CHAPTER SEVEN

Electric drives

Learning outcomes

1. Describe the structure of Electric Drive systems and their role in various applications such as flexible production systems, energy conservation, renewable energy, transportation etc., and making Electric Drives an enabling technology.

2. Understand basic requirements placed by mechanical systems on electric drives.

3. Understand the basic principles of power electronics in drives using switch -mode converters and pulse width modulation to synthesize the voltages in dc and ac motor drives.

4. Describe the operation of dc motor drives to satisfy four-quadrant operation to meet mechanical load requirements.

5. Learn speed control of induction motor drives in an energy efficient manner using power electronics.

Why Variable Frequency Drive?

1. Energy crisis

Current scenario is that everywhere the energy has got a limited source at continuous increasing cost. Energy can only be earned by saving it. So option of installation of VFD is one of the best options to save energy.

2. Profit increasing by eliminating waste (gaspillage).

As now a days and henceforth price control is not in hand of manufacturer, the only option to increase the profit margin is, eliminate the waste to the best possible.

3. Technology is available (faisabilité)

As all needs are technology driven we can say that it is now available and you can make it your need for betterment of yours only.

Basic Electric Motors drive

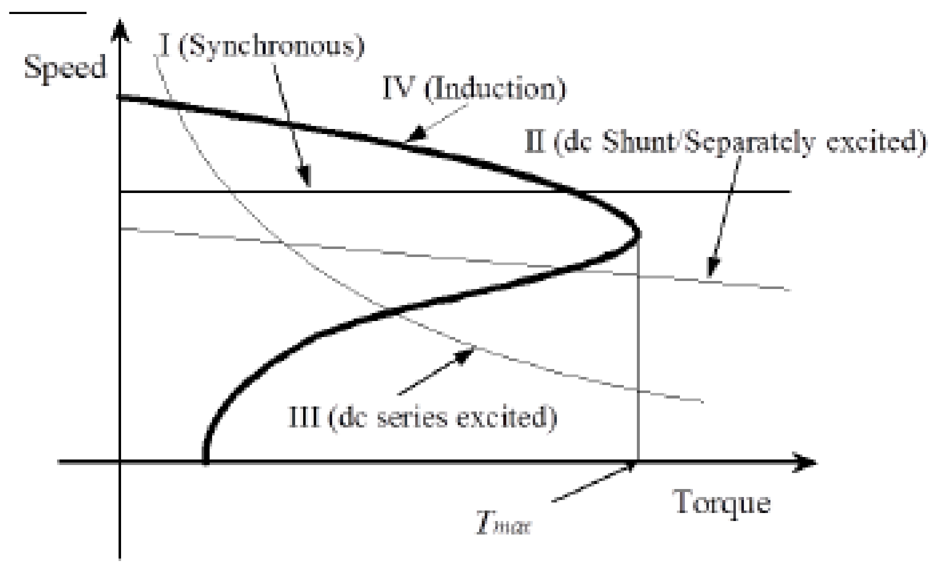
<u>AC electric motors</u>

The synchronous or asynchronous speed being defined as: $N_{syn} = \dfrac{60 \times f_{syn}}{p}$

<u>Direct-current motors</u>

Allow for changes of speed by changing the voltage applied to the armature. $E_A = k_{\phi}\Omega$

Various Motors characteristics



Reasons for using adjustable speed drives

Process control and energy savings are the two primary reasons for using an adjustable speed drive.

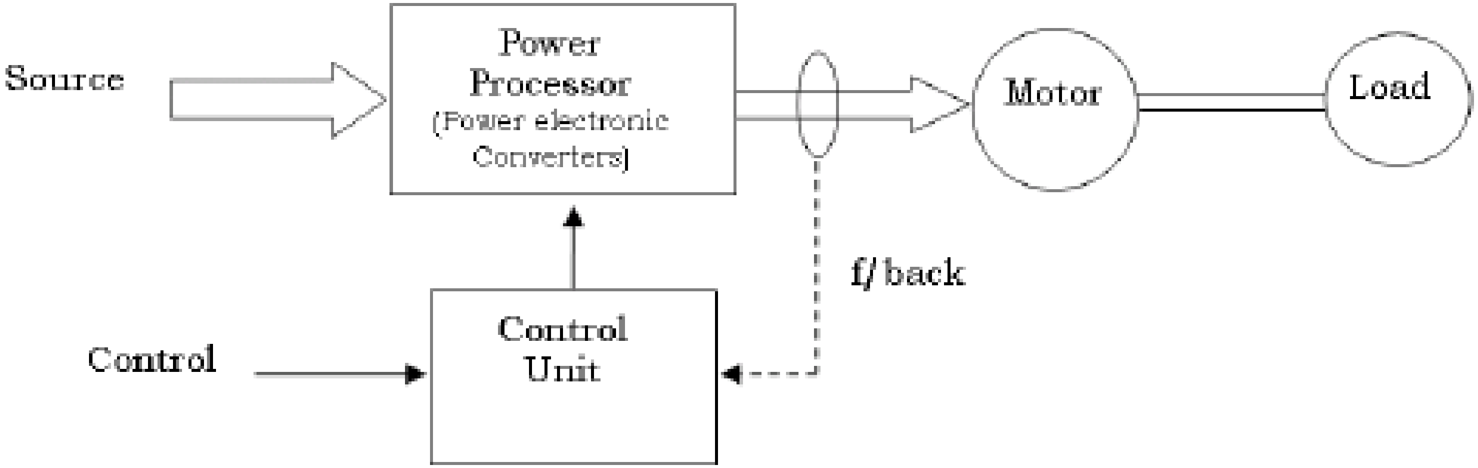
The following are process control benefits that might be provided by an adjustable speed drive:

