



Saving electrical energy efficiently can have both short and long term rewards

Sustainable energy strategies for more energy efficient industrial processes

Energy efficiency is not a new concept, and has been a topic of discussion for many years. The oil crisis of the early 1970s emphasized the importance of energy as a concern for everyone. Although the focus on energy efficiency can ebb and flow with the cost of energy, recent shortages of supply demonstrate why cost alone should not be the driving factor. This became particularly apparent to consumers in California in the early 2000s, as power blackouts became a common occurrence in many parts of the state. Looking forward, energy efficiency is a key component of Sustainable Energy, helping to ensure that current energy usage does not come at the expense of future energy needs.

Globally, industrial users account for approximately one third of total energy consumption.¹ Although, electrical energy ranks third among energy sources for Industrial users, it is among the fastest growing form of energy and is expected to remain so over the next 20 years.² This article will help industrial users identify energy savings opportunities and provide examples of energy efficient solutions.

Opportunity - Electrical Energy Usage in the United States

Consistent with the global trend, industrial users in the US account for approximately 1/3 of the total energy consumed (Figure 1).³ While the efficiency of energy use is difficult to quantify as a whole, a study from the Rocky Mountain Institute (RMI) states: "If the rest of the country achieved the normalized electric productivity of the top performing states, with 100% adoption, the country would save a total of ~1.2 million (30% of our annual electricity use) gigawatt-hours annually."⁴

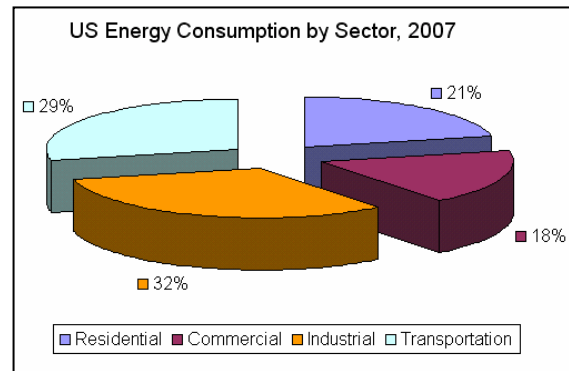


Figure 1: Source: Energy Information Administration, Report: No. DOE/EIA-0384(2007), "Energy Consumption by Sector, 2.1a"

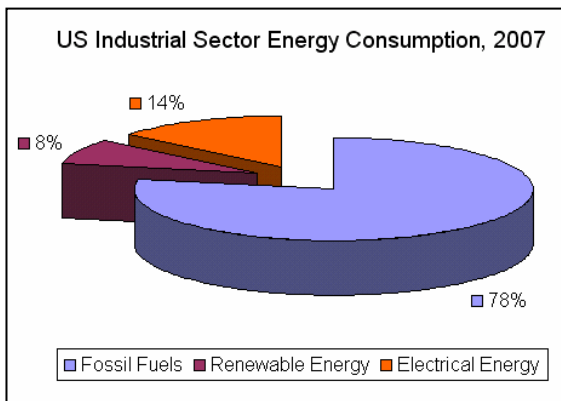


Figure 2: Source: Energy Information Administration, Report: No. DOE/EIA-0384(2007), "Industrial Sector Energy Consumption by Sector, 2.1d"

This does not mean there is a 30% efficiency gain to be had in the industrial sector. However, it does provide an indication there is a large opportunity to become more energy efficient. So, what does this mean for the industrial sector, of which approximately 14% (~3,432 Trillion Btus) of energy consumed is electrical (Figure 2)? Physicist Armo Lovins of RMI states that in industrial settings, "there are abundant opportunities to save 70% to 90% of the energy and cost for lighting, fan, and pump systems; 50% for electric motors; and 60% in areas such as heating, cooling, office equipment, and appliances."⁵



