Optimizing Drive Systems for Energy Savings

William B. Gilbert

Management Summary

In looking for potential opportunities to reduce energy consumption via the drive system, a number of areas should be considered:

- The use of a common DC bus architecture as an alternative to individually powered AC drives will conserve energy by sharing the normally wasted regenerative energy from unwinds and other regenerating driven sections.
- In addition to sharing and saving energy, true common DC bus systems also conserve energy by eliminating many of the typical energy-wasting system components.
- Utilization of active front end (AFE) power sections to reduce system power factor and harmonics. AFEs provide near-unity power factor and produce minimal harmonics. AFE's can also compensate for the effects of poor power quality issues.
- Reducing mechanical losses with direct-drives, as certain power transmission components can waste significant energy.
- Optimizing drive sizes and tuning through mechatronic practices and tools. Oversized drives will use more power and adversely affect the system power factor. Poorly tuned drive systems can be a common source of energy waste.
- Retrofitting older DC drive systems with more efficient AC drive systems. AC drive systems offer greater energy efficiency over older DC technology. Some AC drives can automatically reduce their magnetizing current under low load conditions.
- Utilizing energy efficient motors for across-the-line applications, and AC drives in front of the motors in place of mechanical dampers and valves.

Introduction

Energy savings are an extremely important topic in virtually every segment of industry today. This paper will discuss the ideal areas where energy savings can be realized from the major power consumers in converting lines and machinery.

In general, the largest consumer of power in a converting line or machine is the drive system. But as energy costs continue to increase and energy conservation becomes a greater priority, do technologies or methods exist that can be implemented to reduce converting machinery energy consumption?

Saving Energy with a Common DC Bus

Pulse width modulation (PWM) technology review. Before looking into the details and benefits of DC common bus drive systems, consider the typical standalone AC drive. The power design of today's pulse width modulated AC drive is made up of three sections: 1) the input section is the rectifier that converts single- or three-phase AC voltage into DC voltage; 2) the DC link is the middle section containing a capacitor bank to smooth and buffer the DC voltage; 3) and third, the fast-switching inverter section that pulses the DC voltage into a three-phase power signal suitable for an inverter duty-rated AC motor.

AC/AC drive systems. Figure 2 shows the configuration of standard AC/AC drives that are applied in a multi-axis, coordinated drive system. Here each individual drive is connected to the AC line via individual line components—fuses, reactors, contactors and component wiring. Each drive section must deal with its regenerative power individually.

Now let's consider a drive system for a converting line with unwind, pull-roll master section, coater, laminator and rewind. In this scenario the machine sections that add tension to the web—unwind and laminator—must return their power to the drive, and in turn this energy is subsequently dissipated by the re-gen resistors connected to the individual drives. The result: 75A of current is wasted as heat.

In some cases a pseudo-common DC bus is created with AC/AC drives that have an external bus connection by wiring the bus connections together. However this application is problematic, as the current-carrying capability of these bus connections do not always match the drive power rating. Precaution also must be taken to prevent the smaller drives from charging the larger drives. In any case, the added components required to create a pseudo-common DC bus are costly and inefficient.

Common DC bus architecture. True common DC bus drive systems are far more efficient in several ways than systems composed of standalone AC/AC drives. When drive systems utilize a common DC bus design, a shared rectifier section is used to convert the AC power supply into a DC bus common to the parallel connected motor modules (inverters).

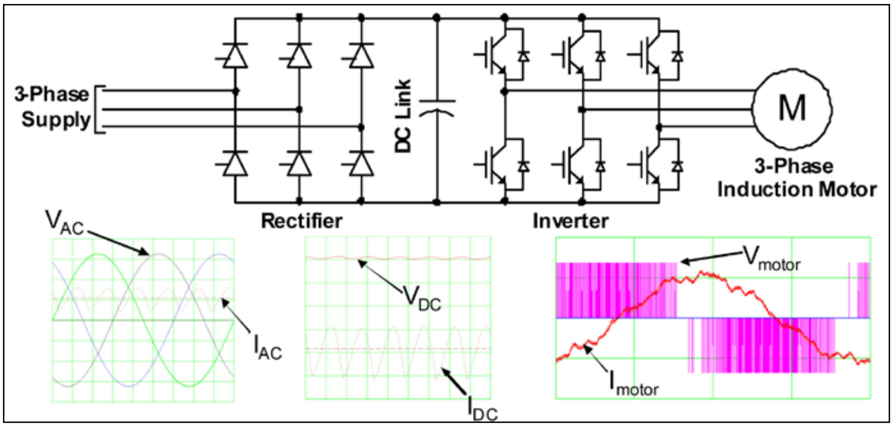

Figure 1—Standalone AC/AC drive.