- ✓ Energy savings
- ✓ Acceleration control
- ✓ Lower system maintenance
- ✓ Reduced voltage starting
- ✓ Adjust the rate of production
- ✓ Allow accurate positioning
- ✓ Control torque or tension

The following are process control disadvantages that might be provided by an adjustable speed drive:

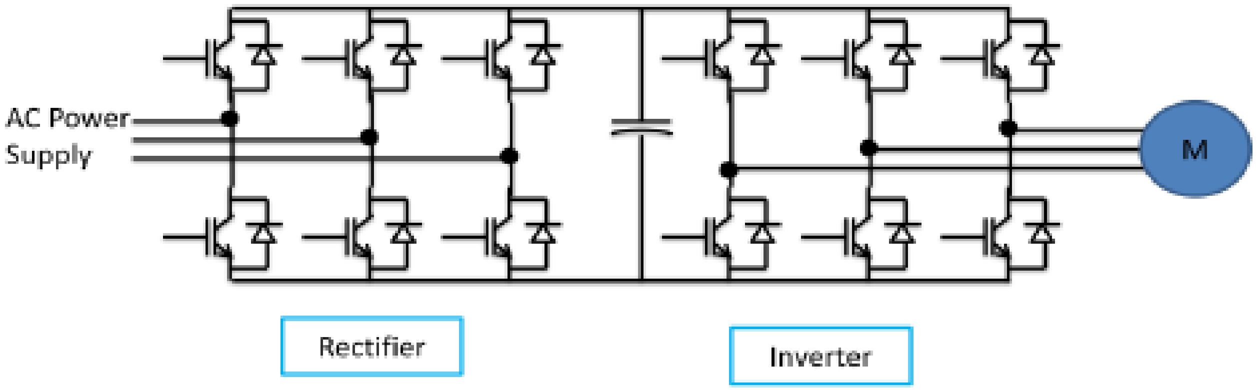
- ✓ initial cost
- ✓ Motor heating at low speeds
- ✓ Output harmonics
- ✓ induced power line harmonics

Modern electric drives (With power electronic converters)



