Optimizing Drive Systems for Energy Savings

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Acknowledgement

This paper and the accompanying presentation are based on the paper and presentation with the same title presented by William Gilbert of Siemens Industry., Inc., USA at the AIMCAL Applied Web Handling Conference May 2010 in Rochester, NY, USA.

My thanks to Bill for letting me use his material with some modifications for the paper and presentation at the AIMCAL Web Handling Conference June 2012 in Prague, Czech Republic.

Abstract

The largest consumer of electrical power in a converting line or machine is in general the drive system. As energy costs continue to rise and energy conservation gains greater priority, technologies and methods that can be implemented to reduce the energy consumption, despite the increase in capital expenditure, are becoming increasingly attractive to both OEMs and end-users.

Methods to reduce overall energy consumption as well as balance or recover energy within the drive system based on state-of-the art drive technology are presented.

Introduction

When looking for potential opportunities to reduce to overall energy consumption of the drive system of a converting line machine or line several areas should be taken in to consideration.

- The use of a common DC-bus architecture as an alternative to individually powered AC drives. This will conserve energy by sharing the normally wasted, e.g. as heat in braking resistors, regenerative energy from unwinds and other regenerating 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, e.g. by employing a single line rectifier/regenerative infeed unit.

- Utilizing active line rectifier/regenerative power sections to correct system power factor and reduce harmonics. This results in a near-unity power factor and minimal harmonics. Active line rectifier/regenerative power sections can also compensate for the effects of poor line power quality issues, such as undervoltage.

- Reducing mechanical losses with direct drives. In this case certain power transmission components, such as gearboxes which can waste significant energy, are eliminated. Additional benefits include perceivable noise reduction, space saving requirements on the machine and reduced maintenance costs due to reduced mechanical wear.

- Employing mechatronic practices and tools to optimize drive sizing and tune the drive system. Oversized drives use more power and adversely affect the system power factor. Poorly tuned drive systems can also be a common source of waste of energy as well as poor overall machine performance.

- Retrofitting older DC-drive systems with more efficient AC-drive systems. Modern AC-drives are additionally able to automatically adapt their magnetizing current depending on load conditions, again saving energy.

- Utilizing energy efficient motors for across-the-line applications together with AC-drives in place of mechanical dampers and valves round off the measure.

Saving Energy with a Common DC-Bus

PWM Technology Review

Before looking in to the details and benefits of DC common bus drive systems we should first take a look at the typical stand-alone AC-drive. The power section design of today's PWM (Pulse Width Modulated) AC-drive is made up of three sections. The input section is the line rectifier which converts a single or three phase AC voltage into a DC voltage. The middle section is the DC link, which comprises a capacitor bank to smooth and buffer the DC voltage source power supply. The third, and final stage, is the fast switching inverter section, which using a PWM technique, pulses the DC voltage into a three phase power signal suitable for an inverter duty rated AC-motor (see figure 1).

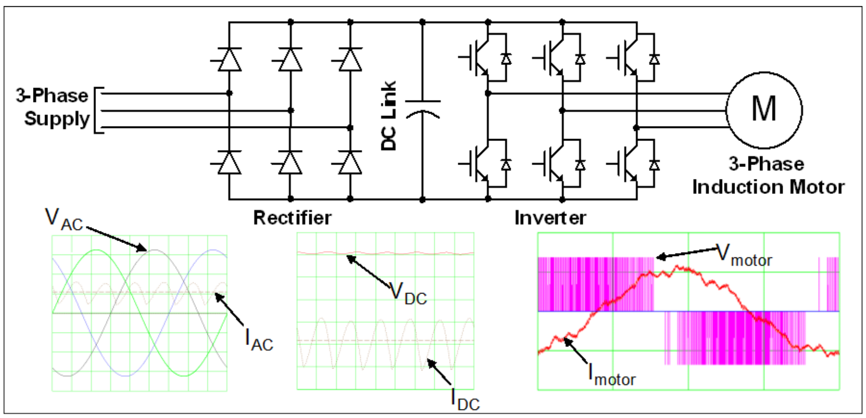

Figure 1: Stand-alone AC/AC-Drive

AC/AC-Drive Systems

Figure 2 shows an example of the configuration of standard AC/AC-drives that are applied in multi-axes coordinated drive systems. Here each individual drive is connected to the AC line via individual line components (fuses, reactors, contactors, etc.) and suitable component wiring. Each drive section must deal with its regenerative power individually, e.g. by dissipating the energy as waste heat using either an internal or external braking chopper together with a braking resistor appropriate for the application.

