EFFICIENT USE OF ELECTRICITY IN PROCESS OPERATION

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Contents

Summary

Electrical energy is becoming increasingly important to industry due to the more prevalent use of improved electric process systems and the development of new electrotechnologies. As a result, the potential for reduced energy use through the implementation of electrical-efficiency improvements is substantial.

This article presents the most common electrical-efficiency opportunities for the four main end-use categories: motors and drives, air-compression systems, process heat, and electrolysis. In addition, an explanation for the trend toward electrification is presented along with a list of some of the electrotechnologies that have entered the industrial sector.

1. Introduction

The world consumption of primary energy increased from 3.65×10^{11} GJ (3.46×10^{11} MBtu) in 1990 to 4.01×10^{11} GJ (3.80×10^{11} MBtu) in 1999. This equates to an average annual increase of ~1%. Industry continues to be the leading end-use sector for energy consumption. Currently, in the United States, the industrial sector accounts for 37% of total energy consumption.

Since the oil embargo of the mid 1970s, industrial energy consumption has experienced some fluctuations. Initially, in reaction to increased fuel costs, industrial consumption decreased from its high in 1973. Energy use was reduced by two main mechanisms: efficiency measures and a change to less energy-intensive products.

Energy use has since increased and surpassed its mid-1970s high. However, productivity has also significantly increased (by roughly one-third in the United States). As a result, there has been an appreciable reduction in the energy consumed per unit of output.

Worldwide consumption of electricity produced by nonfuel means (including hydroelectric, nuclear, geothermal, solar, wind, wood, and waste electric power) rose from 4.72×10^{10} GJ (4.48×10^{10} MBtu) in 1990 to 5.84×10^{10} GJ (5.54×10^{10} MBtu) in 1999. This is equivalent to an average increase of 2.4% per year. Currently, in the United States, electricity generation by fossil fuels accounts for ~70% of the net electricity generation.

Throughout the world, industrial sectors account for a significant fraction of industrialized countries' electricity consumption. For example, industry currently accounts for 32% of electric utility retail sales in the United States (see Figure 1).

The residential and commercial sectors of the United States are also significant electricity consumers, and respectively they represent 35 and 30% of total utility retail sales. Other countries have similar breakdowns of electricity consumption. Table 1 lists the quantities and percentages of industrial electricity consumption for selected countries in 1997. In many countries, industrial electricity consumption comprises more than half of total electricity consumption.

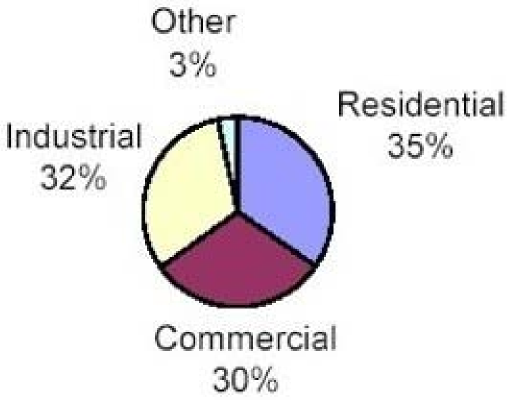

Figure 1. Electric utility retail sales, 11-month total for 2000 (United States), total sales = 3 124 767 GWh (11 months)
Source: Data compiled from Energy Information Administration (EIA), US Department of Energy (US DOE), (2001), Monthly Energy Review, Table 7.5, available on-line at www.eia.doe.gov/emeu/mer/

Area/Country	**Industry**		**Area/Country**	**Industry**	
	GWh	**% of Total**		**GWh**	**% of Total**
USA	1 032 538	34	Macedonia	2500	45
Austria	19 442	39	Monaco	236	59
Belgium	35 446	50	Norway	43 490	38
Denmark	9850	31	Romania	42 875	75
Finland	41 578	59	Slovania	5068	53
France	160 000	42	Switzerland	16 229	33
Germany	228 400	48	Czech Rep.	24 242	46
Greece	13 997	37	Hungary	11 437	38
Ireland	6786	40	Poland	51 176	48
Italy	134 500	53	Slovakia	11 370	47
Luxembourg	3161	62	Algeria	8224	48
Netherlands	41 710	45	Brazil	124 987	45
Portugal	13 821	44	Cyprus	488	20
Spain	66 022	41	Israel	8115	26
Sweden	59 200	45	Japan	380 182	47
UK	94 784	31	Korea	112 207	56
Albania	418	20	New Zealand	15 006	45
Croatia	2700	23	Tunisia	2882	44
Iceland	3761	72	Turkey	45 008	56
Lithuania	5324	59			

