Egyptian program for promoting
Industrial Motor Efficiency
SAVE TODAY ... POWER TOMORROW

Motor Systems Optimisation Refresher Course

(2020 Egypt Edition)

Presented by:

Samir Khafagui & Siraj Williams

UNIDO

Ministry of Trade & Industry
وزارة التجارة والصناعة

ENCPC
Egypt National Cleaner Production Center
مركز تكنولوجيا الإنتاج الأنظف

مركز تحديث الصناعة
INDUSTRIAL MODERNISATION CENTRE

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Welcome…

- Name
- Organisation
- Energy management experience
- What do you expect to learn over these days?

Acknowledgements

Thanks to

- UNIDO, Vienna
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- Hugh Falkner
- Gihan Bayoumi Attia
- Siraj Williams

Programme Objective

Current Problem

In 2014, Egypt emitted 272.69 MtCO2. Although only accounting for 0.6% of the total greenhouse gas (GHG) emissions worldwide, the country is one of the fastest growing emitters in the world and one of the most vulnerable places to climate change adversities. In fact, Egypt's GHG emissions have grown by over 121% between 1990 and 2014. The GHG emissions growth rate is even higher for the electricity/heat consumption which grew by 244% over the same period.

Aim

The project aims to improve the efficiency of Electric Motor Driven Systems (EMDS) and accelerate the market penetration of energy efficient motors in the industrial sector and reduce GHG emissions through supporting low carbon technologies. The cost-effective motor system optimization measures and the replacement of inefficient motors expected to result in 40% reduction in energy use.

Visual Concept

Energy-Efficient motors possess a number of benefits since they are comprised of superior materials and elevated manufacturing techniques. They have increased reliability because of their longer bearing lives, lower waste heat output, higher service factors and less vibration.

As efficient electric motors achieve greater efficiency by reducing the losses the visual concept put along with the slogan "Save Today … Power Tomorrow" encourage target audience in the Egyptian Industrial Market to identify the opportunity of high energy efficient motor potentials.

Course Outline

1. Electric Motor Fundamentals
2. Motor System Operation Control and Maintenance
3. Motor Load Applications
4. Motor System Assessment
5. Latest Motor Markets

1. Electric Motor Fundamentals

Why do we use motors?

to drive some mechanical application…

(always connected to something to create movement to do “work”)

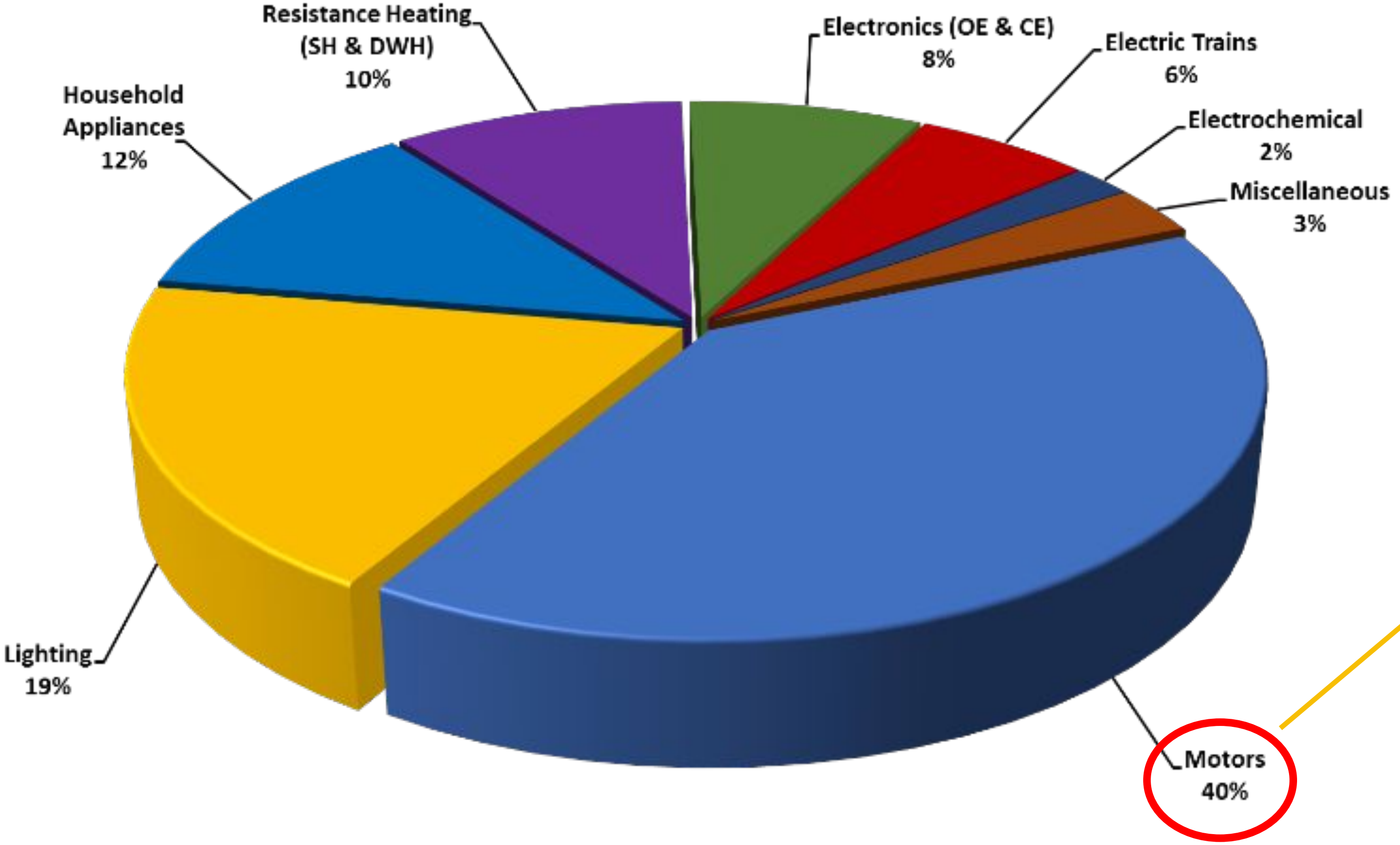
BUT

…

- Motors cost money to install and maintain

- Motors consume energy of which there is currently limited supply

Why do we focus on electric motors?



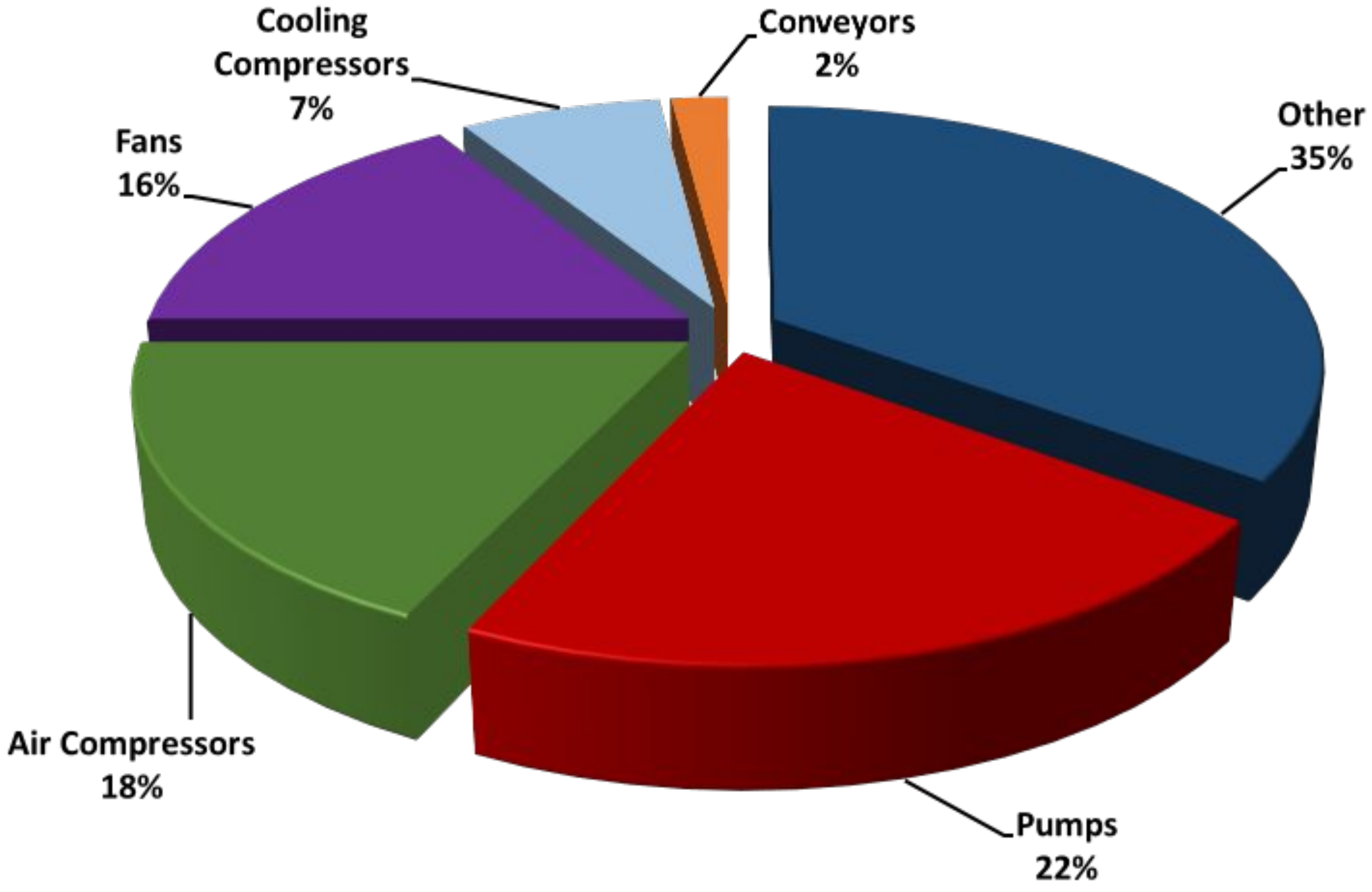
Motors 40%

Global electricity demand by end-use
Source: A+B International 2008

Electric motors in industry

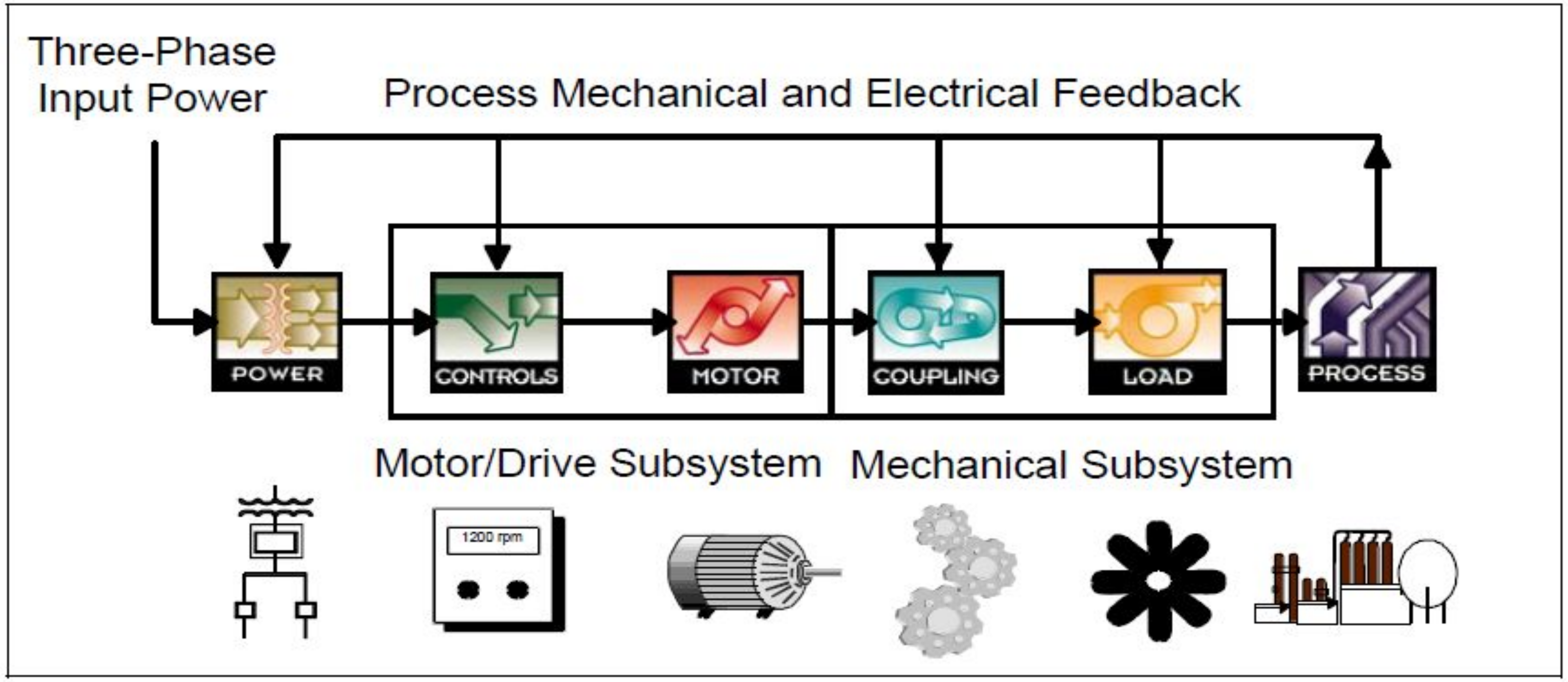
Motor Systems Electricity Consumption by Application

