

# Optimising energy efficiency of conveyors

by Daniel Clénet

## Executive summary

With more than 2.5 million conveyors put in operation annually in the world, conveying is an important energy consumer. This paper outlines methods to propose ways to improve the efficiency of belt and roller conveyors. Specifically, it details how operating mode, energy compensation, soft starters, and variable speed drives are smart solutions to make significant savings on a conveying line.

# Summary

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# Executive summary

In any human activity, handling cannot be ignored. Moving and transporting goods are part of the daily life of each individual.

In manufacturing and distribution activities, it is very often the bottleneck where can focus many problems.

Indeed, handling has an influence on the machines productivity located upstream and downstream, it has an impact on the work-in-progress and thus presents a capital investment.

Frequently, handling has an effect on the quality of the product

With more than 2,5 million conveyors put in operation annually in the world, conveying is an important energy consumer.

Smart choices allow to:

- increase the productivity by optimizing the operating modes,
- reduce the energy needs and thus limit the exploitation costs.

The judicious use of soft starters or variable speed drives reduces maintenance by limiting the electric and mechanical shocks

**Making energy saving through a smart approach of operating modes and the use of specific products.**

# Introduction

Handling consists in moving a load from one place to another one without alteration.

Several solutions can be used :

- lifting : the load is freely hung from a lifting gear, operation is discontinuous. Flexibility is possible within some limits,
- belt conveyors or roller tables : the load is supported by the machine and is carried by the movement of the belt or the rotation of the rollers. Operation is usually continuous, with very little flexibility,
- overhead conveyors with or without trolley : the load is hanged to a chain moving continuously through the whole process. Operation is uninterrupted with little flexibility if any,
- motorized overhead conveyors running on a common monorail with switch points. Operation is discontinuous. Flexibility is possible within some limits.
- automatic guided vehicles (AGV's) which follow a Guide Cable layed in the ground or a path controlled by a radio signal. Operation is discontinuous, flexibility is virtually unlimited.

Despite their apparent disparity, these solutions can be grouped in two main categories :

1. manually operated conveyors ( transpallets, forklifts or lifting means) controlled by an operator,
2. automated devices in which we find the conveyors family.

The first solution is sometimes the only possibility, for example loading from a warehouse.

In manufacturing industries or distribution of products, the second solution is essential, because it enables to reduce the handling costs. Furthermore cycles of production are shortened and the risk of damage to packed products is greatly reduced.

**What follows is dedicated to belt and rollers conveyors and the goal of this White Paper is to propose ways to improve their efficiency.**

# Introduction

To cover the majority of the needs, conveyors adopt three current arrangements :

- linear conveyors to move loads between production units,
- transfer tables to change a course or to relocate a load from a conveyor to another one,
- turntables which carry out a similar function while revolving the load.

Conveyors benefits are multiple :

- cost reduction of manual operations,
- loading and unloading are easy and safe,
- work-in-progress control and possibility of just in time production,
- intermediate stock limitation between production units,
- pallets or products can be move to a large distance without damage.

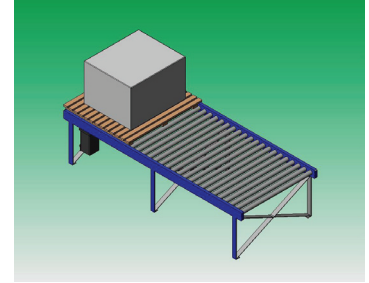
The conveyors, however, present indirect costs, more or less related to their use:

- power consumption,
- maintenance expenses,
- wearing parts replacement,
- investments and return on investments,
- insurances.

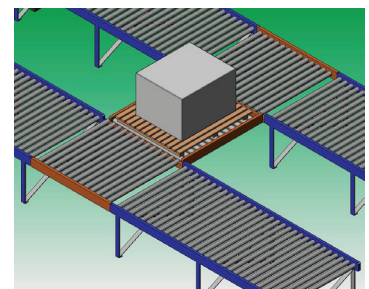
It is easily understandable that the choice of a conveyor and the manner of controlling it will have noticeable influences on the production or distribution costs. An in depth study must drive the choice of the solution.

These devices require motors, sensors and control devices adapted to the function to be realized.