Power sharing is now enabled between each different drive section linked on the DC bus. When power sharing occurs on the DC bus between drives that are motoring and generating simultaneously, the drive system now uses less power from the rectifier and the generating drive sections can return their power to the DC bus for sharing with the motoring or consuming drive sections. In contrast with the above example, the common DC bus system will use almost 75A *less* than the AC/AC drive system.

Additionally, the line components (i.e., contactor, reactor, fuses) and rectifier can be sized based on the maximum current draw of the system—not the summation of the individual motors. This also results in a more size-optimized and energy-efficient design be-

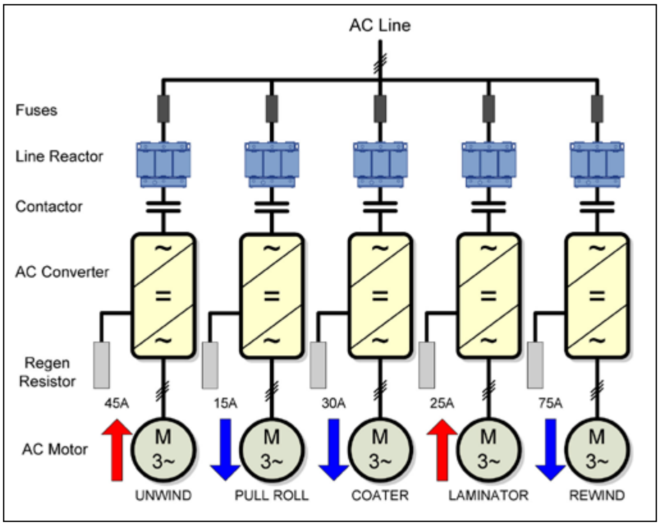

Figure 2—AC/AC-coordinated drive lineup.

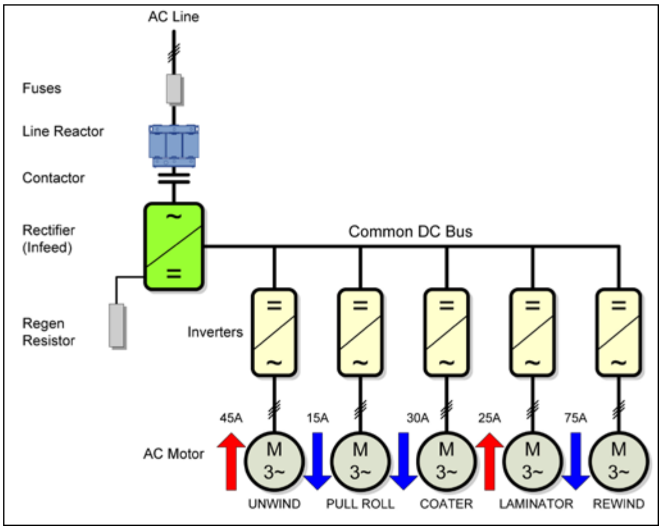

Figure 3—Common DC bus-coordinated drive lineup.

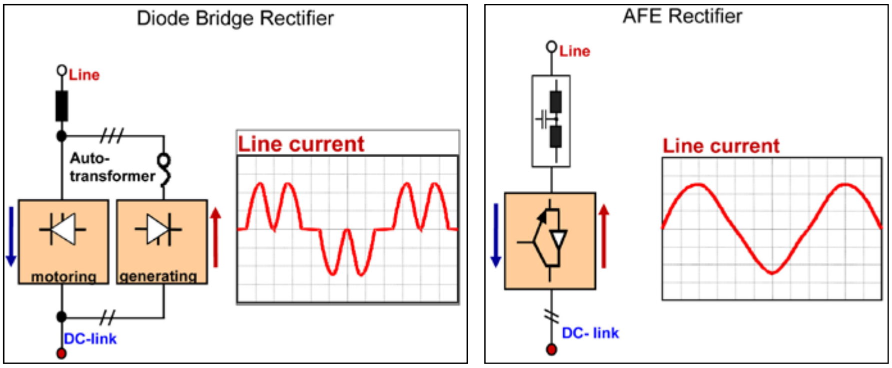

Figure 4—Comparison of line current diode bridge vs. AFE rectifier.