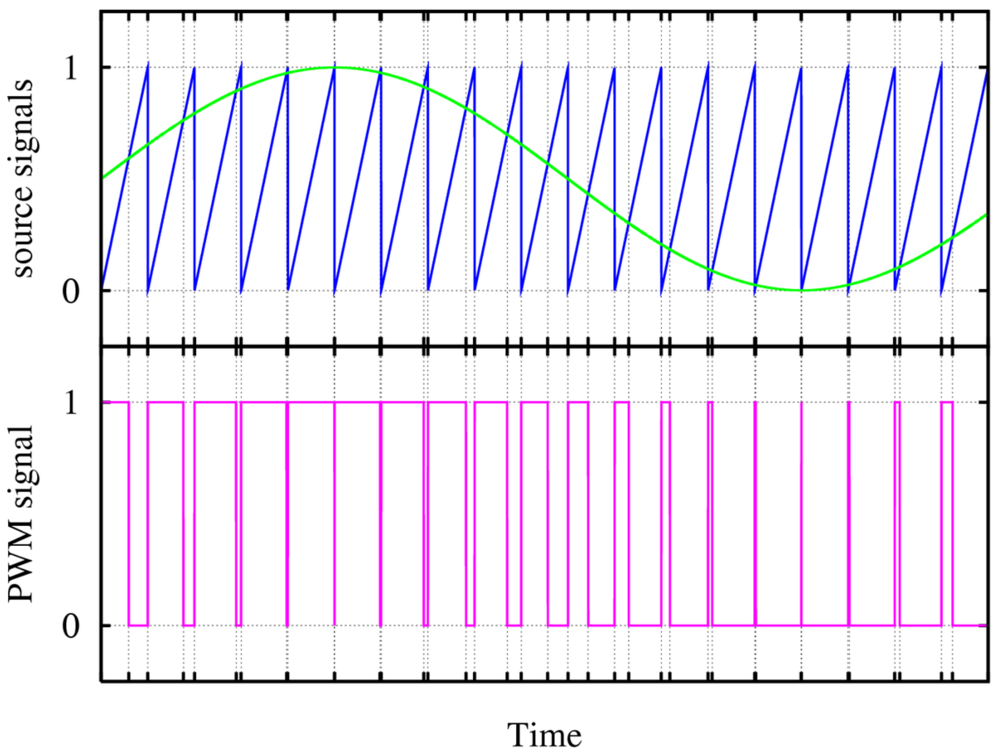
- ✓ Small
- ✓ Efficient
- ✓ Flexible

Topology of VFD

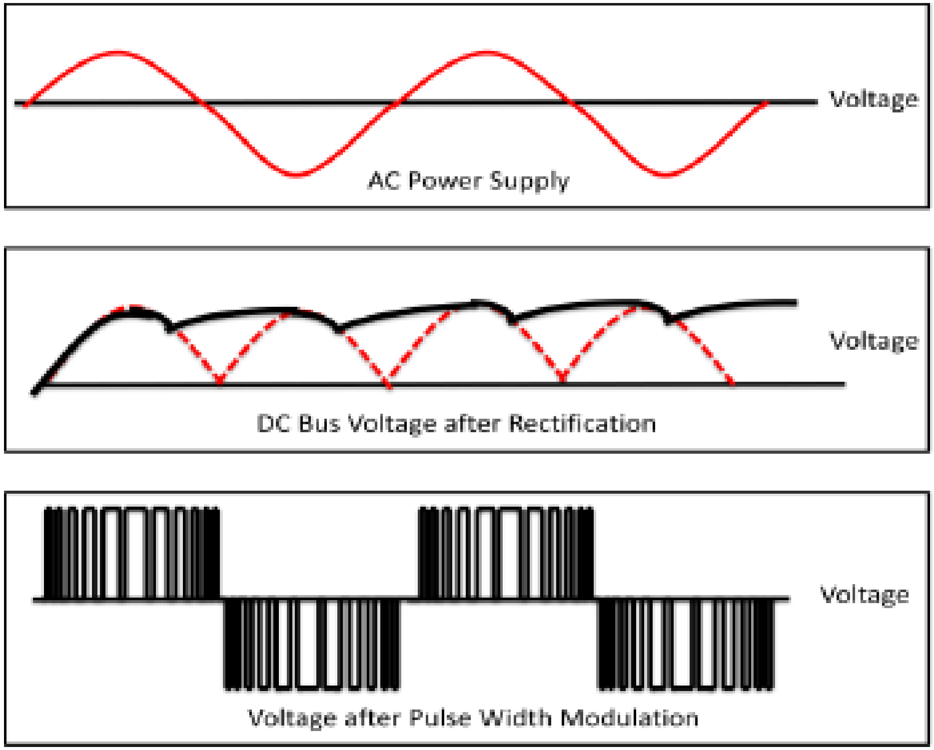


Pulse-Width Modulation-PWM(MLI)

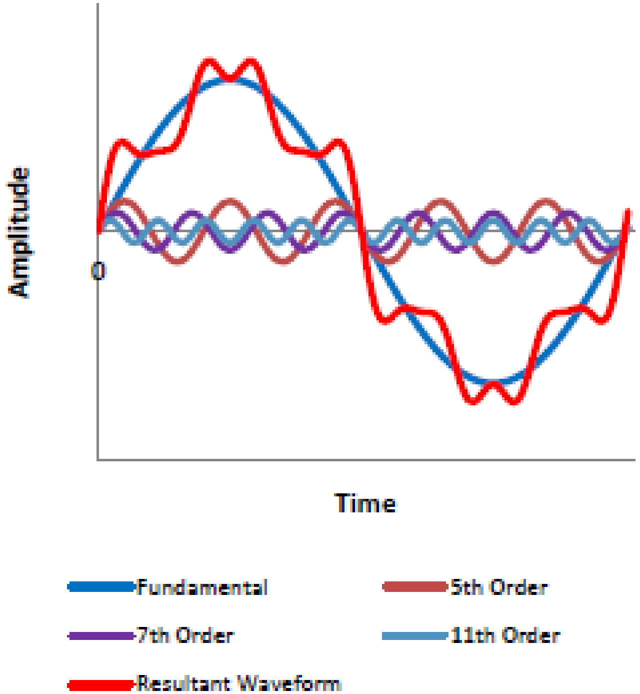
PWM is the most straightforward method used to vary drives' motor voltage (or current) and frequency.



Working Principle of VFD



Harmonic Distortion



Harmonic distortion happened when the AC current to the load distorted from ideal sinusoidal waveform.

Harmonic current is generated by the input rectifier in the AC drive. Harmonic content can result in excessive stress on components connected to the same supply line.

This can increase the winding and core losses as this current will not contribute towards output torque.

When using active end configuration, PWM is used to create a sinusoidal back EMF.

This will remove the need of harmonic filter and reduces the generator sizing requirement.

VARIABLE FREQUENCY DRIVE

PRINCIPLE OF OPERATION

- ✓ When it is desired to operate an induction motor at variable speed, it is necessary to consider the effect of voltage of frequency on flux and torque.
- ✓ The magnitude of the field is controlled not by the strength of the current but by the voltage induces in the field winding by the supply. This induced voltage can be expressed as:

$$E = k \times \phi \times f$$

At rated frequency any further increase in voltage leads to increase in current and subsequently increase in losses.

From the above $\phi = \dfrac{E}{k \times f}$

This shows that since k is a constant a linear relationship must be maintained between E and frequency, if flux is to remain constant at different speed.

