor nameplate information, identification, process, and location codes; load type, operating hours and working environment descriptions; and such measured data as voltage, amperage, power factor and speed at the load point.

The user can choose from a variety of descriptor-based motor inventory sorts within the Field Data Module. Motors operating under abnormal power supply conditions can also be detected. Measured values are used to determine existing motor loads and efficiencies. Batch analyses can be conducted automatically for populations of motors, determining the costs and energy savings due to changing out all motors in a given facility or process, or only those motors with simple paybacks below a stated value.

MotorMaster+ Version 3.0 also includes

- A database of performance and price information on more than 20,000 IEC (metric) and National Electric Manufacturers Association (NEMA) Design B, C, and D three-phase motors. The motors range from 1 to 4,000 horsepower (hp), with speeds of 900, 1,200, 1,800, and 3,600 rpm, and open drip-proof (ODP), totally enclosed fan-cooled (TEFC), totally enclosed non-ventilated (TENV), weather-protected (WP), totally enclosed air-over (TEAO), totally enclosed blower-cooled (TEBC) and explosion-proof (EXPL) enclosures. Motors rated to operate at 200, 208, 230, 460, 575, 220/440, 796, 2,300, 4,000, and 6,600 volts are included. Full- and part-load efficiency values are measured in accordance with the IEEE 112 protocol to guarantee consistency. Manufacturers supply the information, and the database is updated annually.

- Technical data that can help optimize a drive system, such as data on motor part-load efficiency and power factor; full-load speed; locked-rotor, breakdown, and full-load torque; and idle and locked-rotor amperage.
- Purchase information, including list price, warranty period, catalog number, motor weight, and manufacturer's address.
- Analysis features that calculate the energy savings, dollar savings, simple payback, cash flows, and after-tax rate of return on investment from using a particular energy-efficient motor in a new purchase or retrofit application. Variables such as motor efficiency, purchase price, energy costs, hours of operation, load factor, and utility rebates are taken into account.
- Utility rate schedule and motor rebate program data, including minimum qualifying efficiency and rebate dollar values.
- Energy accounting, conservation savings tracking, and greenhouse gas emissions reduction reporting capabilities.
- Menus and extensive help screens that make MotorMaster+ easy to learn and use.

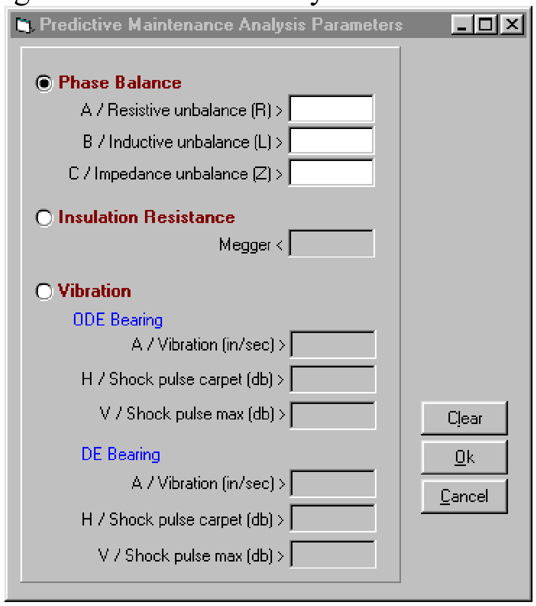
MotorMaster+ Version 3.0 contains many motor energy management features. An informed MotorMaster+ user can:

- Create a list of available new motors that meet your purchase specifications.
- Determine both energy and dollar savings from selecting and operating an energy-efficient motor model.
- Compute annual cash flows and the after-tax rate of return on a motor systems investment.
- Create a company motor inventory database and generate searches and reports based on motor and load descriptors.
- Initiate motor repair or replacement analyses for populations of motors within a company.
- Produce energy conservation summary, facility reduction in consumption, and greenhouse gas emissions reduction reports.