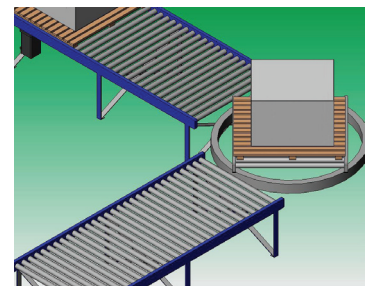
Regardless of their specific use, they share number of essential functions such as start and stop, devices for loading and unloading, operator interfaces, safety functions to prevent accidents and, eventually, soft starters or variable speed drives.



Linear conveyor



Transfer table



Turntable

# Introduction

The traditional centralized PLC's or controller solution is gradually phasing out to totally decentralized architectures controlling limited zones.

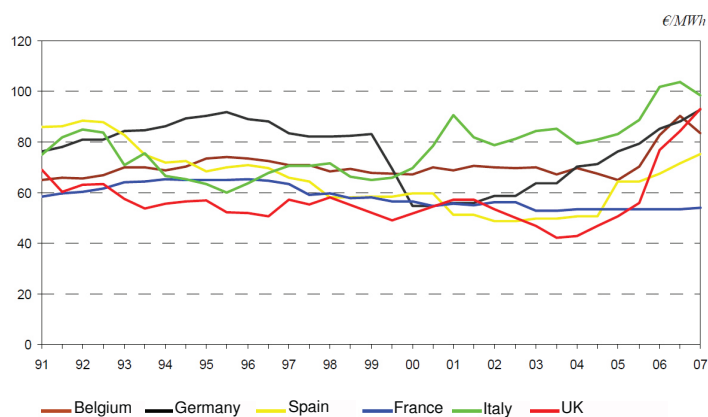
This architecture allows a greater flexibility, the autonomy of small production islands and an easier adaptation.

Decentralization also allows modularity and the rationalization of the conveyors, thus a reduction of the design cost for the system supplier and acquisition cost for the user.

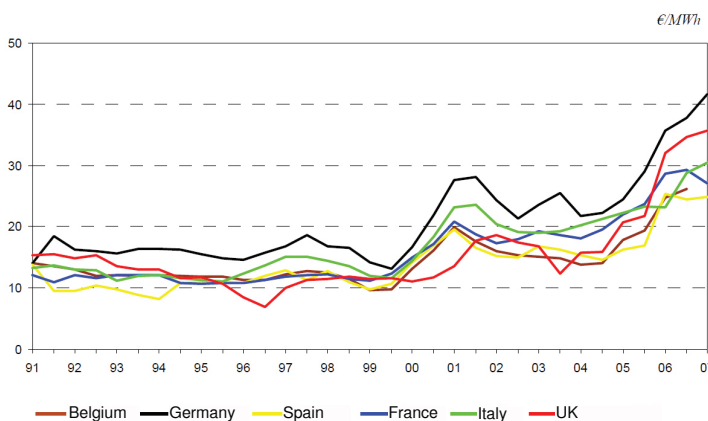
These savings are partly linked to the use of common parts, reducing the spare parts inventory and facilitating the maintenance operation.

The growing cost of energy, in particular for fossil energies, (cf graphs hereafter from the Observatory of Energy according to Eurostat - January 2007) imposes new strategies for the use of conveyors.

It becomes interesting to shut down a conveyor or use a variable speed drive to realize savings.



Cost of electricity (without VAT) for industrial use



Cost of natural gas (without VAT) for industrial use



Optimising energy efficiency  
of conveyors

# Reducing expenses

Savings are a major consideration when designing a conveying line. Due to the large number of conveyors, cost can easily be unacceptable and the return on investment may be problematic

The following table gives the usual cost family

	Variable expenses	Constant expenses
Direct costs	<ul style="list-style-type: none"> <li>● Raw products, goods linked to the products, components</li> <li>● Labor</li> <li>● Sub contracting</li> </ul>	<ul style="list-style-type: none"> <li>● Rental , dedicated equipment amortizing; dedicated insurances,</li> <li>● Commercial and distribution costs,</li> <li>● Other specific costs</li> </ul>
Indirect costs	<ul style="list-style-type: none"> <li>● Power consumption in the workshops,</li> <li>● Workshop expenditures</li> <li>● Miscellaneous supplies... ..</li> </ul>	<ul style="list-style-type: none"> <li>● Investments</li> <li>● Overheads (<i>research and development; public relationship, accounting, audits, lawyers, patents</i>)</li> </ul>

• **CELL N°1** : Direct and variable costs. The resources listed in this cell are exclusively used for the products; these expenditures are directly charged to the products.