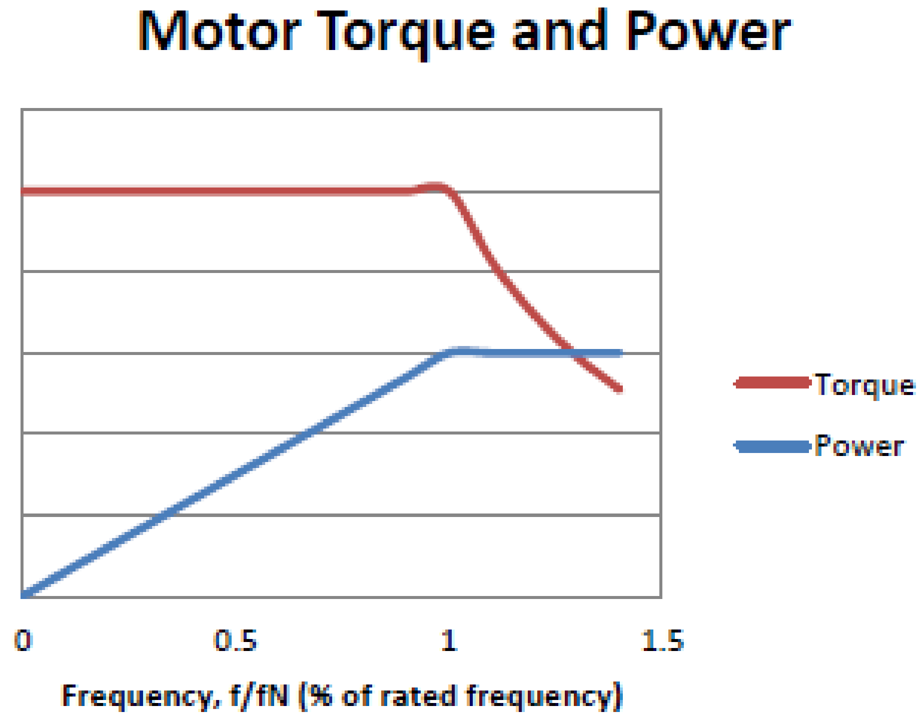
- ✓ This linear relationship is known as constant V/f.
- ✓ This is the optimum production of torque.
- ✓ This is the principle of operation of variable frequency drive (VFD).

The efficiency of induction motor is good at rated load.
At lower load, motor performance degrades.

OPERATING CONDITIONS

There are two operating condition in VFD…

1. Above BASE speed.
2. Below BASE speed



Installation:

1. OPEN LOOP INSTALLATION
VFD to be installed in series of application motor. The feed back for variable frequency will be by manual intervention as per requirement. Such installation of VFD is operator dependent, thus result in inconsistence benefits of VFD.

2. CLOSE LOOP INSTALLATION
VFD to be installed in series of application motor. The feed back for variable frequency will be taken through proper set of instrumentation. Such installation of VFD is not operator dependent, thus results in consistence benefits of VFD.

In words, using an adjustable speed drive saves energy by?

Reducing the speed of a variable torque pump or fan significantly reduces the energy usage of the driving motor.

The "why" can be summarized by a set of rules called the affinity rules.

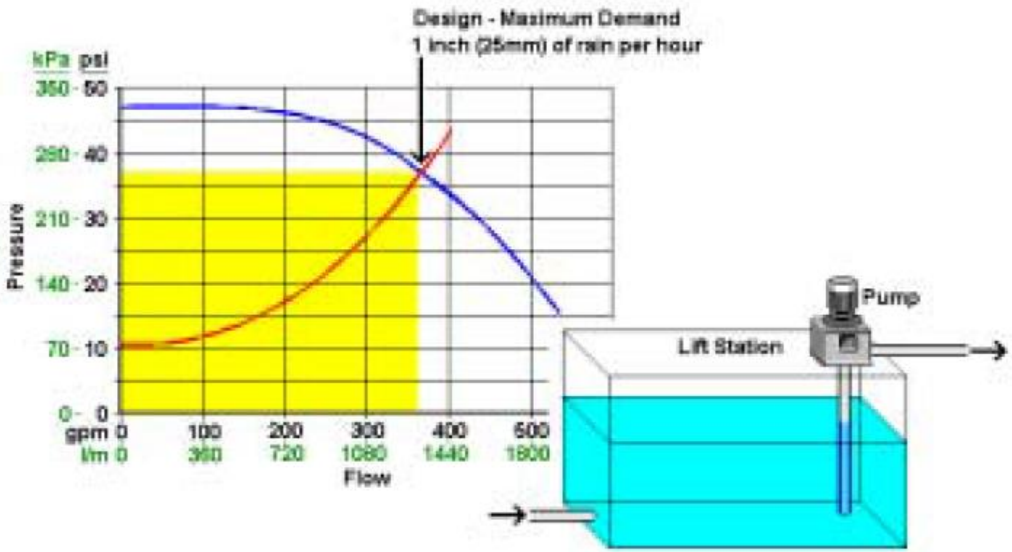
1. Flow produced by the system is proportional to the motor speed.
2. Pressure produced by the system is proportional to the motor speed squared.
3. Horsepower required by the system is proportional to the motor speed cubed.

