SEA LAND
ELECTRIC PUMPS

INVERTER

- Quick Guide -

INTRODUCTION

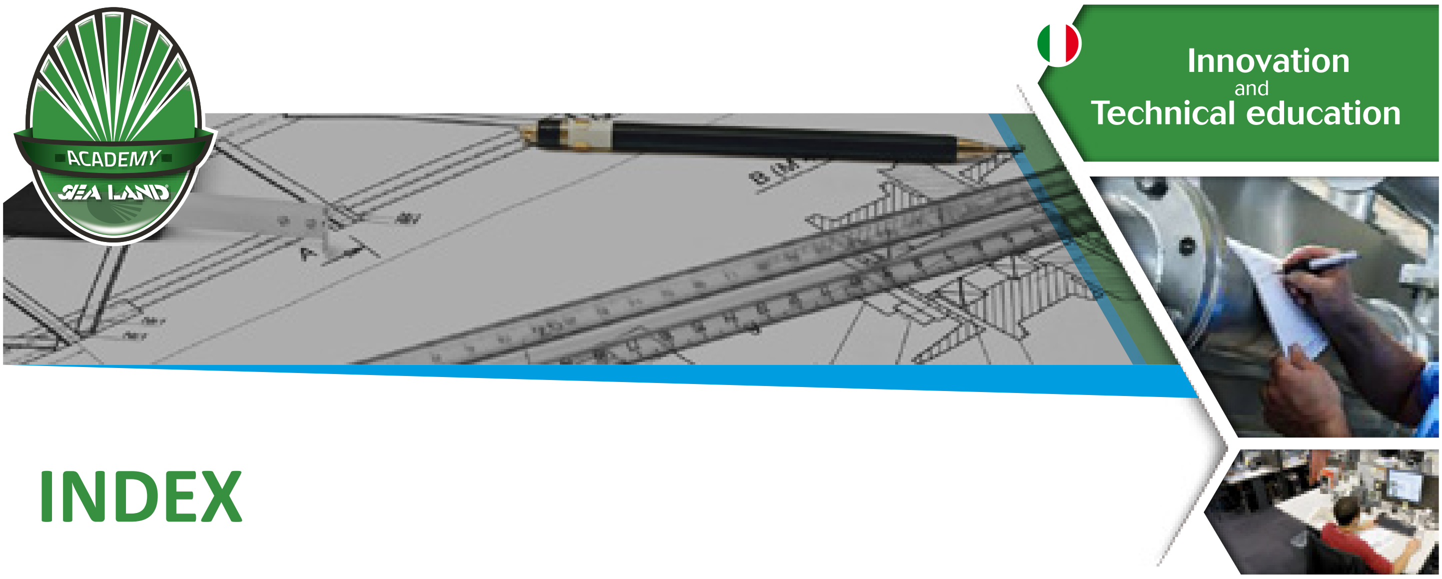
What you are going to read is the second e-book arising from Sea-Land Academy program.

Sea Land has set up the Academy program at the beginning of 2017 mainly to:

- support, in cooperation with both centers of excellence and qualified experts, the never-ending professional evolution required from the market. The even faster technical, economic and social innovation all over the world does need a new business model connecting the work experience to the academic learning. The result of such contamination is a professional skillset which does increase the value of Human Capital;
- promote the know-how acquired through our Value Chain, our distributors and suppliers too, to set up a strategic long-term cooperation.

These are the reasons why we planned a class about Inverters.
Both our Technical and Sales Departments remain at your disposal for any information you might need.

Enjoy!



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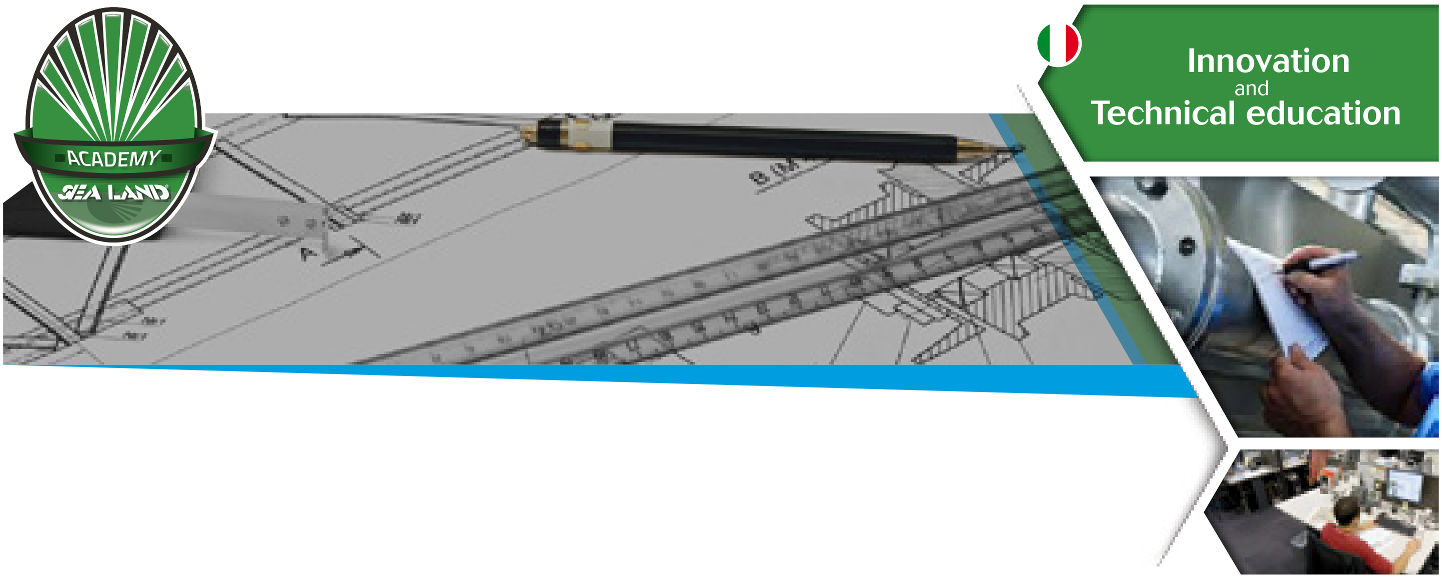
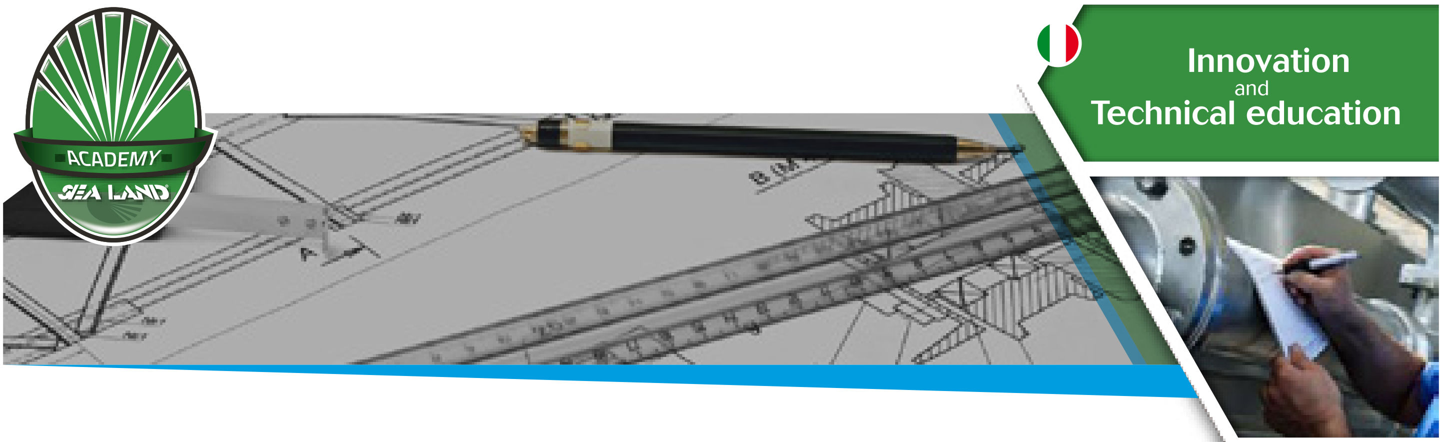




1. MOTOR AND DRIVE SYSTEM BASICS

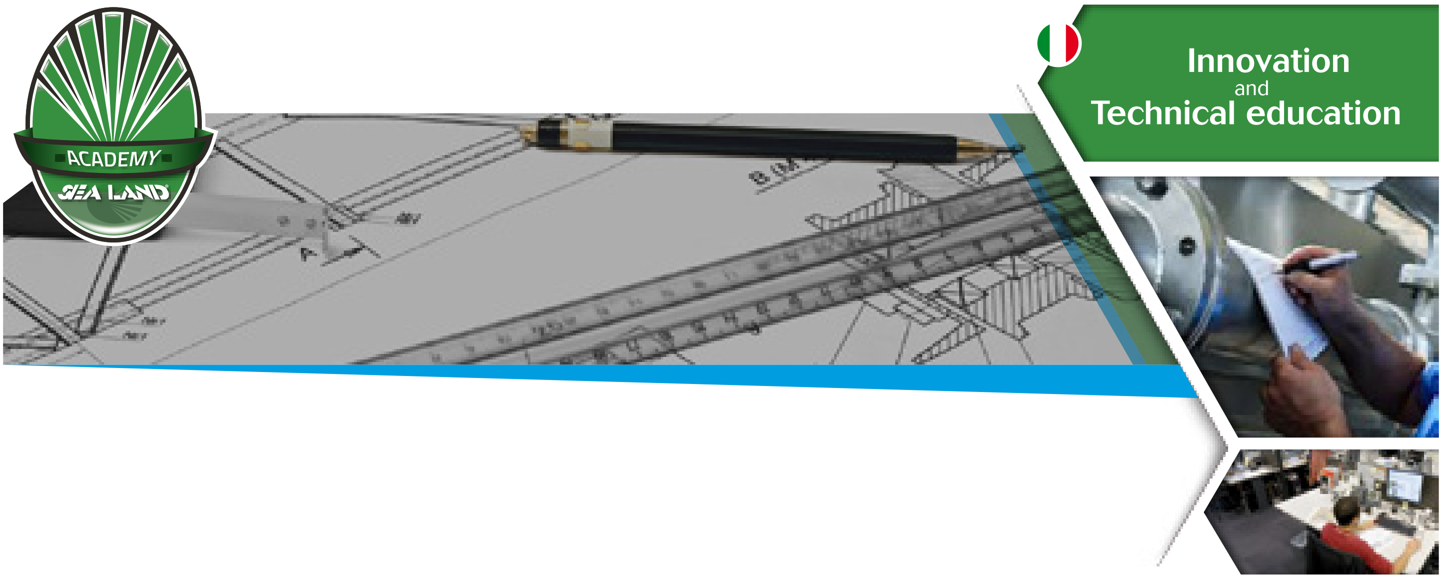
1.1 A SYSTEM APPROACH

Cost-effective operation and maintenance of a motor and drive system require attention not just to individual pieces of equipment but the system as a whole. A systems approach analyzes both the supply and demand sides of the system and how they interact, essentially shifting the focus from individual components to total system performance. Operators can sometimes be so focused on the immediate demands of their equipment that they overlook how the system's parameters are affecting that equipment.

A common engineering approach is to break down a system into its basic components or modules, optimize the selection or design of those components, and then assemble the system. An advantage of this approach is that it is simple. A disadvantage is that this approach ignores the interaction of the components. For example, sizing a motor so that it is larger than necessary — essentially giving it a safety factor— ensures that the motor can provide enough **torque** to meet the needs of the application. However, an oversized motor can create performance problems with the driven equipment, especially in turbomachinery such as fans or pumps. In certain circumstances, an oversized motor can compromise the reliability of both the components and the entire system.

In a **component approach**, the engineer employs a particular design condition to specify a component. In a **systems approach**, the engineer evaluates the entire system to determine how end-use requirements can be provided most effectively and efficiently. Focusing on systems means expanding possibilities, from looking for one piece of equipment that can meet worst-case requirements to evaluating whether components can be configured to maintain high performance over the entire range of operating conditions.

A basic premise of a systems approach is that industrial systems usually do not operate under one condition all the time. Motor and drive system loads often vary according to cyclical production demands, environmental conditions, changes in customer requirements, and so on. To optimize system performance, the engineer must configure the system to avoid inefficiencies and energy losses. For example, motors that typically run at more than one-half to full load usually operate

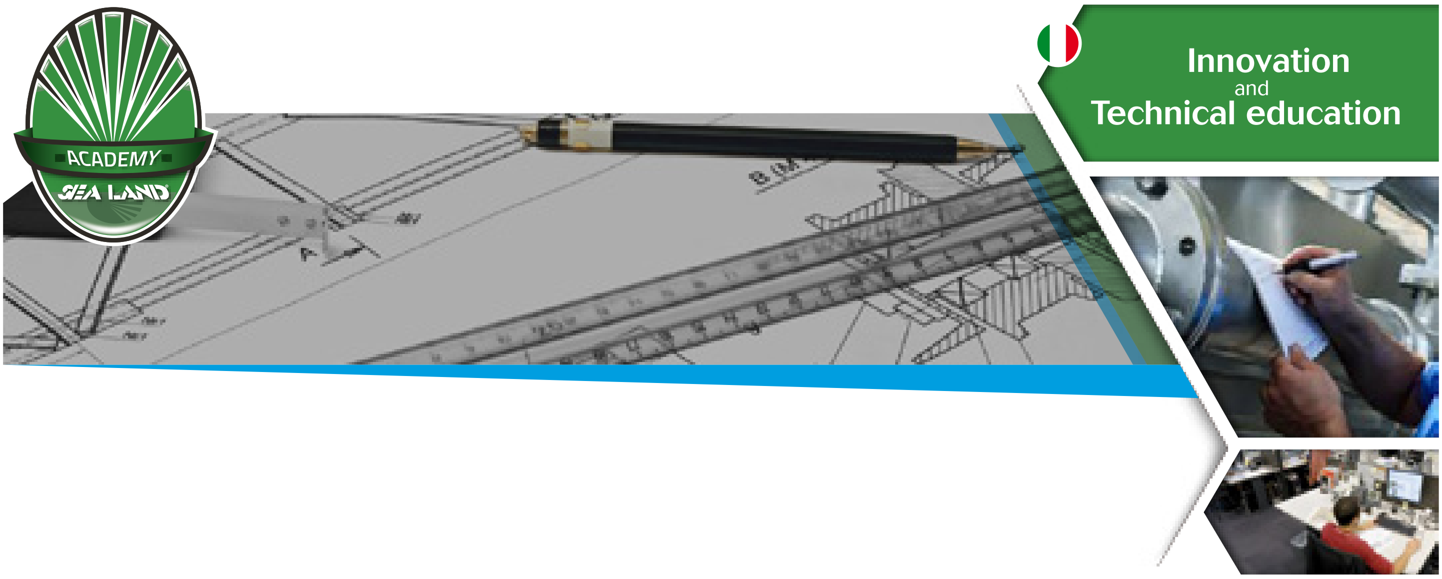


much more efficiently than they do at less than one-half load or into their service factor. The service factor of an **alternating-current (AC)** motor is a multiplier which, when applied to the rated motor **horsepower (HP)**, indicates a permissible loading for operation under usual service conditions. Though operation within the service factor is permissible, it is not recommended because a motor operating at any service factor greater than 1 will have a reduced life expectancy. Common service factor values are 1.10 and 1.15. Other avoidable losses occur when throttling valves or dampers are used for flow regulation.

For example, suppose that a **motor-driven pump** supplies water to several heat exchangers and has a flow requirement that the system piping and heat exchangers were designed to handle. The pump was specified according to the requirements of this flow condition. However, actual operating conditions can vary according to the season, the time of day, and the production rate. To handle the need for variable flow rates, the system is equipped with throttling valves and recirculation bypass lines. This equipment provides the desired flow regulation, but at the expense of wasted energy.

In addition to increasing energy costs, an inefficient motor and drive system often increases maintenance costs. When systems do not operate efficiently, thermal and mechanical energy losses must be dissipated by piping, structures, dampers, and valves. Additional system stresses can accelerate wear and create loads for which the system was not originally designed. For example, in a pumping system, excess flow energy must be dissipated across throttle valves or through bypass valves, or it must be absorbed by the piping and support structure. As a result, all of this equipment can degrade more easily. Throttle and bypass valves can require seat repair, and piping and support structures can develop cracks and leak as a result of fatigue loads. Repairing or replacing this equipment can be costly.

Also, inefficient system operation in an industrial plant can create poor working conditions such as high levels of noise and excessive heat. High noise levels can be the result of flow noise, structural vibrations, or simply normal equipment operation. Also, inefficient systems often add heat to the workplace. This added heat usually must be removed by the facility’s heating, ventilating, and air-conditioning (HVAC) system, further increasing total operating costs.



1.1.1 ALTERNATING-CURRENT MOTORS

AC motors are the most widely used in the industry. Industry's preference for AC motors springs from their simplicity, low cost, and efficiency. There are two primary types of AC motors: induction (also referred to as asynchronous) and synchronous.

In both types of motors, the stator circuit creates a magnetic field that rotates at a **synchronous speed**. This speed depends on the number of poles and the **frequency** of the electricity supply; and it is determined by the following equation:

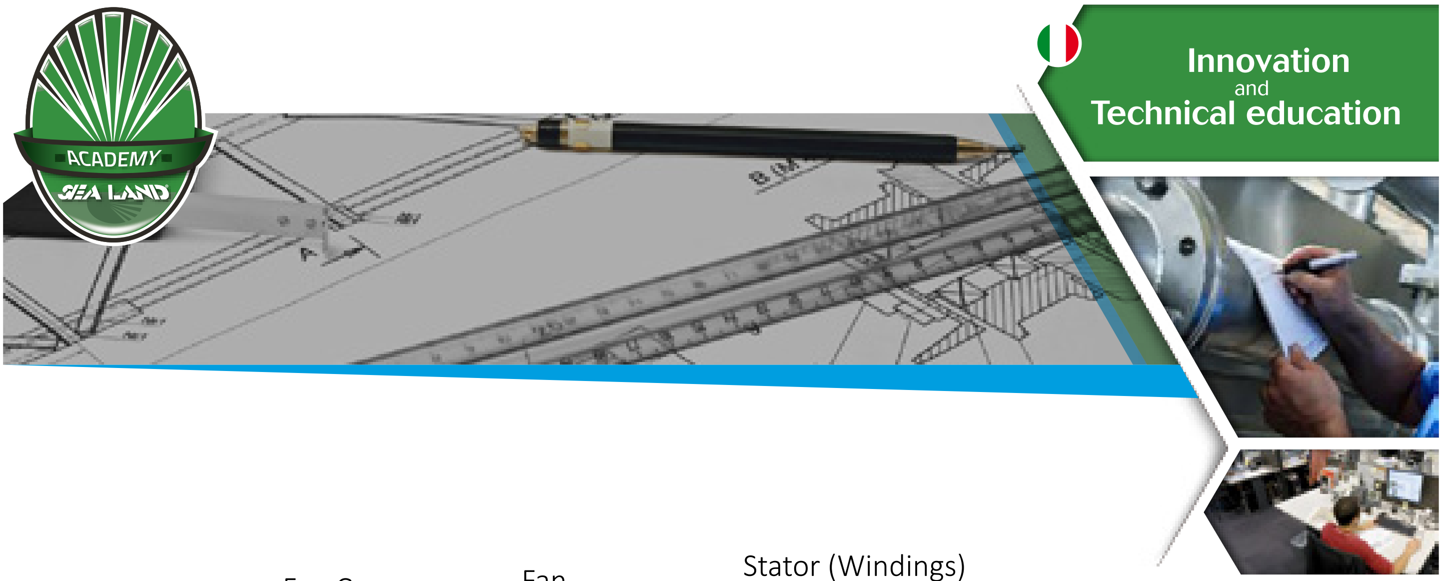
$$\textbf{Synchronous speed} = \frac{\textbf{120} \times \textbf{frequency [hertz (Hz)]}}{\textbf{number of poles}}$$

For example, in a 60-Hz system, the stator field in a 2-pole motor rotates at 3,600 revolutions per minute (RPM). Instead, in a 50-Hz system, the stator field in a 2-pole motor rotates at 3,000 revolutions per minute (RPM).

An important operating difference between induction motors and synchronous motors is that induction motors operate at somewhat less than synchronous speed. The difference between the actual speed and synchronous speed is known as **slip**. Synchronous motors operate without slip at synchronous speed.

INDUCTION MOTORS

Induction motors include squirrel-cage and wound-rotor types. Induction motors rely on a magnetic field to transfer electromagnetic energy to the rotor. The induced currents in the rotor create a magnetic field that interacts with the stator field. The speed of the rotor's magnetic field is slightly less than that of the stator (this difference is the slip). As the load on the motor increases, the slip also increases. The full-load speed is typically shown on the motor nameplate. A typical induction motor is shown in figure.



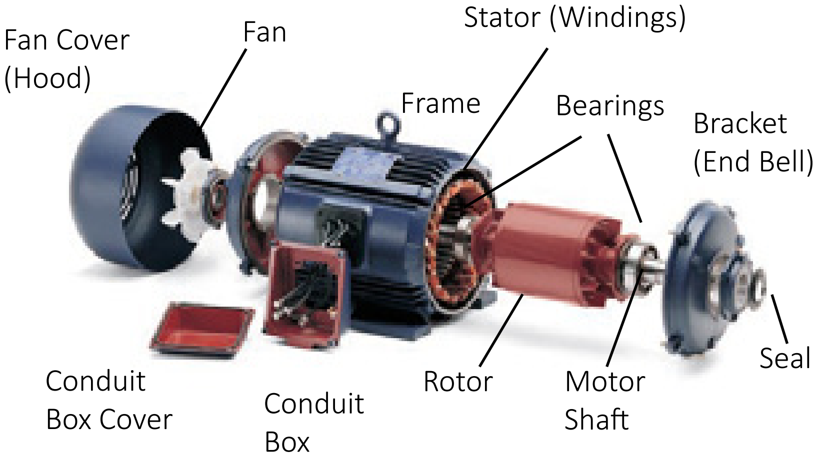


Figure. Induction motor

SQUIRREL-CAGE MOTORS

The most common type of industrial motor is the squirrel-cage induction motor. The name derives from the similarity between the rotor and the type of wire wheel commonly found in pet cages at the time this motor was first developed (see the figure). Rotor bars are either welded or cast to two circular end rings, forming a circuit with very little resistance.