Consider a drive system for a converting line with an unwind, pull-roll master section, coater, laminator and rewind. Notice how in this scenario the machine sections that add tension to the web (unwind and laminator) must return their braking energy to the drive, and in turn this energy must subsequently be dissipated (as waste heat) by the braking resistors connected to the individual drives. Here 75A of current is transformed in to wasted heat.

In some cases a pseudo-common DC-bus system is made up using AC/AC-drives by connecting their dc-links together. However in practice this is somewhat problematic as the current capacity of the individual dc-link bus terminals does not always match the drive power rating. Precautions also must be taken to prevent the line rectifier of smaller drives from charging the dc-links of the larger drives. The added components required to build up a pseudo-common DC-bus solution are however usually costly and inefficient.

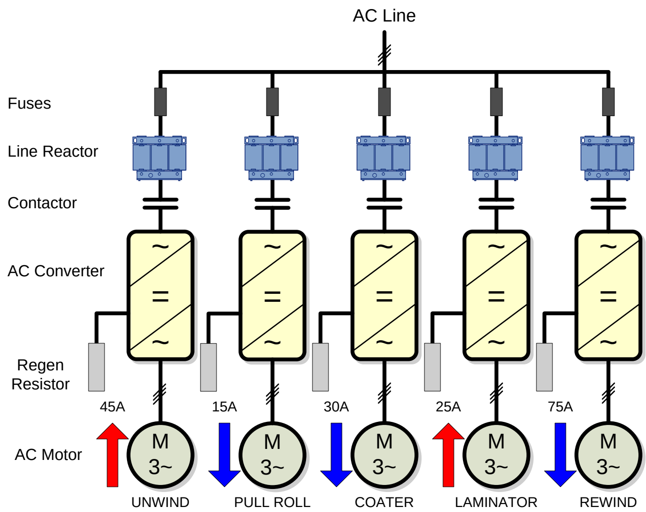

Figure 2: AC/AC-Coordinated Drive Line-up

Common DC-Bus Architecture

True common DC-bus drive systems as shown in figure 3 are in many ways significantly more efficient than the system previously described consisting of stand-alone AC/AC drives. When drive systems share a common DC-bus, a central line rectifier section is used to convert the AC-power supply into a DC power source, which is common to all of the inverters connected in parallel.

True power sharing is now possible between each of the different drive sections connected to the common DC-bus. When power sharing occurs between drives that are simultaneously motoring and generating via the DC-bus, the drive system requires less power to be supplied by the line rectifier as the generating drive sections can return their power via the DC-bus to be used by the motoring drive sections.

In the example shown in figure 2 above, a common DC-bus system would draw almost 75A less than the AC/AC-drive system.

Additionally, the line components (e.g. contactors, reactors, fuses, etc.) and the line rectifier can be sized based on the maximum current drawn by the system and not the summation of the individual motor currents. This results in a better size optimized and energy efficient design, as losses due to individual line components and line rectifiers are eliminated.