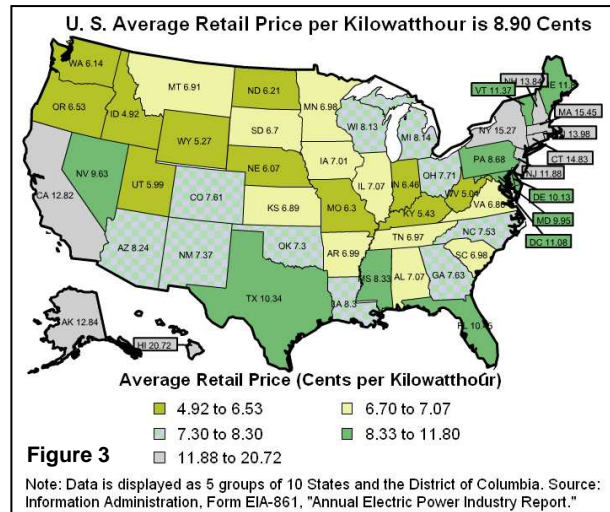
Understanding the cost of Electricity

In order to identify opportunities for electrical energy savings, it is important to understand the cost of electricity for industrial customers. Exact charges for industrial customers may vary depending on the utility. For example, some utilities include fixed service charges, fuel charges, and energy cost adjustments as part of an industrial consumer's bill. This article will cover the basic items common to most US utilities including energy charges, demand charges, and sometimes power factor.

Energy charge

The amount of electricity used over a period of time (hours) is charged at a price per Kilowatt-hour (kWh). Figure 3 shows average retail kWh prices by state. Rates can vary based on the season, the beginning/middle/end of the billing month, energy cost adjustments, etc.

Rates may also be based on time-of-day or time-of-use. These are often referred to as on-peak and off-peak rates. Off-peak rates are lower than on-peak and are commonly applied at night, as the cost to make power can be lower at night and overall usage may be lower at night.



Demand charge

Demand is a measurement of how much electricity, in kilowatts (kW), is being used at a given time. Utilities measure a customer's demand over a fixed period, commonly 15 minutes. A charge is then applied for the highest (peak) 15 minute demand period over the billing period (typically 1 month).

Some industrial customer's demand charges may be impacted by historical demand data or by contract demand rates. These factors may set a minimum demand charge based on demand in previous months. Therefore, it is critical to understand how demand charges are calculated to get the most out of any efforts to minimize the charges.

Electric Bill Example: The utilities energy charge is 7.63 cents per kWh and demand charge = \$5.08 per kW.

Example 1:

The customer runs a 50kW load for 5 hours.

Energy usage = 50kW x 5 hours = 250kWh
Demand = 50kW

Energy charge = 250kWh x 0.0763 = \$19.08
Demand Charge = 50kW x 5.08 = \$254.00
Total = \$273.08

Example 2:

The customer runs a 5kW load for 10 hours.

Energy usage = 5kW x 10 hours = 50kWh
Demand = 5kW

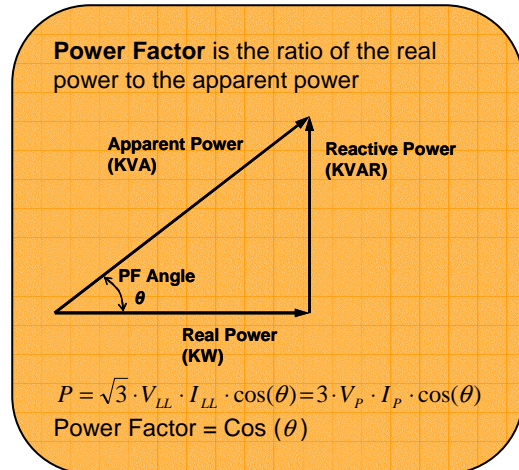
Energy charge = 50kWh x 0.0763 = \$3.82
Demand Charge = 5kW x 5.08 = \$25.40
Total = \$29.22



Power Factor

In general, power factor is a measure of how efficiently power is being used. A unity (1.0) power factor means that all the power being utilized is doing productive work, where as a power factor below unity indicates that a reactive power component is present. Although reactive power is necessary for inductive loads, such as AC induction motors, it does not do any productive work. A power factor well below unity may require the utility to increase the capacity of their transmission and distribution system to handle the additional reactive power component. As a result, some utilities charge industrial customers for a power factor below 0.95.⁶

Low power factor can also result in a decrease of available capacity in the distribution system of an industrial facility due to an increase in losses. As a result of the additional reactive current component, industrial customers may see a voltage drop at the point of use, which can result in inefficient operation of equipment.⁷



Identifying Opportunities

Based on how industrial customers are billed for electrical energy, it makes sense to look for ways to reduce energy usage, reduce peak demand, and ways to more efficiently use energy. Keeping these factors in mind should help identify opportunities that will yield the best return on any investment in necessary equipment or services. Opportunities can be found on individual pieces of equipment, entire production machines, or at the plant level affecting multiple areas of the facility.