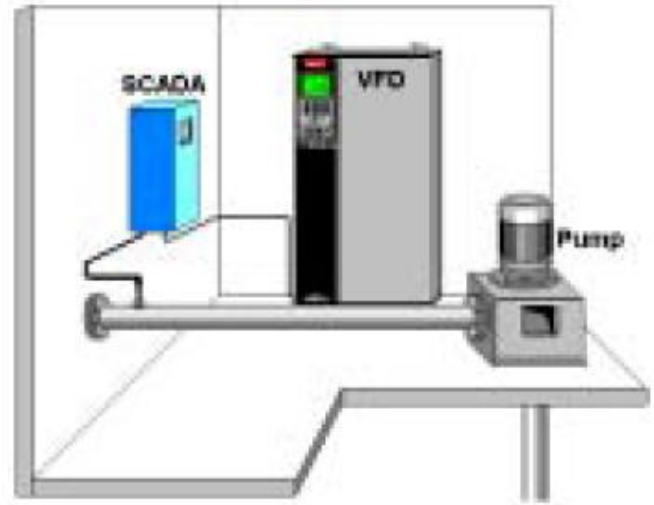
Some applications of electric drives:

Centrifugal Pumps (variable torque)

Water systems are designed for the “worst case” situations. Most of the time they have excess capacity.

Controlling flow below its maximum
– Saves energy
– Improves system operation





$$Flow: \frac{Q_1}{Q_2} = \frac{n_1}{n_2}$$

$$Pressure: \frac{H_1}{H_2} = \left(\frac{n_1}{n_2}\right)^2$$

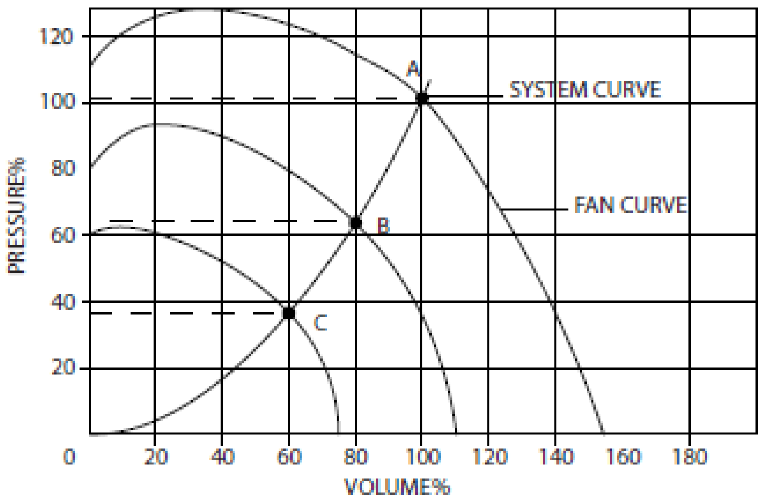
$$Power: \frac{P_1}{P_2} = \left(\frac{n_1}{n_2}\right)^3$$

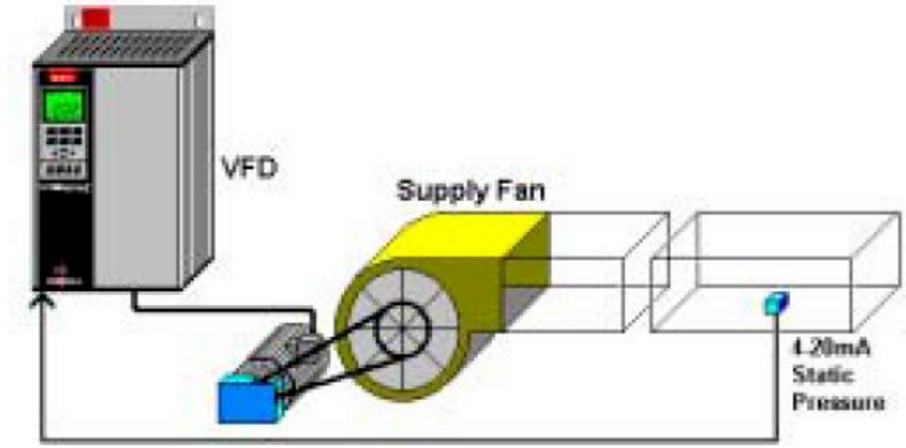
In the picture above, the Blue line shows the pump curve and the red line the system curve

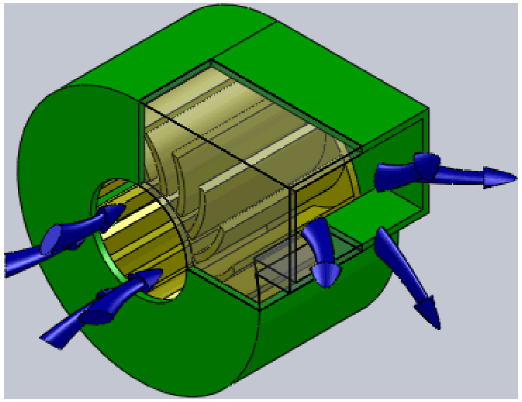
Some applications of electric drives:

Centrifugal Funs (variable torque)

A centrifugal fan is a mechanical device for moving air. These fans increase the speed of air stream with the rotating impellers. Centrifugal fans accelerate air radially, changing the direction (typically by 90°) of the airflow.