• **CELL N°2** : Direct and constant expenses. They can directly be affected to the cost of the products. When their amount is significant, these expenses are separated from the fixed common charges and used in an additional stage during the calculation of the partial costs. What has the advantage of refining the analysis and to have a correct idea of the contribution of each product to cover the common fixed charges.

• **CELL N°3** : Indirect and variable costs. In fact these costs are difficult to evaluate and require a complex process and an in depth analysis. Energy efficiency has the most impact on these costs

• **CELL N°4** : Indirect and fixed costs. They are generally difficult to reduce. They are managed in a different way according to the selected method of analysis.

Ways to progress exist for each cell. Sometimes it is mandatory to reconsider the operation of the production line.

The saving, impossible to circumvent, consists of moving the fixed costs to variable costs (2 towards 1). In other words allowing what is just necessary for the operation. This can be done by modifying the operating modes of the equipment, for example make it running only when required.

Ideally, it is desirable to transfer direct costs into indirect variable costs (1 and 4 towards 3) by subcontracting some work or eliminating the superfluous costs.



# Reducing expenses

In the real world, one can estimate that nearly 60% of the conveyors, loaded or unloaded, are running continuously. The result is a fixed energy consumption.

An analysis of the relations between the power consumption of a conveying line and the tasks which it carries, defines 4 modes of operation:

1. **WORK IN PRODUCTION** : the line moves loads. In this mode, control and actuators are energized.
2. **STANDBY** : the machine is running while waiting for loads, because the preceding or following machine is not ready. Energy is wasted,
3. **STOP** : an operator places the conveying line in this mode when the production is stopped (defect, factory shutdown...) The machine is then in a safety mode (actuators should not be able to restart) and an automatic restart is impossible. Parts of control are off (pre-actuators) but some remain connected to the power supply (PLC's, MMI, I/O's...)
4. **OFF** : the conveying line is inert (maintenance, breaker power off...).

The three goals in order to reduce the financial cost can be summarized as follows:

1. **TRANSFORMATION OF THE FIXED DIRECT COSTS IN VARIABLE DIRECT COSTS (2⇒1)**

Modification of the operating modes of the mechanical equipment which is started only when required.

2. **LOWERING THE FIXED COSTS (⇨2)**

Elimination of reactive power

3. **LOWERING THE FIXED INDIRECT COSTS (⇨4)**

Install soft starters or variable speed drives to increase the lifetime of the equipment by limiting the mechanical shock due to direct on line starting.

# Reducing expenses

## From fixed direct costs to variable direct costs

### OPERATION ANALYSIS

The first step for energy efficiency consists of analyzing the operating modes of the conveyor and, by extension all the line.

This analyse will evaluate the duration and the frequency of the idle time..

Diagram 1 represents a basic conveyor equipped with:

- an AC motor and its gearbox,
- an upstream sensor (Input<sub>sensor</sub>)
- a downstream sensor (Output<sub>sensor</sub>).

We represented a single load, but in the real world, this load will be generally a whole of elements distributed in a more or less uniform way on the conveyor.

We are going to examine the constraint imposed on a conveyor started at the approach of the load.

The velocity of the upstream conveyor is the same as the studied conveyor (Conveyor<sub>velocity</sub>).

The position of the Input<sub>sensor</sub> relative to the loading zone of the conveyor (Sensor<sub>distance</sub>) must cover two constraints:

- $Sensor_{distance} < Load_{length}$

(where Load<sub>length</sub> is the size of the load)

- $Sensor_{distance} \geq Conveyor_{velocity} \times Starting_{time}$

(where Starting<sub>time</sub> is the time needed to start the conveyor till its nominal speed (Conveyor<sub>velocity</sub>) is obtained.

Thus:

$$Conveyor_{velocity} \times Starting_{time} \leq Sensor_{distance} < Length_{load}$$

Respecting this physical constraint allows the best optimization as well from the point of view of energy efficiency as transfer time of the load.