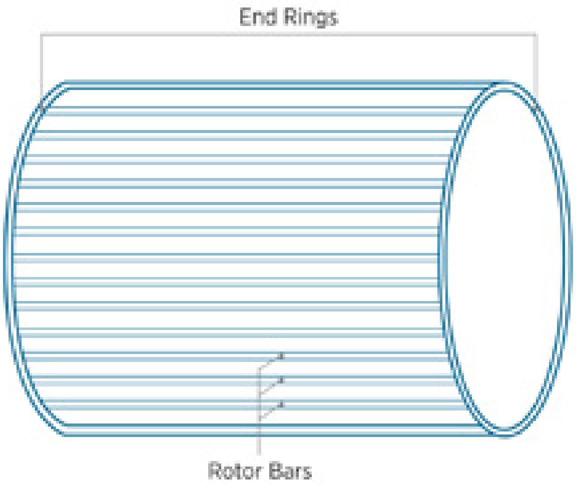
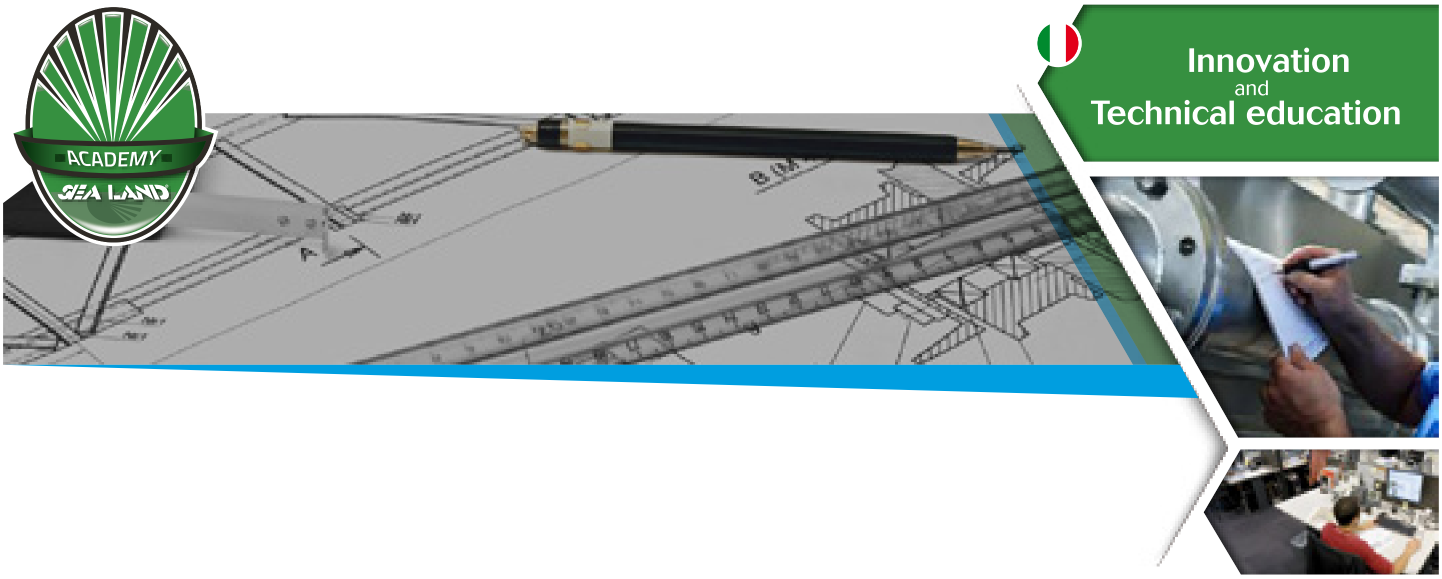


Figure. Squirrel-cage rotor



Advantages of this type of motor include the following:

- Low cost
- Low maintenance
- High reliability
- A fairly wide range of torque and slip characteristics.

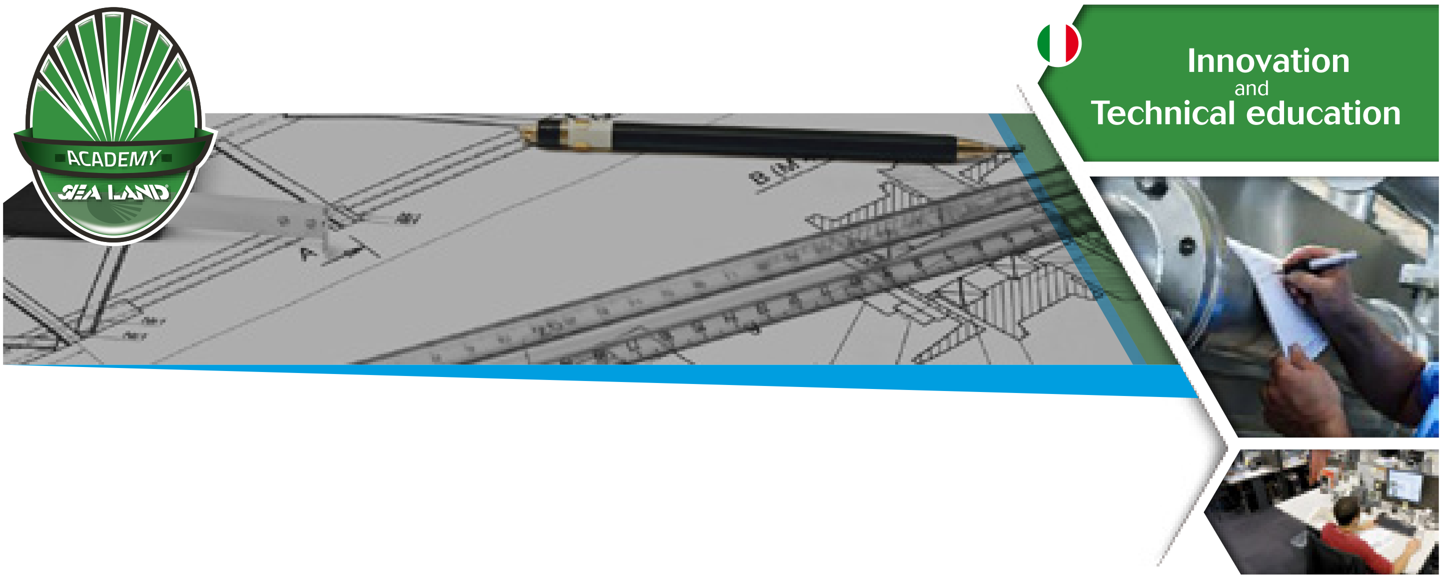
Because squirrel-cage induction motors can be designed and built to have a relatively wide range of torque and slip characteristics, the IEC (International Electrotechnical Commission) for the world and NEMA (National Electrical Manufacturer Association) specifically for USA, have developed a set of classifications for these motors. These classifications help engineers and designers select the right motors for applications that require certain starting torques, operating torques, and slip rates.

SYNCHRONOUS MOTORS

These motors operate at the same speed as the rotating magnetic field. Although they are more expensive to purchase and maintain, they can be 1% to 2% more efficient —depending on motor size— than induction motors. They can also add a leading power factor component to a distribution system, which makes them attractive to many industrial facilities. In fact, synchronous motors are occasionally operated without a load, as synchronous condensers, just to increase a facility’s power factor.

In industrial synchronous motors, an external supply of DC power is usually supplied to the rotor by a set of slip rings and brushes. In newer models, brushless excitation systems and PM generators are built into the rotor. Because the direct current does not change the polarity, the rotor needs a separate squirrel-cage winding during starts. But once the rotor approaches operating speed, the squirrel-cage winding becomes inoperative; as the direct current is applied, the rotor speed is pulled into synchronicity with the rotating magnetic field created by the stator.

The most common type of industrial motor is still the squirrel-cage induction type. Because mo-



tors are indispensable to plant operations, facilities tend to resist using a new motor technology if the current system is performing adequately. Adopting better operating practices or incorporating better controls into existing induction motor systems incurs less risk and can result in the same levels of efficiency and performance that new motor technologies exhibit.

1.2 MOTOR OPERATING CHARACTERISTICS

The most important motor operating characteristics are horsepower, operating speed (measured in RPM), and torque. These are related by the following equation:

$$\text{Power} = \frac{\text{Torque x Speed}}{k}$$

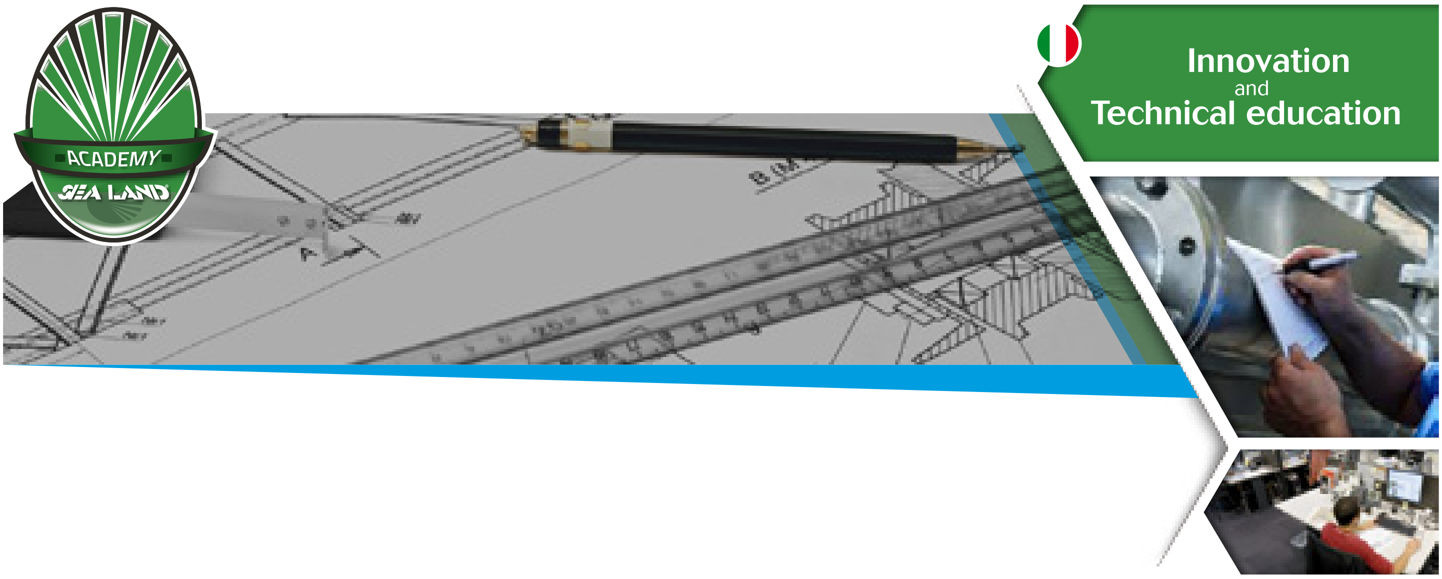
k = coefficient that depends on the units of measurement

Motor performance depends on how well these operating characteristics match the load. T**he load on a motor is not always constant**, and the response of the motor to changes in load is a fundamental factor in selecting the right motor for an application.

1.2.1 VARIABLE LOADS

There are four basic types of loads:

1. Variable torque
2. Constant torque
3. Constant horsepower
4. Cyclic loads.



The most common type of load has **variable torque** characteristics, in which horsepower and torque vary with respect to speed. For example, in centrifugal pumps and fans, torque varies according to the square of speed.

In a **constant-torque** load, the torque is independent of speed. Common applications include conveyor systems, hoists, and cranes. For example, conveying a 500-pound load along an assembly line requires the same amount of torque whether it is moving at a constant speed of 5 feet per minute or 10 feet per minute. Although horsepower varies linearly with respect to speed, torque is constant.

In a **constant horsepower** load, the torque increases with decreasing speed and vice versa. A good example of this type of load is a winding machine in which the torque increases as the roll thickness builds up and the rotational speed slows down. Machine tools such as lathes and cutting machines also display these operating characteristics.

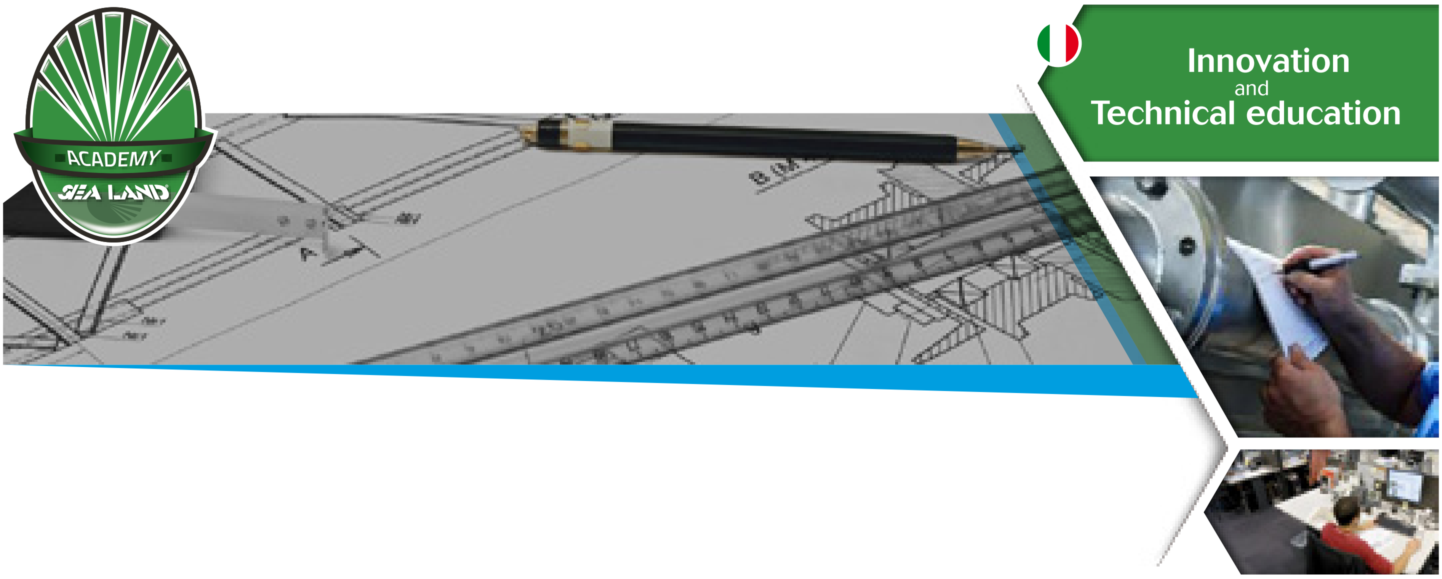
A **cyclic load** is one in which the torque changes significantly within a cycle or over a series of cycles. An example is an oil well pump; in this application, the downstroke of the pump piston requires much less force than the upstroke.

1.3 INTRODUCTION TO VARIABLE SPEED

The utility power supply is of constant frequency, and it is 50 or 60 Hz. Since the speed of AC machines is proportional to the frequency of input voltages and currents (see paragraph 1.1.1), they have a fixed speed when supplied from power utilities. A number of modern manufacturing processes, such as machine tools require variable speed.

This is true for a large number of applications, some of which are the following:

- Electric propulsion
- Pumps, fans, and compressors
- Plant automation
- Flexible manufacturing systems

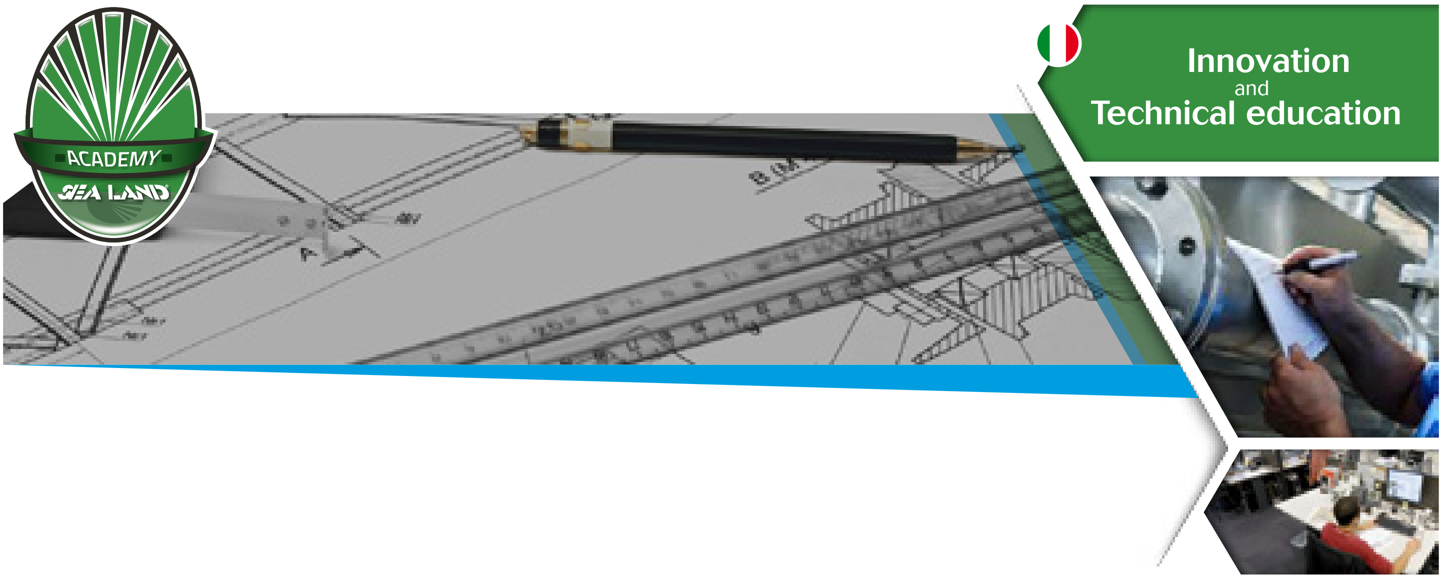


- Spindles and servos
- Aerospace actuators
- Robotic actuators
- Cement kilns
- Steel mills
- Paper and pulp mills
- Textile mills
- Automotive applications
- Underwater excavators mining equipment, etc.
- Conveyors, elevators, escalators, and lifts
- Appliances and power tools
- Antennas

The introduction of variable-speed drives increases the automation and productivity and, in the process, efficiency. For instance, nearly 65 % of the total electric energy produced in the USA is consumed by electric motors. Decreasing the energy input or increasing the efficiency of the mechanical transmission and processes can reduce the energy consumption. The system efficiency can be increased from 15 to 27% by the introduction of variable-speed drive operation in place of constant-speed operation.

It is to be noted that many companies' profits, in recent times, stem mainly from saving in their energy bills. The energy-saving aspect of variable-speed drive operation has the benefits of conservation of valuable natural resources, reduction of atmospheric pollution through lower energy production and consumption, and competitiveness due to economy. These benefits are obtained with **initial capital investment in variable-speed drives that can be paid off in a short time.** The payback period depends on the interest rate at which money is borrowed, annual energy savings, cost of the energy, and depreciation and amortization of the equipment.

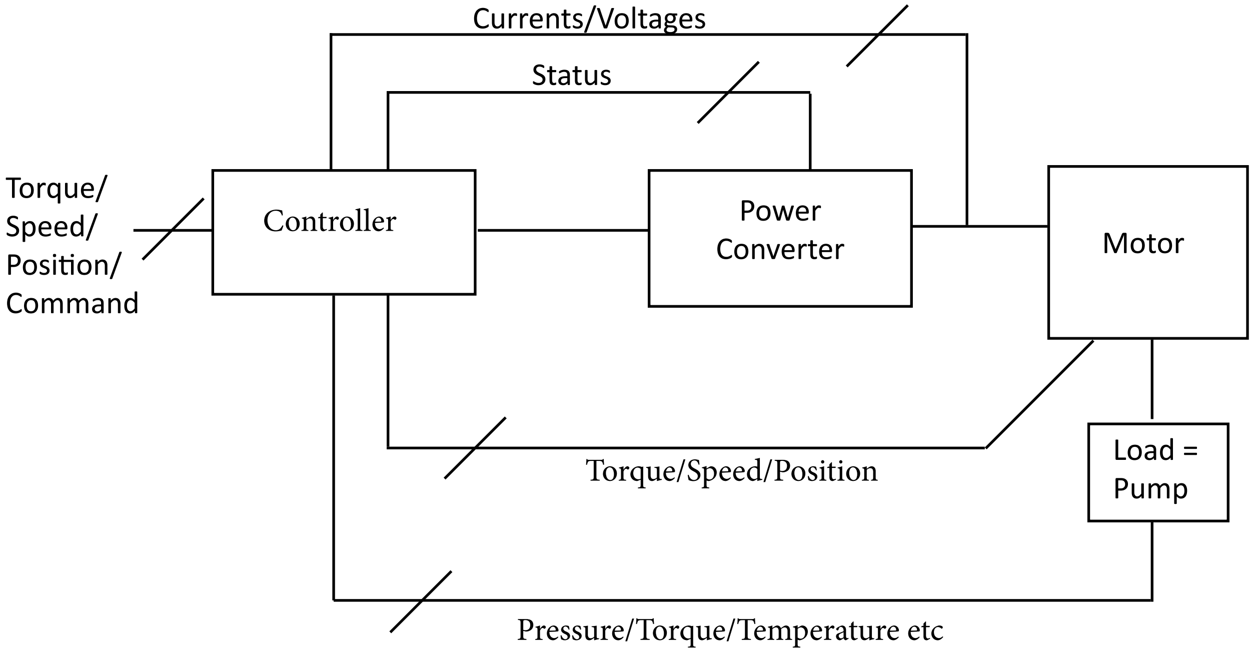
For a large pump variable-speed drive it is estimated that the payback period is nearly 3 to 5 years at the present, whereas the total operating life is 20 years. That amounts to 15 to 17 years of profitable operation and energy savings with variablespeed drives.