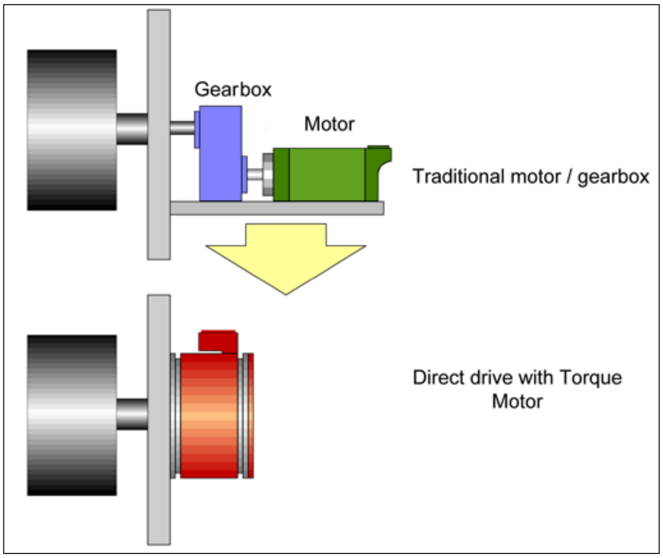

Figure 5—Gear drive vs. direct drive.

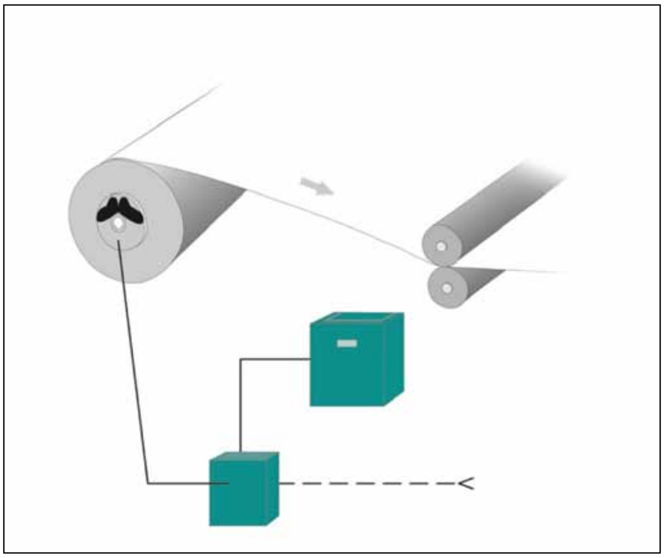

Figure 6—Mechanical brake unwind.

cause losses are realized in each individual line component and rectifier.

Active-Front-End Technology

Active-front-end (AFE), in-feed technology transforms the DC common bus system to a level of additional energy savings. An AFE is an IGBP (insulated gate bipolar transistor)-based rectifier that regulates or controls the DC bus level for both over and under voltage. This type of rectifier is suitable as either a substitute or replacement for the basic or re-gen SCR (silicon-controlled rectifier)-based modules discussed in the common bus overview.

In addition to line re-gen capability, this functionality also allows the input voltage and current waveforms to the drive to be sinusoidal, prevents harmonics from being generated back to the line and offers near-unity power factor. Although a reduction in harmonics can be very important to plant operation, the main energy savings from the AFE derive from the improvement in power factor. Indeed, AFE-controlled drives can have a .99+ power factor. In Figure 4 the effective line current in a diode bridge rectifier and AFE rectifier is detailed.