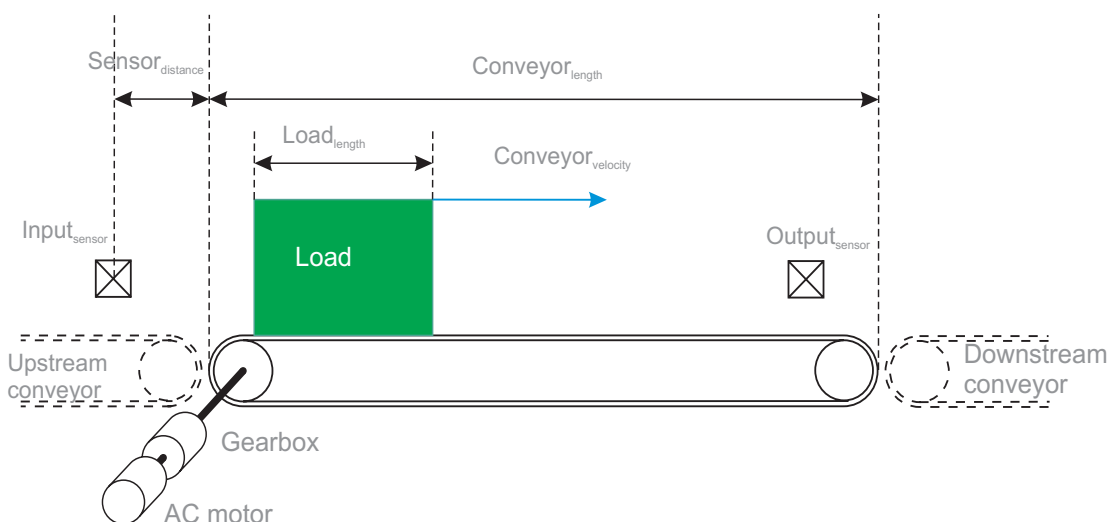


Diagram 1

# Reducing expenses

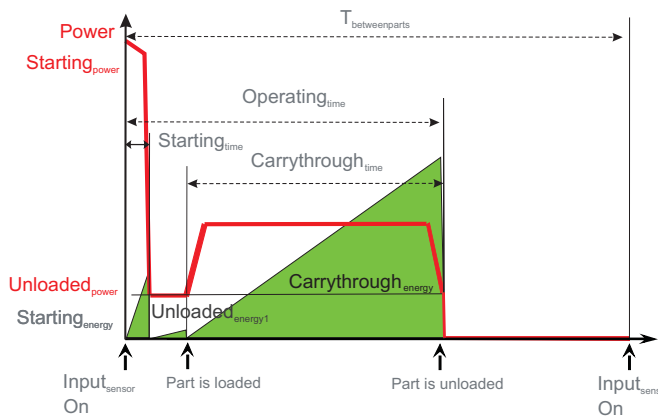
## VALIDATION OF THE OPERATING MODE

In this second step, we answer the question :

$$\text{Starting}_{\text{energy}} = \text{Starting}_{\text{power}} \times \text{Starting}_{\text{time}}$$

Is it wise to keep the conveyor running if unloaded?

Carrythrough<sub>energy</sub> : energy needed to carry the load from input to output



Unloaded<sub>power</sub> : real power needed to move an unloaded conveyor,

Unloaded<sub>energy</sub> : energy needed to move an unloaded conveyor,

The conveyor will be deenergised according to the time elapsed between two consecutive parts. Conveyor parameters must be taken into account (operating time, electrical values).

The above diagram shows the evolution of powers and energy consumptions according to the status of the conveyor.

The sufficient condition to stop the conveyor while making energy saving is:

$$\text{Unloaded}_{\text{power}} > \frac{\text{Starting}_{\text{power}} \times \text{Starting}_{\text{time}}}{T_{\text{betweenparts}} - \text{Operating}_{\text{time}}}$$

In this diagram, the conveyor is energised when the load is detected and runs unloaded before its introduction. The conveyor is stopped when the load has been unloaded.

According to the type of load and specific mechanical constraints, it can be necessary to increase the running time (Operating<sub>time</sub>) in order to make sure that the load is correctly transferred onto the downstream conveyor. That is done by adding a time delay after the activation of the Output<sub>sensor</sub> as represented on the diagram below.