Controlling air flow below its maximum

– Saves energy

– Improves system operation

$$\text{Flow}: \frac{Q_1}{Q_2} = \frac{n_1}{n_2}$$

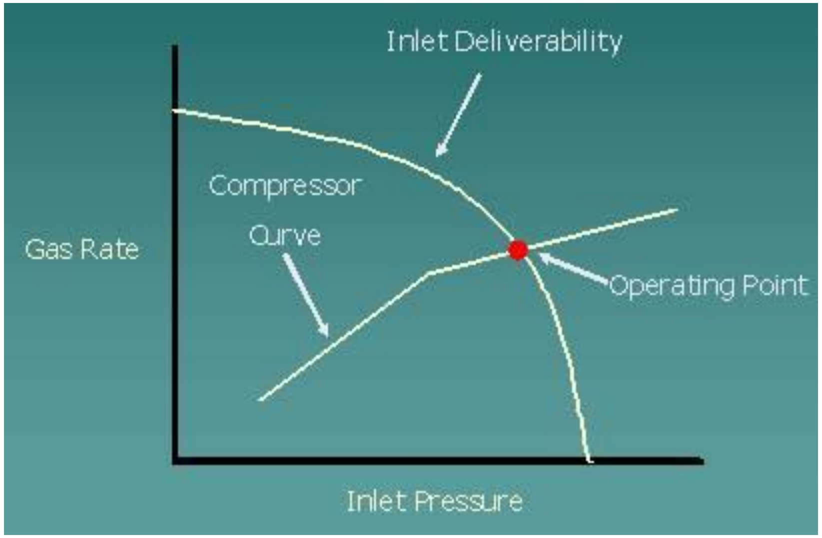
$$\text{Pressure}: \frac{H_1}{H_2} = \left(\frac{n_1}{n_2}\right)^2$$

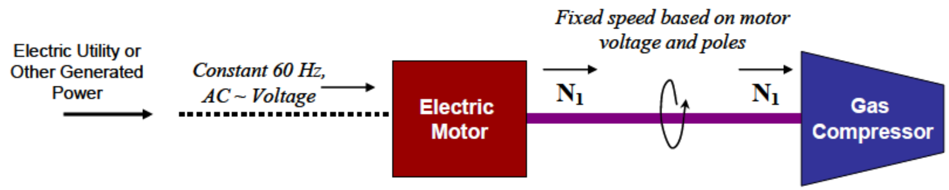
$$\text{Power}: \frac{P_1}{P_2} = \left(\frac{n_1}{n_2}\right)^3$$

Some applications of electric drives:(conveyers, mixers, elevators, compressors)

Compressors (constant torque)

An air compressor is a device that converts power (usually from an electric motor) into kinetic energy by compressing and pressurizing air.





- CT used on Reciprocating Compressors
- Torque stays relatively constant from 5Hz to 50Hz.
- AC motors have low torque at slow speeds

Controlling pressure below its maximum

– Saves energy

– Improves system operation

Obtain Even More Energy Savings by Using Drives on Variable Torque Loads

	Potential Energy Savings
Air conditioning	20-25%
Compressors	20-25%
Central refrigeration	25-35%
Blowers and fans	30-35%
Feedwater pumps	30-50%

Components in electric drives

E.g. Single drive - sensor less vector control

Components in electric drives

Motors

DC motors - permanent magnet – wound field

AC motors – induction, synchronous, brushless DC

Applications, cost, environment

Power sources

DC – batteries, fuel cell, photovoltaic - unregulated

AC – Single- three- phase utility, wind generator - unregulated

Power processor

To provide a regulated power supply

Combination of power electronic converters

- ✓ More efficient
- ✓ Flexible
- ✓ Compact
- ✓ AC-DC DC-DC DC-AC AC-AC

Control unit

- ✓ Complexity depends on performance requirement
- ✓ Analog- noisy, inflexible, ideally has infinite bandwidth.
- ✓ Digital – immune to noise, configurable, bandwidth is smaller than the analog controller's
- ✓ DSP/microprocessor – flexible, lower bandwidth - DSPs perform faster operation than microprocessors (multiplication in single cycle), can perform complex estimations

DC drives vs AC drives

DC drives:
Advantage in control unit
Disadvantage in motor

AC Drives:
Advantage in motor
Disadvantage in control unit

Exercise 1

Consider a real case when a motor pump system of 15kW works 300 days a year, 24 hours a day and pumps 1200m^3 of water per day. By on/off and throttling control, only, the system uses 0,36kWh/m^3 of pumped water to keep the pressure rather constant for variable flow rate.

Adding a P.E.C (Power Electronics), in the same conditions, the energy consumption is 0,28kWh/m3 of pumped water, with a refined pressure control.

Let us consider that the cost of electrical energy is 4cts/kWh.

Calculate the energy savings per year **S**

Solution:

The energy savings per year S is:

$$S = 1200 \times 300 \times (0{,}36 - 0{,}28) \times 0{,}04 / year) = 1152.euros / year$$

Now the costs of a 15kW PWM - P.E.C. for an induction motor is less than 4000euros.

Thus, to a first approximation, the loss savings only pay off the extra investment in less than 4 years

Why use an AFD?

- ✓ The process requires it
- ✓ The process can be improved by it
- ✓ Energy savings
- ✓ Easier on driven equipment
- ✓ Acceleration of high inertia load
- ✓ To avoid frequent motor starting
- ✓ As a replacement for gearing

Why worry about the motor? What's different?

- ✓ Can the motor produce the required torque throughout the operating speed range?
- ✓ Will the motor have adequate cooling at low speeds?
- ✓ Will harmonics from the drive cause the motor to overheat?
- ✓ Will the motor fly apart at over speed?
- ✓ Will the drive voltage waveform damage the motor windings?
- ✓ Will the drive voltage waveform damage the motor bearings?