Source: Data compiled from UNIPEDE. (1998). *UNIPEDE Electricity Outlook 1998*, Eurelectric, Tables 4a, 4b, and 4c

Table 1. Industrial electricity consumption by country, 1997
Source: Data compiled from UNIPEDE. (1998). *UNIPEDE Electricity Outlook 1998*, International Union of Producers and Distributors of Electrical Energy (UNIPEDE), Brussels, Belgium, Tables 4a, 4b, and 4c

Figure 2 shows the current breakdown of industrial energy use by fuel type in the United States. About 10% of industrial energy consumption in the United States is in the form of electricity distributed by electric utilities; this percentage does not include facility use of electricity that is generated onsite with primary fuels. Electricity losses result from generation, transmission, and distribution.

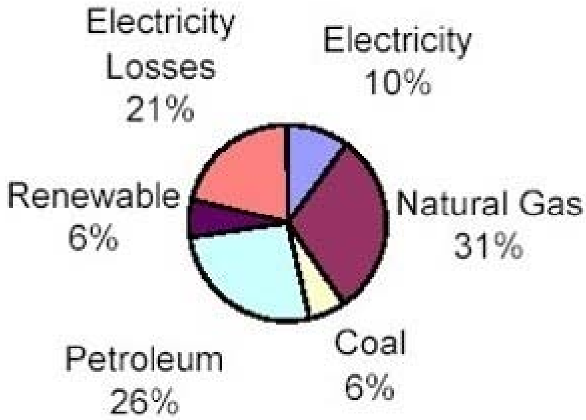

Figure 2. Industrial sector fuel consumption, 11-month total for 2000 (United States)
Source: Data compiled from Energy Information Administration (EIA), US Department of Energy (US DOE), (2001), Monthly Energy Review, Table 2.4, available on-line at www.eia.doe.gov/emeu/mer/

The main end uses of electricity in industry include electric drives, electrolysis, electric process heat, and lighting. Electric drive systems account for the vast majority of electricity use in industry. In the United States, motors and drives consume almost 70% of industrial electricity.

Figure 3 shows the percentage breakdown for each end-use category in the United States. Since this article is concerned with electrical efficiency in process applications, only the first three end uses (motors and drives, electrolysis, and process heat) are applicable. Lighting is a part of building energy use, and is discussed in *Efficient Use and Conservation of Energy in Buildings*. Sections 2 through 5 discuss the energy-efficiency opportunities for four types of process systems: motors and drives, air compressors, process heat, and electrolysis.

Air compressors represent a type of drive system that has the potential for significant efficiency improvements. Consequently, air-compression systems are considered separately from motors and drives. In addition, Section 6 describes the trend toward electrotechnologies, and lists some of the technologies that are entering the industrial sector.

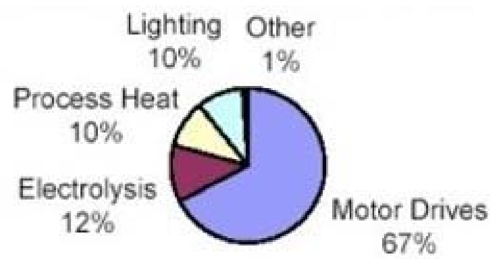

Figure 3. End use of electricity in industry, 1987 (United States)
Source: Data compiled from *Energy Efficiency—Challenges and Opportunities for Electric Utilities*, OTA-E-561, 90 pp. Washington, DC: U.S. Congress, Office of Technology Assessment.

In Sections 2 through 5, the electrical energy-efficiency opportunities in the given end uses may be separated into two main categories: operation and maintenance measures and equipment retrofit and replacement measures. The above categories of energy-efficiency opportunities apply to all types of equipment and systems. The first category consists of measures that are relatively easy, inexpensive, and can be implemented almost immediately. The measures in the second category require more capital expenditure and more effort and time to implement, but generally achieve higher energy savings. Before a measure is implemented, it is important to verify that the measure meets financial criteria, such as an acceptable payback period, return on investments, and/or benefit-to-cost ratio.