- Pumps, fans and air compressors make up 56% of industrial applications



Electricity Consumption in the European Union Industrial Sector
Source: ISR – University of Coimbra (2012)

The Motor System



Three-Phase Input Power

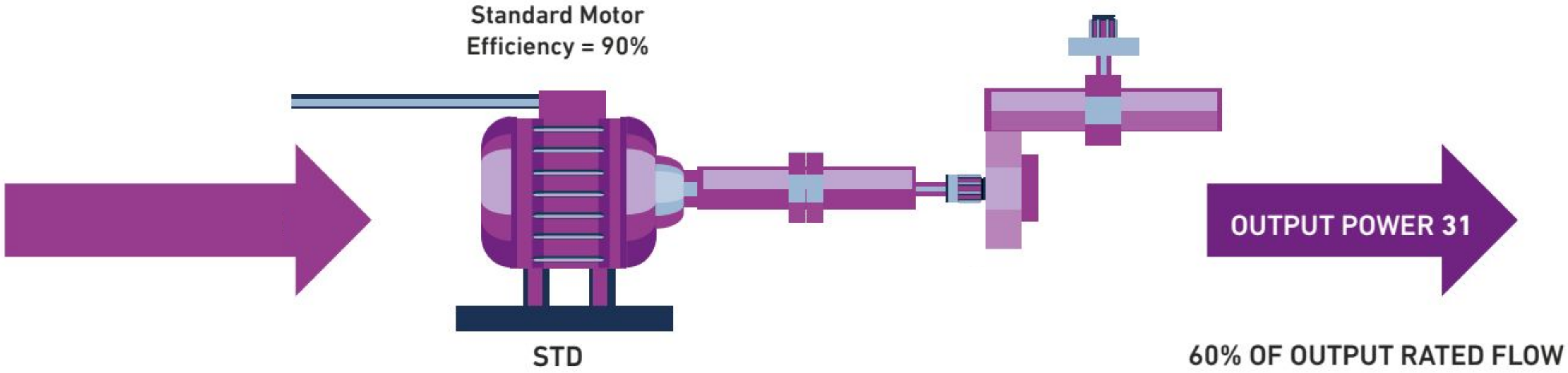
Process Mechanical and Electrical Feedback

Motor/Drive Subsystem

Mechanical Subsystem

$$\eta_{system} = \eta_{VSD} \cdot \eta_{motor} \cdot \eta_{transmission} \cdot \eta_{end-use} = \frac{P_{useful}}{P_{input}}$$

Case Study: an electric motor in a pump application

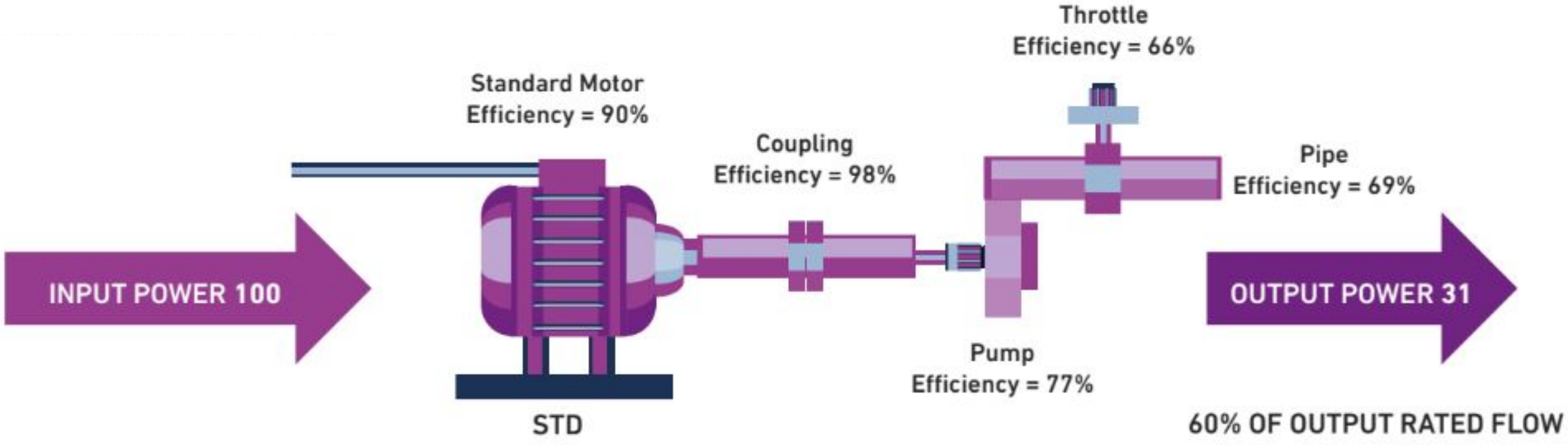


Source: de Almeida, A & Ferreira, F & Both, D 2004

- The motor is operating at full speed and driving the pump.
- The pump is providing fluid to the production process.
- The throttle is used to control the volume of the flow to 60% of the maximum pump output and is manually controlled by an operator.
- The motor is 90% efficient. ☺

How efficient is the **system**?

Case Study: an electric motor in a pump application



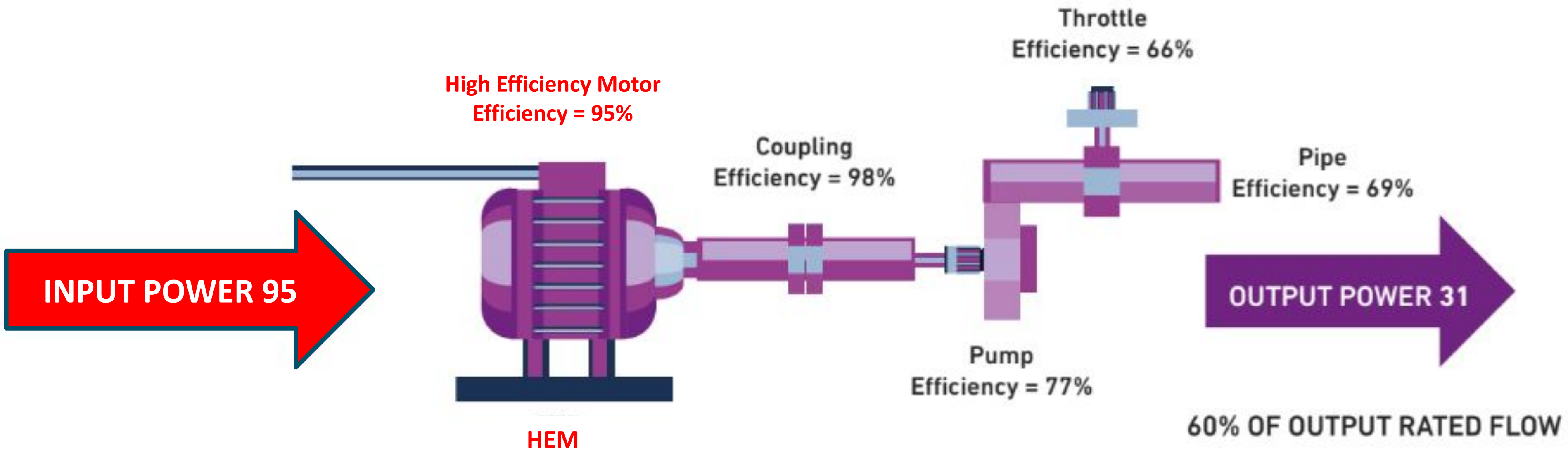
System efficiency is the product of the efficiencies of the individual components

- Efficiency (η) = $\eta_{motor} * \eta_{coupling} * \eta_{pump} * \eta_{throttle} * \eta_{pipe}$

$$= 90\% * 98\% * 77\% * 66\% * 69\% = \boxed{31\%}$$

Is this acceptable?

Case Study: Improving motor efficiency only



High Efficiency Motor
Efficiency = 95%

INPUT POWER 95

HEM

Coupling
Efficiency = 98%

Throttle
Efficiency = 66%

Pipe
Efficiency = 69%

Pump
Efficiency = 77%

OUTPUT POWER 31

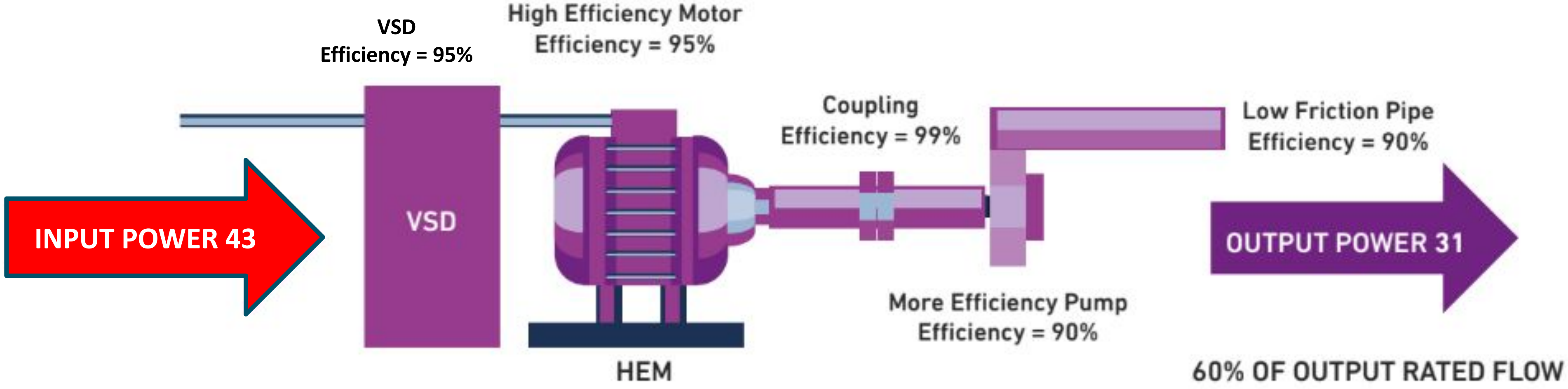
60% OF OUTPUT RATED FLOW

New Efficiency (η) = $\eta_{motor} * \eta_{coupling} * \eta_{pump} * \eta_{throttle} * \eta_{pipe}$

= 95% * 98% * 77% * 66% * 69% = **32.6%**

Is this acceptable?

Case Study: Improving all system components



- Replace throttle control with VSD
- Install high efficiency motor
- Improve transmission coupling
- Install more efficient pump
- Install low friction piping

New System Efficiency (η) = **72%**

We have created a virtual power station worth 57 power units!

Optimisation: Using the Systems Approach

- Using the system approach, savings of between 5-40 % may often be realised.
- At component level, replacing the motor with a more efficient one only, will usually yield about 1-4 %.

Where do we start?