Power factor savings. "Power factor" (*Ed.'s Note*: *The offset in time—or the delay—between voltage and current being delivered, defined as the cosine of that offset. Source:* the-power-factor-site.com) is a measure of how effectively electrical power is used; a high power factor approaching unity) indicates efficient use of the electrical distribution system, while low power factor indicates ongoing inefficiency.

Power factor is the ratio of *real* power to *apparent* power. To determine power factor (*PF*), divide real power (*kW*) by apparent power (*kVA*). In a sinusoidal system, the result is also referred to as the cosine *0*.

When a utility serves an industrial plant that has poor power factor, the utility must supply higher current levels to accommodate a given load. A utility is paid primarily on the basis of energy consumed and peak demand supplied; without a power factor billing mechanism, the utility would receive no more income from the second plant than from the first. As a means of compensation for

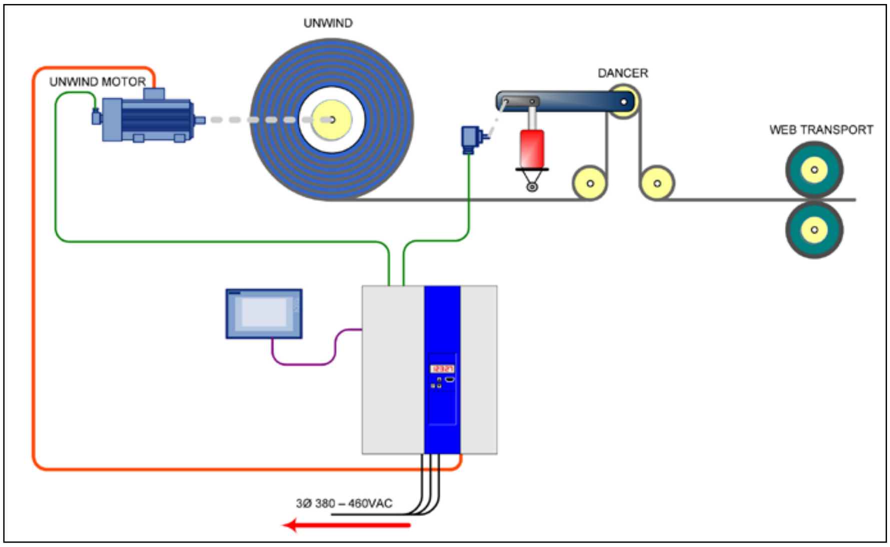

Figure 7—Driven unwind.

the burden of supplying extra current, utilities typically apply what is industry-known as a "power factor penalty" in their rate schedules. A minimum power factor value is established—usually 95 percent; when the customer's power factor drops below the minimum value, the utility imposes the penalty.

Eliminating Mechanical Losses

There are two major areas in converting machinery where significant energy is lost through friction and mechanical inefficiency—mechanical drive systems or gearboxes with high ratios; and unwinds with mechanical tension-control brakes.

Replacing gearboxes with direct-drive torque motors. High gear ratios are required when optimizing motor sizes for driving large-diameter rolls or for very-low-speed web applications. Where planetary gearboxes are fairly efficient, it is common for high-ratio, multistage worm gearboxes to experience efficiencies under 60 percent.

Low-speed applications previously limited to inefficient gearboxes are now commonly direct-driven with torque motors—and even conventional motors—thus eliminating the energy losses. Typical applications on converting lines utilizing torque motors with direct-drive are chill rolls, large-diameter casting rolls and very-low-speed web control in applications such as sputtering metallizers.

Driven unwinds vs. mechanical brakes. Unwinds with mechanical brakes are an ideal source for recovering energy. Mechanical brakes friction creates web tension and the heat generated in this process is recoverable energy.

Pneumatic or electromechanical tension-control brakes are commonly replaced with an AC drive system with line-regenerative capability.

A driven unwind must return the tension energy back to the AC line. In the past, re-gen DC drives have been

100 HP		
FLA Motor Current	125.0	A
Magnetizing Current	50.0	A

30 HP		
FLA Motor Current	40.0	A
Magnetizing Current	16.0	A

Figure 8—Single-drive energy savings.