Equipment Level

For the purpose of this article, opportunities for energy savings through component replacement or with individual devices will be referred to as equipment level. Examples include lighting, pumps fans, compressors, chillers, or cooling towers. All of these may be part of a larger system or process, but when viewed alone, can also yield significant opportunities for energy savings.

According to the American Council for an Energy-Efficient Economy (ACEEE), "lighting accounts for 20% of all electricity used in the US".⁸ Lighting can be a good place to start, and can quickly yield results. With fluorescent lighting, savings can be achieved simply by reducing the amount of lighting in an area by removing some bulbs in a multi-lamp fixture. To get the most out of the reduced amount of lamps, new reflectors can be installed. Another method for reducing energy usage could be through the use of load shedding ballasts which allow lighting levels to be electronically controlled. Lighting levels could then be reduced at certain times, and increased only when required. Ultimately, more energy efficient fluorescent fixtures can be installed, cutting power consumption by as much as 35%.

Case Example:
Mount Sinai Medical Center in New York

- Replaced standard fluorescent tubes and incandescent lamps with high-efficiency fluorescent lamps, electronic ballasts, and new reflectors.
- Resulted in savings of \$485,000 per year
- 45% annual return on investment.

Source: Nadel, Steven SAVING LIGHTING ENERGY in COMMERCIAL BUILDINGS. Retrieved March 2, 2009, from American Council for an Energy-Efficient Economy Web site: <http://www.aceee.org/press/op-eds/op-ed5.htm>



Many warehouses and factory floors still use metal halide fixtures. In these cases, a significant opportunity exists for reducing energy costs by moving to a different lighting technology. For example, replacing a 400 watt metal halide fixture with a new fluorescent high bay fixture could yield energy savings as high as 50%.⁹

Approximately 64% of electrical power is used for electric motors, indicating another good opportunity for energy savings.¹⁰ A good place to start when looking at electric motors is motor efficiency. For new equipment purchases or as replacements, NEMA premium efficiency motors may make sense. Although these motors typically cost 10-15% more than other energy efficient motors, annual operating costs can give a quick payback on this investment (Figure 4).

Table 1. Annual Savings from Specifying NEMA Premium Motors				
Horsepower	Full-load Motor Efficiency (%)		Annual Savings from Use of a NEMA Premium Motor	
	Energy Efficient Motor	NEMA Premium Efficiency Motor	Annual Energy Savings, kWh	Dollar Savings \$/year
10	89.5	91.7	1,200	\$60
25	92.4	93.6	1,553	78
50	93.0	94.5	3,820	191
100	94.5	95.4	4,470	223
200	95.0	96.2	11,755	588

Note: Based on purchase of a 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.

Figure 4: Source: US Department of Energy. (2005). Energy Tips - Motor Systems (DOE/GO-102005-2019 ed.) [Brochure]. Washington, DC

Making sure motor power ratings have been closely matched to the load or application (often referred to as sizing) is another way to ensure a motor is being used efficiently. Motors run most efficiently when operated around 75% of the full load rating. Additionally, when a motor is run below its nameplate power rating, the resulting power factor suffers. On new equipment proper sizing may be relatively easy to implement, but often for existing equipment motor replacement may not be an option. In these cases, Variable Frequency Drives (VFDs) offer a number of benefits. VFDs offer energy savings benefits on a variety of different equipment such as pumps, fans, chillers, compressors, and cooling towers. Commonly the actual demand in these applications does not match the equipments full load capability on a continuous basis. Because of this, VFDs can yield savings on energy usage, demand charges, and also power factor.

Starting an electric motor with full line voltage, results in a large “inrush current” that can be 6 to 10 times the motors full load current (Figure 5). For large HP motors, this can be an enormous amount of current which may even result in momentary voltage sags on the facilities distribution system. The end result may be a large peak demand and inefficient operation of other equipment due to the momentary voltage sag. A VFD can address both issues by slowly ramping the motor up to the desired speed. The starting current is reduced to levels required to accelerate the load to the desired speed, eliminating the voltage sags that would have resulted from the large inrush of current.