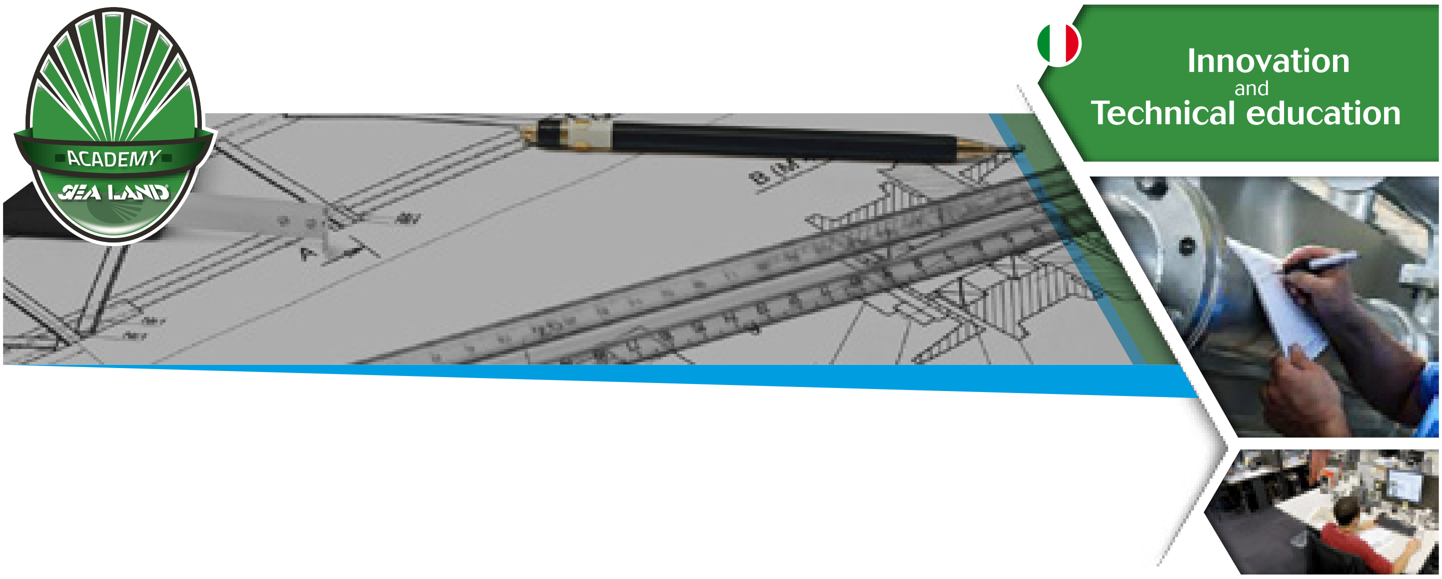


1.4 MOTOR DRIVE

A modern variable-speed system has four components:

1. Motor- AC or DC supply
2. Power converter- Rectifiers, choppers, inverters and cycloconverters
3. Controllers- Matching the motor and power converter to meet the load requirements
4. Load





1.4.1 ELECTRIC MACHINES

The electric machines tipically used for speed control, in industrial applications, are AC machines, i.e. induction or permanent-magnet synchronous motor.

Some factors go into the selection of a machine for a particular application:

- Cost
- Thermal capacity
- Efficiency
- Torque-speed profile
- Acceleration
- Power density, volume of the motor
- Ripple, cogging torques
- Availability of spare and second sources
- Robustness
- Suitability for hazardous environment
- Peak torque capability

They are not uniformly relevant to any one application. Some could take precedence over others. For example, in a position-servo application, the peak torque and thermal capabilities together with ripple and cogging torques are preponderant characteristics for application consideration.

EFFICIENCY COMPUTATION

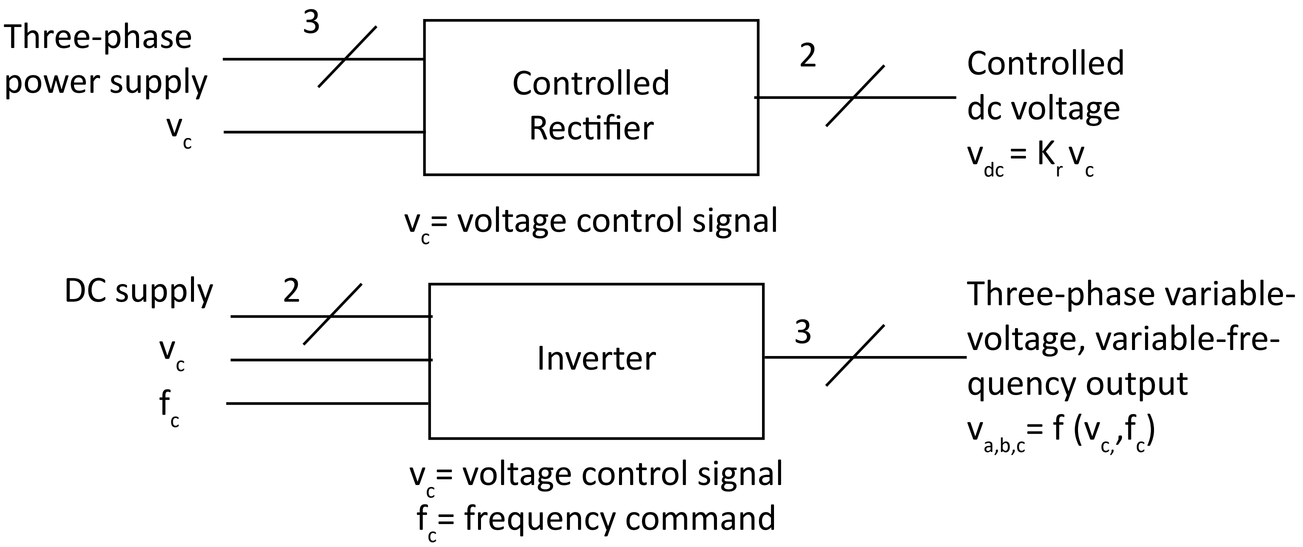
The interest in **energy savings** is one of the major motivational factors in the introduction of **variable-speed drives** in some industries.
Therefore, it is prevalent to encounter the efficiency computation for electric motors whenever a variable-speed operation is considered.

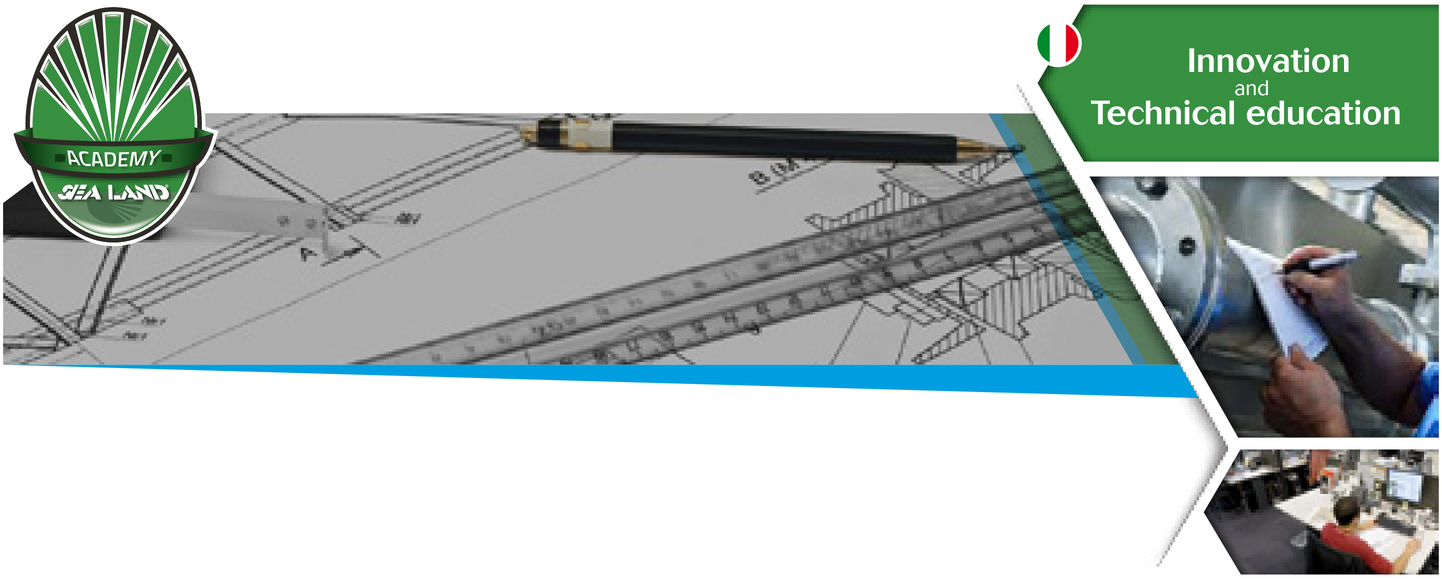
1.4.2 POWER CONVERTERS

The power converters driving the electrical machines are:

1. Controlled rectifiers: They are fed from single and three-phase AC mains supply and provide a DC output for control of the DC machines or sometimes input DC supply to the inverters in the case of AC machines.
2. Inverters: They provide variable alternating voltages and currents at desired frequency and phase for the control of AC machines.
   Because of the DC intermediary, known AC DC link, between the supply AC source and the output of the inverter, there is **no limitation** to the attainable output frequency other than that of the power device switching constraints in the inverters.

These power converters can be treated as black boxes with certain transfer functions. In that case, the referred converters are symbolically represented as shown in figure.



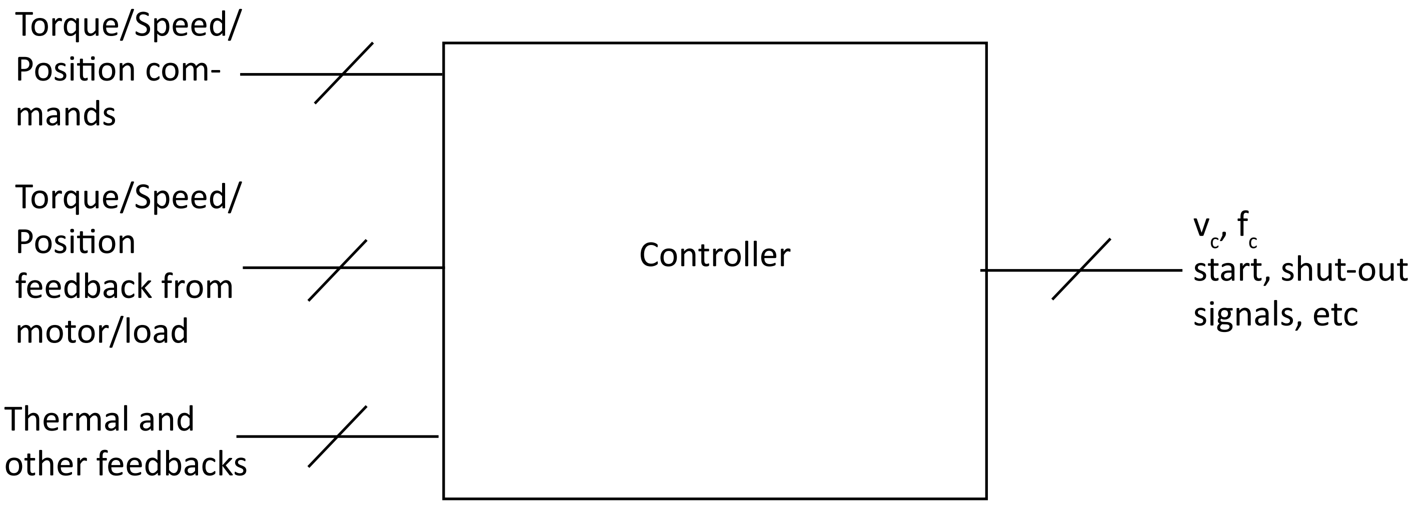


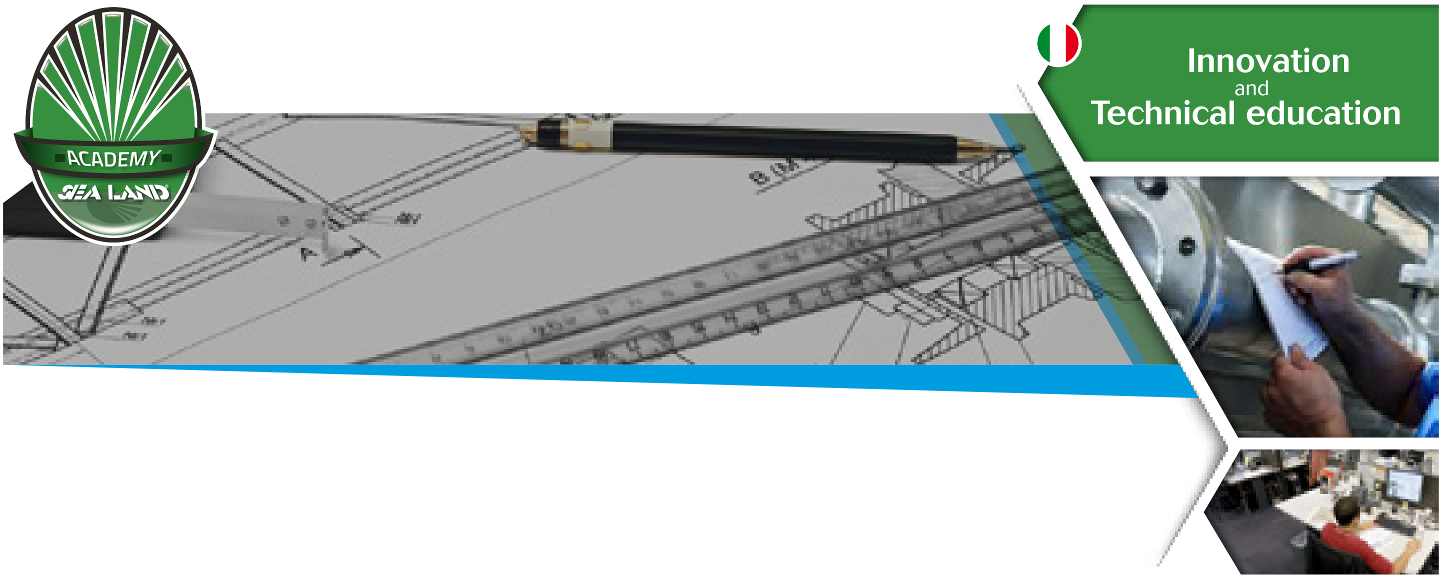
1.4.3 CONTROLLERS

The controllers embody the control laws governing the load and motor characteristics and their interaction. To match the load and motor through the power converter, the controller controls the input to the power converter. Very many control strategies have been formulated for various motor drives, and the controllers implement their algorithms. The laws governing the control are usually complex.

The schematic of the controller is shown in the figure. Its input consists of the following:

- Torque, flux, speed, and/or position commands
- Their rate of variations, to facilitate soft start and preserve the mechanical the integrity of the load
- The measured torque, flux, speed, and/or position for feedback control
- Limiting values of currents, torque, acceleration, and so on
- Temperature feedback and instantaneous currents and/or voltages in the motor and/or converter
- The constants in the speed and position controllers, such as proportional integral, and differential gains.





The controller may also perform the protection and other monitoring functions and deal with emergencies such as sudden field loss or power failure.
Also, they lend themselves to software and remote control, hence paving the way to flexible manufacturing systems and a high degree of automation.

1.5 MATCHING MOTORS AND DRIVES TO THEIR APPLICATIONS

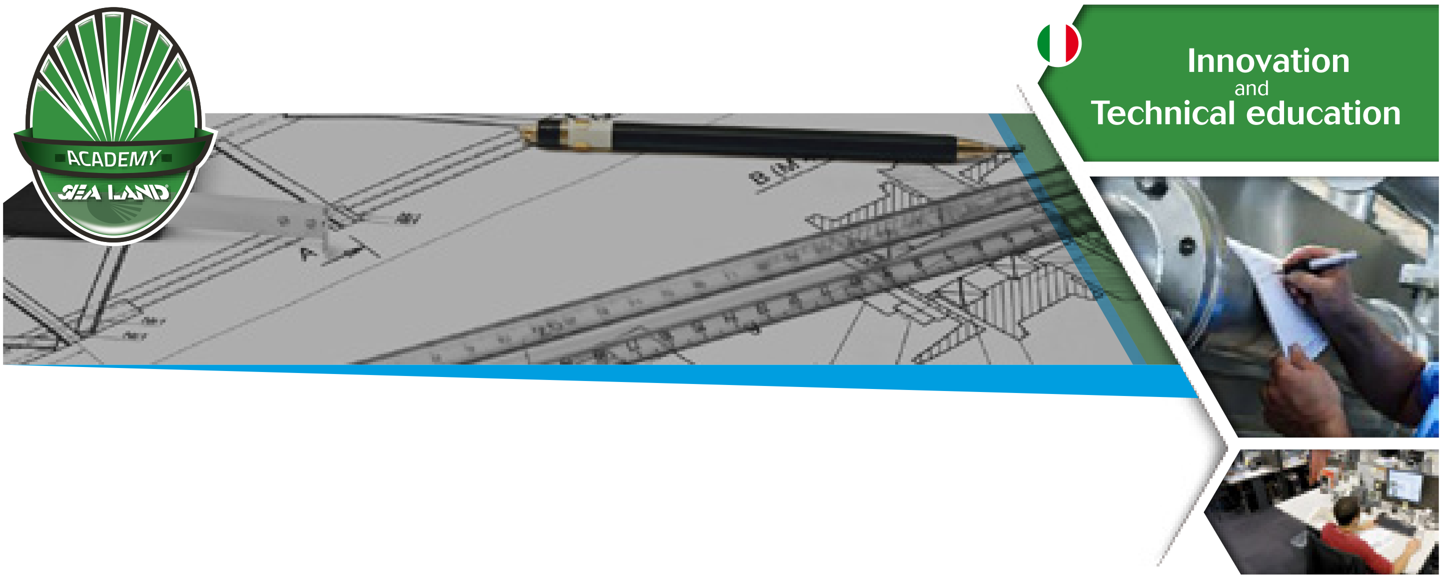
To select the proper motor for a particular application, the engineer needs to consider the basic requirements of the service. These include the load profile, environmental conditions, the importance of operating flexibility, and reliability requirements. About **60% of the energy** consumed by industrial motor-driven applications is used to drive **pumps**, fans, and compressors. Within these applications, centrifugal pumps and fans share some common relationships between speed (commonly measured in RPM), flow, pressure, and power; these are known as affinity laws ***(see sidebar).***

AFFINITY LAWS

$$\text{Flow}_{\text{final}} = \text{Flow}_{\text{initial}} \left(\text{RPM}_{\text{final}} / \text{RPM}_{\text{initial}} \right)$$

$$\text{Pressure}_{\text{final}} = \text{Pressure}_{\text{initial}} \left(\text{RPM}_{\text{final}} / \text{RPM}_{\text{initial}} \right)^{2}$$

$$\text{Power}_{\text{final}} = \text{Power}_{\text{initial}} \left(\text{RPM}_{\text{final}} / \text{RPM}_{\text{initial}} \right)^{3}$$

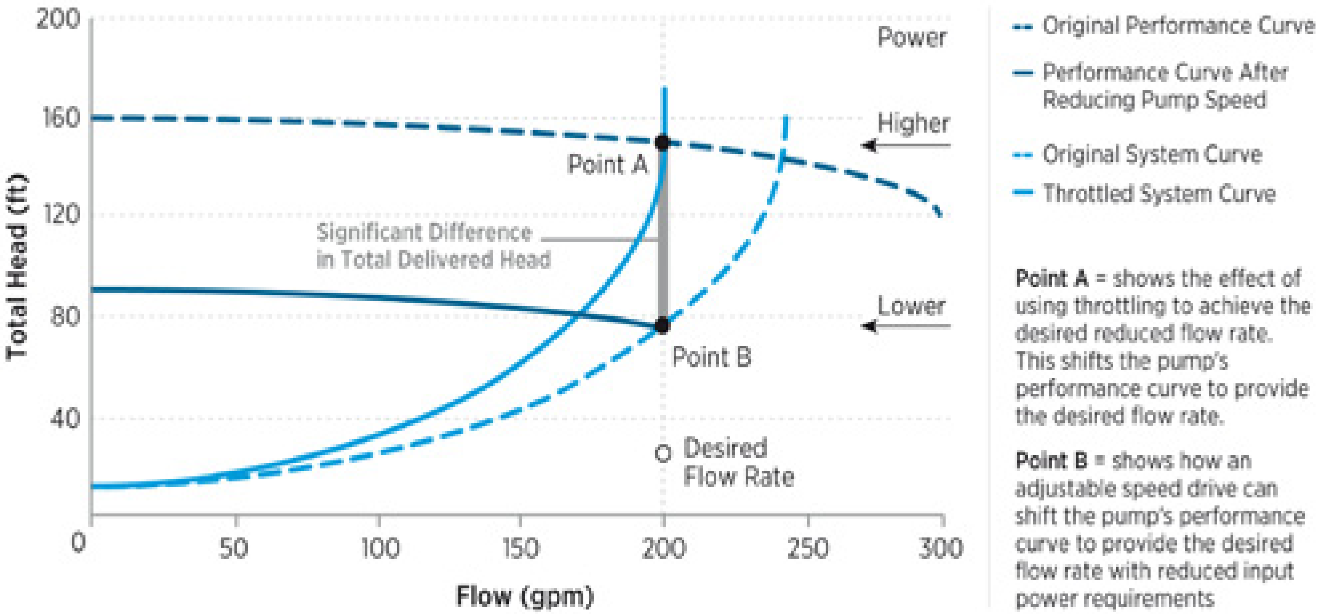


One important implication of these laws is that **power consumption is highly sensitive to operating speed**. Increasing the speed of a fan or a pump requires a relatively large increase in the power required to drive it. For example, doubling the speed of the machine requires eight times more power. Similarly, decreasing the speed of a fan or pump removes a significant load from the motor.

The pump performance curve shown in figure 1 illustrates the relationship between power and speed. The operating point is the intersection between the system curve and the pump's performance curve. To achieve the desired operating flow with a fixed-speed pump, a throttle valve is used to control flow. The throttle valve increases the pressure in the pipe and takes pump performance to Point A on the original performance curve. Opening the throttle valve drops the pressure.

The input power to the pump-drive motor is proportional to the product of the flow and head at the operating point. Note how the amount of pressure supplied by the pump is dramatically reduced by slowing its rotational speed. Reducing the pump's speed with an ASD takes the pump to operating Point B. Although operating Point B provides the same desired flow rate, it does so with reduced pressure and power requirements. At Point B, the pump operates much more efficiently, thus saving energy. There is no longer a large pressure drop across the throttle valve, so maintenance requirements, system noise, and system vibration are reduced. Additional examples of this relationship are shown in figures 2 and 3.