MotorMaster+ Modification

A modification to the existing MM+ was necessary in order to perform the condition analysis portion of the PG&E market transformation project. The modification was to allow for the ability to enter and search phase balance data in resistance, impedance and inductance, insulation resistance, and vibration analysis data in velocity and shock pulse. BJM CORP coordinated and led the effort to implement this "first ever" industry funded modification to the MM+ software. Other industry participants also included Pruftechnik, Inc.; Dreisilker Electric Motors, Inc.; Washington State University; Pacific Gas & Electric; Boeing; General Motors; Oak Ridge National Labs; the US Department of Energy and many others. BJM CORP, Dreisilker Electric Motors, Inc., Pruftechnik, Inc., and Pacific Gas & Electric worked together to define and promote the MM+ modification. This group coordinated with Washington State University and the US Department of Energy to implement the change. US DOE and WSU welcomed the industry recommendations and financial support for the MM+ modification. The version of MotorMaster+, which includes this recent modification, is available for anyone to download.

Figure 5: Condition Analysis Search Screen



Electrical Data Collection and Logging

There were two basic approaches selected for data collection. One was “snap-shot” data collection for basic data entry into MM+ of Voltage, Current, Power Factor and kW. The second was data logging of these measurements over time. The first instrument selected was the Fluke 41B which provided the snapshot measurements required for under $2K per instrument, was portable, and simple to learn. The data-logger was selected as the PowerSight 3000 which provided the datalogging capabilities, ease of use, cost under $4k each and were already on-hand to the utility and its customers. Flowcare, Inc., the primary contractor for the project, developed a special tool for consolidating the electrical data and providing it in a manner that data entry into MM+ was made much simpler.

Motor Circuit Analysis

A number of motor circuit analyzers were studied for implementation into the project. Both on-line and off-line instruments were reviewed and a number tested[10]. Most testing devices were found to be extremely expensive while providing limited information that could be directly related to energy costs. On-line tests were found to have challenges when applied in certain electrical environments, including variable frequency drive outputs and required a great deal of training and experience. The ALL-TEST IV PRO was selected because it was a static (off-line) impedance-based meter, which provided the necessary measurements of resistance, impedance and inductance unbalance for the project. It was found to be the simplest to use, the most accurate, weighs less than 2

[10] “Static Motor Circuit Analysis: An Introduction to Theory and Application,” IEEE Electrical Insulation Magazine, Howard W. Penrose, Ph.D and James Jette, July/August 2000, Volume 16, Number 4, p. 6 – 10.

pounds, was the least intrusive of the off-line tests (less than 4 minutes for a complete battery of tests) and cost under $8K.

Vibration Analysis

There were a much larger variety of vibration analyzers that were available for review. Based upon a survey of equipment users, ease of use, portability and best cost (less than $10K), the Pruftechnik Vibratip was selected as the vibration analyzer of choice. It provided the necessary measurements of velocity, carpet shock pulse and max shock pulse that allowed for a quicker determination of bearing condition. Shock pulse was selected because this measurement type was not proprietary to the equipment.

Equipment Implementation Costs

As part of the implementation phase of the utility study, a number of case studies are underway. The effectiveness of both a basic (electrical data only) and advanced (energy and condition data) industrial survey, reviewing best cost of training, personnel, equipment and results are being reviewed. A two day training program covering data collection, data entry, equipment use and analysis, and report writing was developed, one of the benefits of the selected tools ease of use. Equipment costs were as follow:

- Basic Analysis Equipment – data-logger and snap-shot instrument with MM+: $6,000
- Advanced Analysis Equipment – data-logger, snap-shot instrument, motor circuit analyzer and vibration analyzer: $24,000

By using a variety of tools, more than one person may be collecting a variety of data at one time. Presently, systems to automate data entry are under development.

The first site selected was a paperboard plant. Forty electric motors ranging from 15 to 200 horsepower were found to yield annual savings of $15,000 per year based upon just the basic analysis and energy savings. The simple paybacks on all motors varied from one to five years, the return on investment was well over 20% and the benefit to cost ratio was over 2:1, with 16 motors found to be oversized, 2 overloaded, and 22 inefficient. This study provided a small sample of the electric motors within the plant selected and could be used to assist in the justification of a much larger survey.