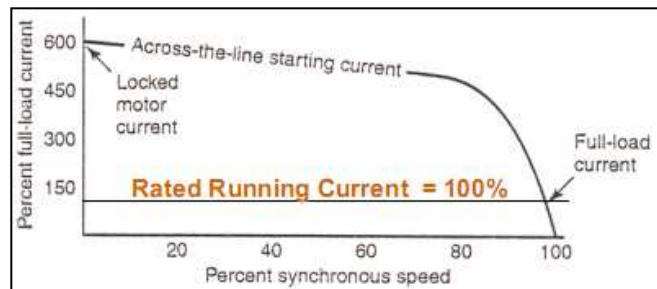


Figure 5: Source: (2004). Seminar on 3 Phase Motor Starting. In I.E.E.E Industry Applications Society



Another benefit a VFD can offer over an electric motor run directly across the line is improved power factor. Electric motor power factor is dependant on the individual motor and the load at which it is run. A VFD can improve the Displacement Power Factor (DPF) across the speed range required by the application. This can be helpful when seeking to reduce low power factor charges, as utilities typically meter and bill only on DPF.¹¹

Power Factor Comparison:

- 200HP Premium Efficiency motor
Power factor = 0.87
(At full load)
- 200HP VFD
Power factor ~ 0.98
(DPF across speed range)

Variable torque applications such as fans and pumps provide an excellent opportunity for a VFD to provide energy savings. The affinity laws quantify the relationship between several application variables for centrifugal pumps, fans, and compressors. The relationships between flow, speed, pressure and power are the basis of the energy savings opportunity.

The fans in an HVAC (heating, ventilating, and air conditioning) application provide a good example to review. Constant speed motors are often used on the fan(s) of an HVAC system in conjunction with variable inlet vanes and output dampers used to control flow. As the flow is mechanically restricted, load is removed from the fan/motor. Power will drop to a degree, but motor efficiency will suffer.

Removing the variable inlet valve, output damper, and using a VFD to vary the speed of the fan to control flow, will result in a much more energy efficient system. As fan speed decreases, the power required decreases as the cube of the speed. As a result, the power can drop significantly with a relatively small drop in fan speed. Figure 6 shows an energy comparison between the two systems.

Affinity Laws:

- Linear relationship between flow and speed

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2}$$

- Pressure is proportional to square of speed

$$\frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2$$

- Power is proportional to cube of speed

$$\frac{P_1}{P_2} = \left(\frac{N_1}{N_2}\right)^3$$

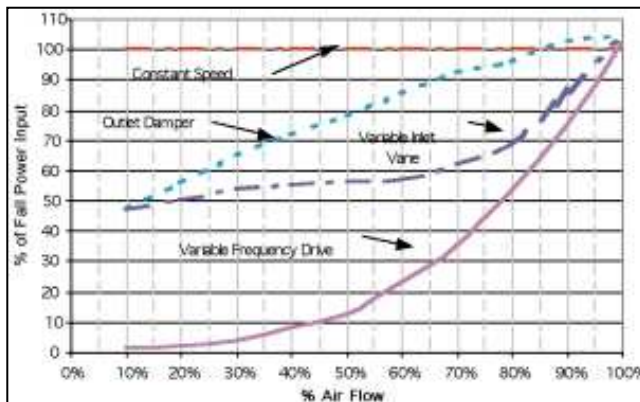


Figure 6: Source: Energy Innovators Initiative, Office of Energy Efficiency, Natural Resources Canada. (2002). *Use of Variable Frequency Drives for Fan and Pump Control* (M92-242/2002-11E ed.) [Brochure]. Ottawa ON



Machine Level

Beyond the infrastructure equipment discussed so far, additional opportunities for energy savings exist on the production machines themselves. This is particularly of interest to machine manufacturers, as it is generally more effective to design a machine with efficiency in mind. However, many of these concepts can also be applied to existing machine retrofits.

One place to start may be in the selection of a control system. This can be particularly important for high speed machines or machines with complex motion control systems. Latencies introduced by the control system can negatively impact machine throughput or performance. This may result in longer production cycles to produce a given amount of product, leading to increased energy costs due to longer operating schedules.

The machine design phase is the best time to ensure motors and drives are sized correctly for the application. As discussed earlier, motors operated well below their rated capability can be very inefficient. This means a higher operating (energy) cost for the end user, as well as a higher initial product cost for the manufacturer. In order to properly size a drive system, consider the following application parameters: the performance requirements, movement profiles, the mechanical drive system (couplings, gear boxes, and inertias), and the ambient temperatures where the equipment will be operated.