2. Motors and Drives

2.1. Perspective

Electric motors and drives use ~55% of all electricity in the United States. In addition, electrically driven equipment accounts for ~67% of industrial electricity use in the United States. There are several types of motors used in industrial applications, including: direct-current (DC) motors, permanent-magnet DC motors, synchronous motors, reluctance motors, and induction motors. Induction motors are by far the most common motor used in industry, and account for over 90% of all the motors of 5 hp (3.7 kW) and greater. As a result of their prevalence, the efficient use of motors and drives presents a considerable opportunity for energy savings in the industrial sector and beyond. Applications of electric drives include compressors, refrigeration systems, fans, blowers, pumps, conveyors, and assorted equipment for crushing, grinding, stamping, trimming, mixing, cutting, and milling operations.

Operation and Maintenance
• Use high-quality lubricants
• Lubricate with the appropriate amount
• Provide adequate cooling to motors
• Clean heat transfer surfaces and vents

• Prevent spillage into motor windings
• Minimize no- or low-load operation
• Match the motor to the application and load
• Use high quality winding techniques and materials
• Consider batch vs. continuous operation
• Properly align belt drives
• Adjust belt tension correctly
• Minimize friction in bearings, gears, belt drives and clutches
• Convert roller chains to silent chains
• Use direct driven loads
• Operate motors at rated voltage
• Balance three phase power supplies
• Minimize losses in power systems
Equipment Retrofit and Replacement
• Modify equipment to recover heat
• Install scheduling, feedback, and power factor controls
• Install variable speed drives, replace throttling valves
• Replace pneumatic drives with electric motors
• Replace steam jets with electric vacuum pumps
• Install high efficiency motors in all new designs
• Install high efficiency motors when motors need replacement
Fans, Blowers, and Pumps
• Reduce flow volume with smaller motors, or different pulleys
• Trim impellors or replace with smaller pump to reduce flow

Table 2. Summary of energy-efficiency opportunities for motors and drives

Section 2.2 includes general energy-efficiency opportunities for electric-drive systems, and a discussion of high-efficiency motors. In addition, a few specific measures to reduce the flow volume through fans, blowers, and pumps are presented. Energy-efficiency measures for air compressors are not presented here, but are discussed in detail in Section 3. Section 2.3 presents calculations showing the energy and cost savings of a high-efficiency motor compared with a standard motor. Table 2 is a summary of the main energy-efficiency improvements that are described below.

2.2. Energy-Efficiency Opportunities

It is best to focus on the entire drive system to realize maximum energy savings. A drive system includes the following components: electrical supply, electric drive, control packages, motor, couplers, belts, chains, gear drives, and bearings. There are losses in each component that need to be addressed for maximum efficiency. In general, efficiency improvements can be made in four main categories: the prime mover (motor), drive controls, drivetrain, and electrical supply. Indirect energy savings can also be realized through efficient motor and drive operation. For example, less waste heat is generated by an efficient system, and therefore a smaller cooling load would result for an environment that is air conditioned. This section focuses on efficiency opportunities in (a) the operation and maintenance of electric drive systems, (b) equipment retrofit and replacement, and (c) controls and alterations to fans, blowers, and pumps.

2.2.1. Operation and Maintenance

The efficiency of motors and drives can be improved to some extent by better operation and maintenance practices. Operation and maintenance measures are typically inexpensive and easy to implement, and provide an opportunity for almost immediate energy savings. The main energy-efficiency opportunities for motors, drivetrains, and electrical-supply systems are described here.

Motors

- It is important to use high-quality lubricants that are appropriate for the particular application. Too much or too little lubrication can reduce system efficiency.
- Adequate cooling of motors can reduce the need for motor rewinds and improve efficiency. Cleaning heat-transfer surfaces and vents will help improve cooling.
- Prevent the spillage of water into motor windings. This is facilitated by choosing leak-proof motors
- Eliminate motors that are operating infrequently or at low loads. Efficiency decreases as the percentage of loading is decreased.
- Size the motor correctly to fit the application. Match its torque characteristics to the load.
- Use high-quality winding techniques and materials (such as copper) when rewinding motors. Consider replacing or rewinding motors with aluminum windings.
- Analyze the merits of continuous vs. batch operation. Is it more efficient to run smaller motors continuously, or larger motors in batch operation?