Keywords :

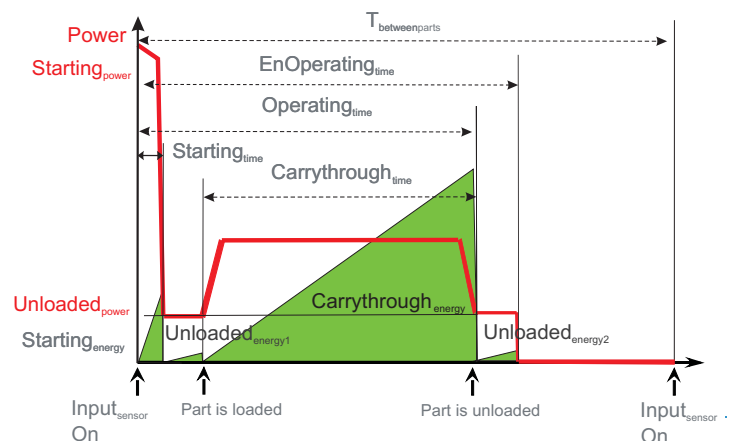
T<sub>betweenparts</sub> : time between 2 consecutive loads on the conveyor.

Carrythrough<sub>time</sub> : time needed to move the load from input to output

Operating<sub>time</sub> : time elapsed from starting to stoppage of the conveyor

Starting<sub>time</sub> : time needed to obtain nominal speed,

Starting<sub>power</sub> : real power needed to start the conveyor,



# Reducing expenses

Keyword :

$EnOperating_{time}$  : time elapsed from starting to stoppage of the conveyor with an additional time delay

Thus the equation becomes:

$$Unloaded_{power} > \frac{Starting_{power} \times Starting_{time}}{T_{betweenparts} - EnOperating_{time}}$$

The time delay, in order to increase the running time, can be empirical or calculated according to the length of the load and the position of  $Ouput_{sensor}$  (which is  $Input_{sensor}$  for the downstream conveyor).

It is possible to chose a value for the time delay considering an uniforme distribution of the load.

Thus, running time will be:

$$EnOperating_{time} > Operating_{time} \times \frac{Lenght_{load}}{2 \times Conveyor_{velocity}}$$

At last, to make sure of the relevance of the operating modes modification, the right thing to do is to check the following equation:

$$Time_{betweenparts} > Operating_{time} + \frac{Lenght_{load}}{2 \times Conveyor_{velocity}} + \frac{Starting_{energy}}{Unloaded_{power}}$$

If, and only if, this condition is true, the modification of the operating mode will generate an energy saving without degrading the performance of the conveyor.

If the above condition is false, it is strongly recommended to keep the conveyor running continuously.

The energy consumption is:

$$E = Starting_{energy} + Carrythrough_{energy} + Unloaded_{energy1} + Unloaded_{energy2}$$

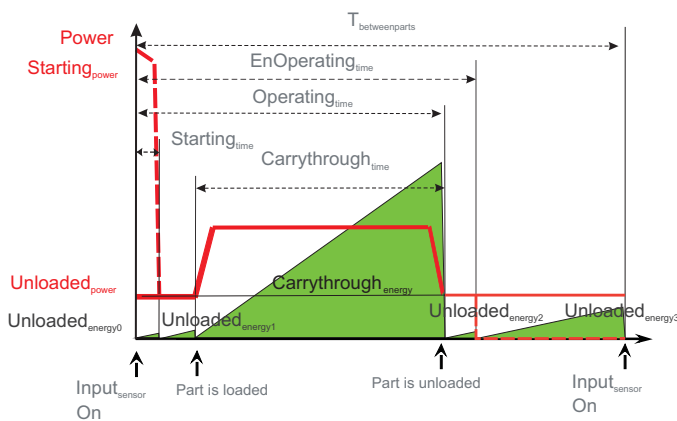
# Reducing expenses

## ENERGY SAVINGS

Energy saving corresponds to the difference in energies between the continuous operating process (diagram below) and the operating process of the previous diagram.

So:

$$Re\ activeenergy_{saving} = Q \times (Starting_{time} + T_{betweenparts} - EnOperating_{time})$$



On all diagrams we can see at a first glance that if the starting time is short, the starting energy can be neglected. This makes calculations easier to complete.

The Starting<sub>time</sub> term thus disappears from all equations.