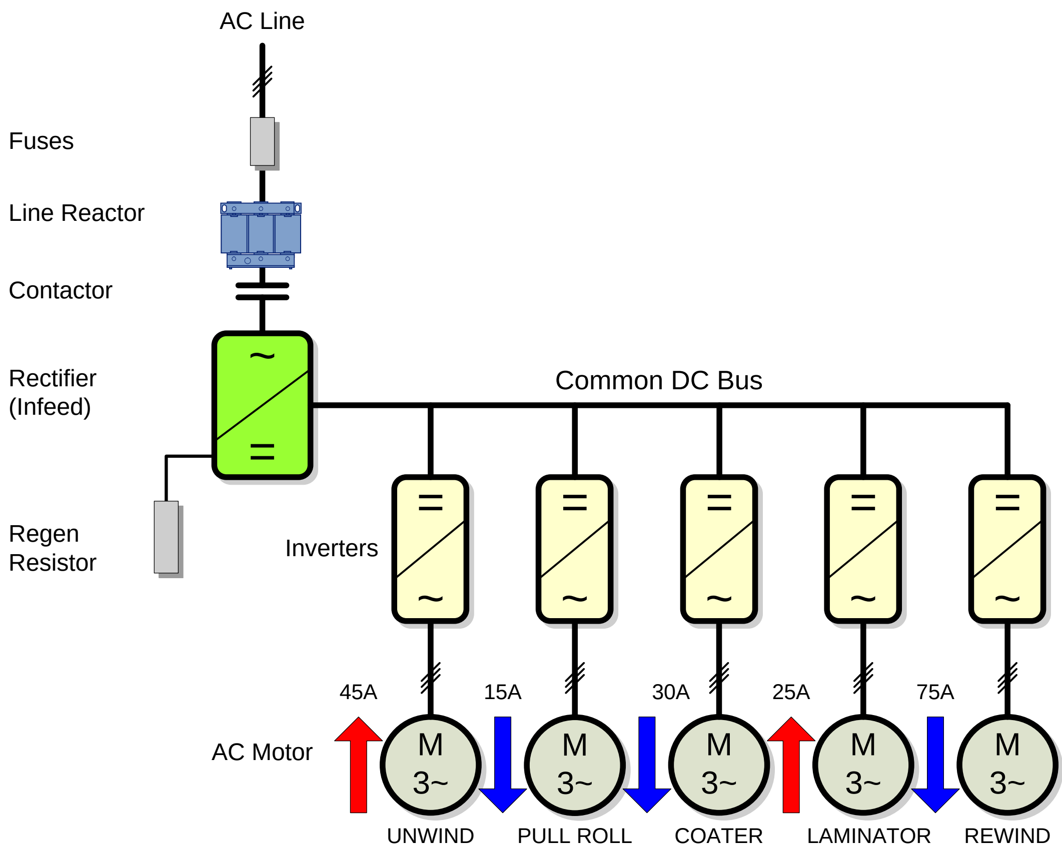

Figure 3: Common DC-Bus Coordinated Drive Line-up

Active Line Infeed Technology

Active line infeed technology takes the common DC-bus system to an additional level of energy savings. An active line infeed rectifier is an IGBT-based rectifier that regulates or controls the DC-bus voltage level, for both over and under voltage. This type of rectifier is suitable as a substitute or replacement for the standard diode bridge rectifier or thyristor rectifier/regenerative based modules discussed in the common DC-bus overview.

In addition to line regeneration capability, its 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 the reduction in harmonics can be very important to plant operation, the main energy savings from the active line infeed rectifier come from the improvement in power factor. A drive system with active line infeed technology can be set to have a power factor of almost unity. In Figure 4 the effective line current in a diode bridge rectifier and an active line infeed rectifier is detailed.

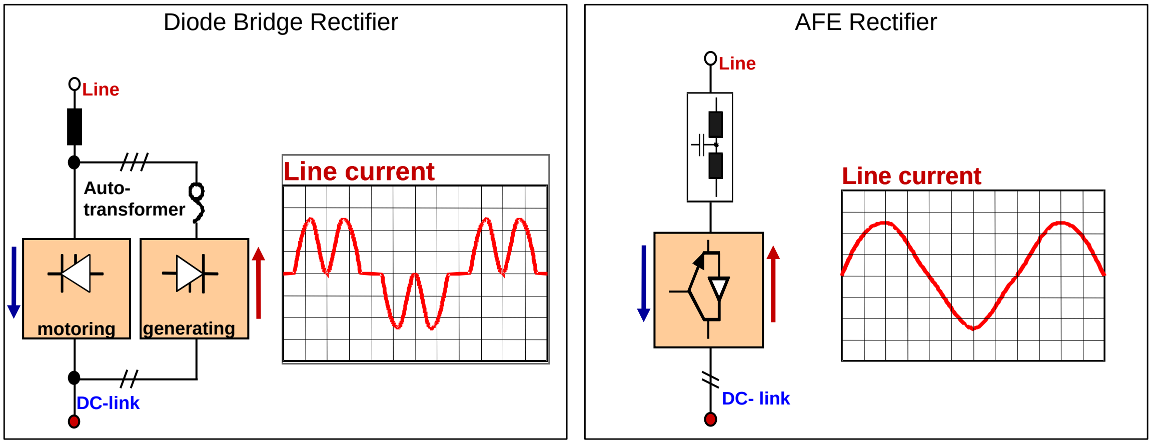

Figure 4: Comparison of Line Current in a Diode Bridge vs. Active Line Infeed Rectifier

Savings through Power Factor Optimization

Power factor is a measure of how effectively electrical power is being used. A high power factor (close to unity) indicates efficient use of the electrical distribution system while a low power factor indicates poor use of the system.