Application of Energy and Condition Analysis

In 1999, the University of Illinois at Chicago Energy Resources Center was contracted by Dreisilker Electric Motors, Inc. to perform a combined energy and reliability assessment at a coal-fired power plant. The primary tool used for analysis was the MotorMaster+ software tool, version 3.0. The project was a challenge as no listing or locations of electric motors existed for the plant. The survey was limited to support motors only.

The survey identified 366 motors for evaluation with 328 in-service and 38 spare electric motors. Of the in-service electric motors, 315 were Design B, 12 Design C, and one

Design D. The Design B motors are primarily used with fans, pumps and air compressors, the Design C motors were used for coal conveyors and the Design D was a hopper motor. Of particular importance was the use of Design C motors for the incline coal conveyors. This is because of the particular torque requirements for the startup and movement of the conveyors loaded with coal. The Design C motor is excellent for this type of application because of high start-up, pull-up and breakdown torques. If a Design B motor were to be used in place of a Design C, as was the case at the plant prior to the survey, it would most likely stall during the pull-up torque portion of the torque curve.

Figure 6: Plant Survey

Because of the age of the plant, a number of other considerations for retrofitting or repairs versus replace decisions had to be observed:

- As many of the larger electric motors are original frame or U-frame, base retrofits or modifications have to be considered as an additional cost.
- Shaft couplings may have to be changed out to fit newer electric motors, due to different shaft sizes.
- Heaters, fuses, starters and wiring must be properly sized to work with appropriate electric motors.
- Possibility of variable frequency drive applications for fans, pumps, and air compressors.
- Operating speed differences between newer energy efficient and older electric motors.

Through the use of MotorMaster+, retrofit and repair versus replace decisions were analyzed from an energy standpoint. For the purposes of the study, the following information was used: Estimated energy costs, \$0.025/kWh usage and \$10/kW demand; a 35% discount factor for a particular brand of electric motors selected by the plant; and a maximum 5-year payback. As a result, 15 of the in-service electric motors were found to be excellent retrofit candidates, with a use reduction of 68,705 kWh and a demand reduction of 8.2 kW for a 37% after-tax return-on-investment and a 1.7 Benefit-to-Cost ratio. In addition, 51 electric motors were found to be excellent replace instead of repair candidates with a use reduction of 197,254 kWh and 23.5 kW demand ending with a 92.9% return-on-investment and a 3.2 benefit-to-cost ratio.

MotorMaster+ was then used to analyze the in-plant spare motors. Of the 38 electric motors in stock:

- MM+ was used to compare the existing in-use motors to the spares. It was found that 23 of the 38 electric motors did not match any motors in the plant.
- Of the remaining electric motors, due to storage practices, not a single spare was ready for use. A majority were rusty with seized shafts and the remainder were failed motors.

Finally, a series of recommendations for reliability, preventive, predictive, root-cause-analysis and corrective maintenance program were recommended. The MM+ database and capabilities were implemented as part of the program. It was determined that program implementation, including equipment costs, would have an initial 3-month simple payback and a 0.5 month annual cost payback due to reduction in failures, downtime and corrective action costs.

Conclusion

A combined energy and reliability program, using MotorMaster+ and selected data-logging and analysis tools, will have a tremendous payback in energy and industrial assessment programs. With the latest improvement within MotorMaster+, electric motors found in poor electrical or mechanical condition can be analyzed for repair versus replace using an energy-based financial assessment. The fact that the necessary modifications were fully funded by industrial users shows that industry recognizes the potential impact of this type of analysis. The combined energy, reliability, waste stream and production cost avoidance impact in virtually any type of industrial or commercial facility are staggering, allowing for the improved competitiveness of US industry.

Presently, energy and reliability assessments are underway with commercial buildings in Chicago, a national lab in association with a motor repair center and utility, a number of industrial sites, including chemical and petroleum, and as case studies for at least one utility. It is expected that overall operating costs will be improved by at least 10% at each of the facilities.

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His first two books of 2008 are

'Physical Asset Management for the Executive: Caution Don't Read This If You Are On An Airplane' a business strategy book designed to communicate the importance of reliability and maintenance to the profitability of a company; and, 'Electrical Motor Diagnostics: 2nd Edition' which is a textbook that provides information on motor circuit analysis, electrical and current signature analysis, standard testing technologies, time to failure estimation and the development of your motor management program.