Review load requirement first

Review complete system and identify low cost opportunities within the system

Lastly, review the motor and motor drive for the system

Benefits of Motor System Optimization

Egyptian program for promoting Industrial Motor Efficiency
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Energy Savings / cost reduction

Peak power reduction

Improved operational reliability and control

Ability to increase production without requiring additional, and possibly constrained, energy supply

Avoidance of capital expenditures through greater utilization of existing equipment assets

Recognition as a “green company”

CO_2 emission reduction

Benefits of Motor System Management

Increased Productivity	Improved Reliability	Reduced Costs
Greater control over process requirements	Scheduled downtime instead of breakdown maintenance	More efficient operation
Flexibility in meeting production requirements	Longer production runs between maintenance outages	Reduced maintenance costs
Reduced scrap and rework	Longer equipment life	Lower unit cost

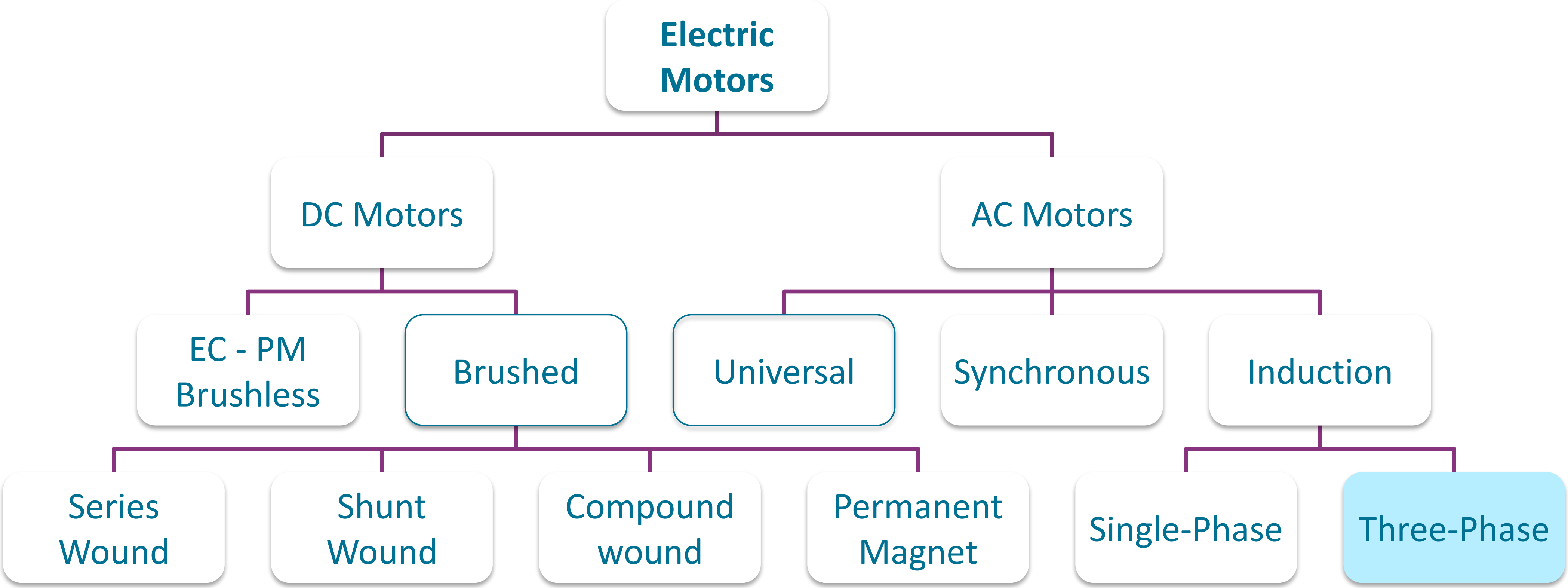
Effective motor system management develops synergies between preventive and predictive maintenance programs, equipment operation and process productivity to establish a repair/replace policy based on a commitment to energy-efficient equipment selection and operation.

Barriers to MSO and energy efficiency

Information, Behavioral, Organizational and Market Barriers to MSO and energy efficiency

- **Limited knowledge and access to information about energy saving technologies.**
- **Perceived technical and operational risks of implementing energy efficiency projects.**
- **Professional and functional boundaries within the organisation limit collaboration.**
- **Energy prices and taxes are subsidised in some countries. No incentive to optimise.**
- **Companies lack access to capital.**
- **Investments impose too high a risk due to lack of familiarity with energy-savings projects relative to core business projects and difficulty in predicting future energy prices.**
- **Perception that capital should be used for growth and expansion. Optimisation should be financed from maintenance budget with almost no capital funding.**

Motor types



Electric Motors

DC Motors

AC Motors

EC - PM Brushless

Brushed

Universal

Synchronous

Induction

Series Wound

Shunt Wound

Compound wound

Permanent Magnet

Single-Phase

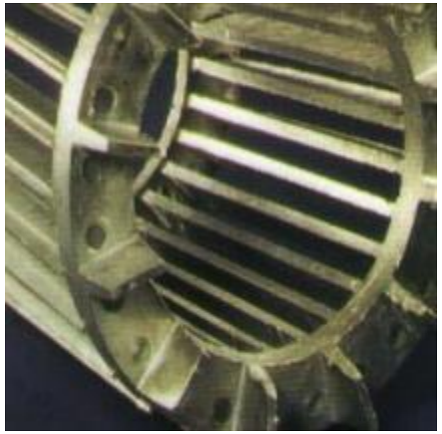
Three-Phase

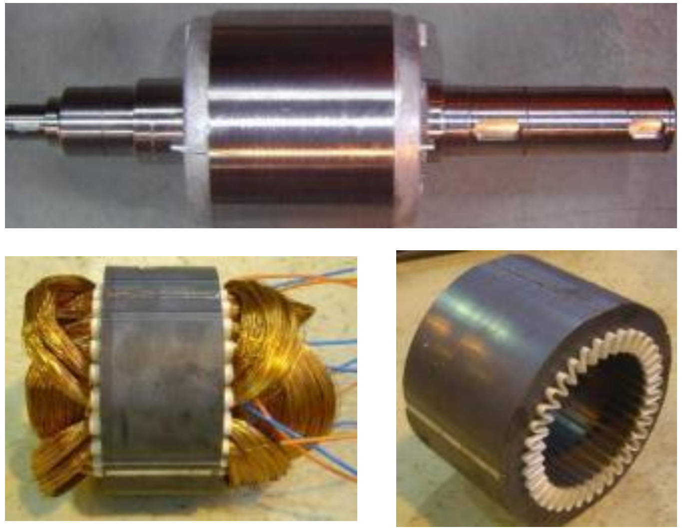
EC – Electronically Commutated
PM – Permanent Magnet

Squirrel-Cage Induction Motors

Used in more than 90% of electric motor systems;

- Good efficiency and high realibility (reduced maintenance);
- Low cost (when compared to other motor types);
- Easy to control, when fed by Variable Speed Drives (VSDs).





Permanent Magnet Synchronous Motors (PMSM)

Also called:

Brushless DC Motors (BLDC)

Electronically Commutated Motors (ECM)

PMSM is preferred

Motor behavior similar to DC motors, but have no brushes

- Stator design similar to induction motors (3 phase stator winding
- Rotating permanent magnet in the rotor
- Powering of the 3 phases according to rotor position

- Synchronous operation, eliminates electric and magnetic losses in the rotor – a typical reduction of 20% of the motor losses
- May become more attractive: cost reduction is likely with cheaper magnets and mass production

LSPM Motors

Hybrid motor with squirrel cage rotor fitted with high energy permanent magnets (NeFeB**) making it suitable for direct on line start

Interchangeable with induction motors (same output x frame ratio)

**alloy of neodymium, iron and boron

Switched Reluctance Motors (SR)

- An SR motor is a doubly salient design with phase coils mounted around diametrically opposite stator poles.
- Energisation of a phase will cause the rotor to move into alignment with the stator poles, so minimizing the reluctance of the magnetic path. As a high performance variable speed drive, the motor's magnetics are optimized for closed-loop operation.
- Rotor position feedback is used to control phase energisation in an optimal way to achieve smooth, continuous torque and high efficiency.

Motor Losses

Electrical losses

(also called Joule losses) are expressed by I^2R, and consequently increase rapidly with the motor load. Electrical losses appear as heat generated by electric resistance to current flowing in the stator windings and in the rotor conductor bars and end rings.

Magnetic losses

occur in the steel laminations of the stator and rotor. They are due to hysteresis and eddy currents, increasing approximately with the square of the magnetic flux-density.

Mechanical losses

are due to friction in the bearings, ventilation and windage losses.

Stray load losses

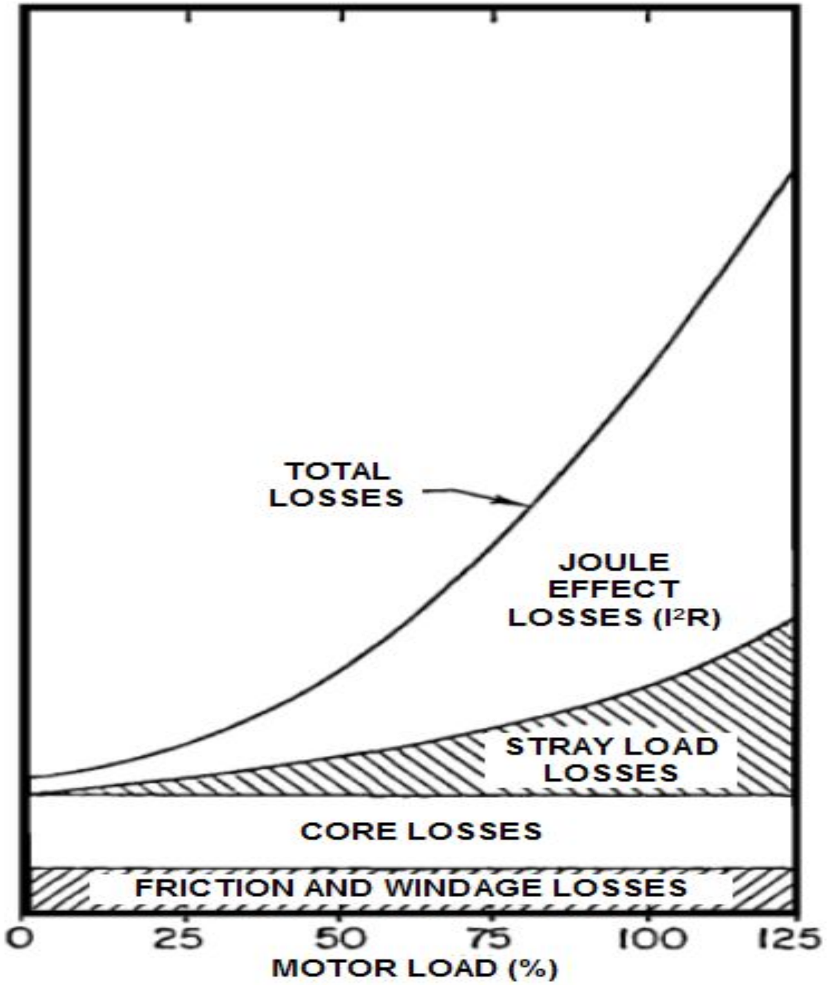
are due to leakage flux, harmonics of the air gap flux density, non-uniform and inter-bar currents distribution, mechanical imperfections in the air gap, and irregularities in the air gap flux density.

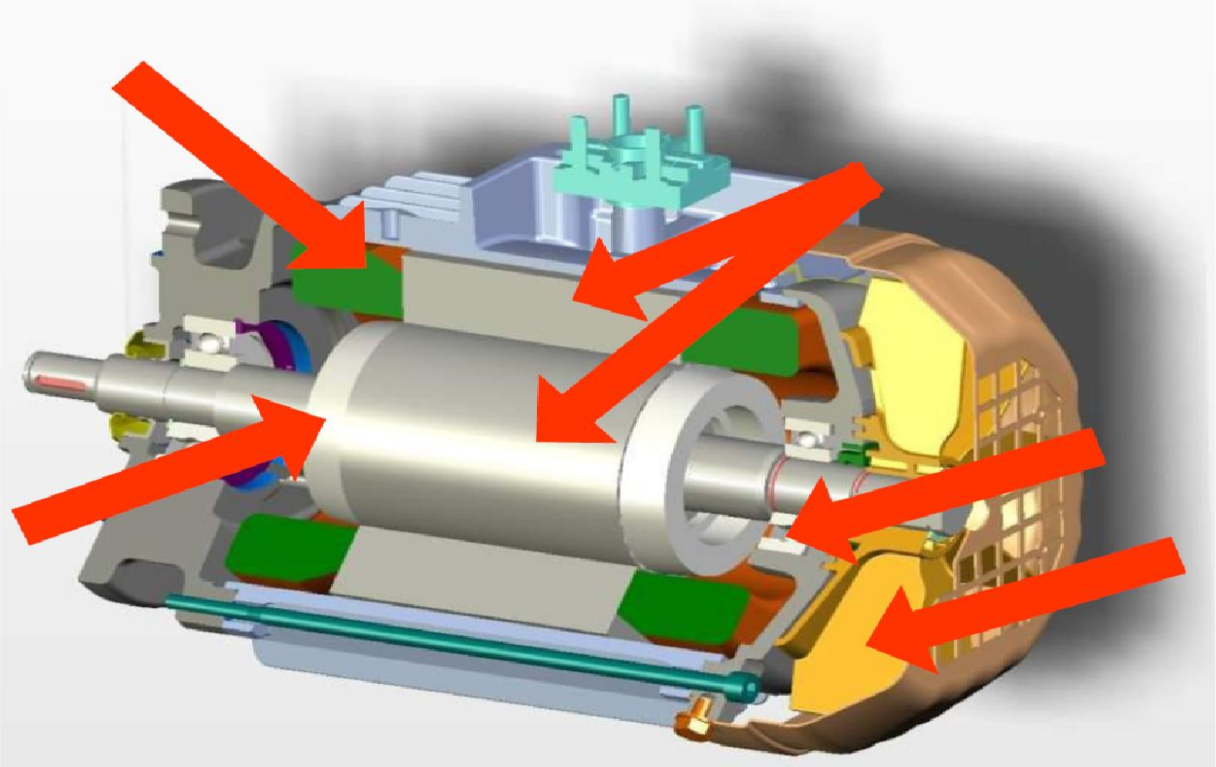
The brush contact losses (only for motors with brushes)

result from the voltage drop between the brushes and the commutator, as well as include additional friction losses.