Power Converter

- ✓ Rectifiers
- ✓ Choppers
- ✓ Inverters
- ✓ Cycloconverter

What Is a Variable Frequency Drive?
The operating speed of a motor connected to a VFD is varied by changing the frequency of the motor supply voltage. (Variable speed drives can be electrical or mechanical, whereas VFDs are electrical.)

How Does a VFD Work?
VFDs convert the fixed-frequency supply voltage to a continuously variable frequency, thereby allowing adjustable motor speed.

Exercise 2

The potential energy savings from installing a VFD is illustrated in the following example.

Here, a 40 hp motor is used in an HVAC system with a flow-control damper (régulateur de debit). The system operates 365 days a year with the load/time profile shown in Table below. The damper is removed and a VFD installed. The estimated annual energy savings realized from the use a VFD is shown in Table below.

Airflow Volume (percent of maximum)	Daily Operating Time (hours)	Energy Consumed Using a Damper(kWh/year)	Energy Consumed Using a VFD(kWh/year)	Difference in Energy Consumption (kWh/year)
50%	2	18 500	4 800	13 700
60%	3	29 300	9 800	19 500
70%	6	61 700	26 800	34 900
80%	6	63 300	35 900	27 400
90%	4	44 200	32 600	11 600
100%	3	34 200	35 200	–1 000
Total	**24**	**251 200**	**145 100**	**106 100**

How Much Will I Save?

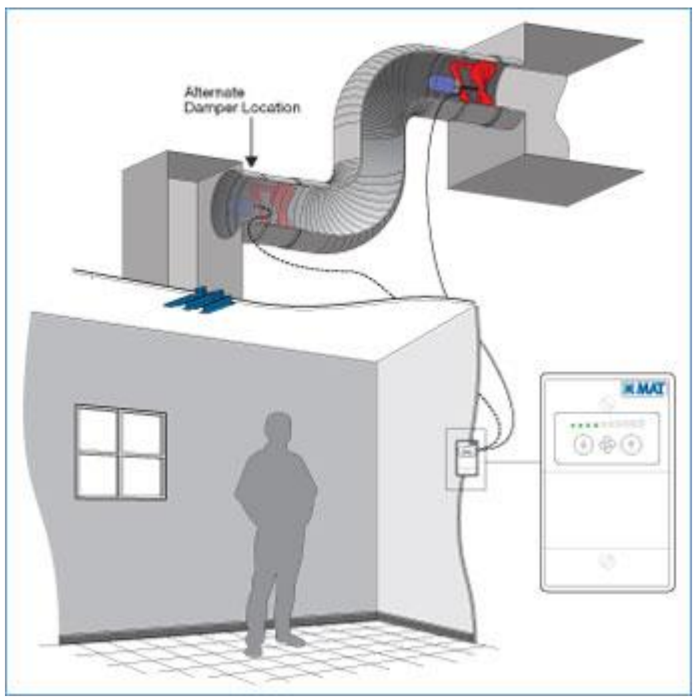
Solution:

The above example shows a possible electrical energy saving of **106 100** kWh per year, resulting from replacement of the existing damper-control system with a VFD. Savings would be less if the existing flow-control system used variable inlet vanes. At energy rates of 0,085uros/kWh, annual savings are 9018euros.

Some applications of electric drives:

Damper control

This damper can switch the electrical power to control additional dampers, minimizing the electrical load on the damper's control circuitry and power transformer.



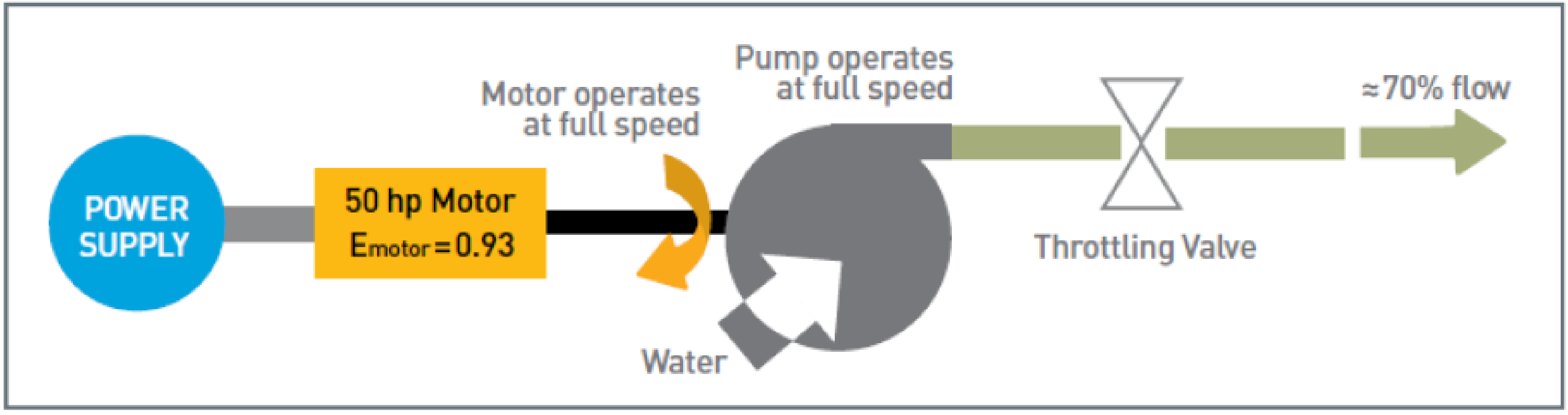
Exercise 3

Consider a real case of Pump System with table data given below.