The sizing analysis should also yield information about the energy flow of the system. When viewed at an individual axis level, it should become apparent whether the axis is motoring or regenerating during machine operation. This could change during different stages of operation, and could require a method for dissipating the regenerated energy. In simple terms, an axis is motoring when power is flowing from the drive to the motor. Conversely, an axis is regenerating when power is flowing from the motor back into the drive.

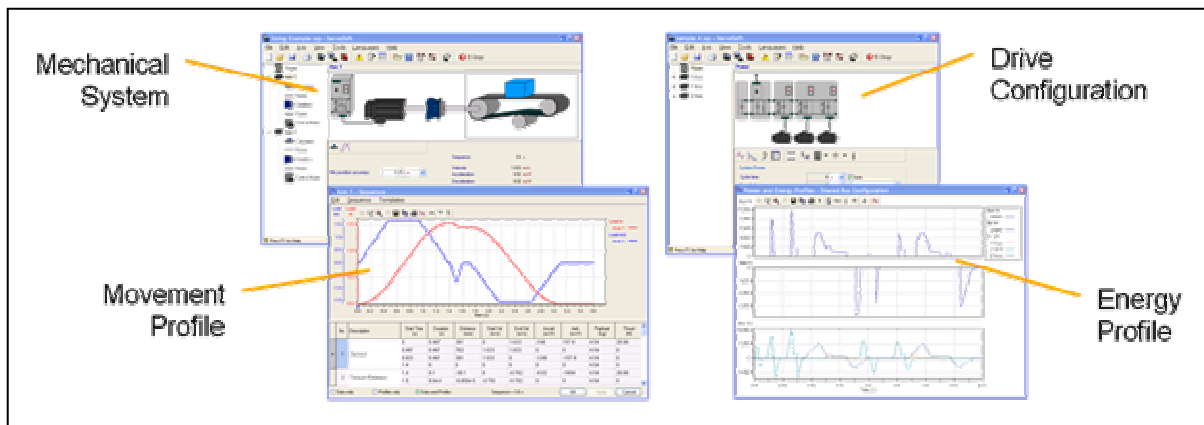


Figure 7: Source: ControlEng Corporation. Retrieved March 2, 2009, from ServoSoft Sample Project 4

System design software can be used to optimize the drive and motor sizes for the application (Figure 7). Additionally, this software can show the energy flow for each axis during different stages of machine operation. This kind of detail is critical to identifying the most efficient method for dealing with regenerative power.



When an axis is regenerating, the power flowing into the drive needs to go somewhere. A common method for dealing with regenerative power is to dissipate the energy with a resistor, often referred to as a braking resistor (Figure 8). While effective in many cases, the regenerative energy is lost as heat. For single axis applications or for applications with minimal regenerative energy, this method may be acceptable.