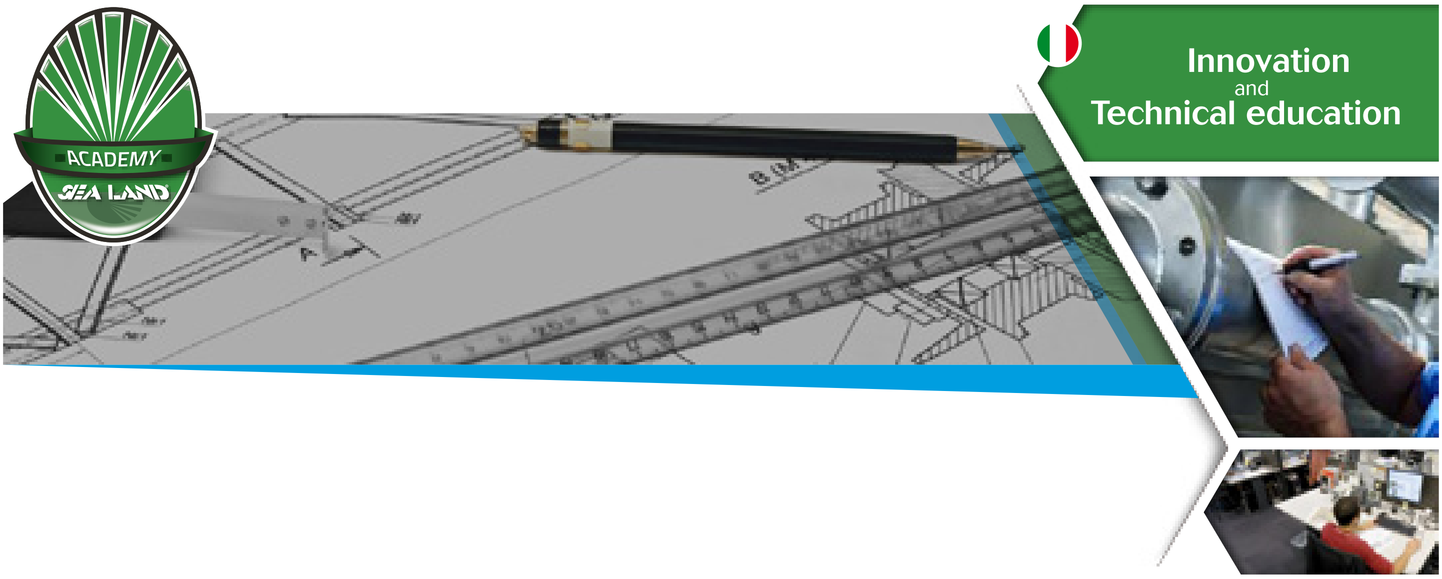
Replacing a control valve with an ASD can increase system efficiency and provide significant energy savings. Note that in figure 2, 100 energy units are supplied to the system; however, in figure 3, the ASD system does the same work while requiring only 80 energy units. With the ASD, much less energy is lost across the throttle valve because the pump generates less flow.



Point A = shows the effect of using throttling to achieve the desired reduced flow rate. This shifts the pump's performance curve to provide the desired flow rate.

Point B = shows how an adjustable speed drive can shift the pump's performance curve to provide the desired flow rate with reduced input power requirements

Figure 1



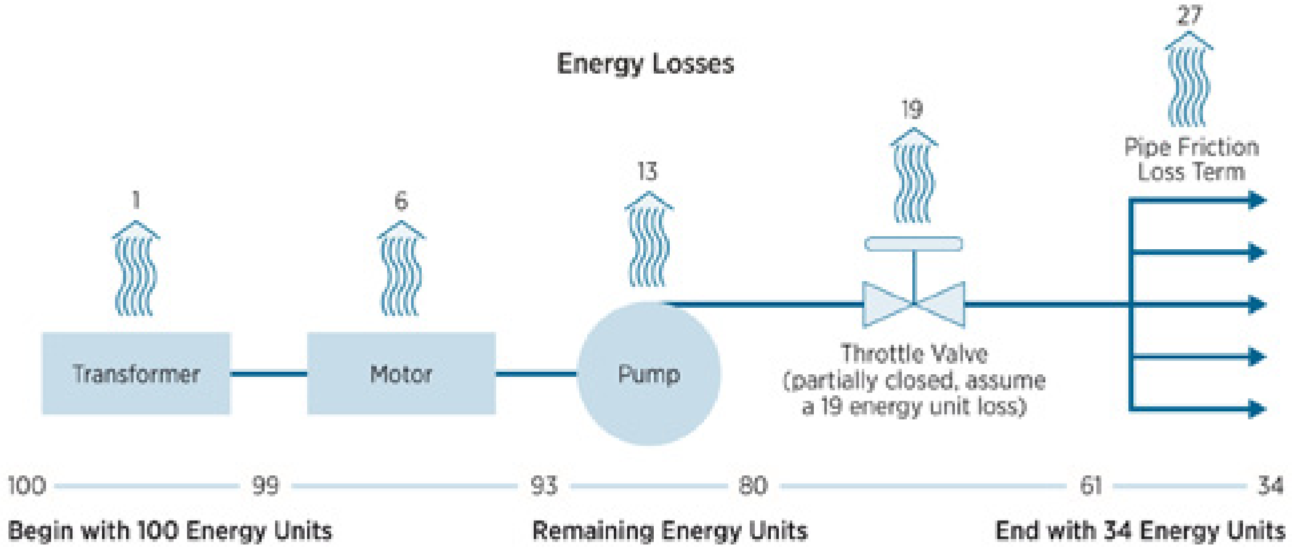


Figure 2

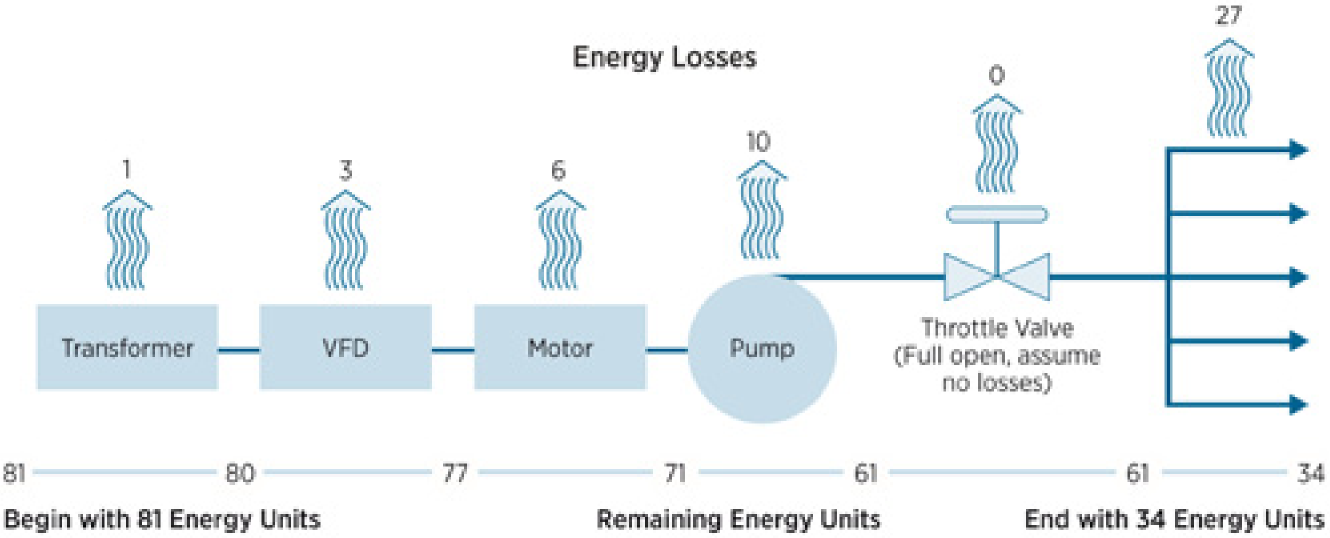
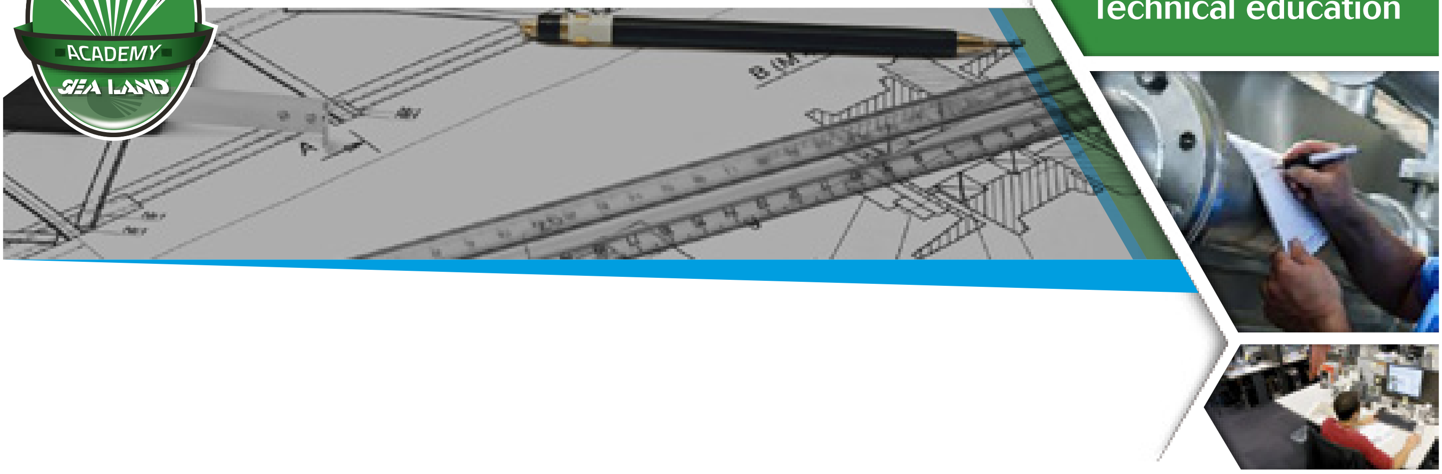
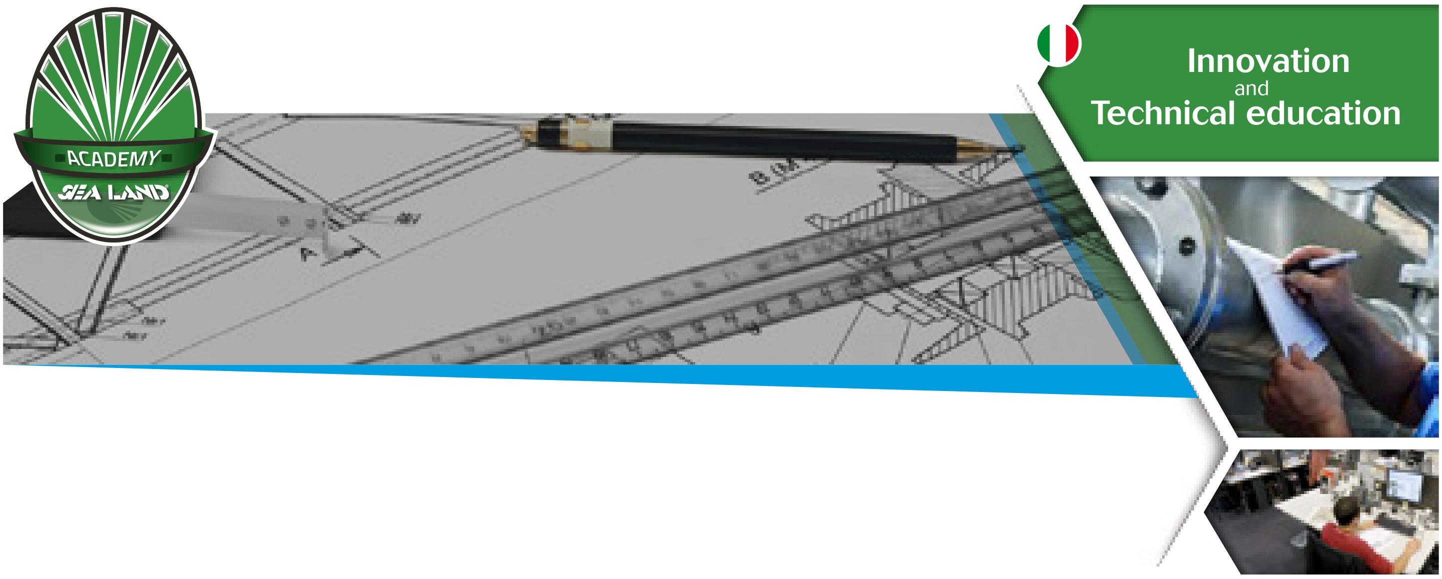


Figure 3



1.5.1 PUMPS

Centrifugal pumps are the type most commonly used, primarily because they are low in cost, simple to operate, reliable, and easy to maintain. Also, they have relatively **long operating lives**.
System designers and engineers need to understand specific system operating conditions to **size a centrifugal pump correctly.** Many engineers tend to be conservative in estimating system requirements, and they often increase the size of the centrifugal pump and motor to accommodate design uncertainties, potential capacity expansions, and increases in friction losses due to system fouling and changes over time in pipe surface roughness. However, **this approach often leads to oversized pump/motor assemblies**. Oversizing can increase throttling and its associated energy losses, resulting in **increased operating costs and maintenance** requirements, and **reduced system reliability** because of added stresses on the system.
Pumping systems often operate inefficiently because of poor flow-control practices. Flow-control options include throttle valves, bypass valves, multiple-speed pumps, parallel pump configurations, and pumps coupled to ASDs. Each flow-control method has advantages and drawbacks, depending on the particular application. When they are incorporated properly into a system, these methods provide adequate and efficient flow control. However, **improper design or use can increase system costs significantly**.
ASDs help to match the flow energy delivered to the system to the system's actual need. **In pumping systems, INVERTERS are by far the most commonly used adjustable speed option**. Reducing the pump speed proportionally reduces the flow while exponentially reducing the power requirement. Although installing VFDs can result in substantial energy savings, **VFDs are not suitable for all applications, particularly those in which pumps operate against high static (or elevation) head.**



1.6 USING VARIABLE FREQUENCY DRIVES (VFD)

The advantages of motor speed control include

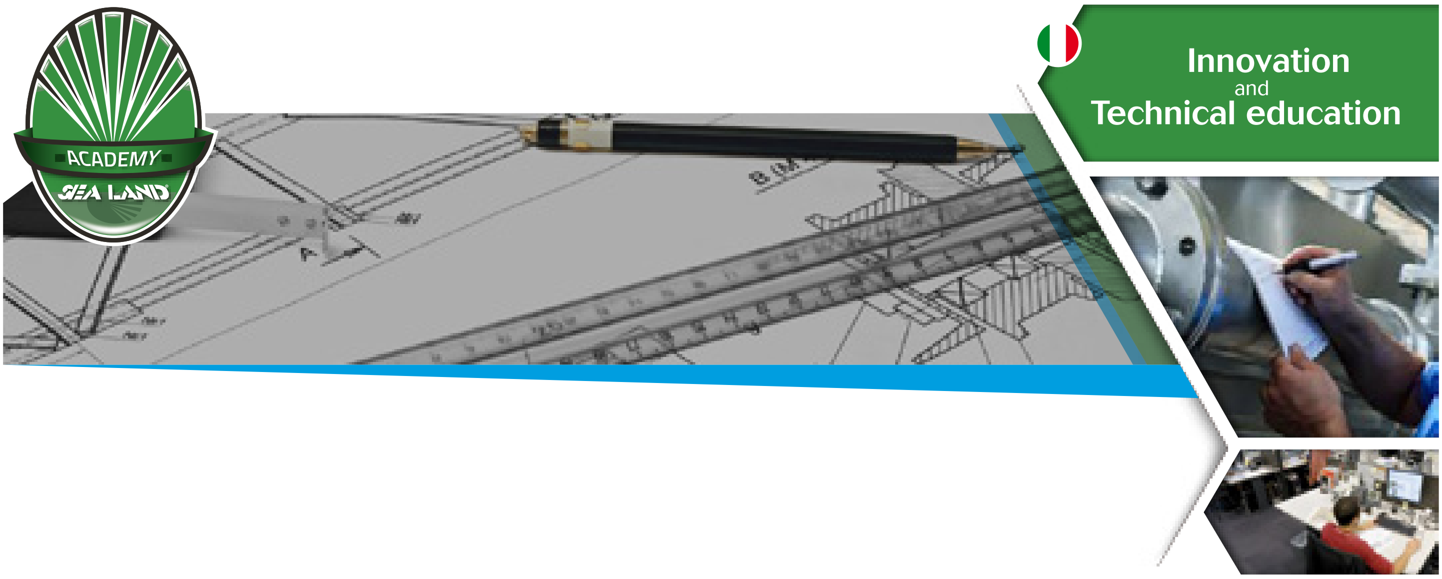
- lower system energy costs
- improved system reliability
- fewer maintenance requirements
- and more effective process control.

Many applications require accurate control of a motor’s operating speed. As a result of improvements in power semiconductor technology, the current practice in the industry is to use VFDs with AC motors.

Some competing ASD technologies, such as hydraulic couplings and eddy-current drives, offer similar advantages regarding speed control. However, VFDs have substantial advantages in comparison to other speed control options. VFDs are highly efficient, reliable, and flexible; and motor users can bypass them for maintenance or repairs without having to take the motor out of service. But VFDs are not recommended for all motor/drive applications, so understanding their performance and application is essential in deciding whether to use them.

1.6.1 COMMON APPLICATIONS

VFDs are used in a wide range of applications, including fluid (gas and liquid) systems, material handling systems, and machining and fabrication processes. These drives can be incorporated into closed-loop control systems, and VFD speed adjustment ratios are similar to those of other speed control systems. **The principal advantage of VFDs is improved operating efficiency**, which means substantial **cost savings** in many motor systems. If they are used in place of mechanical drive options, VFDs can also improve system reliability by **removing potential failure modes** and requiring less maintenance because they have fewer components.



Fluid Systems

Because they can save a significant amount of energy, VFDs are well suited for fluid systems. In fan systems and systems served by **centrifugal pumps** with low static head requirements, there is a cube power relationship between flow and power. Because many fluid systems have to varying flow requirements, a VFD can adjust the output of a pump or a fan to meet these requirements automatically.

VFDs can often be **retrofitted to existing pump** and fan motors; however, all existing motors should be evaluated for compatibility with this modification. But, even if the motor must be changed, other system components can be left intact, which makes this upgrade relatively nondisruptive.

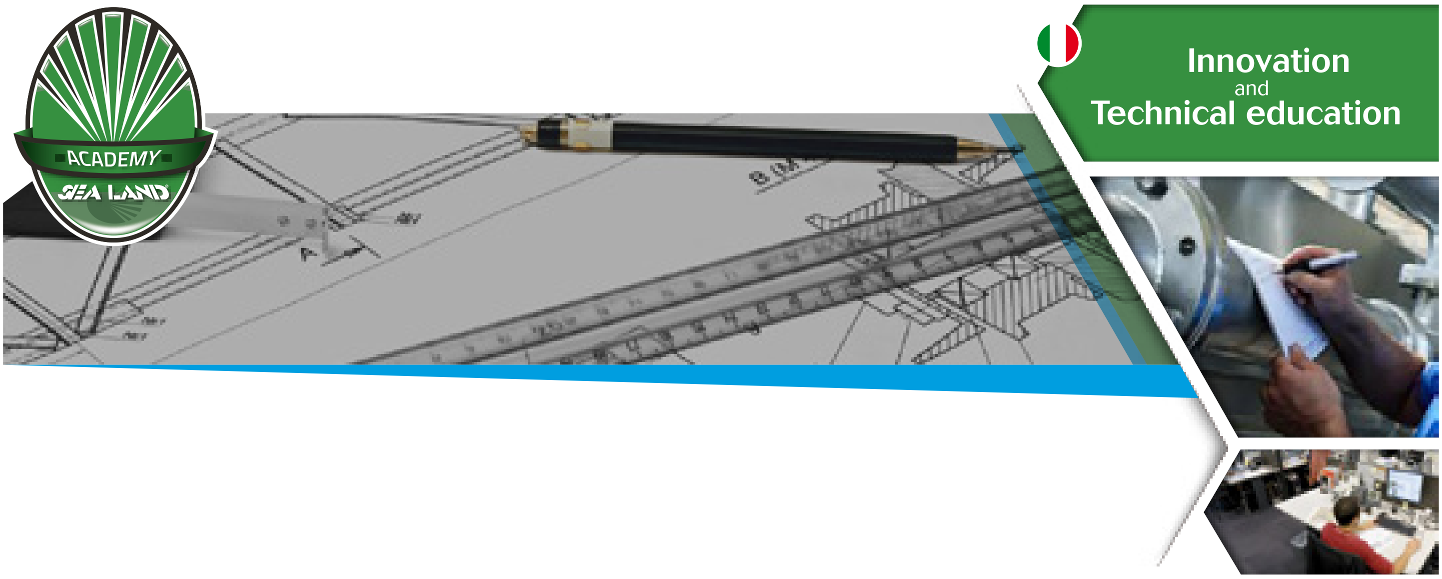
VFDs can provide substantial **flow-control improvements** and reduce the stress on the entire system. Unlike other flow control measures, such as throttle and bypass valves, which dissipate energy after they are added to the system fluid, VFDs reduce the amount of energy imparted to the system. This reduction also reduces stress on the piping system and support structures. VFDs are not suitable for all fluid system applications, and may not be cost effective in systems with low annual operating hours, that use other flow control approaches such as eddy current drives, multi-speed motors, multiple pumps working in parallel, or in high static lift applications where on/off control may be effective.

1.6.2 ALTERNATIVES

There are two principal ways to adjust the speed of motor-driven equipment:

- Adjust the speed of the motor directly
- Use a constant-speed motor with an intermediate device between the motor and the driven equipment that can change the speed ratio.

Historically, when direct control of the motor speed was required, designers had to use DC motors or AC wound-rotor motors. Although each type has advantages, they also have drawbacks in



terms of maintenance and efficiency. For example, DC motors are relatively expensive, need more maintenance, and require a means of generating DC power. Wound-rotor motors add resistance to the rotor circuit for speed control, which is inefficient unless a comparatively complex recovery system is used.

Using an intermediate speed-adjustment device, such as a gearing system or an adjustable pitch-pulley system, adds another component to the motor/drive system. These components increase the risk of failure and increase efficiency losses.

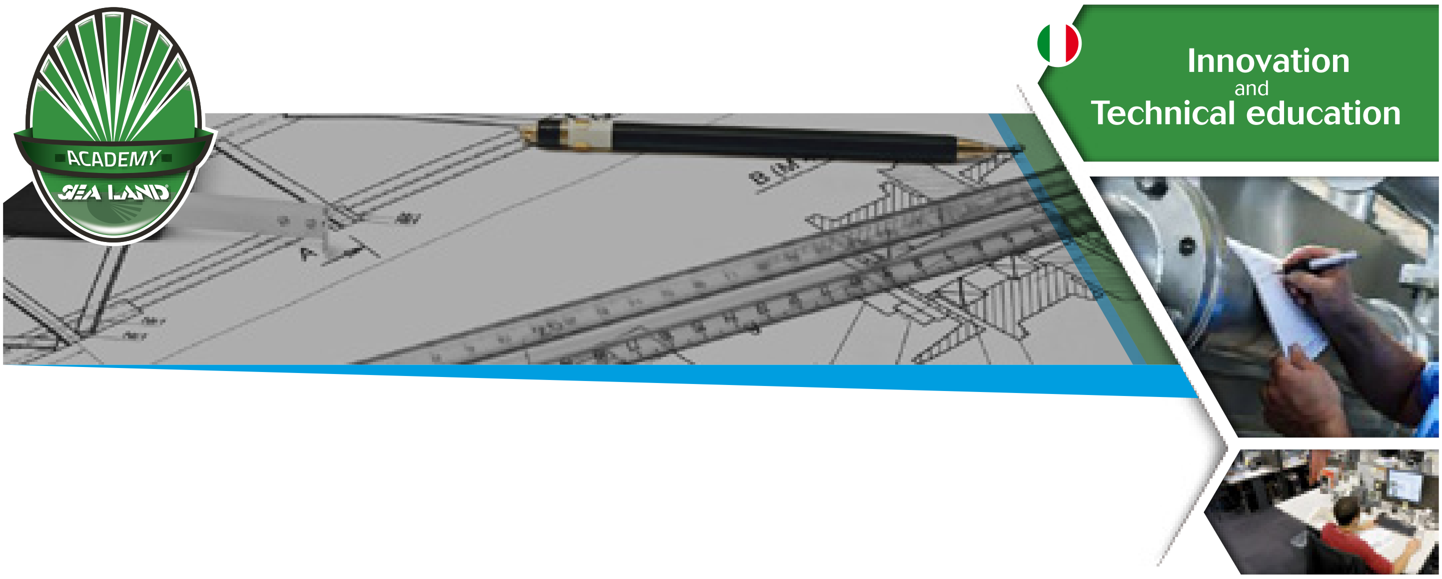
1.6.3 COMPETITIVE ADVANTAGES

Depending on the application, VFDs have many benefits and provide numerous advantages over other control methods. For example, **using VFDs in pumping** and fan systems provides far greater energy savings than other flow control options, such as throttling and bypass.