MOTOR POWER (HP)	50 HP
MOTOR EFFICIENCY	0,93
LOAD FACTOR (LF) [%]	75%
PERCENT FULL RATED SPEED (PFRS)	100%
ANNUAL OPERATING HOURS	4067 hours
ELECTRICITY COST	0,07€/kWh
ASD EFFICIENCY	97%

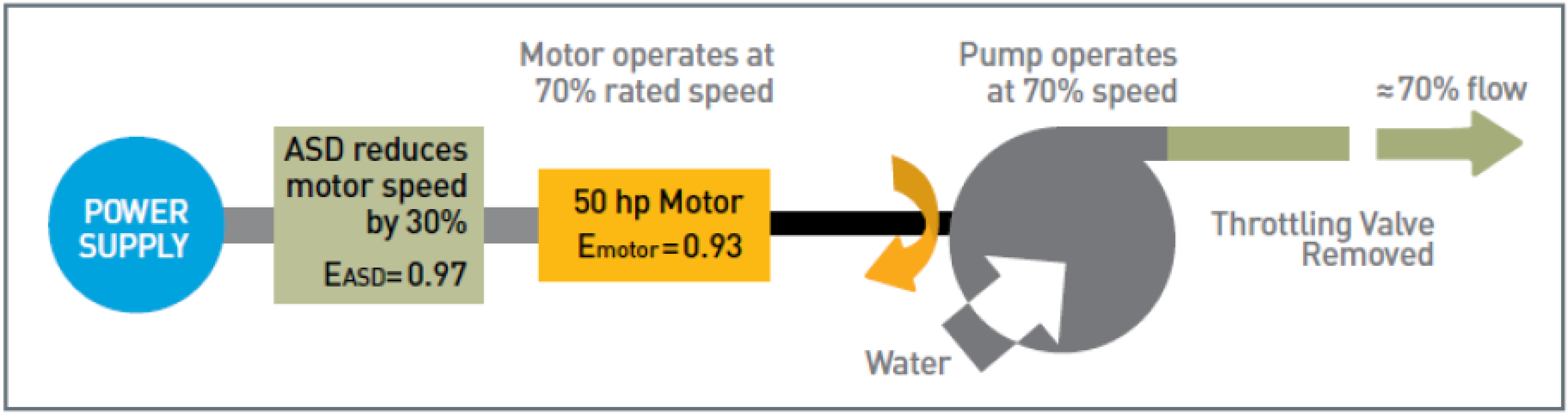
A) Below is a 50 HP centrifugal pump operating 4067 hours annually, with a 75 percent load factor, a throttling valve to regulate flow to 70 percent on average, and primarily frictional losses and negligible static head. The calculations do not account for costs such as ASD purchase and maintenance or utility demand charges.

The Pump System Diagram with Throttling Valve is shown below



1. Calculate the Annual Energy Cost (AEC) with Throttling Valve in Pump System

B. Now the same system appears below, except an ASD replaces the throttling valve to achieve the same flow regulation by varying the motor's rotational speed and (PFRS) [%] = 70%.



2. Calculate the Annual Energy Cost (AEC) with ASD in Pump System
3. Calculate the Annual Energy Cost Savings (S) with ASD in Pump System

Solution:

1. The Annual Energy Cost (AEC) with Throttling Valve in Pump System is:

$$AEC = \frac{P_{(HP)}}{\eta_M} \times LF[\%] \times 0{,}746 \times (PFRS[\%])^3 \times hrs \times \frac{€}{\text{kWh}}$$

$$AEC = \frac{50}{0{,}93} \times \frac{75}{100} \times 0{,}746 \times \left(\frac{100}{100}\right)^3 \times 4067 \times 0{,}07 = 8564€/\text{year}$$

2. The Annual Energy Cost (AEC) with ASD in Pump System is:

$$AEC = \frac{P_{(HP)}}{\eta_M} \times LF[\%] \times 0{,}746 \times \left(PFRS[\%]\right)^3 \times hrs \times \frac{€}{\mathrm{kWh}} \times \frac{1}{\eta_{ASD}}$$

$$AEC = \frac{50}{0{,}93} \times \frac{75}{100} \times 0{,}746 \times \left(\frac{70}{100}\right)^3 \times 4067 \times 0{,}07 \times \frac{1}{0{,}97} = 3028€/\mathrm{year}$$

3. The Annual Energy Cost Savings (S) with ASD in Pump System is:

$$S = 8564 - 3028 = 5536€ / year$$

Review

Q1 Is motor cooling adequate for extended operation at very low speeds?

R1 Motor thermal protection devices will prevent high-temperature damage when motors operate continuously at very low speeds.

Q2 Will harmonics affect nearby sensitive equipment?

R2 Additional line filtering is often required to reduce the propagation of harmonics and radio frequency interference (RFI) to other equipment.

Q3 Can a VFD is used for all types of loads?

R3. Yes.

Q4 How many motors can be operated on a drive?

R4 More than one motor on a drive is common. All receive the same frequency, so they change speed in unison. Each motor must have its own overload protection.


The End