Drivetrain

- Properly align belt drives. Adjust belt tension correctly.
- Reduce losses due to friction by checking operation of bearings, gears, belt drives and clutches.
- Lubricate the chain in chain drives correctly. Use appropriate types and quantities of lubricants.
- Convert V-belts to synchronous belts.
- Convert roller chains to silent chains.
- Use direct-driven loads in the place of gear, belt, or chain drives for maximum efficiency.
- Use high-quality bearings for minimized friction.

Electrical Supply

- Motors are most efficient if they are operated at their rated voltage.
- Balance three-phase power supplies.
- Losses can occur in the power systems that supply electricity to the motors. Check substations, transformers, switching gear, distribution systems, feeders, and panels for efficient operation. De-energize excess transformer capacity.

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Biographical Sketches

Clark Gellings' 30-year career in energy spans from hands-on wiring in factories and homes to the design of lighting and energy systems to his invention of "demand-side management" (DSM). Mr. Gellings coined the term DSM and developed the accompanying DSM framework, guidebooks, and models now in use throughout the world. He provides leadership in EPRI, an organization that is second in the world only to the Department of Energy (in dollars) in the development of energy-efficiency technologies. Mr. Gellings has demonstrated a unique ability to understand what energy customers want and need and then implement systems to develop and deliver a set of research and development programs to meet the challenge. Among Mr. Gellings' most significant accomplishments is his success in leading a team with an outstanding track record in forging tailored collaborations—alliances among utilities, industry associations, government agencies, and academia—to leverage research and development dollars for the maximum benefit. Mr. Gellings has published 10 books, more than 400 articles, and has presented papers at numerous conferences. Some of his many honors include seven awards in lighting design and the Bernard Price Memorial Lecture Award of the South African Institute of Electrical Engineers. He has been elected a fellow in the Institute of Electrical and Electronics Engineers and the Illuminating Engineering Society of North America. He won the 1992 DSM Achiever of the Year Award of the Association of Energy Engineers for having invented DSM. He has served as an advisor to the U.S. Congress Office of Technical Assessment panel on energy efficiency, and currently serves as a member of the Board of Directors for the California Institute for Energy Efficiency.

Kelly E. Parmenter, PhD is a mechanical engineer with expertise in thermodynamics, heat transfer, fluid mechanics, and advanced materials. She has 14 years of experience in the energy sector as an engineering consultant. During that time, she has conducted energy audits and developed energy management programs for industrial, commercial, and educational facilities in the United States and in England. Recently, Dr. Parmenter has evaluated several new technologies for industrial applications, including methods to control microbial contamination in metalworking fluids, and air pollution control technologies. She also has 12 years of experience in the academic sector conducting experimental research projects in a variety of areas, such as mechanical and thermal properties of novel insulation and ablative materials, thermal contact resistance of pressed metal contacts, and drag reducing effects of dilute polymer solutions in pipeflow. Dr. Parmenter's areas of expertise include: energy efficiency, project management, research and analysis, heat transfer, and mechanical and thermal properties of materials.

Patricia Hurtado, P. E. is a mechanical engineer with a master in thermal sciences and over 20 years experience in the energy sector. She has worked as an energy planner for more than 10 years, conducting projects related to energy conservation, pollution reduction, building analysis, engineering modeling, strategic planning, market evaluation, program development and performance assessment, distribution and retail sector analysis, privatization evaluation in the electric utility sector, as well as energy sector restructuring, rate design and analysis. Her consulting assignments have included clients in the United States, Puerto Rico, Mexico, Colombia, and Thailand. Ms. Hurtado's areas of expertise include: energy system design and analysis, engineering simulation models, end-use data and engineering analysis, economic analysis, utility resource and strategic planning, forecasting, rate design and analysis, distribution and retail sector analysis, and technology and market assessments of new products and services.