1.6.4 MISAPPLICATIONS

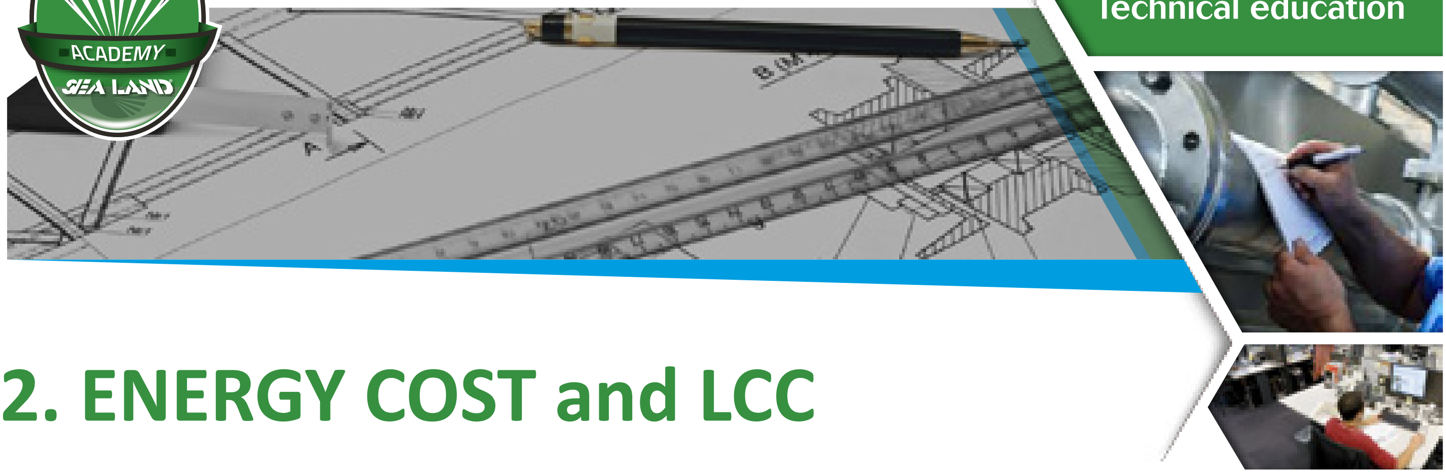
VFDs are not recommended for applications in which slowing down the machine speed causes operating problems, such as insufficient torque or poor cooling. In pumping systems that have high-static head characteristics, slowing down the pump speed too much can force the pump to operate in a virtual shut-off head condition. Under these conditions, the pump can experience damaging vibrations and could fail to provide adequate flow to the system.

Similarly, in applications in which the torque increases at low speeds, such as certain mixing processes, the power requirements of the motor will not drop significantly at lower speeds. In such cases, the integral motor fan may not provide sufficient cooling at lower speeds. In applications in which torque decreases with speed, this concern is not as important because the windings generate less heat. However, in some constant horsepower applications, additional cooling may be required to prevent the motor from overheating. In these cases, a cooling fan powered by its



motor is used.

The load characteristics of other machinery, such as positive displacement pumps, often do not favor the use of VFDs. In these applications, the linear relationship between output, power, and equipment speed tends to favor other control technologies.



2. ENERGY COST and LCC

In normal operation of a plant, there is the possibility to have a working point at partial loads. Also, the pump efficiency widely varies by varying flow ratio to flow at BEP, while motor efficiency varies with a magnitude smaller of 1 order.
A way to keep pump efficiency high when the working point is different comes from affinity laws which, roughly said, say that by changing the sped for a centrifugal pump, will change Q, H and Power, but efficiency does not vary.
It's, therefore, possible to think to use for partial loads of a plant, where it is needed a lower flow, but also a smaller head (and consequently a lower power), a variable speed drive.
The use of a VFD allows keeping almost constant the pump efficiency at partial loads, modifying the table of partial loads efficiency as reported in the table below.

Q/QBEP	**n_p/n_p BEP**
25%	92%
50%	95%
75%	98%
100%	100%
110%	100%

We are now going to evaluate the energy cost for a pump to be installed into a plant.
For easiness of description let's assume following conditions:

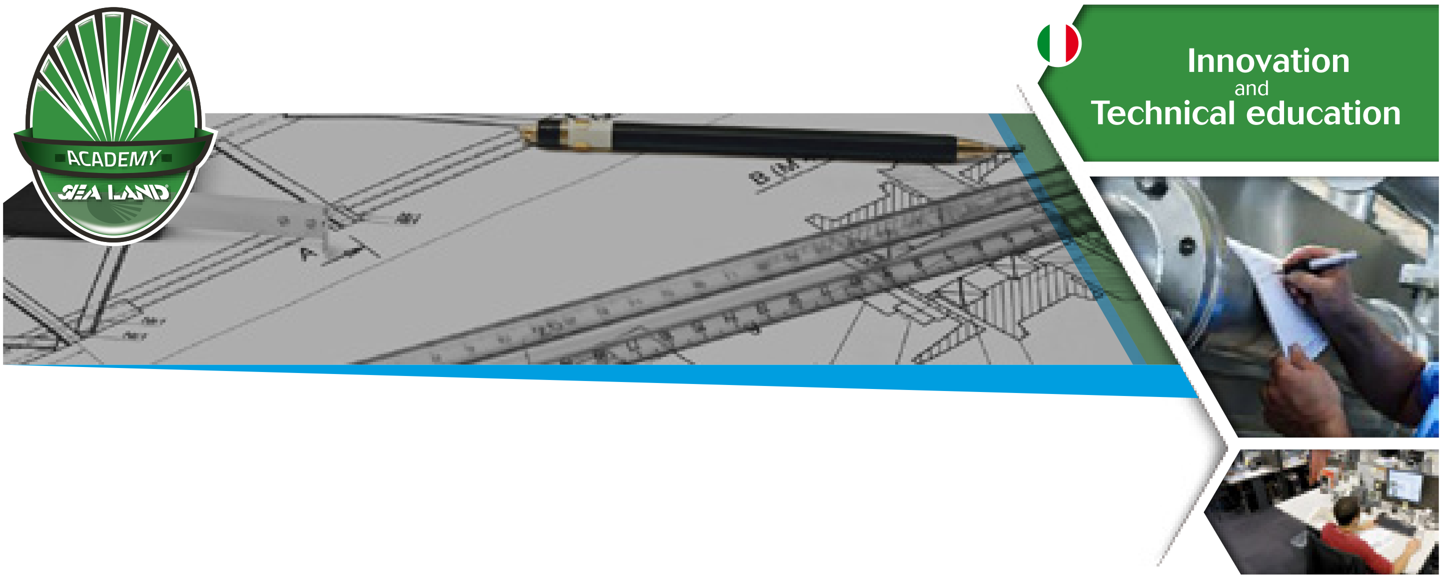
- Two types of pumps
- Two types of installation (A and B, open-loop and closed-loop)
- Two types of configuration (fixed and variable speed)
- Two different levels of energy efficiency performance
- Estimated life of the plant 15 years
- 8 hours per day running time of the pump
- Main working point is the same as flow at BEP.

It is clear that the longer is the operation time, the more significant is energy cost incidence on LCC.

2.1 IN-LINE PUMP, 4 POLES, 1.1KW

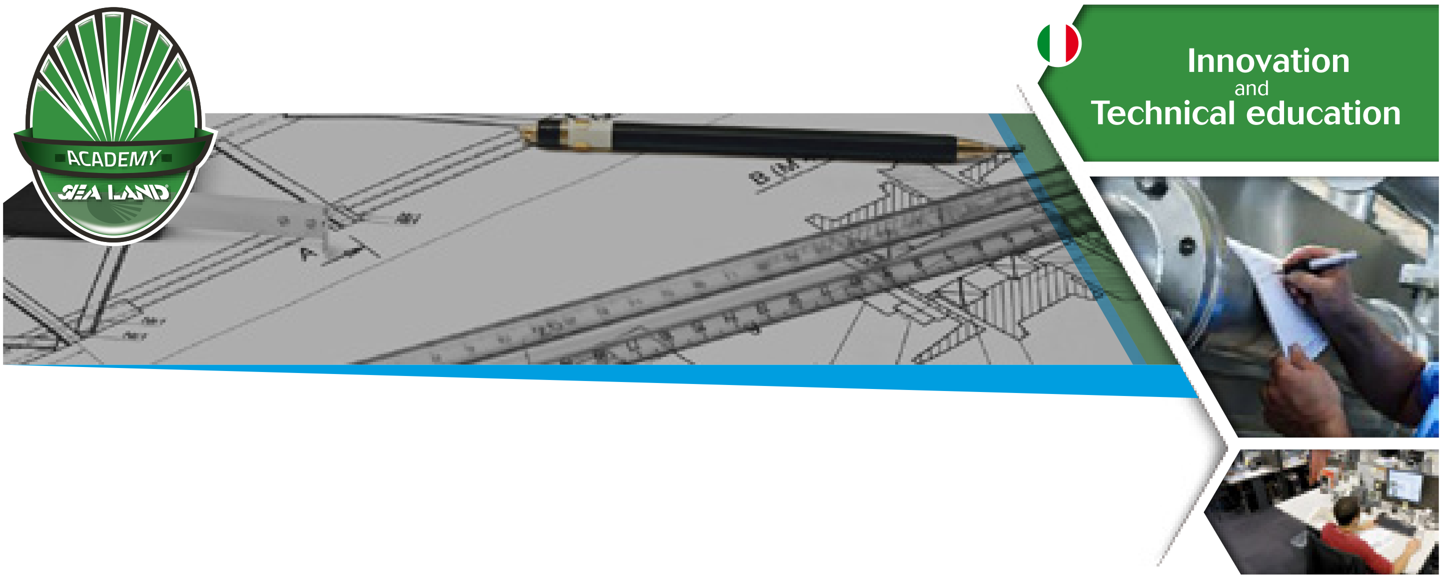
Suitable avergae values for this kind of pump may be:

Q @BEP	250	l/min
H @BEP	11,5	m
P hydr @BEP	470	W
P mech rated	1,1	kW
speed	1450	rpm
Designed life	15	Years
Operating time	8	hours/day

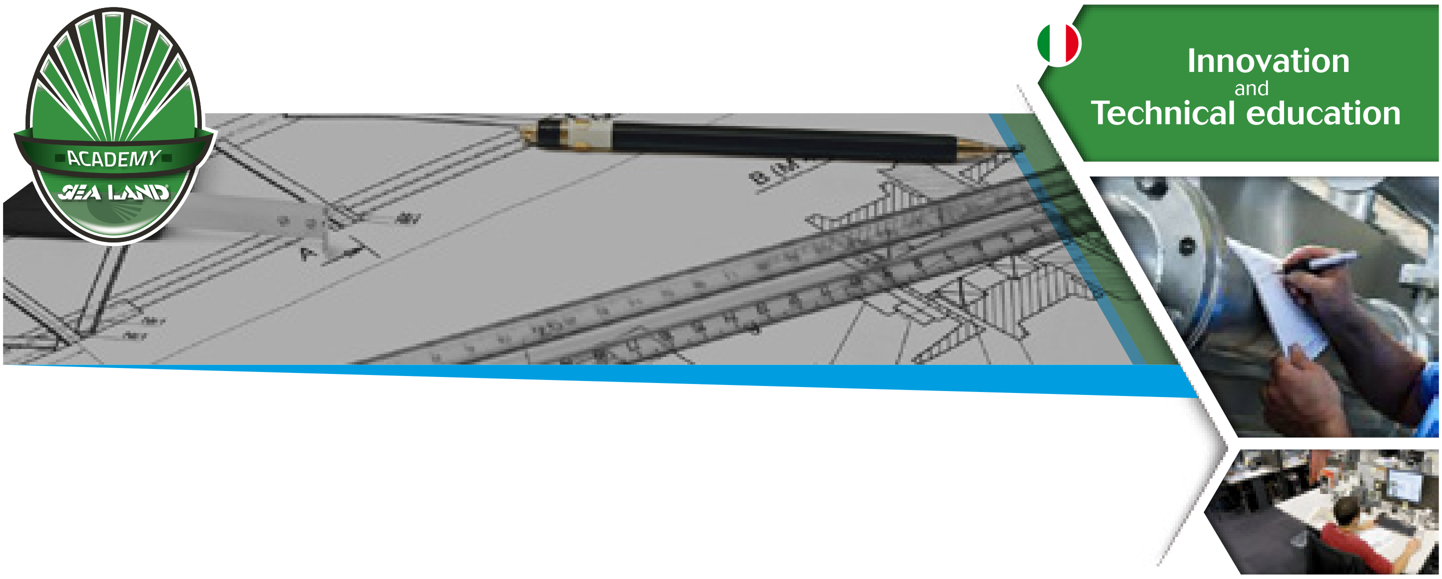


Application A – open-loop

FIXED SPEED		100% QBEP	110% QBEP	75% QBEP
speed	rpm	1450	1450	1450
hydraulic power	P hydr (W)	470	493	399
pump efficiency	MEI 0.7	55%	50%	50%
shaft power	P mech (W)	855	997	807
shaft power / rated power	% P rated	86%	100%	81%
motor efficienct	IE3	84.1%	84.1%	83.7%
absorbed power	P el (kW)	1,02	1,19	0,96
operating time	hours	21900	10950	10950
Energy consumption	kWh	22253	12981	10561
Total Energy consumption	kWh		45795	
Energy cost to LCC:				
@ 0,05USD/kWh (Saudi Arabia)	USD		2300	
@ 0,10USD/kWh (USA)	USD		4600	
@ 0,20USD/kwh (Italy)	USD		9200	



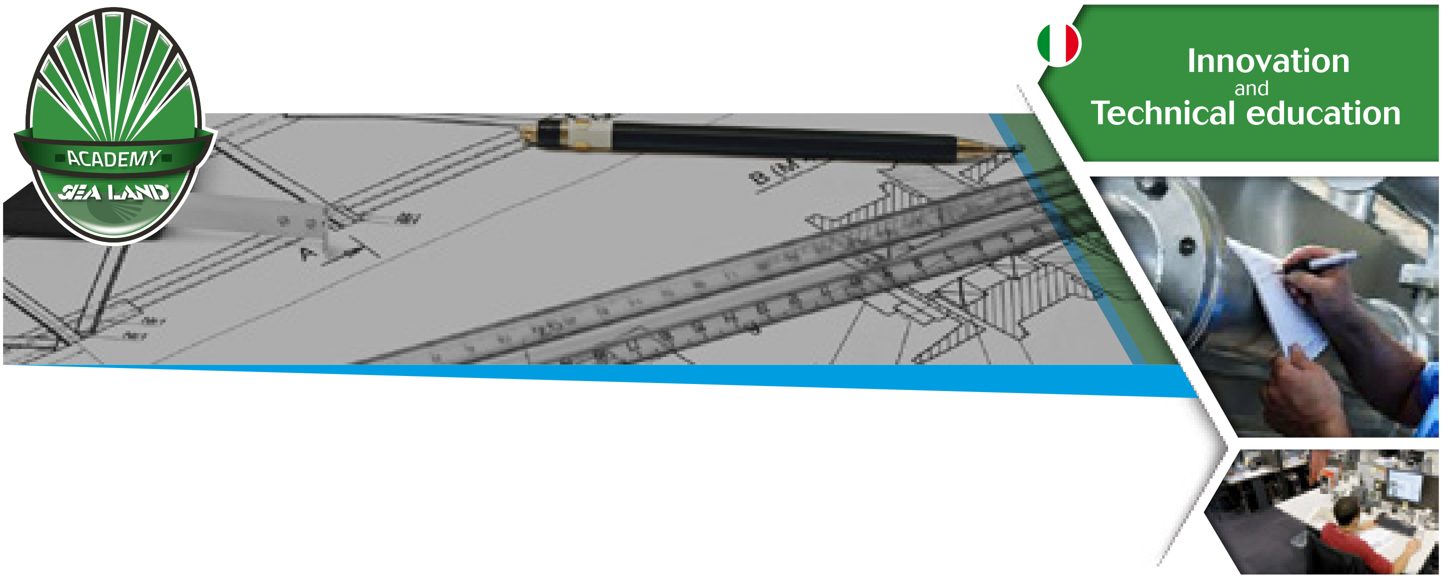
VARIABLE SPEED With VFD		100% QBEP	110% QBEP	75% QBEP
speed	rpm	1450	1595	1087,5
hydraulic power	P hydr (W)	470	626	198
pump efficiency	MEI 0.7	55%	55%	54%
shaft power	P mech (W)	855	1137	368
shaft power / rated power	% P2	86%	100%	81%
motor efficienct	IE3	84.1%	84.1%	83.7%
absorbed power	P el (kW)	1,02	1,35	0,44
operating time	hours	21900	10950	10950
Energy consumption	kWh	22253	14809	4814
Total Energy consumption	kWh		41876	
Energy cost to LCC:				
@ 0,05USD/kWh (Saudi Arabia)	USD		2100	
@ 0,10USD/kWh (USA)	USD		4200	
@ 0,20USD/kwh (Italy)	USD		8400	



Example of LCC in USA, with an in-line pump, 1.1kW 4-poles in an open-loop circuit:

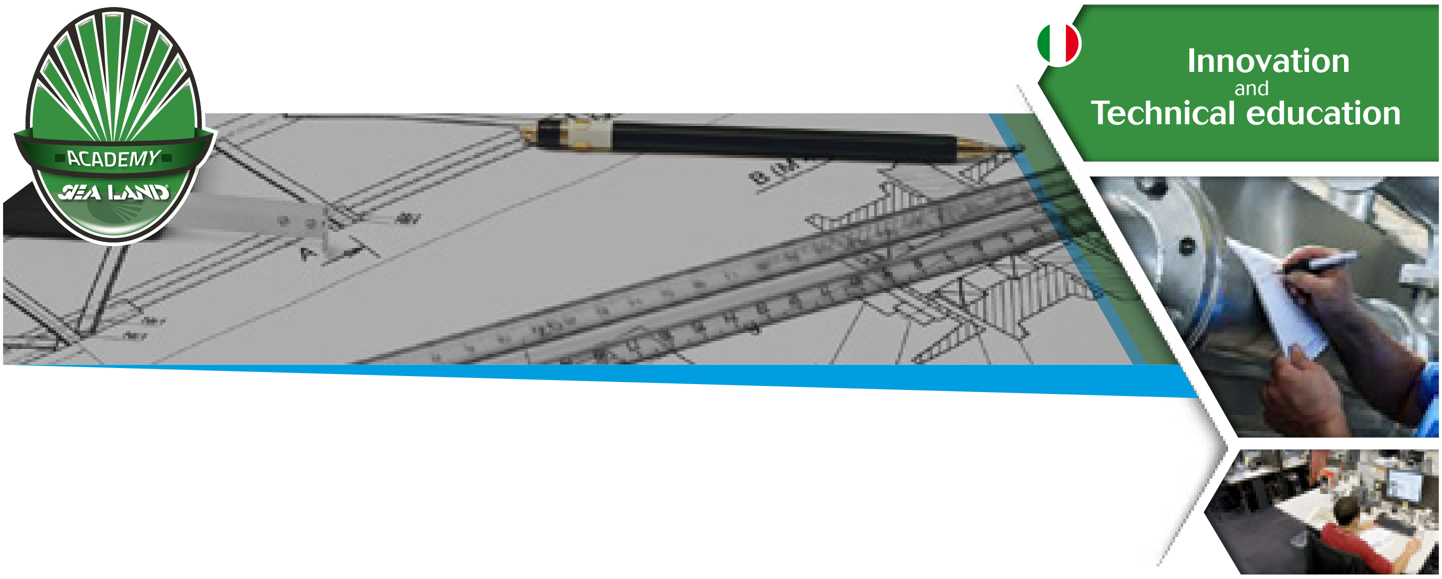
[USD]	**fixed speed**	**variable speed**
	MEI 0.7+IE3	MEI 0.7+IE3
pump cost	1200	1200
VFD cost		1000
Energy cost	4600	4200
Installation cost	500	700
Maintenance cost	4000	3500
Major Lifecycle costs	**10300**	10600

In this kind of application may be suitable to adopt a high-efficiency pump (MEI 0.7 + IE3) without the need of VFD.