MOTOR / DRIVE SYSTEM EFFICIENCY					
SYSTEM	Drive Eff. (%)	Motor Eff. (%)	System Eff. (%)	kWH / year	Annual Power Cost
DC	99.0%	88.0%	87.1%	336,625	$26,930
AC	97.0%	93.5%	90.7%	323,356	$25,868
Kilowatt hours = HP × .746 × annual hours of operation/system efficiency. 100hp motor is running at 90 percent load; 12 hours per day, 7 days a week Assume $.08/kWH					

Figure 9—Drive system efficiency.

Efficiency Rating	System Eff. (%)	kWH / year	Annual Power Cost	Annual Savings
Standard Efficiency	93.5%	348,506	$27,880.45	
High Efficiency IEC IE3	95.0%	343,003	$27,440.24	$440.22
NEMA Premium IEC IE3	96.2%	338,724	$27,097.95	$782.51
Kilowatt hours = HP × .746 × annual hours of operation/system efficiency. 100hp motor is runni ng at 90% load; 12 hours per day/7 days a week Assume $.08/kWH				

Figure 10—Savings from improved motor efficiency.

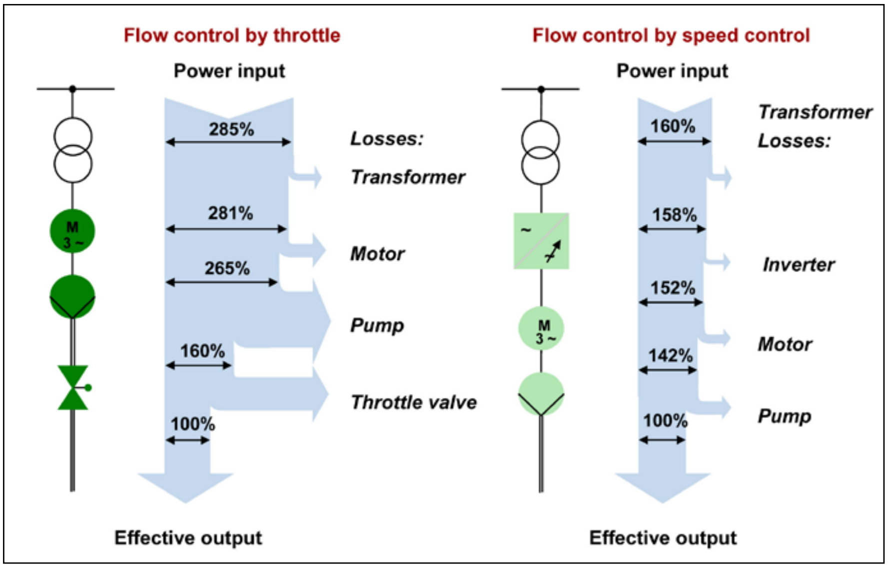

Figure 11—Mechanical throttling vs. speed control.

successfully applied in these applications, but DC drive systems are no longer common; even during their prime they were very costly when compared to their mechanical counterparts. And, older-generation AC drive technology did not have the capability to regenerate power back to the AC line; when applied as unwind brakes, they required re-gen resistors to dissipate the tension energy—a wasteful and costly practice.

Today's AC drive systems have the technology to regenerate the energy to the AC line—just as the DC drive did—but with added benefits to user and machine designer alike. Returning the tension energy to the line means that once-wasted power is now retained and not producing heat and worn parts. And if the drive is AFE-equipped, it will return the energy with near-unity power factor—impossible for any DC drive system.

Drive Optimization (Mechatronics)

Dedicated attention to drive and motor sizes vis-à-vis actual load requirements for specific applications and ensuring that coordinated drives are properly tuned will aid in harvesting energy savings.

Optimal sizing = energy savings. Oversized drive systems simply waste energy. The cost of energy waste is realized in the higher magnetizing current. An AC drive system's magnetizing current can be nearly half of the full-load current (FLC). Consider the example of a 100hp AC drive system applied to an actual 30hp load requirement. In this example, 40 amperes of line current are wasted. That relates to energy savings of 34A for a *single* drive.

Mechatronics and drive-tuning for energy savings. Poorly tuned drives not only affect machine performance and product quality—they waste significant energy. Drive systems tuned beyond the optimal waste energy as they drive the current loop harder, and the overactive current loop wastes energy in the form of motor heat.