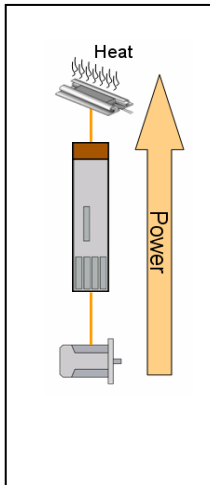


Figure 8

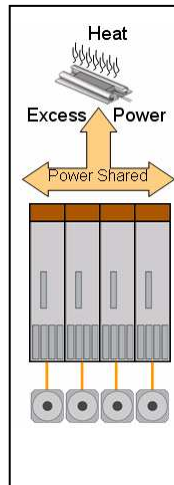


Figure 9

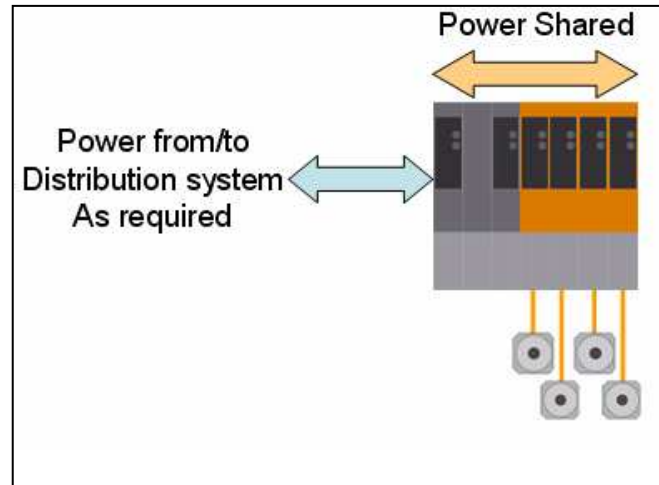


Figure 10

For machines with several axes, interconnecting the DC bus of each drive may be an option. Each drive is still individually fed with its own AC input, however, the shared DC bus connection allows power flowing back into an axis to be used by other axes that are motoring. This will only be effective if other axes are motoring at the same time any given axis is regenerating power. In these cases, a significant amount of energy may be saved and reused by the motoring axes. Any excess regenerative power that cannot be used by another axis can be dissipated with a braking resistor (Figure 9). The amount of excess regenerative power will indicate how efficient this solution will be.

For multi-axis machines there is an additional configuration that may be even more efficient. This solution also requires the DC bus of each axis to be interconnected, but differs in that each drive does not have its own AC input. Instead, each drive receives power from the common DC bus connection. A single Active Front End (AFE) is used to convert its AC input to DC which supplies power to all connected axes. As before, regenerative power from any axis can be used by other motoring axes on the common DC bus. However, instead of losing any excess regenerative power as heat with a braking resistor, the excess energy is put back onto the AC supply (Figure 10). This is extremely efficient as this power is now available for use by other devices. Additionally, because power is shared on the common DC bus, only the net power required needs to be supplied to the drive system.

An Active Front End can have additional benefits beyond reducing overall energy usage. An AFE capable of Power Factor correction can also yield a unity (1.0) power factor. As mentioned earlier, this is a measure of how efficiently power is being utilized. Another benefit of an AFE is the low harmonic content put on the facilities distribution system. Excessive harmonic content can cause a number of inefficiencies in the power system.



An additional item to consider is how to deal with the heat generated by the drive system. Major sources of heat include the drive power electronics, power supplies, and potentially the braking resistors. This may require fans or air conditioning units on the drive enclosure, which then require additional power and maintenance. As discussed earlier, the use of the Active Front End can eliminate the heat generated by braking resistors. To deal with the heat generated by the drive, there are a few options. Many drives are available with heat sink assemblies that can extend through the back of the drive enclosure (often referred to as “heat sink out the back” or flange mount). This places the heat sink on the exterior of the cabinet, removing the majority of the heat caused by the power electronics from the drive cabinet. This heat must still be managed outside the cabinet which may affect air conditioner sizing for the room where the drive cabinet is located.

A more efficient method for removing the heat generated by the drive may be through the use of cold plate cooling methods. Instead of an air cooled heat sink to remove heat from the drive, heat is removed using a liquid (water or oil). Ideally this liquid could be tied into a facilities existing cooling liquid system, through a liquid to liquid heat exchanger. This allows the heat generated by the drive system to be dealt with using existing facility cooling systems.