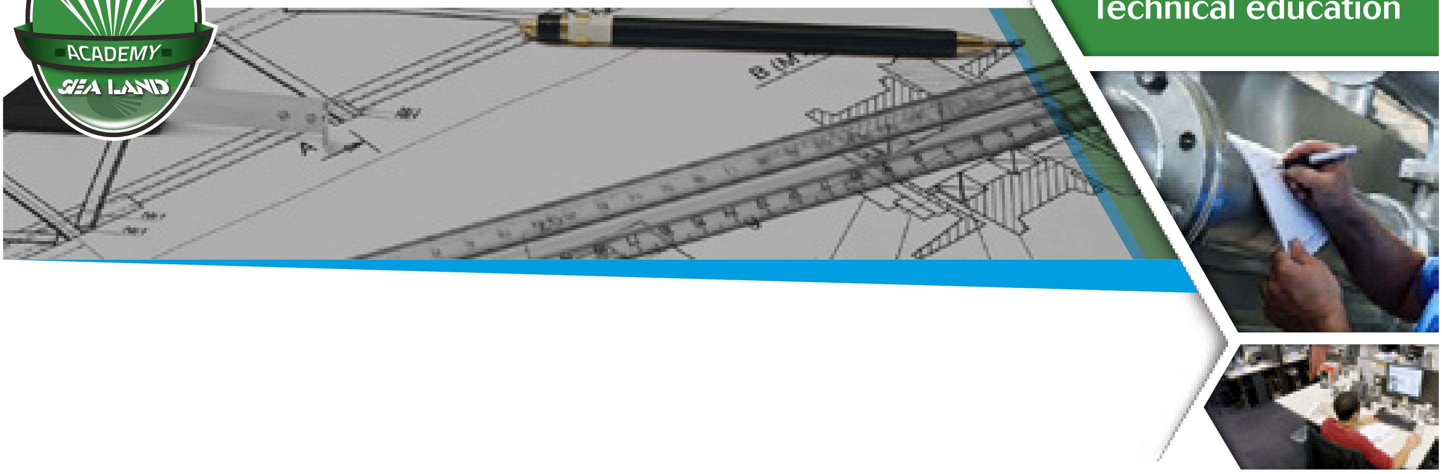


Application B – closed-loop

FIXED SPEED		100% QBEP	75% QBEP	50% QBEP	25% QBEP
speed	rpm	1450	1450	1450	1450
hydraulic power	P hydr (W)	470	399	282	140
pump efficiency	MEI 0.7	55%	50%	29%	25%
shaft power	P mech (W)	855	807	732	565
shaft power / rated power	% P rated	77,7%	73,4%	66,6%	51,4%
motor efficienct	IE3	84,1%	83,7%	82,4%	78,3%
absorbed power	P el (kW)	1,02	0,96	0,89	0,72
operating time	hours	2628	6570	15330	19272
Energy consumption	kWh	2670	6337	13623	13905
Total Energy consumption	kWh		36535		
Energy cost to LCC:					
@ 0,05USD/kWh (Saudi Arabia)	USD		1850		
@ 0,10USD/kWh (USA)	USD		3650		
@ 0,20USD/kwh (Italy)	USD		7300		



VARIABLE SPEED With VFD		100% QBEP	75% QBEP	50% QBEP	25% QBEP
speed	rpm	1450	1087,5	725	362,5
hydraulic power	P hydr (W)	470	198	59	7
pump efficiency	MEI 0.7	55%	55%	54%	51%
shaft power	P mech (W)	855	361	109	15
shaft power / rated power	% P rated	77,7%	32,8%	9,9%	1,3%
motor efficienct	IE3	84,1%	83,7%	82,4%	78,3%
absorbed power	P el (kW)	1,02	0,43	0,13	0,02
operating time	hours	2628	6570	15330	19272
Energy consumption	kWh	2670	2831	2027	357
Total Energy consumption	kWh		7528		
Energy cost to LCC:					
@ 0,05USD/kWh (Saudi Arabia)	USD		400		
@ 0,10USD/kWh (USA)	USD		750		
@ 0,20USD/kwh (Italy)	USD		1500		

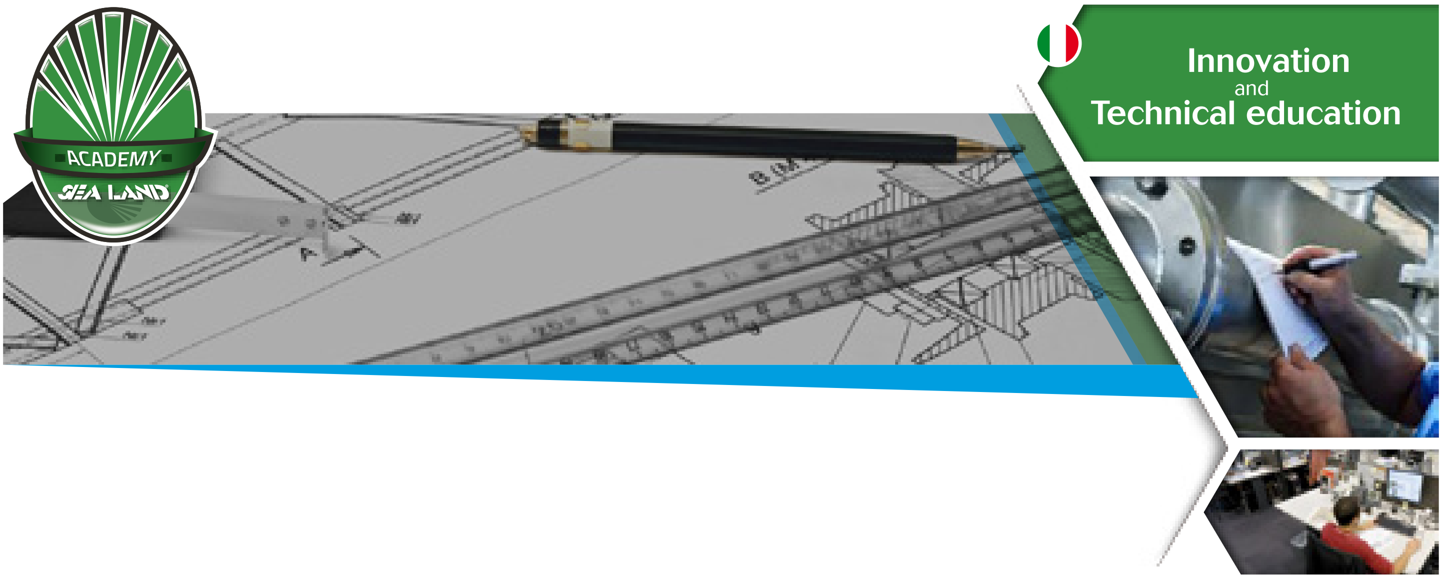


Example of LCC in USA, with an in-line pump, 1.1kW 4-poles in an closed-loop circuit:

[USD]	**fixed speed**	**variable speed**
	MEI 0.7+IE3	MEI 0.7+IE3
pump cost	1200	1200
VFD cost		1000
Energy cost	3650	750
Installation cost	500	700
Maintenance cost	4000	3500
Major Lifecycle costs	9350	**7150**

In this kind of application, it is absolutely convenient to use a VFD on the pump, given the high period of working at partial load.

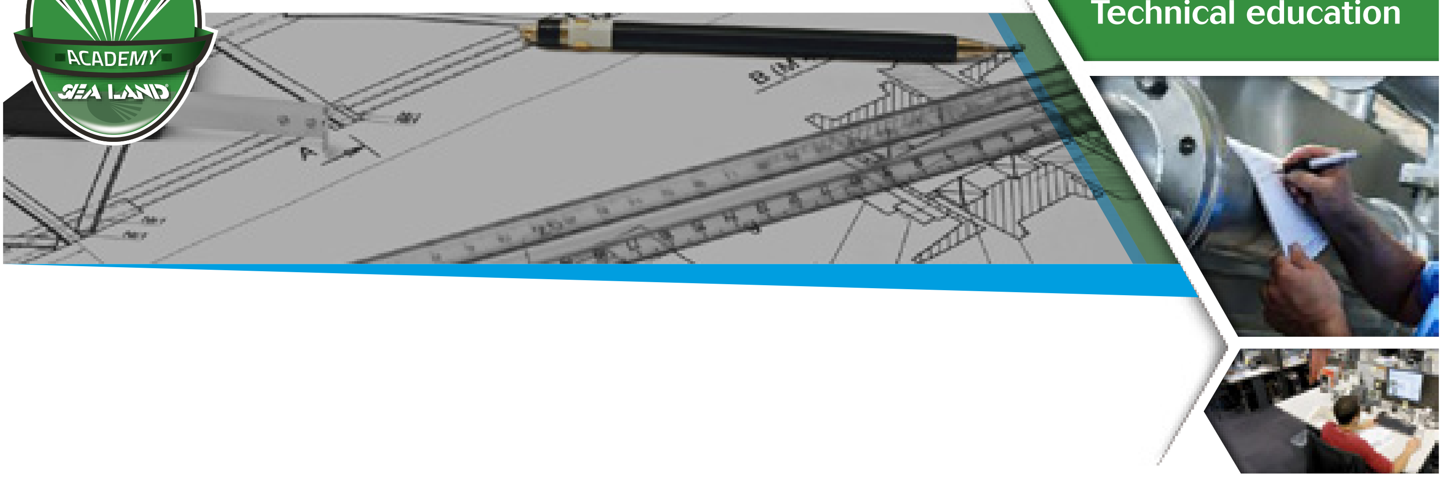
Such a kind of pump is usually adopted for water recirculation into closed-loop, typical of HVAC sector.



2.2 NORMALIZED CENTRIFUGAL PUMP, 2 POLES, 7.5KW

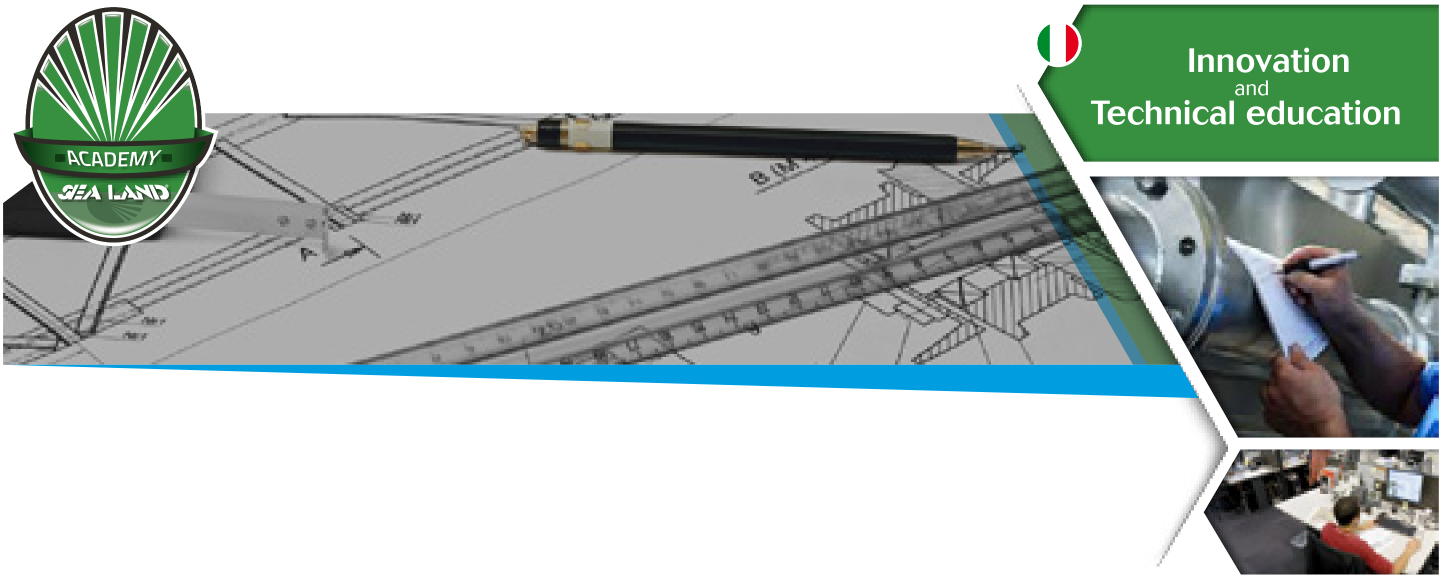
Suitable average values for this kind of pump may be:

Q @BEP	450	l/min
H @BEP	50	m
P hydr @BEP	3’400	W
P mech rated	7,5	kW
speed	2900	rpm
Designed life	15	years
Operating time	8	hours/day

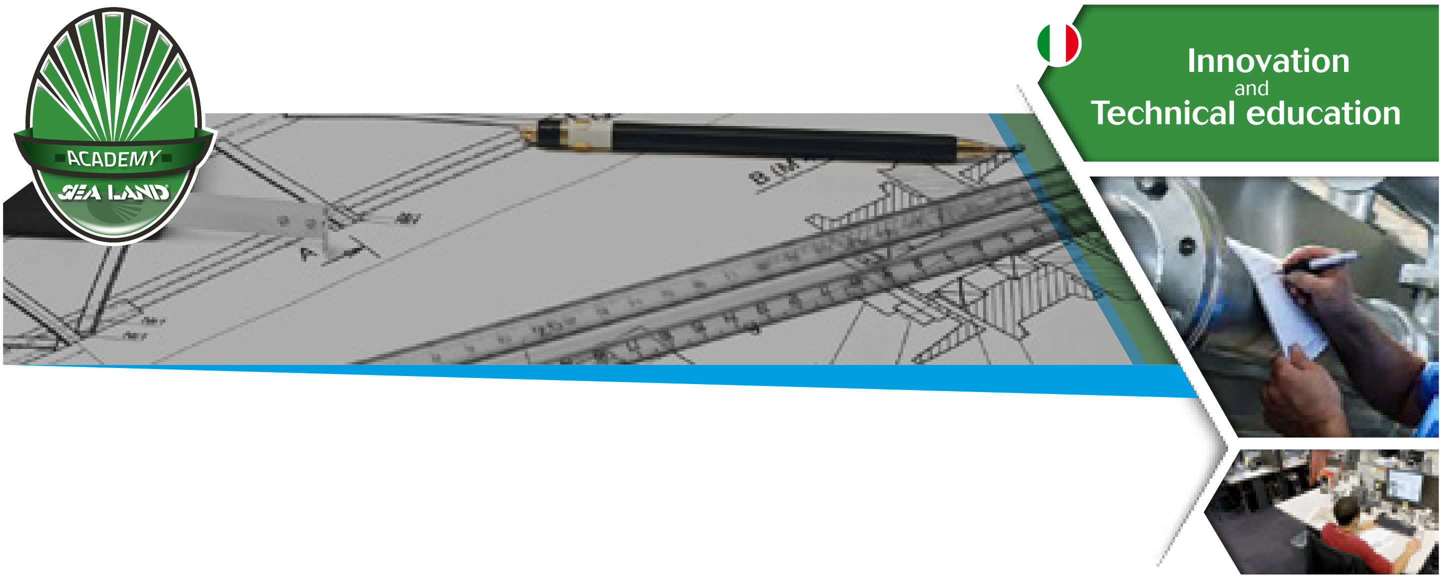


Application A – open-loop

FIXED SPEED		100% QBEP	110% QBEP	75% QBEP
speed	rpm	2900	2900	2900
hydraulic power	P hydr (W)	3400	3570	2890
pump efficiency	MEI 0.7	54%	49%	49%
shaft power	P mech (W)	6296	7346	5947
shaft power / rated power	% P2	86%	100%	81%
motor efficienct	IE3	90,1%	90,1%	89,6%
absorbed power	P el (kW)	6,99	8,15	6,63
operating time	hours	21900	10950	10950
Energy consumption	kWh	153040	89273	72632
Total Energy consumption	kWh		45795	
Energy cost to LCC:				
@ 0,05USD/kWh (Saudi Arabia)	USD		2300	
@ 0,10USD/kWh (USA)	USD		4600	
@ 0,20USD/kwh (Italy)	USD		9200	



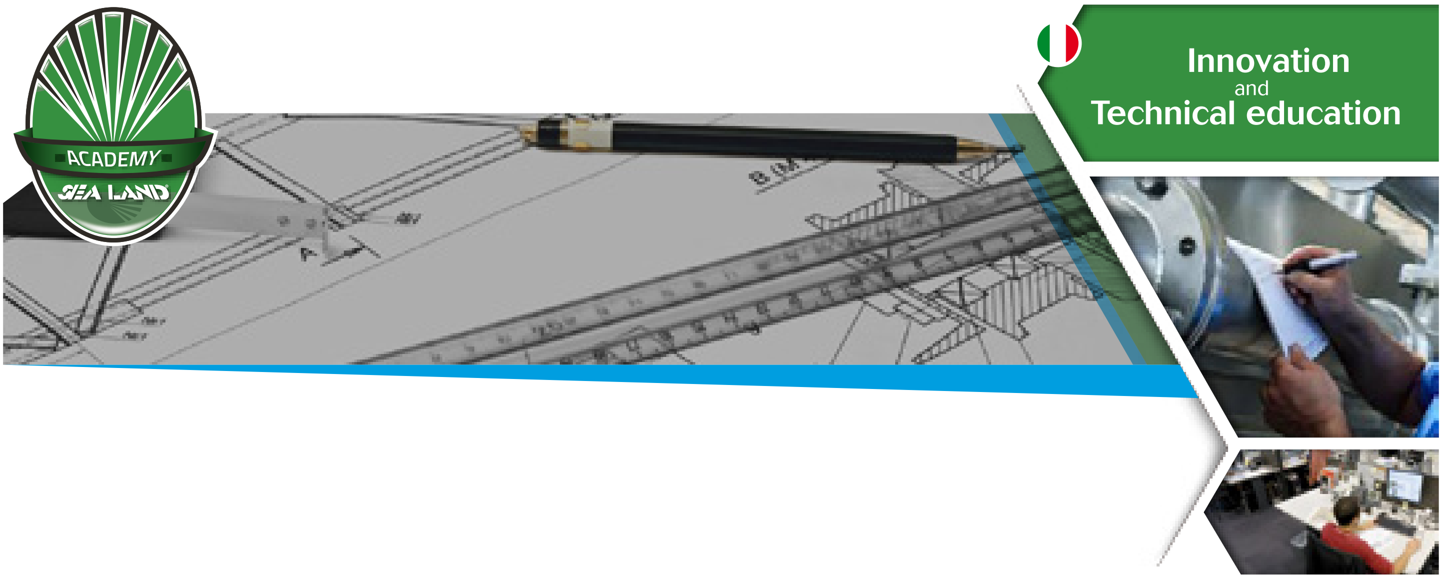
VARIABLE SPEED With VFD		100% QBEP	110% QBEP	75% QBEP
speed	rpm	2900	3190	2175
hydraulic power	P hydr (W)	3400	4525	1434
pump efficiency	MEI 0.7	54%	54%	53%
shaft power	P mech (W)	6296	8380	2710
shaft power / rated power	% P2	86%	100%	81%
motor efficienct	IE3	90,1%	90,1%	89,6%
absorbed power	P el (kW)	6,99	9,30	3,02
operating time	hours	21900	10950	10950
Energy consumption	kWh	153040	101848	33106
Total Energy consumption	kWh		287994	
Energy cost to LCC:				
@ 0,05USD/kWh (Saudi Arabia)	USD		14400	
@ 0,10USD/kWh (USA)	USD		28800	
@ 0,20USD/kwh (Italy)	USD		57600	



Example of LCC in USA, with a normalized centrifugal pump, 7.5kW 2-poles in an open-loop circuit:

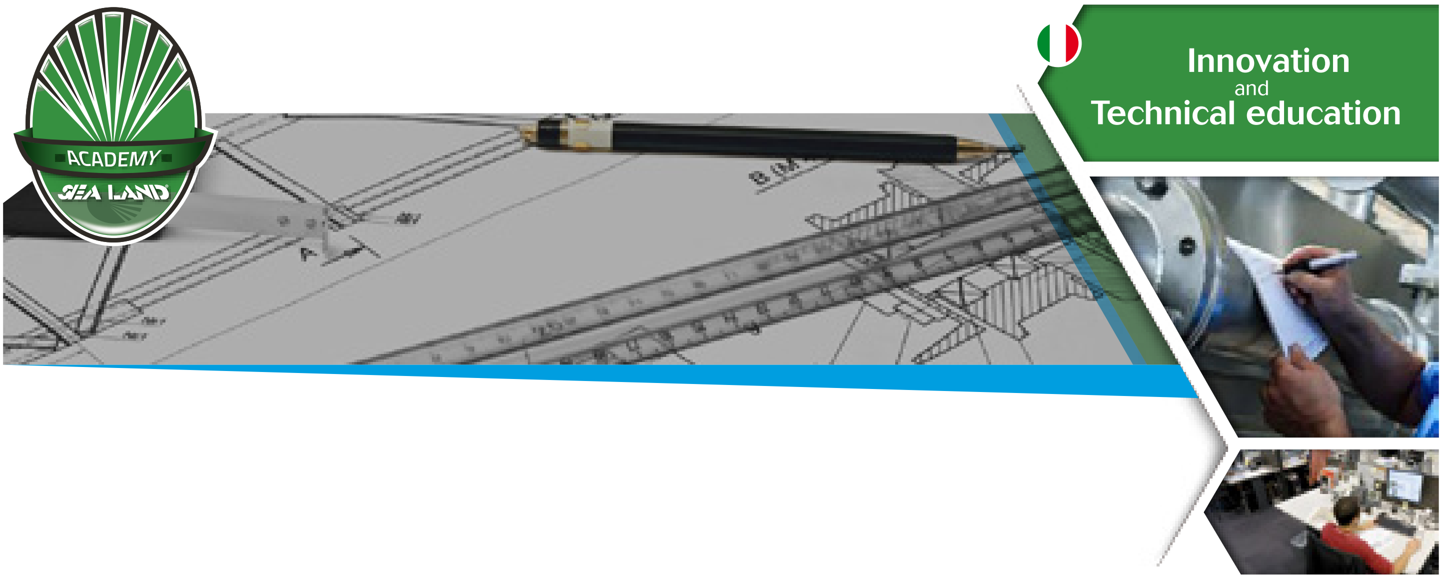
[USD]	fixed speed	variable speed
	MEI 0.7+IE3	MEI 0.7+IE3
pump cost	1700	1700
VFD cost		2000
Energy cost	31500	28800
Installation cost	1000	2000
Maintenance cost	4000	3500
Major Lifecycle costs	**38200**	38000

In this kind of application may be suitable to adopt a high-efficiency pump (MEI 0.7 + IE3) with or even without VFD. Probably it will be chosen a pump without VFD because generally speaking to manage an additional electronic device will bring some smaller additional costs not listed above and depending case by case.