I - current; R – electric resistance

Motor Losses vs Motor Load

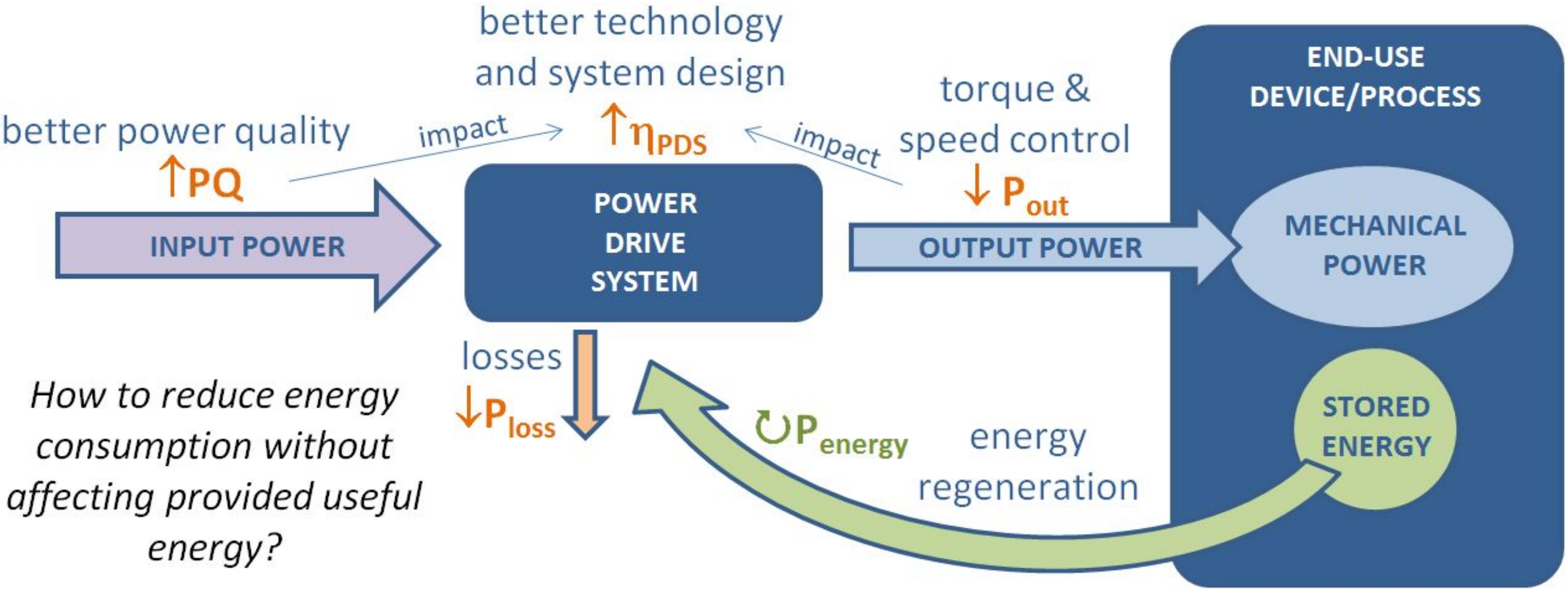




Energy Efficient Induction Motors

- Higher efficiency (2-10% more depending on motor power)
- They can reduce energy bills as well as the maintenance costs
- More material of higher quality – more expensive (25-30%)
- Longer lifetime (lower operating temperature)
- Typically, lower starting torque (depends on the rotor slot shape)
- Higher starting current
- Lower slip
- Higher rotor inertia.

Strategies to improve electric motor system efficiency



How to reduce energy consumption without affecting provided useful energy?

Key Efficiency Test and Related Standards

IEC 60034-30-1 (Edition 1.0: 2014): Efficiency classes of line operated AC motors (IE code

- This standard defines efficiency classes for single-speed motors for operation on a sinusoidal voltage supply (DOL).
- It harmonizes the different efficiency levels in use around the world.
- This standard establishes a set of limit efficiency values based on frequency (50 or 60 Hz), number of poles (2,4,6 and 8) and motor power (120W to 1000kW).
- (No distinction is made between motor technologies).

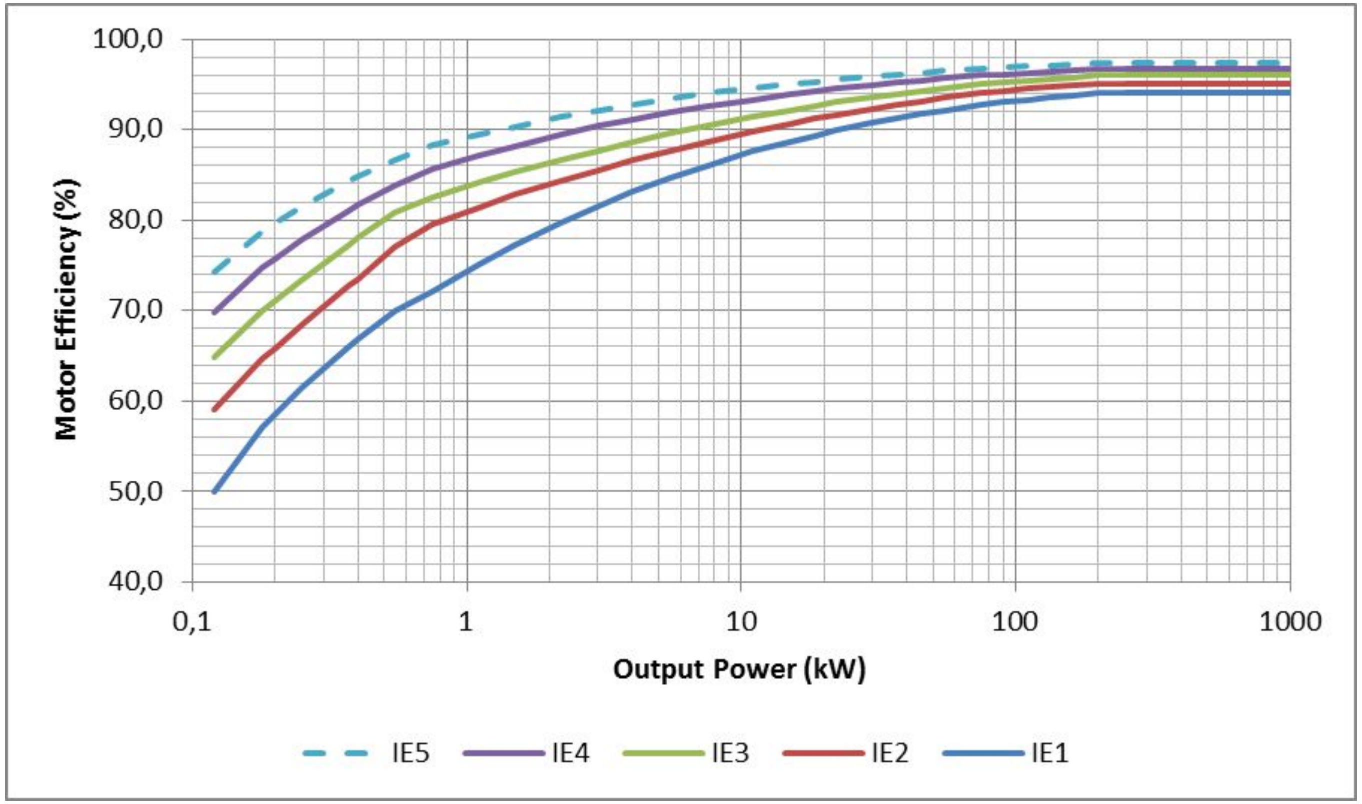
Four efficiency classes

IE1	
IE2	High efficiency (existing Eff1, EPAct)
IE3	Premium efficiency (16-20% lower losses than IE2)
IE4	Super-Premium Efficiency

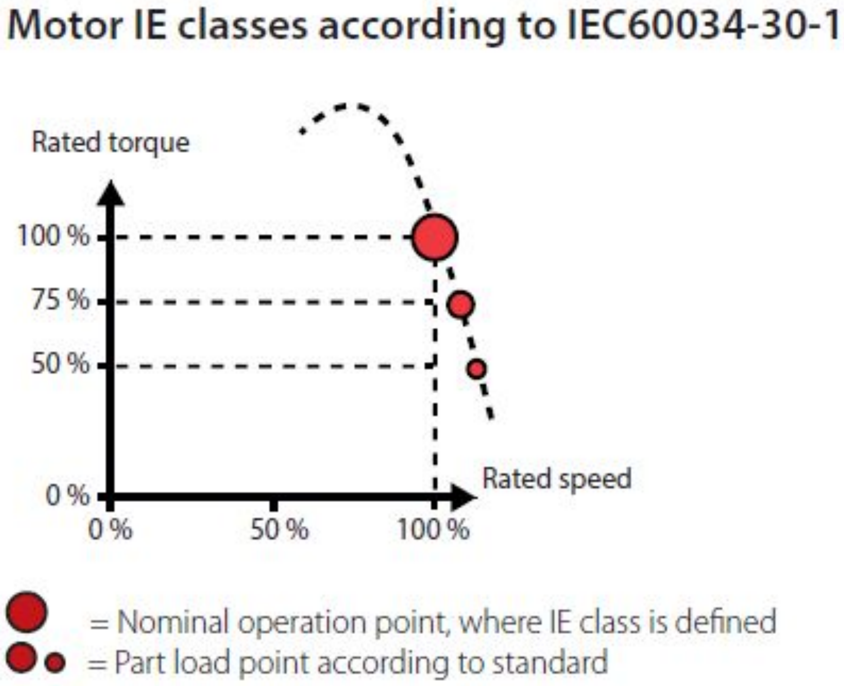
IE5: only presented in the form of an informative annex (Annex A). It is the goal to reduce the losses of IE5 by some 20 % relative to IE4.