When running continuously, the power consumption is :

$$E = Unloaded_{energy0} + Unloaded_{energy1} + Carrythrough_{energy} + Unloaded_{energy2} + Unloaded_{energy3}$$

After optimizing the operating mode, saving is :

$$Saving = Unloaded_{energy0} + Unloaded_{energy3} - Starting_{energy}$$

Where:

$$Unloaded_{energy0} + Unloaded_{energy3} = Unloaded_{power} \times (T_{betweenparts} - EnOperating_{time})$$

$$Starting_{energy} = Starting_{power} \times Starting_{time}$$

Saving relative to real power is :

$$Energy_{saving} = Unloaded_{power} \times (Starting_{time} + T_{betweenparts} - EnOperating_{time}) - Starting_{power} \times Starting_{time}$$

We can also estimate the reactive power saving.

This reactive power is needed to produce the magnetization of the motor and can be considered constant whatever the load of the motor

# Reducing expenses

## APPLICATION EXAMPLE

Let us consider a conveying line equipped with 25 conveyors intended to transport standardized pallets 1200 X 800. The line runs 16 hours per day, 300 days per year.

Each conveyor is driven by a Eff1 1,5 KW AC motor. Characteristics of whose are shown in the following table:

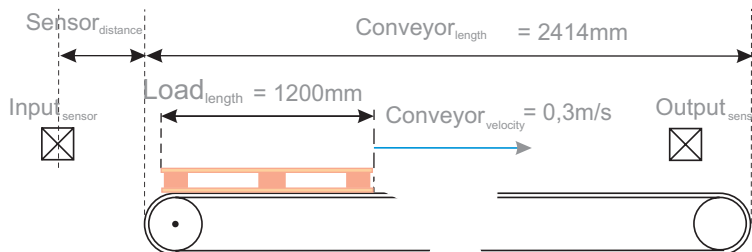
<b>Motor Range :</b>			
Low Voltage Motors - IEC General Purpose - Cast Iron Frame - EFF1 Premium Efficiency			
Frame :	90L	Service factor :	1,00
Nominal power :	1,5 kW	Service :	S1
Frequency :	50 Hz	Ambiant temperature :	-20°C - +40°C
Nb of poles :	4	Altitude :	1000 m
Full load speed :	1450 RPM	Protection degree :	IP55
Slip :	3,33%	Weight:	23,7 kg
Nominal voltage :	230/400 V	Inertia :	0,00672 kgm <sup>2</sup>
Full load current :	5,74/3,30 Amps	Acoustic level :	49 db(A)
Starting current:	43,0/24,8 Amps		Front                      Rear bearings
Current ratio :	7,5		6205 ZZ                      6204 ZZ
No load current :	3,74/2,15 Amps	Lubrification interval	---                      ---
Nominal torque :	9,88 Nm	Qty of grease	---                      ---
Starting torque ratio :	280 %		
Maximum torque ratio :	330 %		
Type :	N	<b>Characteristics when loaded</b>	
Insulation class :	F	Load	Power factor                      Efficiency
Temperature rise :	80 K	100%	0,77                      85,2%
Locked rotor time :	12 s (warm)	75%	0,68                      84,6%
		50%	0,54                      80,5%

Unloaded power = 223 W

Reactive power = 1473 VAR

# Reducing expenses

The mechanical characteristics for each conveyor are shown below :



For this example, we will neglect the energy used to start the conveyor.

Calculation of the optimal distance for the Input<sub>sensor</sub> (mm):

$$300 \times 0,05 \leq \text{Sensor}_{\text{distance}} < 1200$$

Let us choose Input<sub>distance</sub> = 100 mm

The running distance of the pallet is thus :  
2414 + 100 = 2514 mm and its running time is  
2514/300 seconds rounded to 8,4 s

Time between two pallets must be :

$$T_{\text{betweenparts}} > 8,4 + \frac{1200}{2 \times 300}$$

$$T_{\text{betweenparts}} > 10,4$$

Let us select 11s an idle time between two pallets and increase the running time by 9s. The simplified method used for the calculation of energy saving gives for a conveyor and a pallet :

$$\text{Energy}_{\text{saving}} = 233 \times (11 - 9) = 0,13\text{Wh}$$

$$\text{Reactiveenergy}_{\text{saving}} = 1473 \times (11 - 9) = 0,83\text{VARh}$$

Consequently for the line of 25 conveyors running during 1 year long (327 loads per hour) :

$$\text{Energy}_{\text{saving}} = 204\text{kWh}$$

$$\text{Reactiveenergy}_{\text{saving}} = 1288\text{kVARh}$$

**Saving for one year exceeds 18% of the power consumption.**

# Reducing expenses

## Fixed direct costs reduction

### REAL (ACTIVE) POWER, REACTIVE POWER, APPARENT POWER

Any electric machine using AC voltage (motor, transformer) uses two forms of powers: real power (active power) and reactive power.