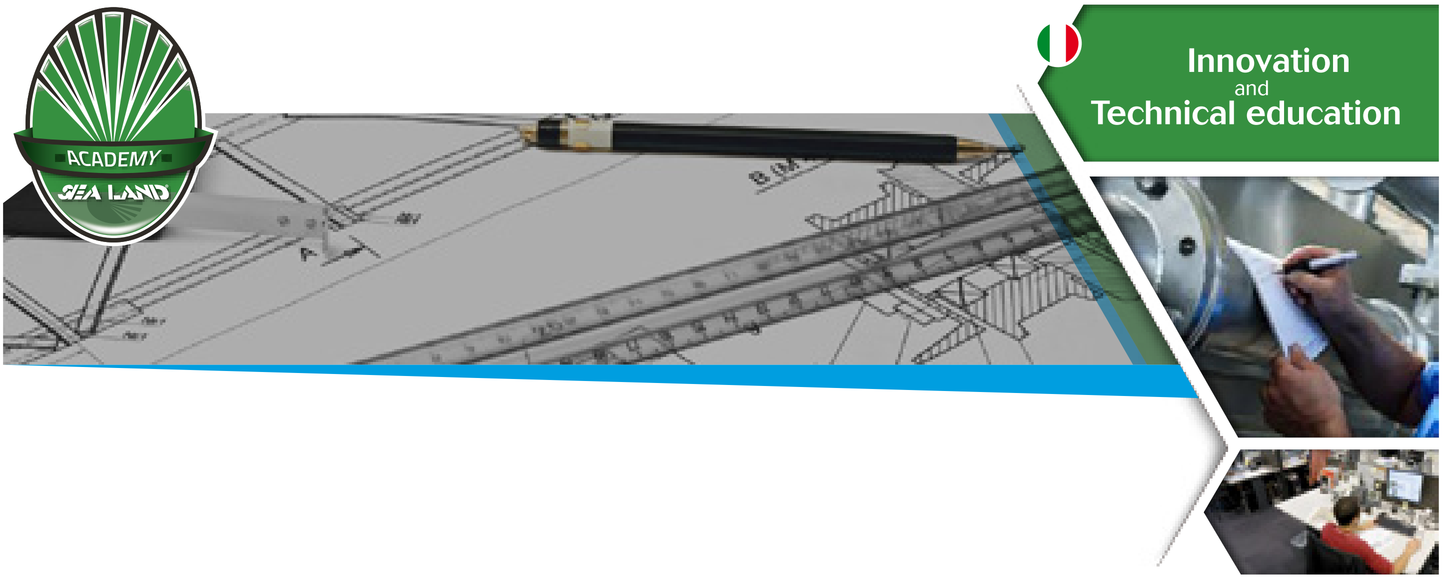


Application B – closed-loop

FIXED SPEED		100% QBEP	75% QBEP	50% QBEP	25% QBEP
speeed	rpm	2900	2900	2900	2900
hydraulic power	P hydr (W)	3400	2890	2040	1011
pump efficiency	MEI 0.7	54%	49%	38%	24%
shaft power	P mech (W)	6296	5947	5397	4163
shaft power / rated power	% P rated	84%	79,3%	72%	55,5%
motor efficienct	IE3	90,1%	89,6%	88,3%	83,9%
absorbed power	P el (kW)	6,99	6,63	6,11	4,96
operating time	hours	2628	6570	15330	19272
Energy consumption	kWh	18365	43579	93691	95627
Total Energy consumption	kWh		251261		
Energy cost to LCC:					
@ 0,05USD/kWh (Saudi Arabia)	USD		12550		
@ 0,10USD/kWh (USA)	USD		25100		
@ 0,20USD/kwh (Italy)	USD		50250		



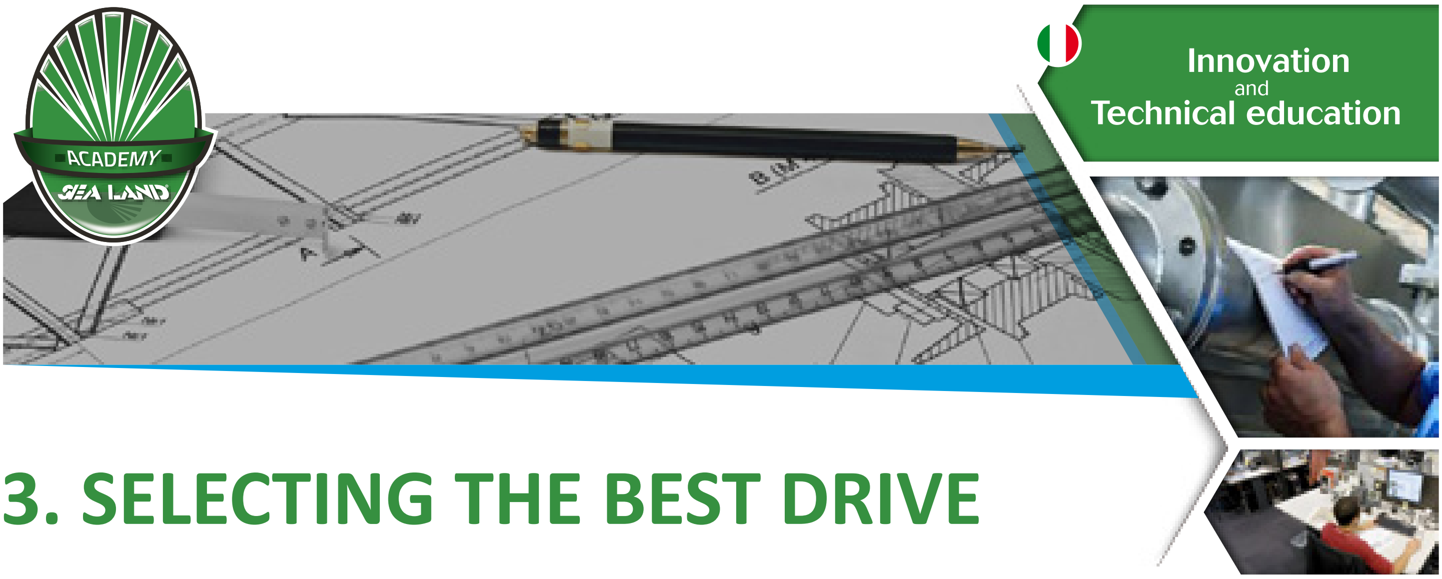
VARIABLE SPEED With VFD		100% QBEP	75% QBEP	50% QBEP	25% QBEP
speed	rpm	2900	2175	1450	725
hydraulic power	P hydr (W)	3400	1434	425	53
pump efficiency	MEI 0.7	54%	54%	53%	50%
shaft power	P mech (W)	6296	2656	803	107
shaft power / rated power	% P rated	84%	35,4%	10,7%	1,4%
motor efficienct	IE3	90,1%	84,7%	72,1%	54,1%
absorbed power	P el (kW)	6,99	3,14	1,11	0,20
operating time	hours	2628	6570	15330	19272
Energy consumption	kWh	20780	23315	19326	4313
Total Energy consumption	kWh		56051		
Energy cost to LCC:					
@ 0,05USD/kWh (Saudi Arabia)	USD		2800		
@ 0,10USD/kWh (USA)	USD		5600		
@ 0,20USD/kwh (Italy)	USD		11200		



Example of LCC in USA, with a normalized centrifugal pump, 7.5kW 2-poles in a closed-loop circuit:

[USD]	**fixed speed**	**variable speed**
	MEI 0.7+IE3	MEI 0.7+IE3
pump cost	1700	1700
VFD cost		2000
Energy cost	25100	5600
Installation cost	1500	3000
Maintenance cost	4000	3500
Major Lifecycle costs	32300	**15800**

In this kind of application may be suitable to adopt pump with VFD, be or not a high efficiency (MEI 0.7 + IE3), since the relevant energy saving derived by using the pump at partial loads.



3. SELECTING THE BEST DRIVE

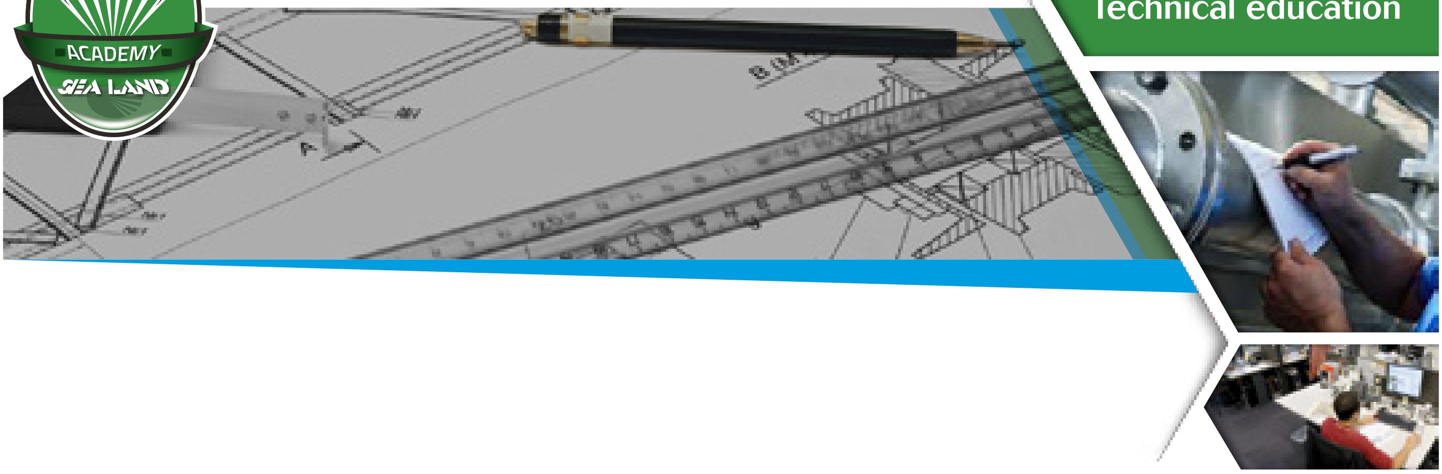
Electric drives (ED) consume a tremendous amount of energy in most manufacturing facilities. Virtually every automated function in a given plant relies on at least one ED. Therefore, engineers should consider energy requirements when specifying quick and integrated drives.
However, a host of factors determines a drive's energy efficiency and complicated methods for choosing "optimal" drives and other components for automation systems. To simplify drive selection, designers and engineers should take an analytical approach to mechanical needs and energy requirements. The following steps will ensure you end up with the right design for an ideal, energy-efficient drive system.

3.1 ANALYZE AND COMPARE DRIVES

It's possible to calculate the system's total energy, and it's also possible to estimate potential energy and cost savings from using DC power recovery instead of a brake resistor.
Another critical factor in getting the most efficiency from a motor-drive system is to choose drive components precisely sized for a specific application. Naturally, over-dimensioning should be avoided, and parts should not be subjected to extreme overloads.
Frequency-optimized motors generate more power in smaller sizes than two motors in standard IE1, so that engineers can use smaller engines for the same loads.

Meeting energy-efficiency goals begins with using design software to determine drive dimensions that will tailor the final system to application requirements. This can prevent the common problem of over-dimensioning motors, drive, and inverter controls.

There is also design software that simulates various scenarios, estimate the energy required, and make component recommendations. This software can provide an energy audit that shows an application's energy consumption, breaking it down by individual drive components. Seeing options lets engineers make side-by-side comparisons of mechanical concepts and drive components.



3.2 FLEXIBILITY OF EFFICIENT DRIVES

The proper drive can give engineers the design freedom to choose a right-sized motor that has equal or more output than more extensive, more costly, and less energy-efficient engines. A classic three-phase AC motor typically increases in size as energy efficiency improves. This can lead to space issues inside a machine, along with other adverse effects.

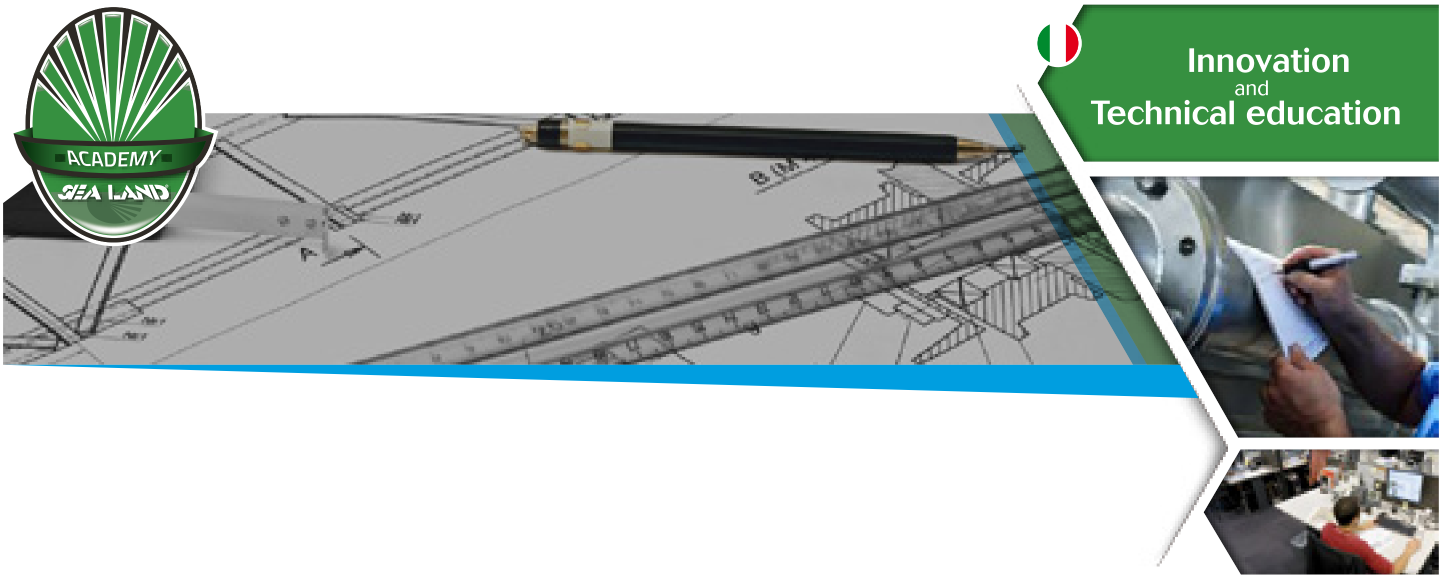
For example, inverter-optimized, asynchronous versions of 120-Hz multi-frequency motors can be up to two frame sizes smaller than conventional IE2 motors while offering the same performance. In addition, because the motor is smaller, the rotor inertia is lower than standard ac motors. This results in short dynamic-response times.

3.3 EFFICIENTLY CONVERT ENERGY

Excess, unused energy is the most costly energy. Many applications with electric drives require frequent acceleration and braking. Therefore, proper use of braking can improve efficiency.

Mechanical power generated by the electric drive must be oriented toward the automated task to use energy in all drive processes effectively. More than a third of newly installed three-phase AC motors are designed for frequency-inverter operation using electronic controls. The advantages of these three-phase motors become even more evident in drive packages with frequency inverters. Combining a decentralized inverter drive with a high-efficiency AC motor makes the connection straightforward and energy-efficient and eliminates the need for a control cabinet.

Beyond traditional cabinet-mounting topology, compact, decentralized inverter units can minimize cabinet space requirements. Decentralized drives, featuring low overall height can be easily mounted directly on a motor.



3.4 CALCULATE ENERGY SAVINGS

Class IE2 efficiency standards have driven many developments in inverter design that have led to higher levels of energy efficiency without sacrificing performance. Many decentralized inverters, for example, adapt the magnetizing motor current to actual process needs, thus reducing losses, particularly in the partial load operation. This, in turn, improves efficiency and reduces energy consumption by up to 30%.

4. INVENTA

4.1 INVENTA

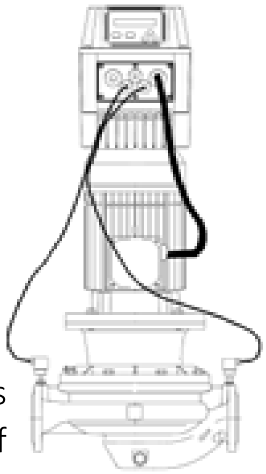
INVENTA is a variable frequency drive designed to control and protect pumping systems by varying the output frequency to the pump.
INVENTA can be applied to both new and existing pumping systems, and provides:

- energy and cost savings
- simplified installation and an overall lower pumping system cost
- longer life of the pumping system and relevant components
- improved reliability

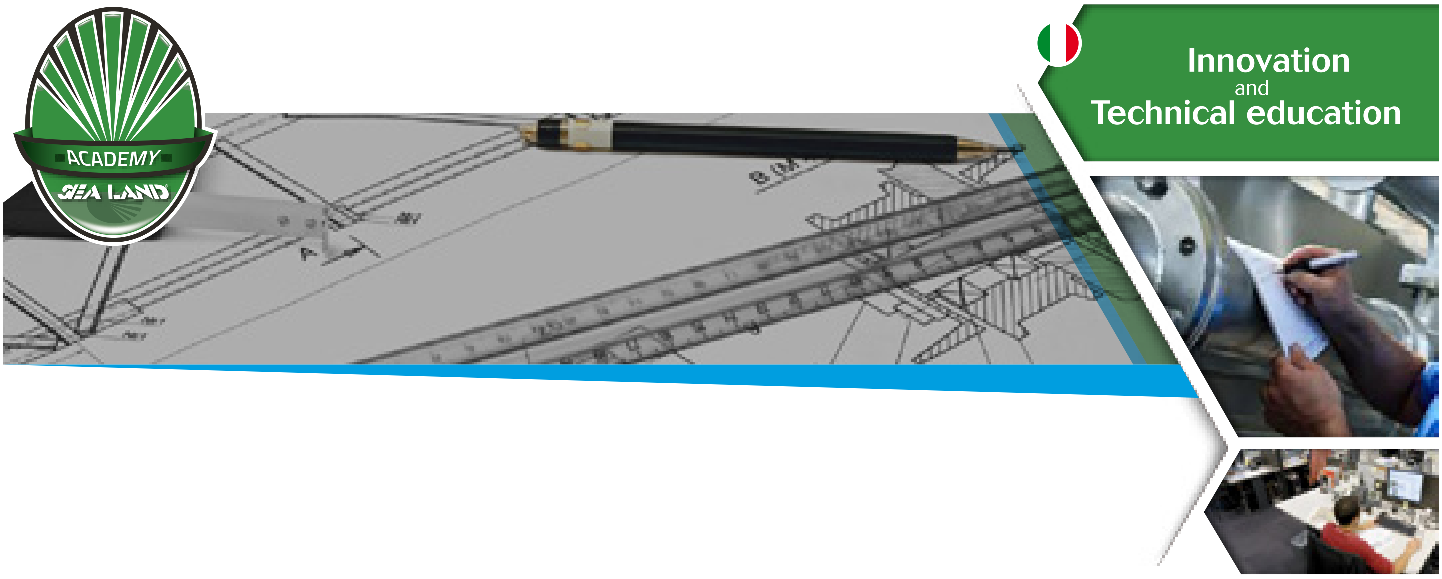
INVENTA, when connected to any pump, manages the system operation to maintain a certain constant physical quantity (pressure, differential pressure, flow, temperature, etc.) regardless of the conditions of use. The pump is operated only when needed thus avoiding unnecessary energy consumption.

INVENTA at the same time is able to:

- protect the motor from overload and dry running
- implement soft start and soft stop to increase the system life and reduce current peaks
- provide an indication of current consumption, voltage, and power
- maintain a record of run time and display any errors and/or failures reported by the system
- control up to two additional pumps at a constant speed (Direct On Line)
- connect to other INVENTA units for combined operation



Through the use of inductive filters (optional) INVENTA eliminates dangerous surges that are induced in long cables, making INVENTA suitable for control of submersible pumps.

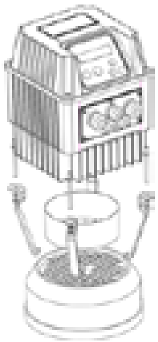


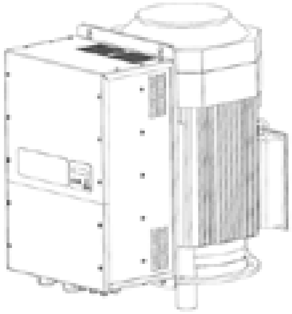
4.2 QUICK INSTALLATION

INVENTA can be installed directly on the motor or directly to the wall with a supplied installation kit.

Motor kit

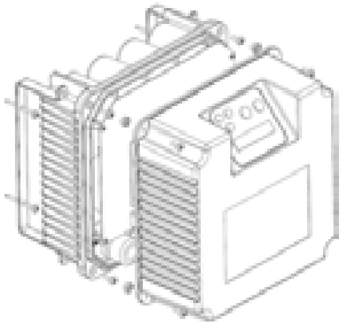
The motor cooling fan cools INVENTA. The motor kit consists of 4 different clamps (or flange adapter) to fix the INVENTA to the motor fan cover (or motor feets).

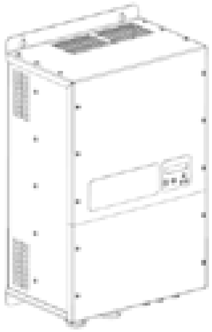


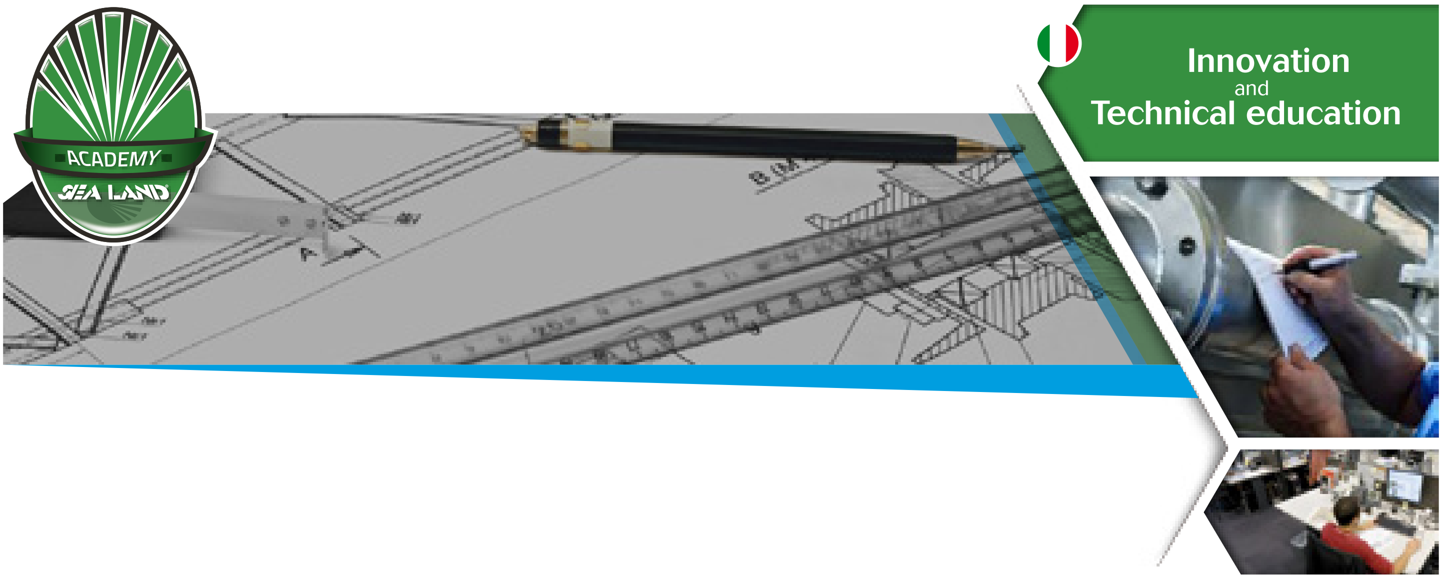


Wall kit

An external cooling fan connected to the inverter radiator cools INVENTA. A special metal bracket is supplied for INVENTA to be mounted to the wall.







Installing INVENTA is intuitive and straightforward, consisting of a few quick steps:

- Connect INVENTA to the power supply.
- Connect INVENTA to pump.
- Connect INVENTA to the sensor, located wherever in the piping you want to maintain the desired constant physical dimension (pressure, flow, liquid temperature,…).
- Set INVENTA to configure the pump to the system and the desired performance.