Worldwide harmonisation of efficiency standards

Harmonization of efficiency classification standards – IEC 60034-30-1

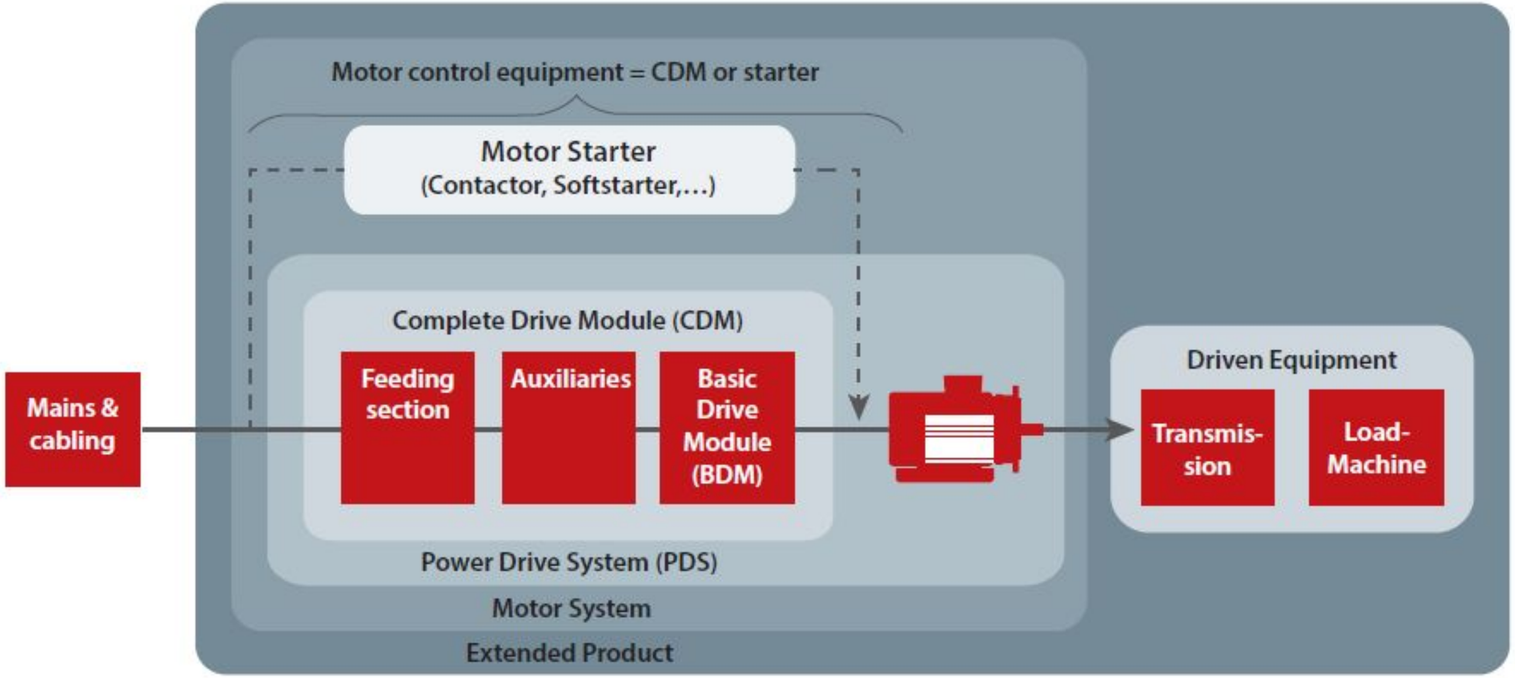


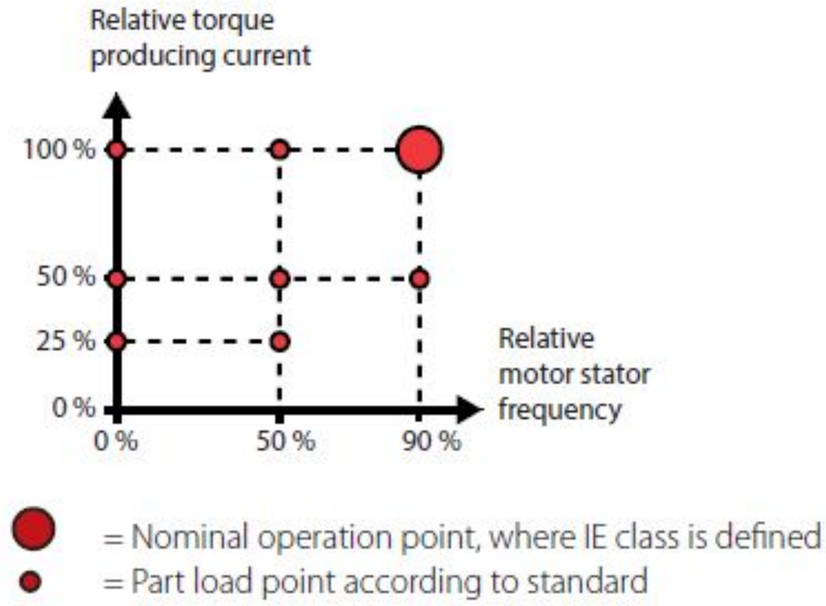
Curves for 50 Hz 4pole motors



IEC 61800-9 Series

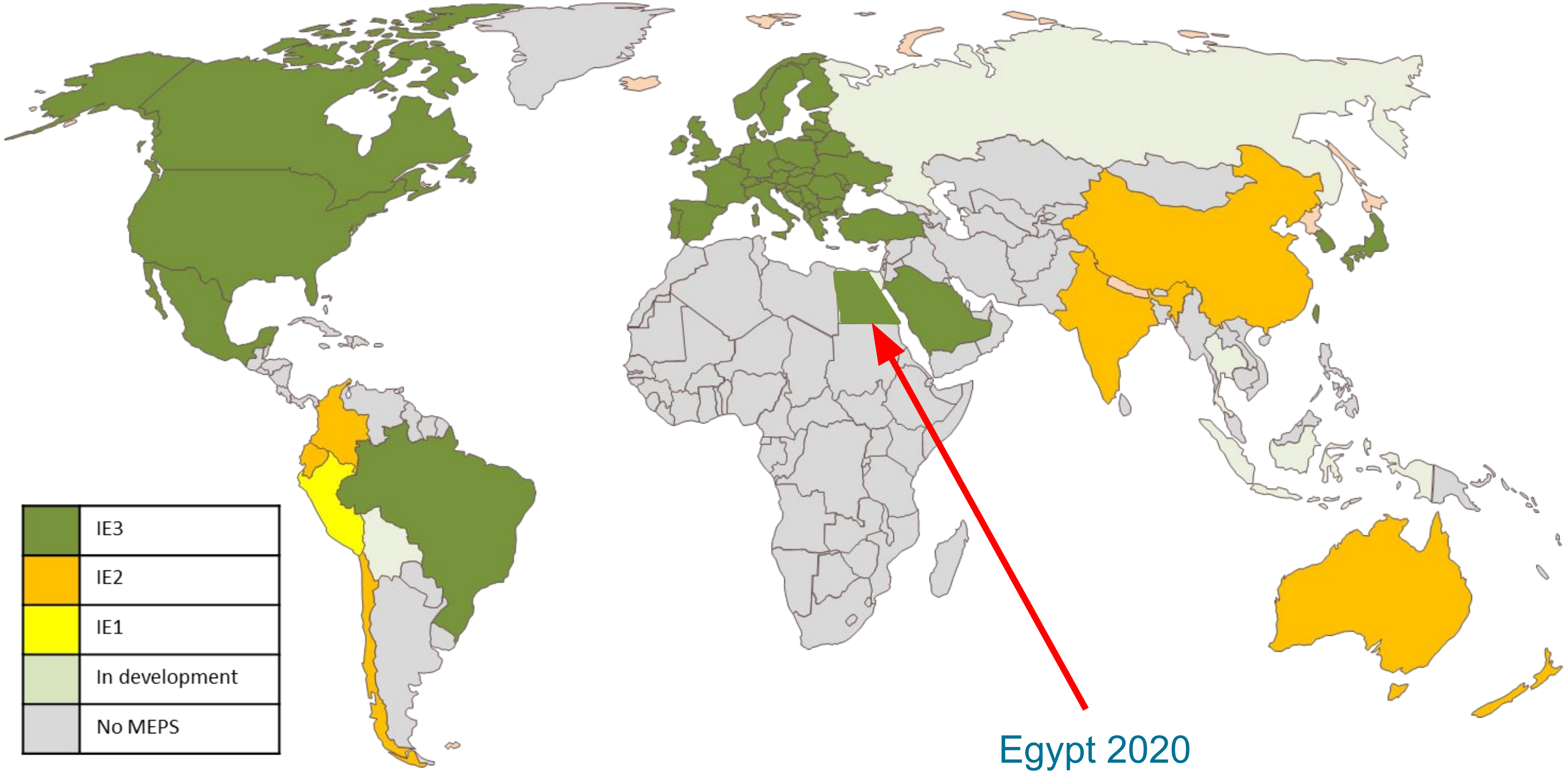
These set of standards specify IE classes from the Energy Efficiency point of view of the complete Motor system and its sub-parts.





Source: Danfoss

MEPS Worldwide



Egypt 2020

Egypt MEPS situation

Policy makers in Egypt decided to move directly to IE3 MEPS in 2020 for all motors, taking into account that:

- 95% of motors sold in Egypt are imported and IE3 and IE2 motors are freely available on the international market at competitive prices, although Egypt has to displace poor quality and cheap motors during its transition;
- The biggest Egyptian manufacturer is ready to start producing IE3 motors;
- MEPS at IE3 would save Egyptian industry **$560 million** in electricity costs by 2030.

IEC 61800-9 Series

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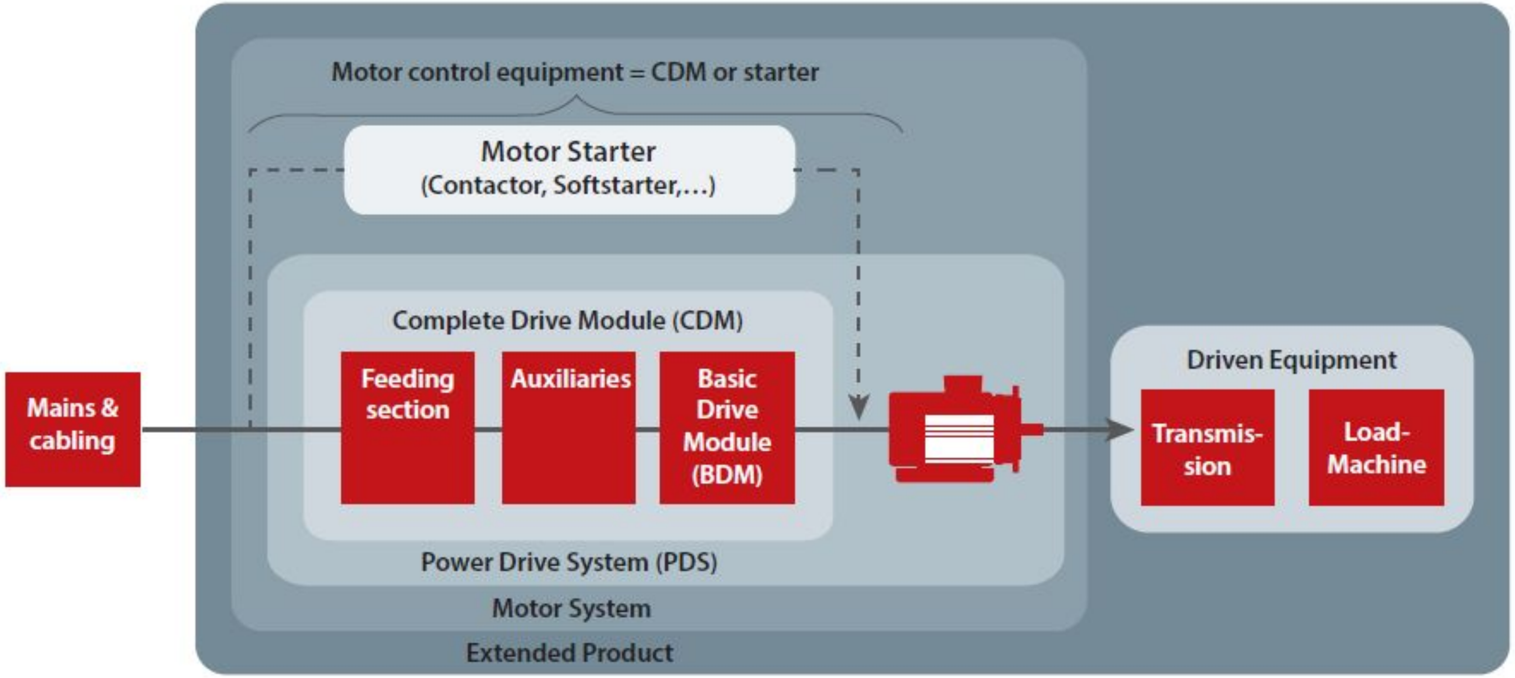
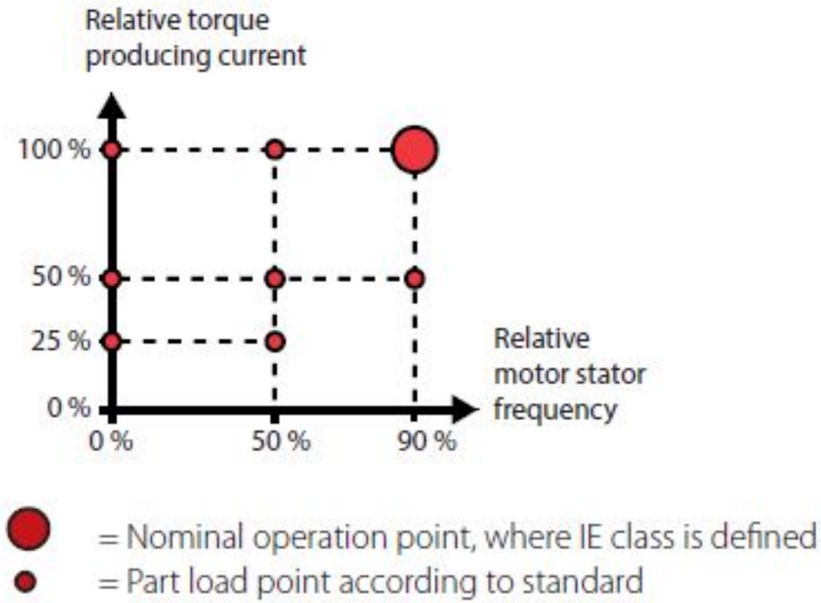




Source: Danfoss

Review & Discussion

- Any questions?