Real energy (kWh) is transformed completely into mechanical work and losses (heat).

Reactive Power (kVARh), i.e. magnetising energy is almost a constant, independent of the load.

Electrical Utilities charge customer for the real power.

However, in an electric power system, a load with low power factor draws more current than a load with a high power factor for the same amount of useful power transferred. The higher currents increase the energy lost in the distribution system, and require larger wires and other equipment.

Because of the costs of larger equipment and wasted energy, electrical utilities will usually charge a higher cost to industrial or commercial customers where there is a low power factor. The invoice for reactive power is voluntarily dissuasive in order to encourage the users to install compensation systems.

### WAYS TO LIMIT THE REACTIVE POWER

The simple fact of reducing the reactive power allows to generate savings, large enough to justify the installation of compensation systems.

There are several devices:

- capacitor banks,
- variable speed drives.

However, a variable speed drive must be equipped with harmonic filters or, best, an active front end.

If not, it will introduce harmonics contents in the input current and a noticeable increase of the apparent power. The cost of the solution may exceed the expected savings.

If savings are the only objective, installation of this solution is not, most of the time, cost effective.

### WAYS TO DECREASE THE REAL POWER

On the other hand, the use of variable speed drives allow to :

- reduce the size of the AC motors,
- simplify the kinematic chain,
- adapt the speed of the conveyors to the production needs
- reduce the starting shocks and avoid damaging the loads.

Resulting savings make it possible to quickly amortize the cost of the equipment.



# The Schneider Electric answer

Schneider Electric has developed a coherent offer based on the SoMachine concept which allows designing an automation system in a single environment.

The PLC, the variable speed drive or the motion control as well as the dialogue are associated with function blocks, fully tested, validated and documented . Without sacrificing performance, flexibility and price, that gives to the machine manufacturer the certainty of :

- easily solve the critical phases of the system,
- build equipment in conformity with the standards and laws of the various countries,
- ensure the safety of the machine and the workers,
- simplify the integration of the different components.

Schneider Electric split its offer for Conveying applications in three categories of machines :

- simple machines that one can define as a single conveyor or an association of several identical conveyors,
- flexible machines which are association of various conveyors for example two lines of parallel conveyors and a transfer table,
- systems where flexible machines are integrated into a complex unit where we find other PLC's, a SCADA or a production control.

These three preceding categories share certain number of needs :

- mechanical part,
- motorisation,
- AC motors control, either direct on line starters, soft starters, or variable speed drives,
- automation and dialogue,
- facility of maintenance,
- control of the ownership costs.

The principal requirement for the simple machines is easy commissioning and a low price.

The requirements for the flexible machines will be a modular architecture, an increased productivity and needs for traceability of the transported products. For the system, the additional requirements will be the possibility of integration to factory ERP system and an efficient and rich information system.

From this analysis, Schneider Electric proposes:

- automatism architectures
- dedicated AFBs
  - ♦ conveyor,
  - ♦ turntable,
  - ♦ transfertable,
- motor starters installed in remote enclosures for distributed control.

# The Schneider Electric answer

## The distributed control offer :

The distributed control offer is articulated around remote enclosures and four types of motor starters. That form a fully integrated function allowing to manage each section in an autonomous way.

Each one of these enclosures is built from various technologies and answers differentiated cost criteria.

All those enclosures can be linked by a CANopen or other field buses.

### • Traditional enclosure :

dedicated to the simple conveyors. It is based on a direct on line starter in order to optimise the cost solution.

### • Compact enclosure :

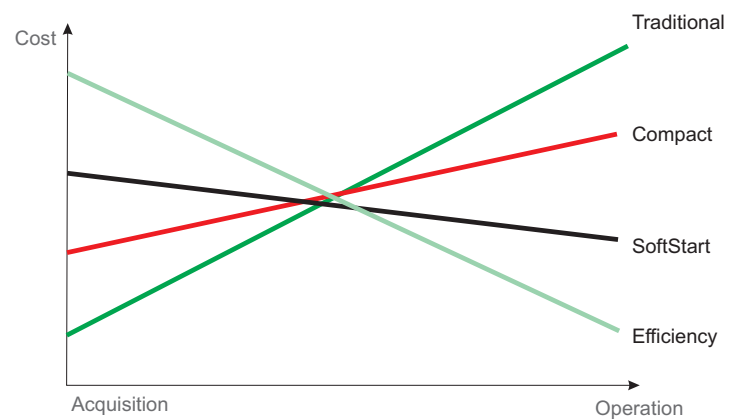
dedicated to the simple conveyors. It is based on a TesSysU motor starter in order to optimise the cost and reduce the size of the solution.