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 deliver higher current to serve a given load. A utility is paid primarily on the basis of energy consumed and peak demand supplied. Without a power factor billing element the utility would receive no more income from a plant with poor power factor than from a plant with a good power factor. As a means of compensation for the burden of supplying extra current, utilities typically establish a "power factor penalty" in their rate schedules. A minimum power factor value is established, usually 0.95. When the customer's power factor drops below the minimum value, the utility collects "low power factor" revenue.

Eliminating Mechanical Losses

There are two major areas in converting machinery where significant energy is lost through friction and mechanical inefficiency. The first is mechanical drive systems or gear boxes with high transmission ratios. The second is on unwinds with mechanical tension control brakes.

Direct Drives as a Replacement for Gearboxes

High gear ratios are required when optimizing motor sizes for driving large diameter rolls or for very low speed web applications. Whereas planetary gearboxes are relatively efficient, high-ratio multi-stage worm gear boxes can easily have efficiencies below 60%.

Low speed applications and driven sections that previously used inefficient gearboxes are more commonly being driven directly with torque motors, thus eliminating the gearbox losses. Typical applications on converting lines utilizing torque motors are chill rolls, large diameter casting rolls and very low speed web control in applications such as sputtering metallizers.

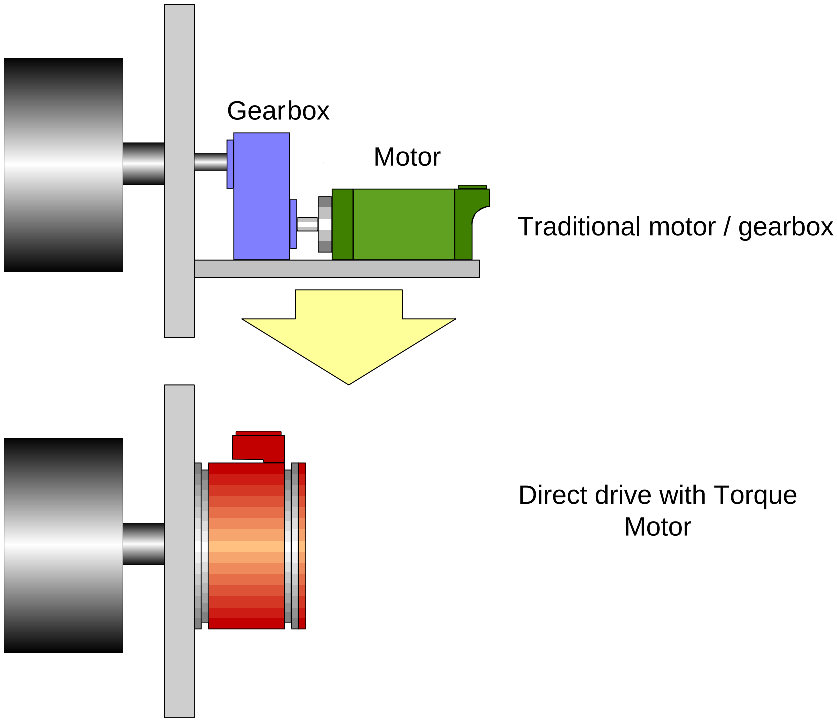

Figure 5: Geared Drive vs. Direct Drive

Driven Unwinds vs. Mechanical Brakes

Unwinds using mechanical brakes are an ideal subject for recovering energy. Mechanical brakes create web tension by friction, and the heat generated in this process is recoverable energy. Pneumatic or electromechanical tension control brakes are more commonly being replaced by an AC-drive system with line regenerative capability.

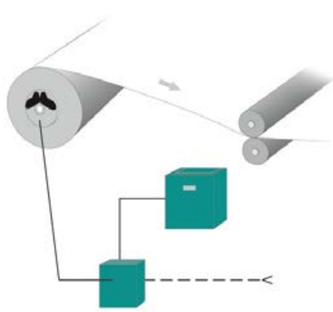

Figure 6: Mechanical Brake Unwind

A driven unwind must return the tension energy back to the AC-line. Previously, regenerative DC-drives have been applied successfully in these applications, but DC-drive systems are no longer so common and, even when, were very costly when compared to their mechanical counterparts. In the early days of AC-drive technology, the drives did not feature the capability to return the power back to the AC-line and when applied as unwind brakes, they required braking resistors to dissipate the tension energy. This was both costly and wasteful.