2. Motor System Operating, Control and Maintenance

Selecting an appropriate motor for the application

Factors to be used

- The mechanical requirements of the driven load
- Motor efficiency classification
- The electrical distribution system
- Physical and environmental considerations
- The evaluation of these characteristics should enable the user to select the most suitable type of motor for the application (AC or DC; single-phase; three-phase; power; mounting arrangement, etc)

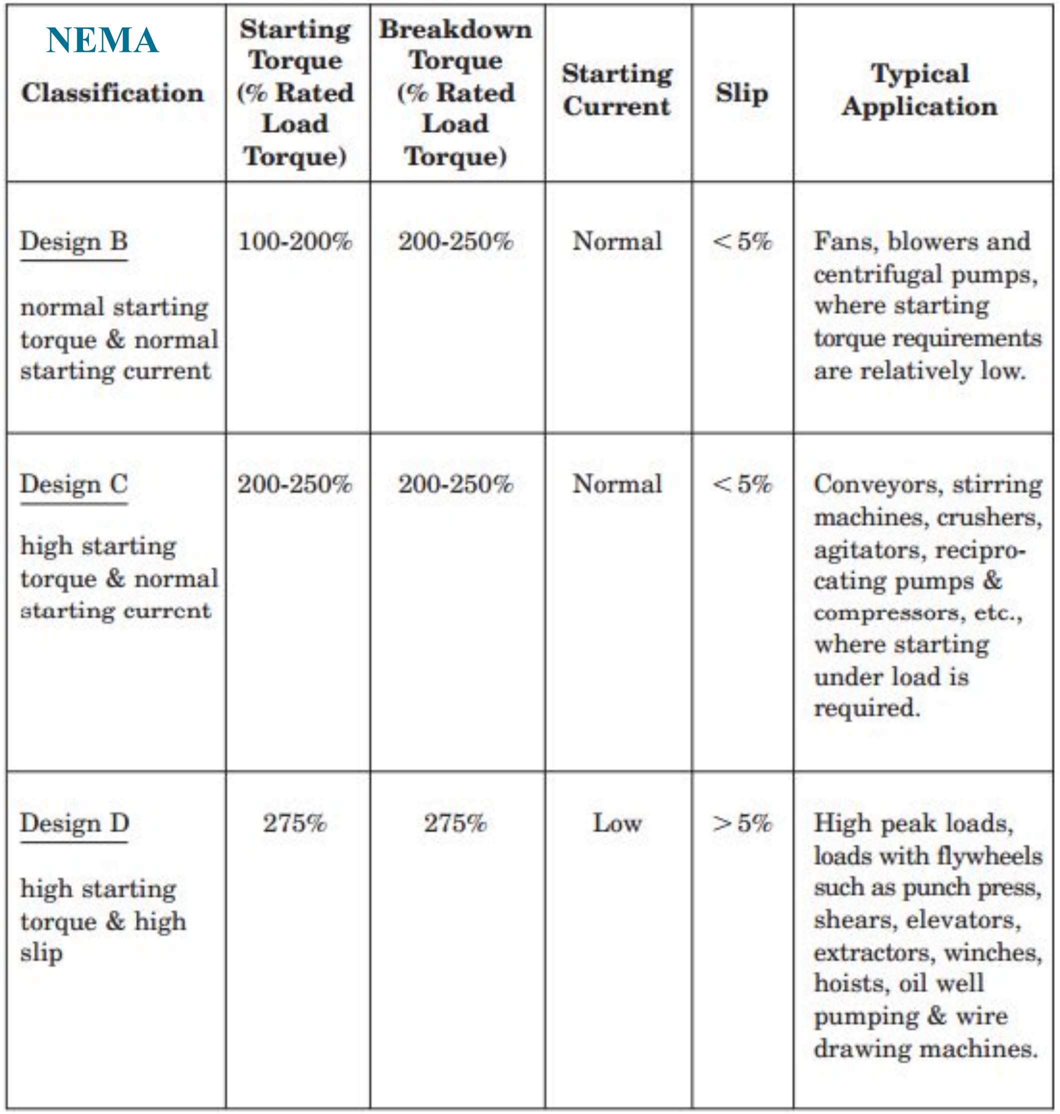
Induction Motor Selection

IEC Design N

IEC Design H

IEC 60034-12 (2002) and

NEMA MG-1 (2011)



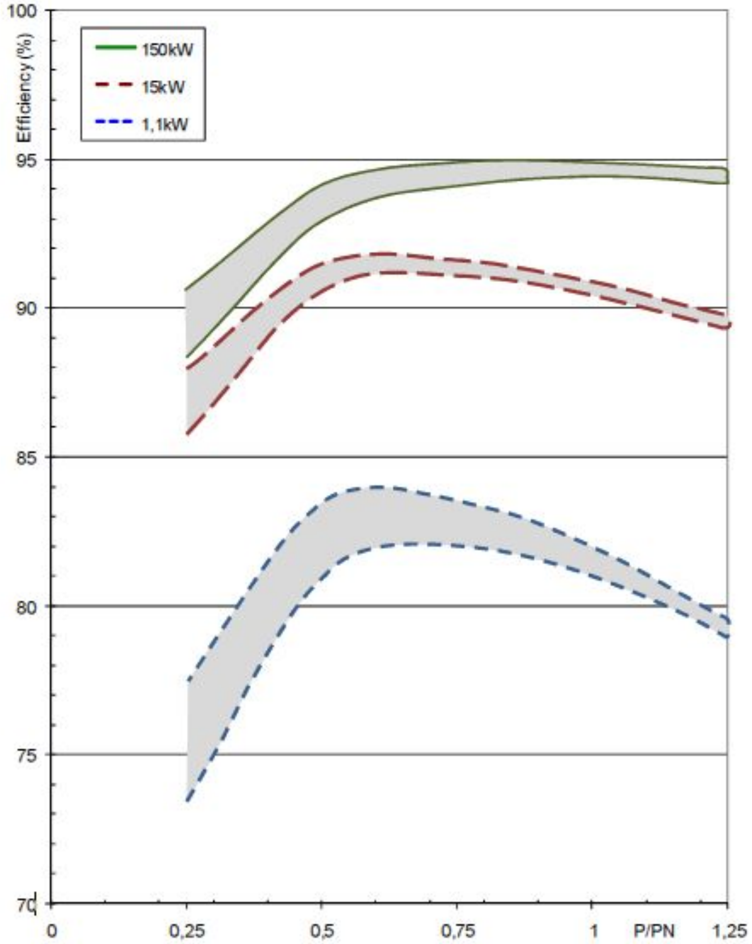
NEMA **Classification**	**Starting Torque (% Rated Load Torque)**	**Breakdown Torque (% Rated Load Torque)**	**Starting Current**	**Slip**	**Typical Application**
Design B normal starting torque & normal starting current	100-200%	200-250%	Normal	< 5%	Fans, blowers and centrifugal pumps, where starting torque requirements are relatively low.
Design C high starting torque & normal starting current	200-250%	200-250%	Normal	< 5%	Conveyors, stirring machines, crushers, agitators, reciprocating pumps & compressors, etc., where starting under load is required.
Design D high starting torque & high slip	275%	275%	Low	> 5%	High peak loads, loads with flywheels such as punch press, shears, elevators, extractors, winches, hoists, oil well pumping & wire drawing machines.

Motor Load

Motors must be sized to accommodate the running load's speed and torque requirements. Load types can be classified into different duty cycles describing operating time and load variations.

If replacing an existing motor is considered, monitoring the power input to the motor over a period of time will determine an optimum size. Inexpensive battery powered data loggers work well for load trending.

Motor Efficiency vs Motor Load



Operating Characteristics to Consider

Frequency of starting and stopping

- For frequent starts, ensure winding and core temperature do not exceed motor rating (Duty types as defined in IEC 60034-1)

Starting torque requirement

- Pay special attention to high inertia loads to ensure motor starting torque is adequate

Acceleration restrictions

- Ensure the motor driving the load reaches full speed quickly enough to avoid tripping the overload protection. Conversely, some loads require time to accelerate to full speed, e.g. a conveyor belt – a variable speed drive may be justified to achieve this and keep current lower when starting up.

Operating Characteristics to Consider

Operating Temperature

- The standard IEC 60085 gives the maximum operation temperature for each thermal class

Thermal classes for insulation systems	A	E	B	F	H
Maximum operation temperature (ºC)	105	120	130	155	180

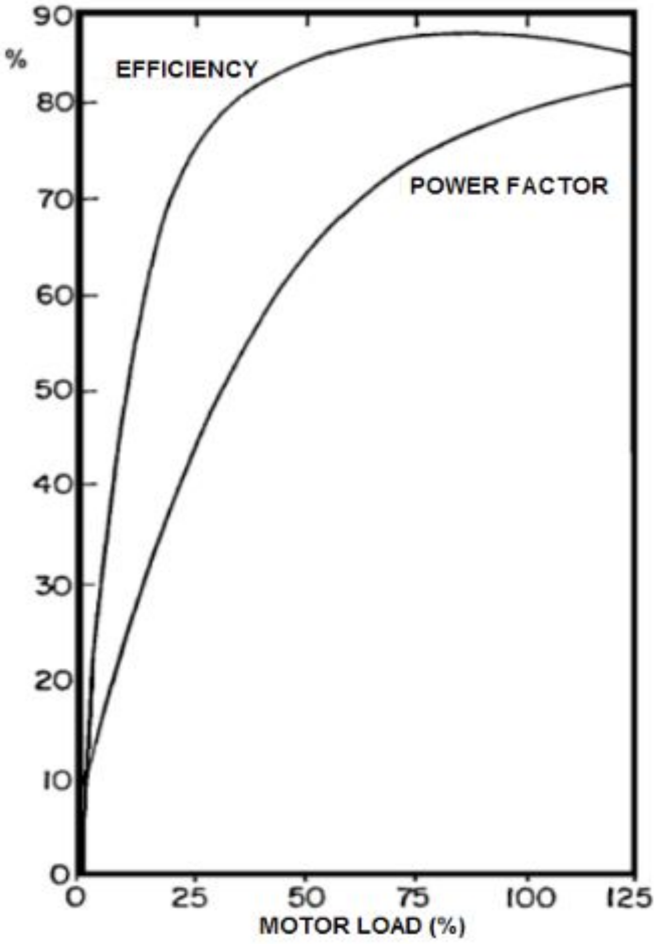
Service Factor

- Motor service factor is an indication of the ability to exceed the mechanical power output rating on a sustained basis. A service factor greater than 1.0 allows a margin for peak power demand without selecting the next larger motor size.

Altitude and Ambient Temperature

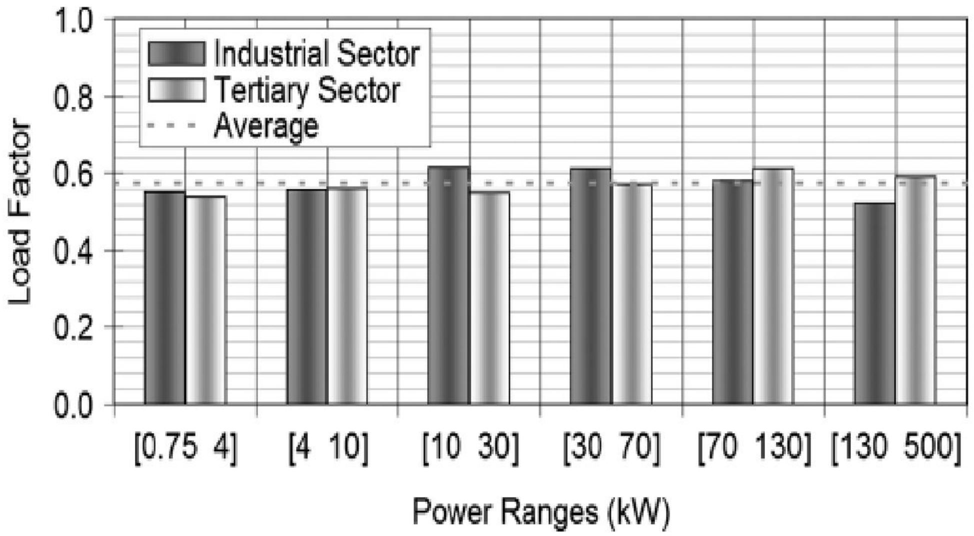
- Motors need to be derated for temperatures above 40° C, and for altitudes above 1000m

Danger of Oversizing Motors



Disadvantages:

- Higher capital cost (motor and command and protection equipment)
- Lower motor efficiency and power factor;



AVERAGE LOAD FACTOR BY POWER RANGE, IN INDUSTRY AND TERTIARY SECTOR, EUROPEAN UNION, 2000.