### • SoftStart enclosure :

this enclosure is built around a solid state soft starter. This solution increases the lifetime of the installations by limiting the mechanical shocks.

### • Efficiency enclosure :

a built in variable speed drive optimises the exploitation cost by adapting speed and limiting the electric and mechanical shocks on the installation.



# The Schneider Electric answer

## The AFBs dedicated to machine

These materials are implemented using preset Automation Functions Blocks (AFBs) dedicated to realise the application quickly and errorless.

These AFBs, whose parameters can be defined for the application, are integrated in the PLC's software suite.

All AFBs incorporates products monitoring function and safety management necessary to the correct operation such as:

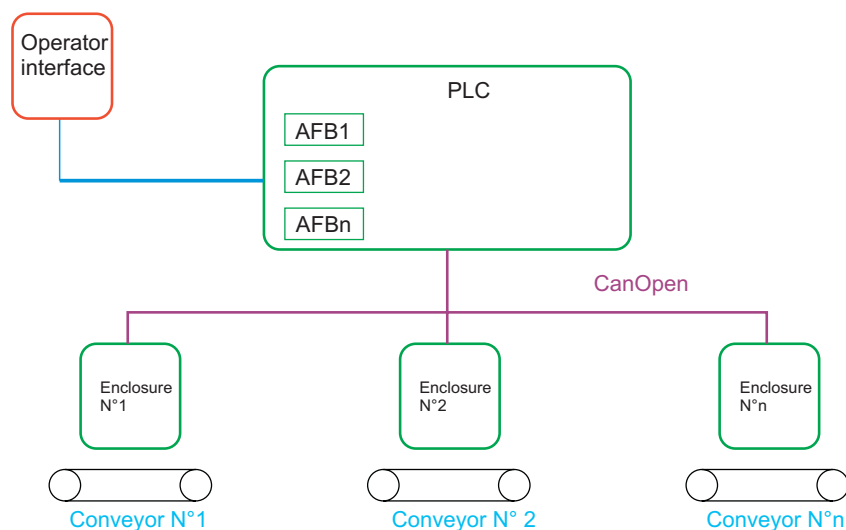
- protection of the equipment, locally or by zones,
- emergency stops.

To ensure a maximum of flexibility, automatic, manual or local operation is possible.

Operation of the machine is displayed on a Human machine interface to inform the operator in order to take corrective actions if needed.

The following AFBs incorporate operating modes allowing to make them "Energy Efficient" in association with the Efficiency distributed control offer :

- 2 speeds, 2 directions conveyor,
- loading/unloading,
- transfer table direction change,
- turntable direction change.



# Conclusion

## An optimised design

The solutions are based on the CANopen field bus which leaves possibility to interface the equipment with third party products with the greatest facility.

Remote control gives flexibility and upgrading capabilities without modifying the whole installation.

The AFBs, fully documented, are preset and usable immediately without requiring a particular adaptation.

Standard architectures give the insurance for an optimum result in a minimum designing time.

The use of soft starters reduces the mechanical constraints and allows to start a line without risk of damage of fragile transported products.

Reduction of these constraints enables to stop and restart a conveyor without impacting its lifespan, thus allowing a substantial reduction of power consumption.

The choice of the variable speed drive (VSD), while adjusting the speed, makes energy savings.

VSD drives, under certain circumstances, improve the AC motors power-factor which, in this case, becomes close to unity at any speed.

The Schneider Electric innovative approach allows the designer as well as the user to have an efficient and economical solution.

**A wise choice of operating mode, the use of energy compensation, soft starters and variable speed drives are smart solutions to make significant savings on a conveying line.**

**Schneider Electric SA**

35 rue Joseph Monier  
F-92500 Rueil Malmaison - France  
Phone: + 33 (0) 1 41 29 70 00  
Fax: + 33 (0) 1 41 29 71 00  
<http://www.schneider-electric.com>