When first powering the INVENTA, a quick initial configuration is required for complete configuration of the drive.

Additional parameters can be configured later by entering three different setting levels:

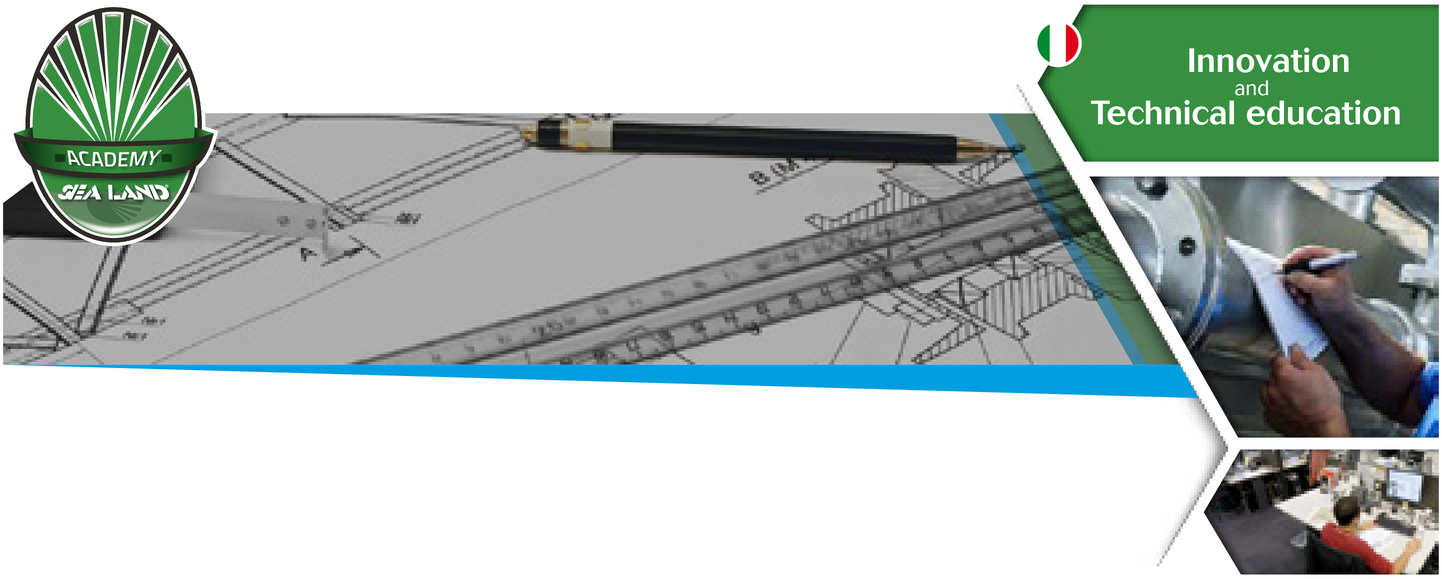
- **End user level**. The only level which can be accessed without a password. It allows the user to monitor electrical and hydraulic parameters and status of the INVENTA and pump.
- **Installer level**. In this level, the installer can configure the INVENTA-pump system to the characteristics of the hydraulic system. An entry password is required.
- **Advanced level**. This level allows the electrical configuration of INVENTA to the pump. Another entry password is required.

4.3 SOFTWARE DESIGNED FOR PUMPS APPLICATION

Software implemented in each drive of INVENTA range is the result of a long-time experience in solving the customer requests and constantly following new drive applications.

Minimum motor frequency

This parameter prevents motor operation below a particular rate, thus avoiding damage to the thrust bearing of the submersible motors.



Minimum motor frequency ramp

The motor can accelerate from 0 to the minimum motor frequency following a high-speed ramp and then go through a slower ramp.

Clever stop of pump at no flow condition

Below minimum control frequency, INVENTA gradually reduces the pump speed while monitoring the pressure transducer signal. If this value is close to the set pressure, INVENTA will reduce the output frequency furthermore till stopping the pump.

Loss compensation proportional to the water flow

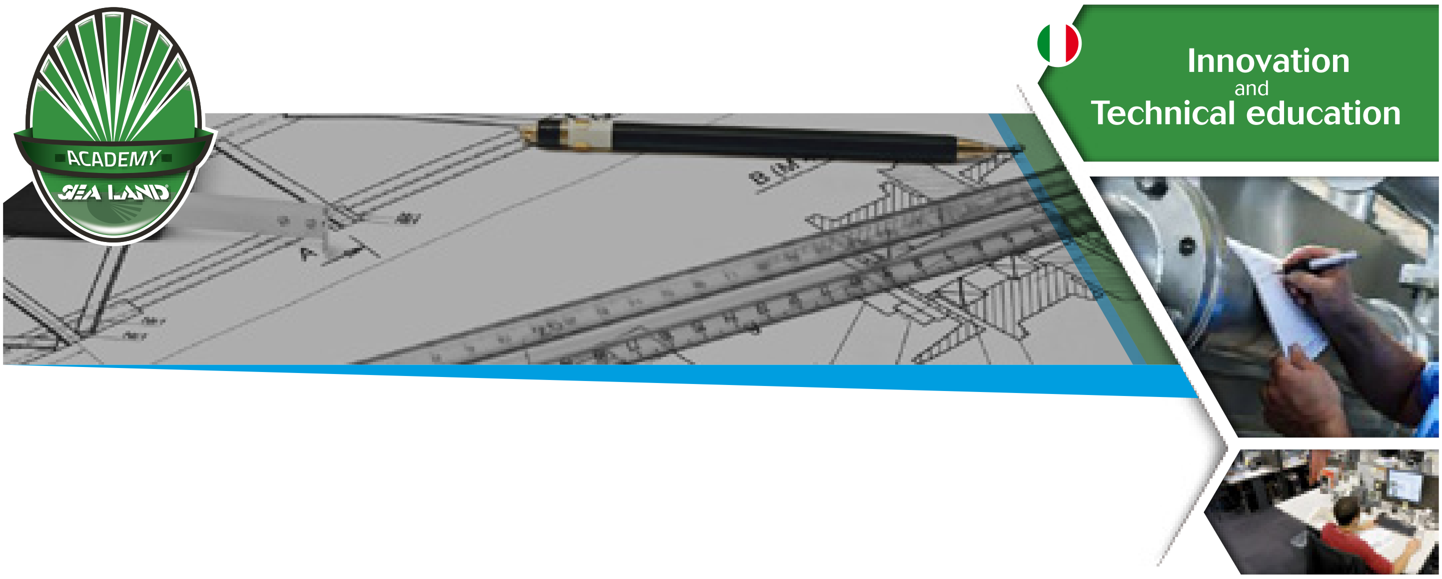
If the pressure sensor is near the pump, pressure value on the working point is lower than set pressure due to the loss equivalent to the water flow. It is possible to vary the pressure placed in a linear relation concerning the frequency to compensate pressure loss in the pipes.

Dry running alarm via cosphi value

If the pump runs dry, its cosphi value drops below a settable cosphi value, and INVENTA stops the pump after 3 seconds. INVENTA will try to make 5 attempts every 10,20,40,80 and 160 minutes, after which it will declare an alarm and stop the pump if the condition persists.

Maximum and minimum alarm pressure

When the pressure rises above a particular settable pressure value, INVENTA will stop the pump to prevent damages to the hydraulic components in the system. Similarly, if the pressure drops below a certain pressure alarm is declared, and the pump stops.



V/f programmable curve

INVENTA allows to choose between two different methods of torque control (voltage) versus pumps speed (frequency):

- constant torque (linear V/f)
- quadratic variable torque (squared V/f)

For centrifugal pumps, it’s possible to obtain energy savings by selecting squared V/f control.
Settable carrier frequency between 2.5, 4, 6, 8, 10 kHz
If INVENTA controls a submersible pump with long cables, it is possible to decrease the carrier frequency value to ensure longer motor life.

Several control modes available

In addition to constant pressure control, INVENTA allows other control modes such as fixed frequency, continuous flow, constant temperature.

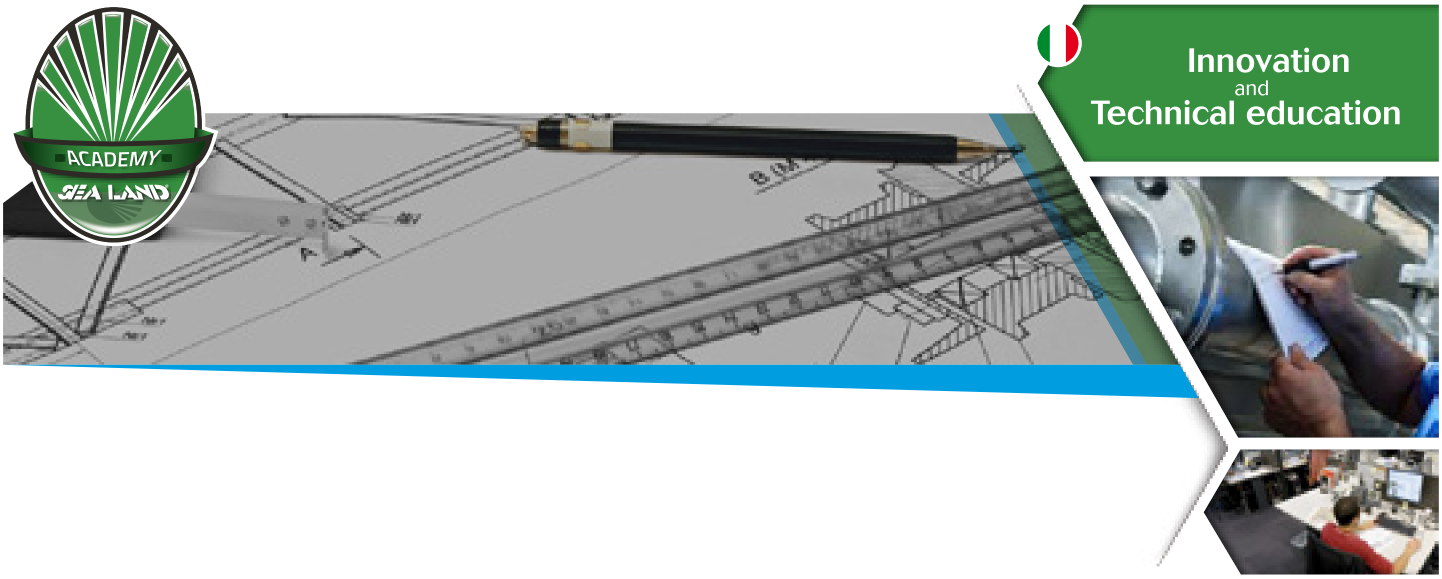
4.4 SEVERAL CONTROL MODES

Constant pressure

INVENTA controls the pump speed to maintain a constant pressure at a set point independent of the water demand in the system. In a hydraulic system equipped with INVENTA, a smaller tank replaces the standard pressure tank, because it maintains the set pressure in the system when the pump stops.

Constant pressure 2 values

By selecting the continuous pressure 2 values control mode, in the case of irrigation systems, only one pump can serve two zones with different pressure sets. It is possible to switch the two values



by acting on a digit input contact.

Fixed frequency 2 values

If it is not necessary to operate at constant pressure but is required to select 2 different speeds of the pump, by selecting fixed frequency 2 values control mode, it is possible to switch the 2 values by acting on a digit input contact.

Constant temperature

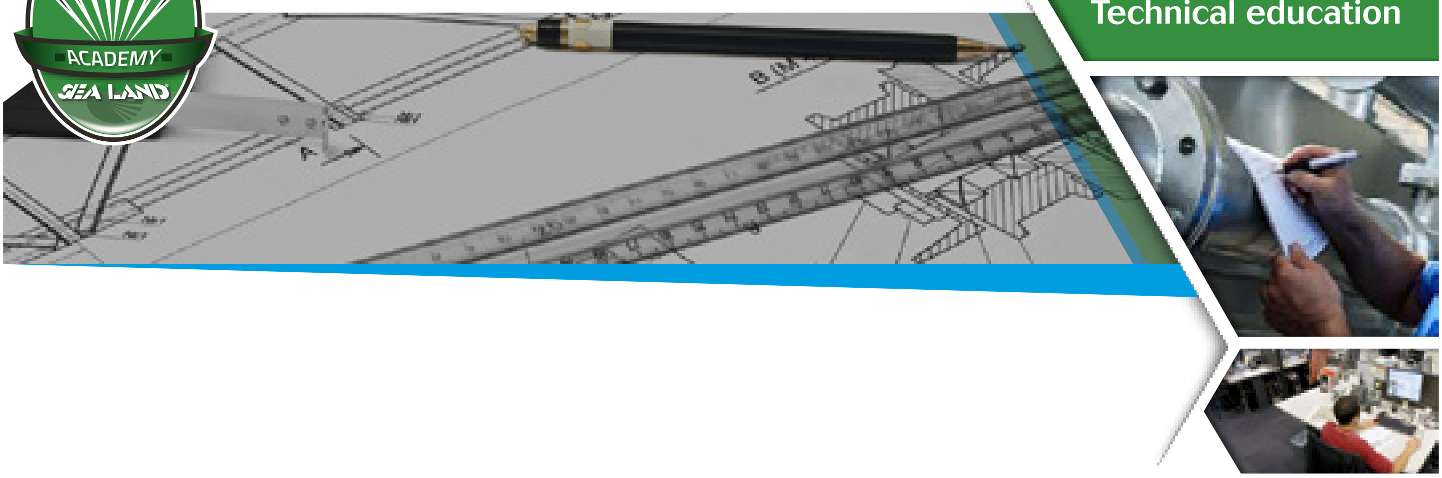
The control method at constant heat is used to maintain the temperature of the pumped fluid to vary the thermal load. This control system is used in air conditioning or refrigeration and cooling towers. In this last case, for example, is kept constant the temperature measured by a sensor located in correspondence of the return water.

Constant flow

By selecting the constant flow control mode and using a flow transducer, it is possible to control the flow of the pumped liquid to vary the system condition. This control mode is used, for example, in a system for filtering the pumped fluid in which the obstruction of the filter would lead to a progressive reduction of the flow rate if an increase of the pump speed doesn’t compensate it.

External frequency

In some application, it is chosen to change the frequency of the pump by using an external signal coming from a trimmer or a PLC. In this case, after selecting the External Frequency control mode, it is enough to connect an input signal 4-20 mA or 0-10V, proportional to the desired frequency, to the AN4 analog contact.



4.5 APPLICATIONS: IN-LINE PUMPS

INVENTA operates at constant differential pressure by using a differential pressure sensor or using 2 pressure sensors installed in the suction and delivery sides of the pump. The difference value is calculated by the INVENTA itself from the two read values.
This solution enables significant cost savings as well as protect cavitation (by setting a minimum alarm pressure on suction side) and against overpressure (by setting a maximum alarm pressure on delivery side).

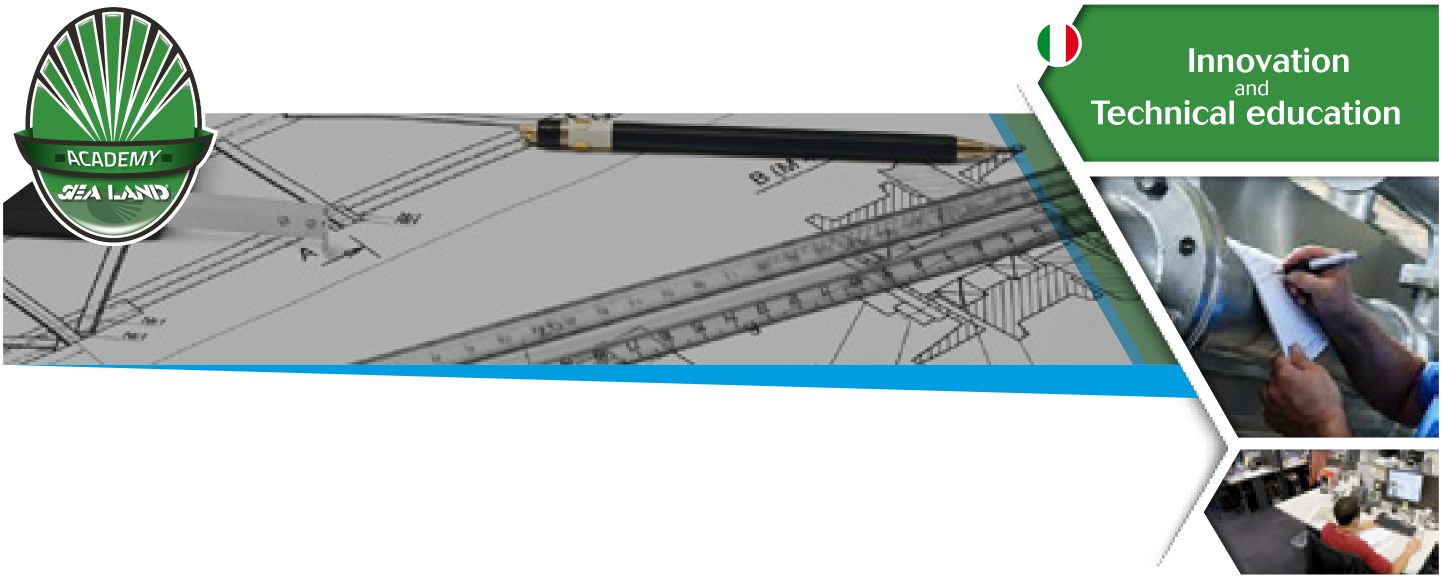
Constant differential pressure control can be extended to the operation of a group, i.e., twin pumps application.
COMBO system ensures the pumps alternate during the operation to average the pumps wearing and easily plan the maintenance operation.
In a system characterized by high-pressure drop, INVENTA performs the proportional differential pressure control, to maximize energy saving.

Submersible pumps

INVENTA can power submersible pumps of various powers.
It’s suggested to set to 2.5 kHz the carrier frequency (PWM parameter), and sometimes it’s necessary to install a filter between pump and inverter to:

- reduce the spikes on the motor windings caused by voltage reflection (dv/dt filters)
- avoid electromagnetic noise in the surrounding environment (sinusoidal filters)

It is recommended to keep separate the motor cable from other cables granting a certain distance.
Nastec can provide filters and shielded cables for a proper pump installation.



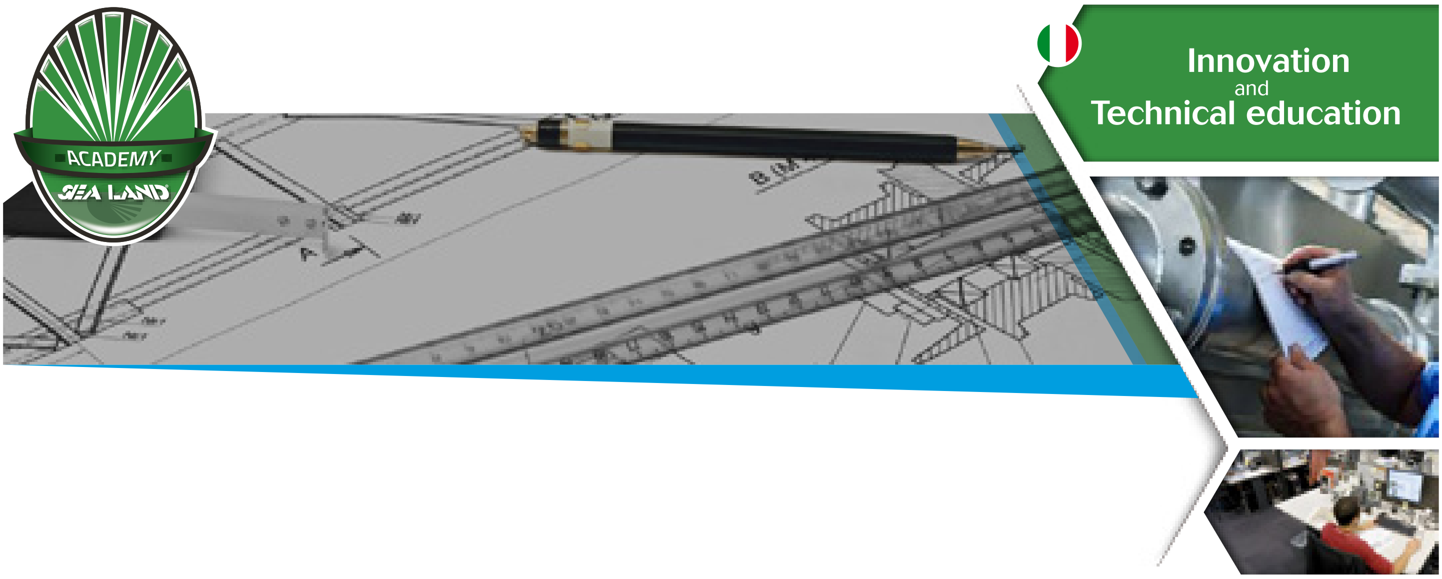
4.6 APPLICATIONS: PRESSURE BOOSTER SETS

With INVENTA inverters is possible to realize booster sets with one or more pumps (up to 8) to be controlled at constant pressure.
INVENTA can be mounted directly to the motor fan cover with a proper kit; the extreme strength of the connection allows the INVENTA installation even on horizontal pumps.
Screen display can be easily rotated to optimize the parameters view.
Motor mounting application guarantees, as well as the compactness and the saving of additional control panels and, wrings, an excellent cooling of the inverter and low electromagnetic emissions due to the reduced length of the motor cable.
IP55 protection allows the installation in humid and dusty environments.
If INVENTA cannot be installed on motor fan cover, it's possible to fix it to the wall with an optional kit composed by a cooling fan fed by the INVENTA itself and a wall metal bracket.
IP55 protection does not require to include INVENTA drive into any additional control box so INVENTA can be installed very near to the pump.
COMBO mode control allows to switch the start of pumps based on real working time and, in case of failure, remaining pumps grant the operation always to guarantee the service.
Once the damaged unit is replaced, COMBO will preferably move the operation on the new pumps to equalize the running time.

1 INVENTA+ 1 or 2 DOL pumps

A first way of splitting consists of installing one pump driven by the INVENTA and 1 or 2 DOL pumps directly connected to the central power (Direct On Line); INVENTA switches on/off the 1 or 2 DOL pumps through contactors.
INVENTA alternates the two DOL pumps to average pump wearing.

From 1 to 8 INVENTAs in COMBO connection



A second way of splitting (named COMBO) consists of using several pumps in parallel (up to 8) each one driven by a INVENTA unit.
In this way, the efficiency and the reliability of the pump group are maximized.
Each INVENTA controls and protects its pump, and the operation is shared among all the connected pumps to average pump wearing; in case of failure, the remaining pumps will maintain the pumping operation.

From 1 to 8 INVENTAs in COMBO connection + 1 or 2 DOL pumps

Additionally, it's possible to equip the system with pumps connected in COMBO mode plus 1 or 2 DOL pumps controlled to satisfy additional water demand.