Motor Torque and Speed

Operating characteristics of electric motors are defined in terms of the **speed** of rotation as well as the **torque** produced on the output shaft of the motor.

$$Torque\,[N.m] = \frac{Power\,[W]}{speed\,[rad/s]}$$

$$Torque\,[N.m] = \frac{Power\,[W]}{2\pi \times speed\,[rps]}$$

$$Torque\,[N.m] = \frac{Power\,[W]}{2\pi \times speed\,[rpm]/60}$$

- *f = frequency (in Hz)*
- *n = Rotations per minute (rpm)*
- *ω = Angular Speed (radians/s)*

Note** $\omega = 2\pi f$

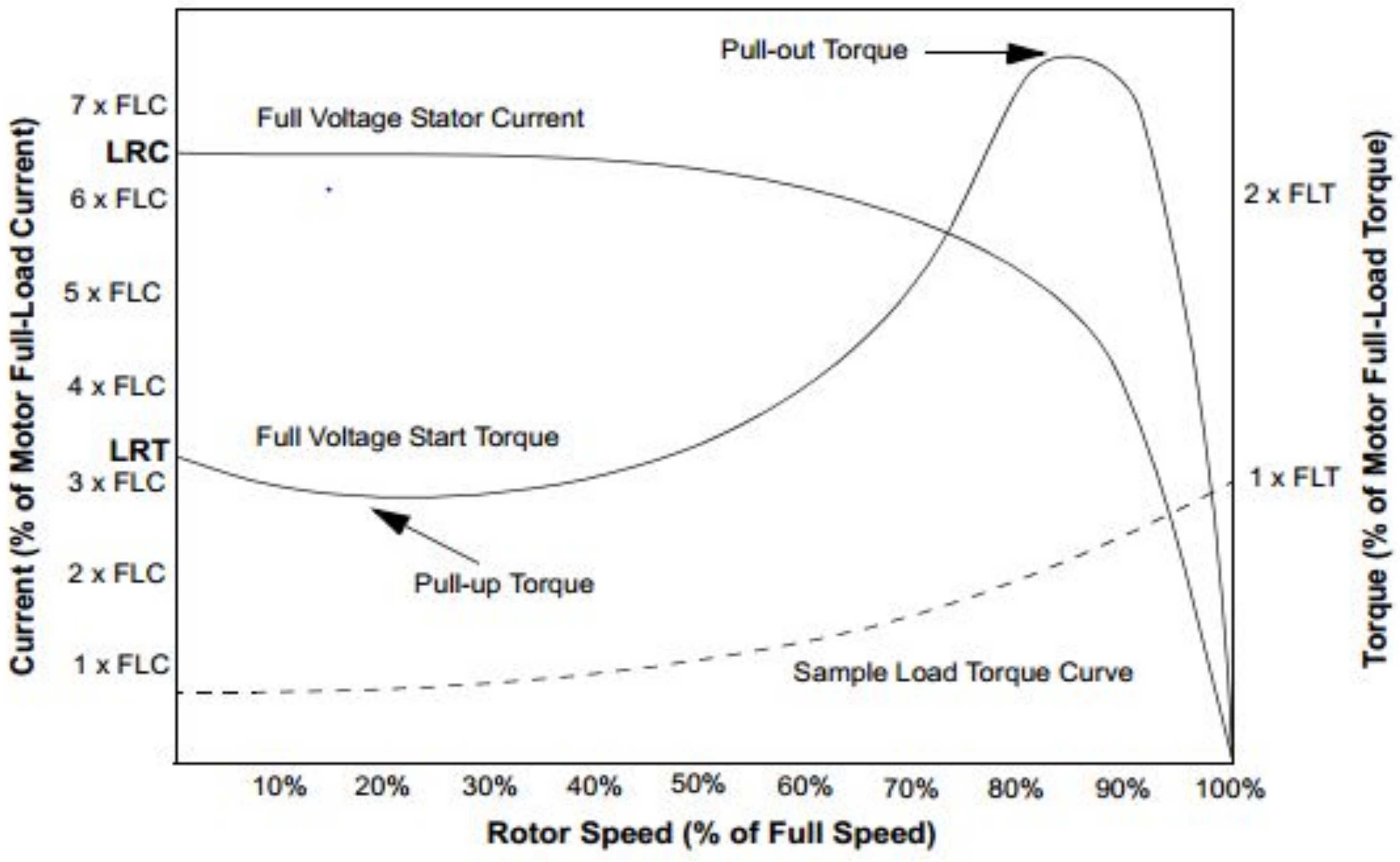
Speed and Slip in Induction Motors

$$synchronous\ \ speed\,[rpm] = \frac{frequency\ of\ \ the\ applied\ voltage\,[Hz]\times 60}{number\ of\ \ pole\ pairs}$$

$$slip\ [rpm] = Synchronous\ speed[rpm] - running\ speed[rpm]$$

$$slip\ [\%] = \frac{Synchronous\ speed - running\ speed}{Synchronous\ speed}\times 100$$

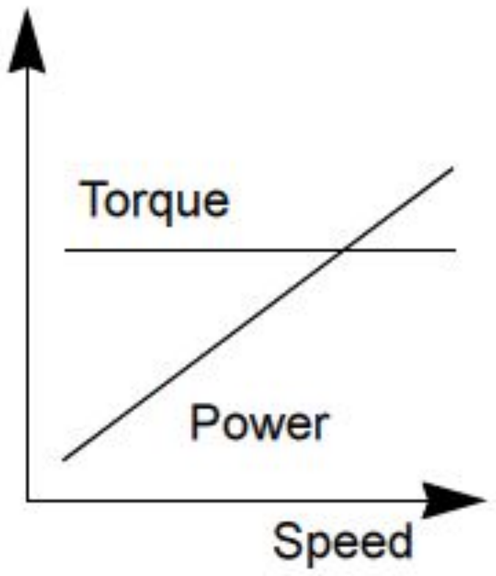
Typical Torque-Speed Curve of 3-ph AC Induction Motor



LRC –Locked Rotor Current, LRT- Locked Rotor Torque, FLC- Full Load Current, FLT- Full Load Torque

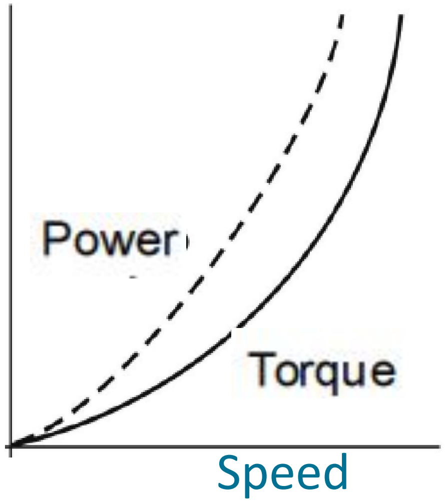
Types of Loads

Constant Torque / Variable Speed



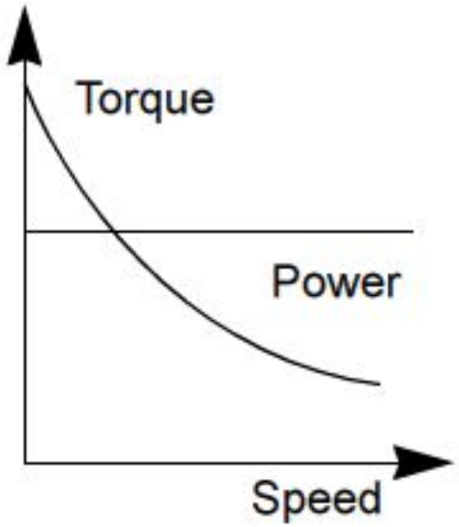
screw compressors, conveyors and feeders