Today's AC-drive systems now provide the technology to return the energy back to the AC-line just as the DC-drive did, but with added benefits to the user and machine designer alike. Returning the tension energy to the line means power that once was wasted can now be retained, instead of the system producing heat and friction-worn parts. Additionally if the drive is equipped with active line infeed technology, it will return the energy with near unity power factor, something previously not possible with any DC drive system.

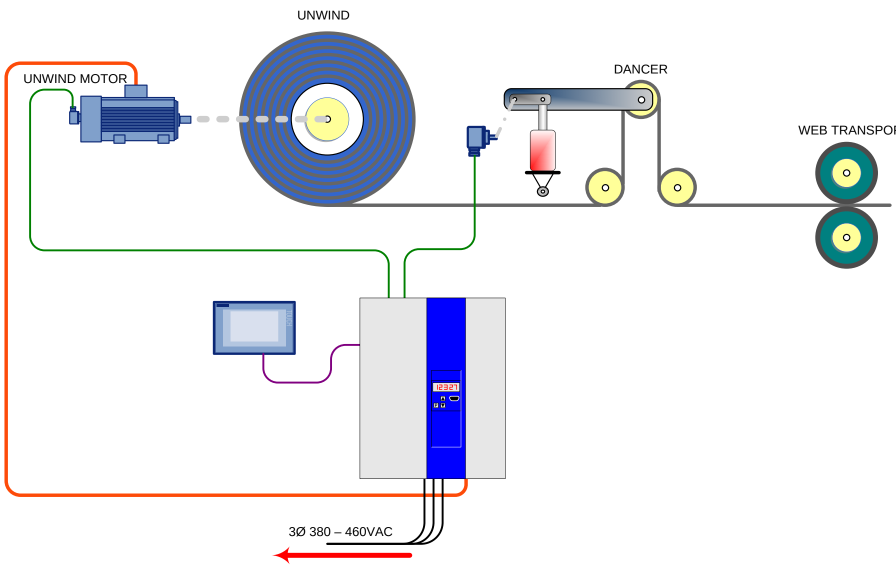

Figure 7: Driven Unwind

Mechatronics and Drive Optimization and Tuning

Paying attention to drive and motor sizes versus actual load requirements for the specific application and making sure that coordinated drives are properly tuned is a point that will help in energy savings.

Optimally sizing for Energy savings

Oversized drive systems simply waste energy. The cost of waste energy stems from the higher magnetizing current. An AC drive system's magnetizing current can be nearly half of the full load current (FLA). Consider the example of a 75 kW AC drive system applied to an actual 22.5 kW load requirement. In this example 34 A of line current is wasted.

75kW		
FLA Motor Current	125	A
Magnetizing Current	50	A

22,5kW		
FLA Motor Current	40	A
Magnetizing Current	16	A

Figure 8: Single Drive Energy Savings

That relates to a current saving of 34 A for a single drive.

Mechatronics and Drive Tuning for Energy savings

Poorly tuned drives not only can affect machine performance and product quality but waste significant energy. Drive systems that are “over-tuned” can waste energy as they drive the current loop harder. The overactive current loop will waste energy by heating up the motor.

As industry trends push the drive systems performance, mechatronics can ensure higher performance without wasting energy. The main issues can arise from:

1. Complex Loads
2. Compliance
3. Lost Motion
4. Machine Resonances

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

AC-drives as a Replacement for DC-drives

Replacing outdated DC-drive and motor systems with AC-drive technology can offer energy savings from the improved energy efficiency of the AC system over its DC counterpart. In addition, savings from improved power factor can also be realized

Efficiency Comparison

While the DC-motor, without regard to the drive, is more efficient than an AC-motor, the AC-drive is far superior to a DC-drive. When considering drive system efficiency, the AC drive system can offer an efficiency improvement in the range of ~3% when operating at near full load, where the DC drive efficiency is at its highest.

Consider the example of single stand-alone drive systems both at 75 kW, running at 90% load, 12 hours a day, and 7 days a week. Just a single AC/AC-drive replacement can provide over 1,000 Euro of energy saving per year.

MOTOR / DRIVE SYSTEM EFFICIENCY					
Drive System	**Drive Eff. (%)**	**Motor Eff. (%)**	**System Eff. (%)**	**kWh/year**	**Annual Power Cost/Euro**
DC	99.0	88.0	87.1	336,625	26,930
AC	97.0	93.5	90.7	323,356	25,868

Figure 9: Drive System Efficiency

kWh = kW x annual hours of operation/System Efficiency
75kW motor is running at 90% load; 12 hours per day, 7 days a week
Assume =0.08 Euro/kWh

Enhanced Drive System Efficiency

Drive technology continues to tend to energy savings. A recent drive feature that is available in some drives helps the drive system in energy saving by reducing the AC-motor's magnetizing current under no or light-load conditions. As discussed earlier, an asynchronous motor's magnetizing current can approach half of the full load motor current. This means that drives that remain enabled under no or light loads can realize significant energy savings from the drive system.