As industry trends push drive system performance, mechatronics can ensure higher performance without wasting energy. The main issues are:

- Complex loads
- Compliance
- Lost motion
- Machine resonances

Applied mechatronics support can help archive the required system performance without wasting energy and affecting machine life.

Making the Switch: Replacing DC Drives with AC

Replacing outdated DC drive and motor systems with AC drive technology offers energy savings derived from the improved energy efficiency of the AC system over its DC counterpart. In addition, savings are gained from improved power factor.

Efficiency comparison. While the DC motor—putting aside, for a moment, the drive component—is more efficient than an AC motor, the AC PWM (pulse width modulator) drive is far superior to a DC SCR drive. When considering drive system efficiency, the AC drive system can offer an efficiency improvement in the range of ~ three percent when operating at near-full-load, where the DC drive efficiency is at its highest.

Consider the example of a *single* standalone drive system at 100 hp and running at 90 percent load, 12 hours a day, seven days a week: a single AC/AC drive replacement can provide over $1,000 of energy savings per year.

Enhanced drive system efficiency. In keeping with drive technology's continued pursuit of energy savings, a recent drive feature now available aids the drive system in energy savings by reducing the AC motor's magnetizing current under no- or light-load conditions. As discussed earlier, asynchronous motor magnetizing current can approach half of the full-load motor current, meaning that drives enabled under no or light loads can realize significant energy savings from the drive system.

Motor Efficiency: Pump and Fan Losses

In certain conditions, AC motors are used in converting lines for which pumps and fans are typically used.

Energy-efficient, across-the-line motors. Today's standards for NEMA and IEC motors have led to their vastly improved efficiency. Consider replacing older AC motors with high-efficiency motors. There are currently three levels of motor efficiency:

1. Standard-Efficiency and IEC IE1; Pre-EPAct = Least Efficient
2. NEMA High-Efficiency and IEC IE2; EPAct Level = More Efficient
3. Nema Premium and IEC IE3 = Best Efficiency

See Figure 10 for details on potential savings from a single 100hp AC motor running at 90 percent load.

Pump and fan losses. In the applications where across-the-line motors are utilized—such as flow control—energy savings can be gained by adding an AC drive. The biggest potential for savings is found in those pumps, fans and compressors still operated with mechanical throttles and valves. Converting to variable-speed drives can produce considerable economic benefits.

With mechanical flow control, the motor runs continuously at a speed required for the maximum delivery rate — rarely needed in practice. Additionally, throttles and valves lose energy and cause high temperatures and vibration levels that can have a negative impact on the drive and production operation.

Variable-speed drives with inverters offer a more economic alternative for a number of reasons—e.g., they can be controlled much more quickly and precisely. But mainly, by adapting the flow rate directly to actual requirements, energy savings of up to 60 percent can be achieved—especially in energy-intensive applications. Consider the comparison of a mechanical throttle to a speed control example shown in Figure 11 for an overview of typical losses. In this example the input power requirement of the driven fan or pump is only 56 percent of the input power requirement of the mechanical throttle example.

Conclusions

Drives and driven systems in converting lines are major energy consumers, but advances in technology continue to offer multiple avenues for reducing total energy costs. In this paper we have addressed some of the areas where significant energy savings or recovery can be found on converting lines and machinery. As technology continues advancing in drive systems, more saving options will soon follow.

References

1. Nelson, Craig. "Multi-Axis Drive Applications Using Common DC Bus," Siemens White Paper.
2. ARC Advisory Group. "A Strategic Roadmap for Sustainable Management and Energy Efficiency for Industrial, Commercial, Municipal and Manufacturing Operations," ARC White Paper, 2009.

For more information:

Siemens Industry, Inc.
5300 Triangle Parkway, Suite 100
Norcross, GA 30092
Phone: 770.625.5658
Fax: 770.871.3888
William.Gilbert@Siemens.com
www.siemens.com/converting

William Gilbert *is a consulting application engineer with the Motion Control Business of Siemens Industry, Inc. He is responsible for the company's converting industry focus and business development for the U.S. market. Gilbert has over 25 years of experience in motion control and web handling-related industries.*