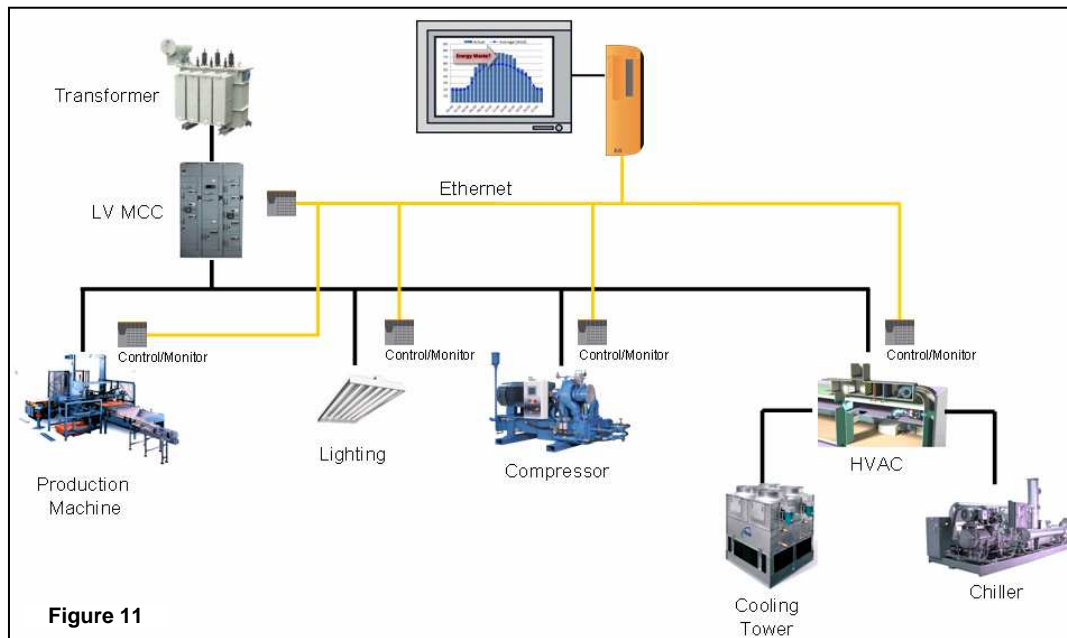
Plant Level

Beyond energy savings opportunities on specific equipment or machines, expanding the scope to the facility or plant level may yield the largest opportunity for energy savings. For example, as shown earlier, changing the type of lamps used in a facility can reduce energy usage. Further reduction in energy usage for lighting may be possible by automatically turning off lighting when not required, or dimming lighting at certain times of the day.

Energy Management Systems (EMS) are a great way to reduce energy usage for an entire facility by taking steps to reduce usage on equipment, groups of equipment, or throughout the facility. EMS devices are commonly used to reduce energy costs by controlling plant wide systems such as lighting, HVAC, compressed air systems, and hydraulic systems. The cost of an energy management system can vary widely, depending on the scope of control and functionality. There is no one system fits all solution, so, some upfront work is required prior to selecting and implementing an EMS device.

A simple EMS device may be a time based system similar to devices used in the home. These devices could also incorporate calendar information such as holidays and weekends. For HVAC systems additional functionality such as inside and outside temperature monitoring could be used to further optimize energy usage by modifying the start times of the system, air flow, and by controlling the use of outside air. The EMS device could be expanded further to incorporate zone control to control air flow to different sections of the facility by controlling damper positions. Control of other related systems such as cooling towers and chillers could also be incorporated into an EMS to fully optimize the entire HVAC system.

Energy Management Systems can also be used to manage demand charges. Monitoring and control devices can be placed at power distribution points and at large loads (Figure 11). Staggering the start of large loads can be used to prevent peak demand charges. Equipment or systems that can be interrupted without disrupting production can also be used to limit demand through Load shedding schemes (shutting off loads to avoid peak demand charges).



As with any activity, it's important to establish energy savings goals. To cut energy cost by 20%, it may only be necessary to complete some of the equipment level measures discussed before. In some cases it may require an energy management program for a given system only, or a multiple system approach may be required. The point is, to focus on activities to achieve the specified goals ensuring the initial cost does not outweigh the cost savings potential.

When evaluating an energy management system, consider how equipment, machines, or whole systems are being used. Are machines run for 16 hours a day or 24 hours a day? What level of lighting is required to perform certain tasks? Does this change throughout the day? Considering these factors can be helpful when selecting a solution or solutions to achieve the established goals.

A manufacturing facility runs (4) production machines that require compressed air. (2) Machines run only during 1st shift. The other (2) Machines run during 1st and 2nd shift. For simplicity, assume each machine requires ¼ of the total compressed air capacity.

- The compressor must be run at full capacity during first shift
- If equipped with a VFD, the compressor could be run at 50% capacity during 2nd shift to match demand.
- The compressor could be shut down during 3rd shift.



Conclusion

There is a significant opportunity in the United States to become more energy efficient, providing both long and short term benefits for all energy consumers. According to a news release from Washington, D.C., "Energy efficiency may be the farthest-reaching, least-polluting, and fastest-growing energy success story of the last 50 years."¹² From a long term perspective, taking steps to use energy more efficiently is a key factor in any sustainable energy strategy. More immediately, there are considerable financial benefits resulting from the use of efficient energy solutions.

By limiting the scope of discussion to electrical energy savings opportunities in the industrial sector, this article has focused on only a small portion of the overall opportunity. Even in the area of electrical energy savings, there are many opportunities beyond those presented. The opportunities chosen for this discussion at the equipment, machine, and plant level provide examples of some typical applications for, and the associated benefits of, energy efficient solutions. The concepts illustrated through these examples should serve to illustrate the importance of energy efficient designs and solutions for both machine manufactures and end users.

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