Motor Efficiency - Pump & Fan losses

In certain conditions across-the-line AC-motors are used in converting lines. Typical applications for these are pumps and fans.

Energy Efficient across the line Motors

Modern standards for both IEC and NEMA motors offer vastly improved efficiency. Consider replacing older AC-motors with high efficiency motors. There are currently 3 levels of motor efficiency.

- ☐ **Standard Efficiency & IEC IE1 - Pre-EPAct, least efficient**
- ☐ **NEMA High Efficiency & IEC IE2 - EPAct Level, more efficient**
- ☐ **NEMA Premium & IEC IE3 - best efficiency**

Efficiency Rating	System Efficiency (%)	kWh/Year	Annual Power Cost (Euro)	Annual Saving (Euro)
Standard, IEC IE1	93.5	351,337	28,107	-
NEMA High, IEC IE2	95.0	345,789	27,663	444.00
NEMA Premium, IEC IE3	96.2	341,476	27,318	789.00

Figure 10: Potential savings from single 75kW AC-motor running at 90% load (fixed speed, no drive)

Kilowatt Hours = kW x Annual hours of operation / System Efficiency
100hp motor is running at 90% load; 12 hours per day/7 days a week
Assume 0.08Euro/kWh

Pump and Fan Losses

In the applications where across-the-line motors are utilized such as flow control, energy savings can be achieved by adding an AC-drive. The biggest potentials for savings are presented by pumps, fans and compressors that are still operated using mechanical throttles and valves. Converting to variable-speed drives can provide considerable economic benefits.

Changing the flow mechanically vs. controlling the flow with an AC-drive has many disadvantages. With mechanical flow control the motor runs continuously at the speed required for the maximum delivery rate, which is rarely needed in practice. Additionally, throttles and valves lose energy and cause high temperatures and vibration levels which can have a negative impact on the drive and production operation.

Variable-speed drives with inverters offer a more economic alternative for numerous reasons. They can be controlled much more quickly and precisely. By adapting the flow rate precisely to actual requirements, energy savings of up to 60 % can be achieved, especially in energy-intensive applications. Consider the comparison of a mechanical throttle to speed control example 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% of the input power requirement of the mechanical throttle example.

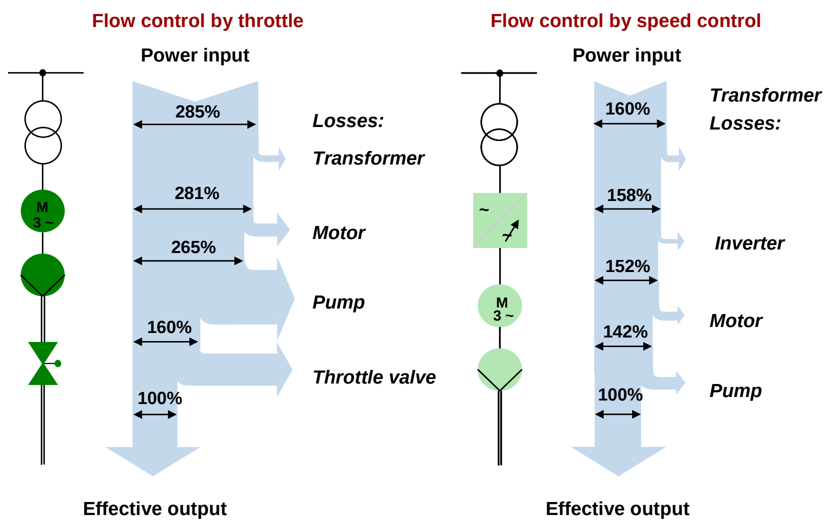

Figure 11: Mechanical Throttling vs. Speed Control

Conclusions

Drives and driven systems in converting lines are major energy consumers, but advances in technology continue to offer multiple avenues of reducing the total energy costs. In this paper the major areas where energy savings or recovery can be found on converting lines and machinery have been identified and addressed. As drive technology continues to make advancements, further energy saving options are to be expected.

References

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