Variable Torque / Variable Speed



centrifugal pumps, fans

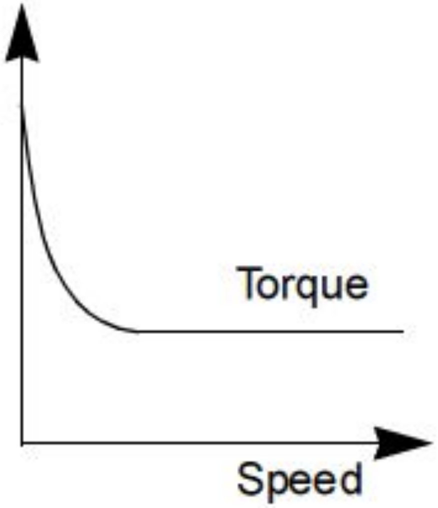
Variable Torque / Constant Power



Traction drives, winders, rolling mills

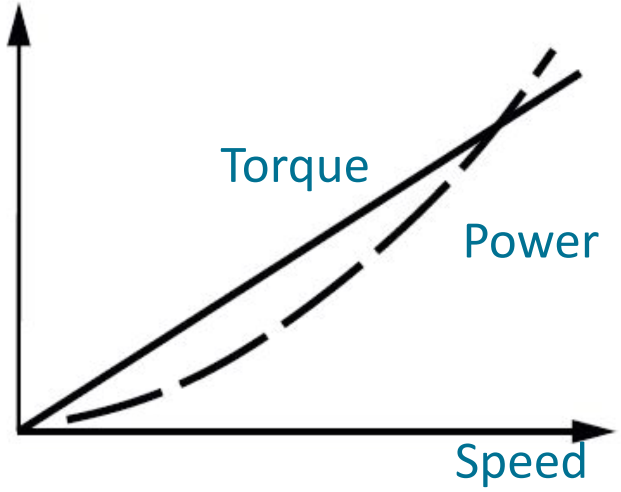
Types of Loads

High Starting Breakaway Torque /
Constant Torque



Extruders, screw pumps

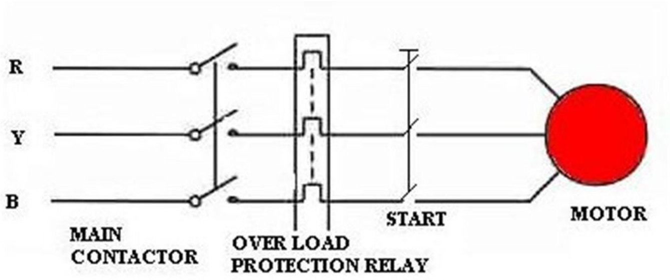
Linear Torque / Power ~ n^2

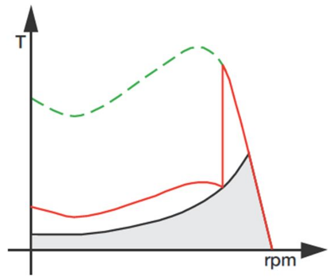


Calenders with viscous friction coupling, mixers, eddy current brakes

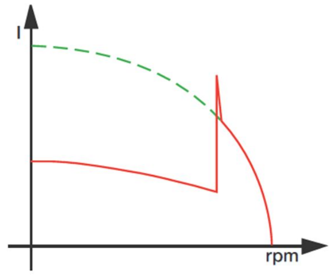
Motor Starting Methods

- Direct on line
- Star Delta
- Soft Starter
- Variable Speed Drive

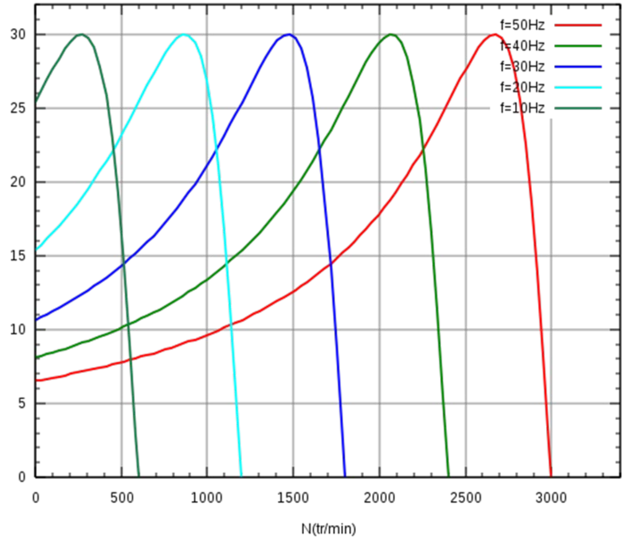


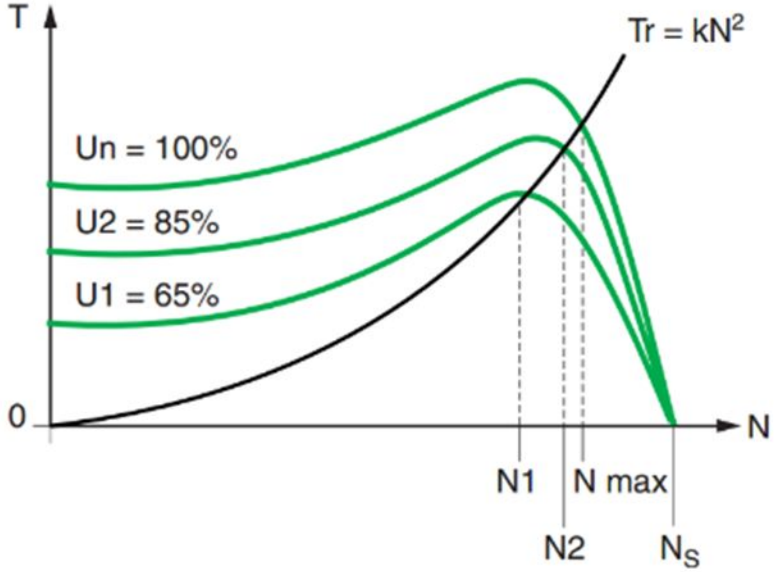


Torque/speed curve at Star-Delta start



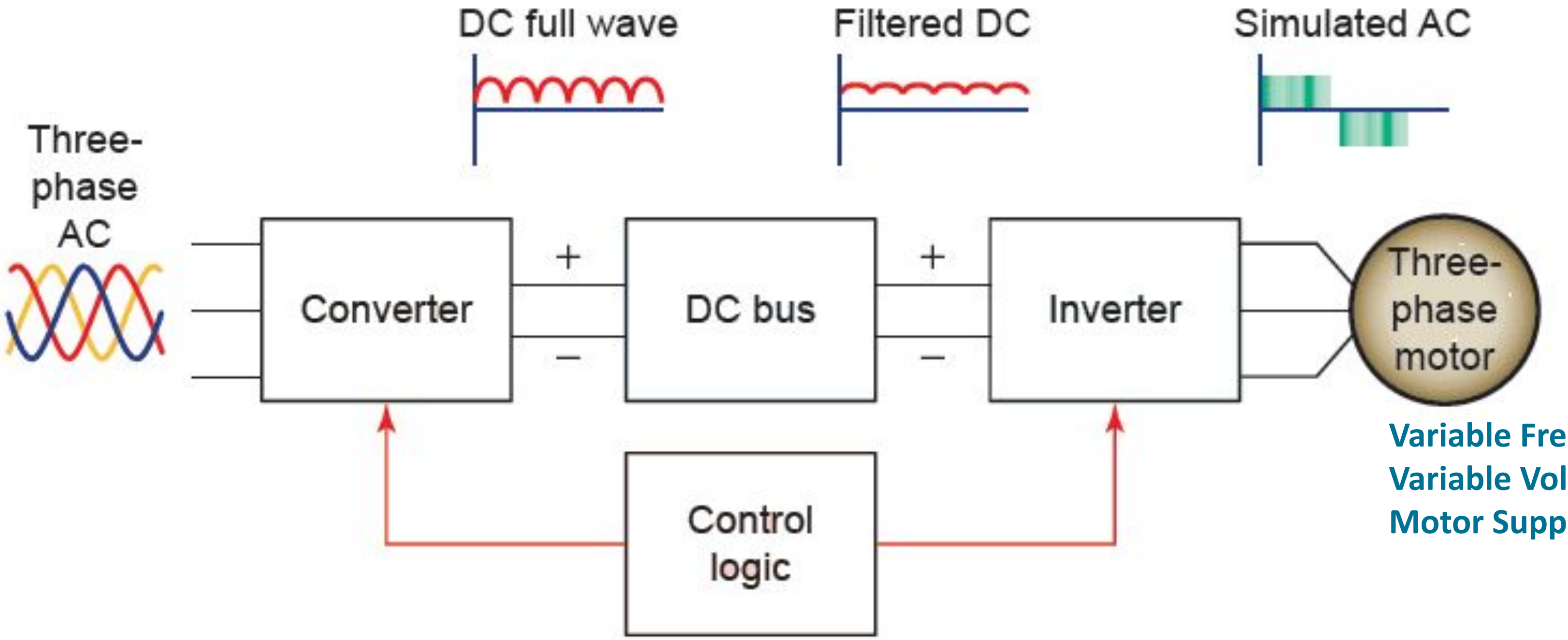
Current curve at Star-Delta start





Variable Speed Drive VSD

- Also called a variable frequency drive (VFD), and adjustable speed drive (ASD)



Variable Frequency
Variable Voltage
Motor Supply

Advantages of VSDs

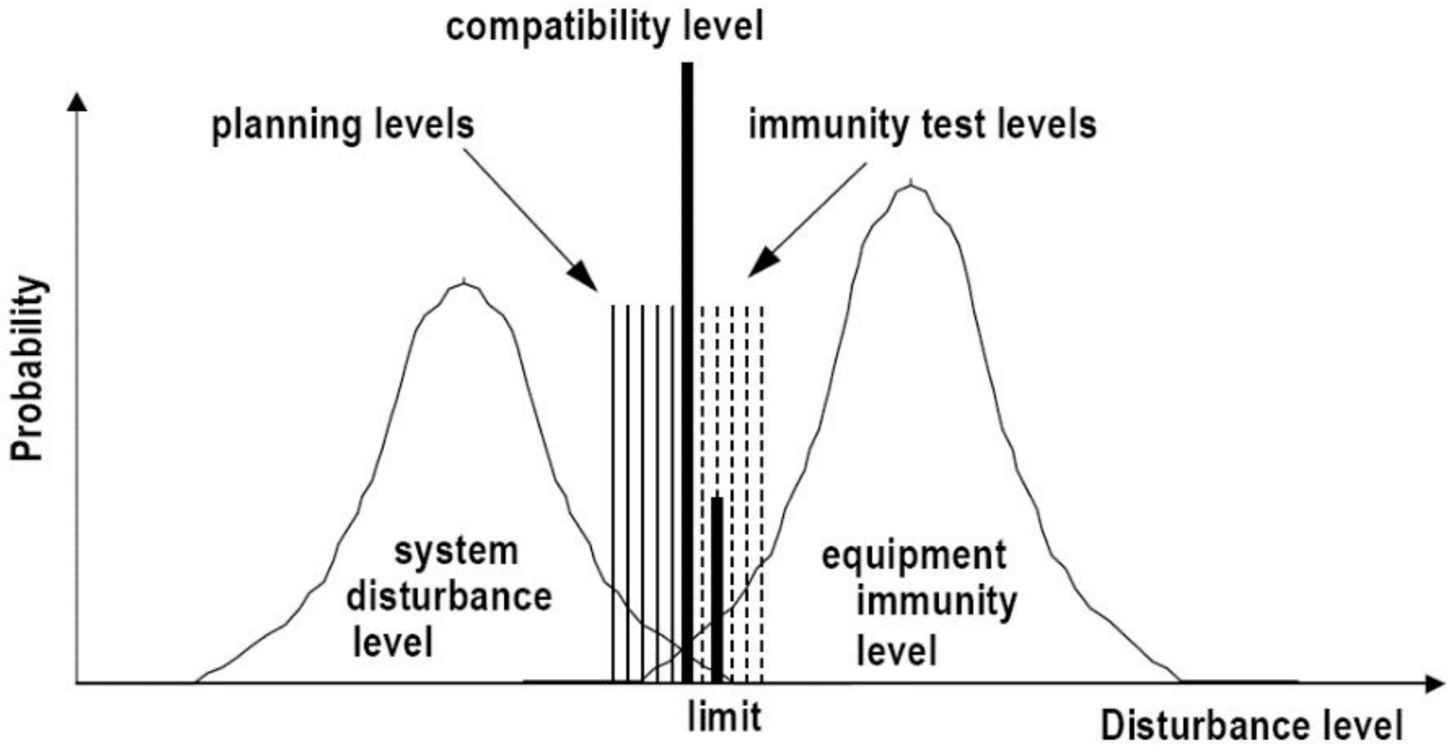
- Energy savings associated to the speed control
- Improvement of the dynamic performance of induction motors
- High efficiency of the VSDs (96-98%) and high reliability
- High power factor (if active front end is used)
- Small size and location flexibility
- Soft starting (savings) and controlled/regenerative braking
- Motor protection features
- Lower acoustic noise and improvement of the process control
- Less wear maintenance needs of the mechanical components

Possible Disadvantages of VSDs

- Inject harmonic distortion in the network
- Voltage spikes leading to failure of insulation in windings of old motors
- Bearing current leading to premature failure
- Introduce a new element in the system (could affect total system reliability)
- May require additional cooling

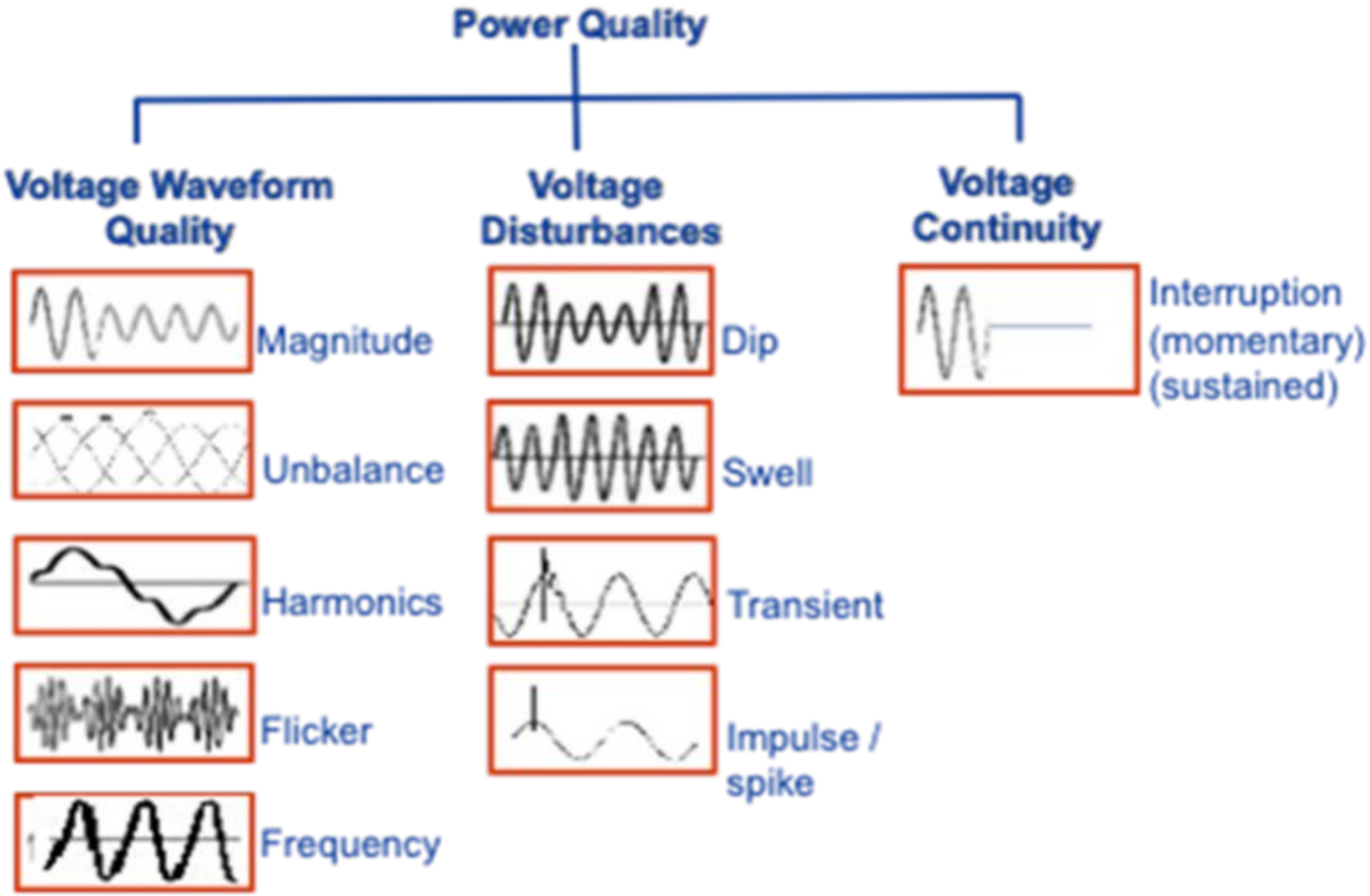
Power Quality

In practice in industry, the objective of power quality is to achieve a level of electromagnetic compatibility that is acceptable to both the electrical supply authority as well as the electricity end user



Source: UNIDO Power Quality Course: South Africa 2020

Types of power quality occurrences

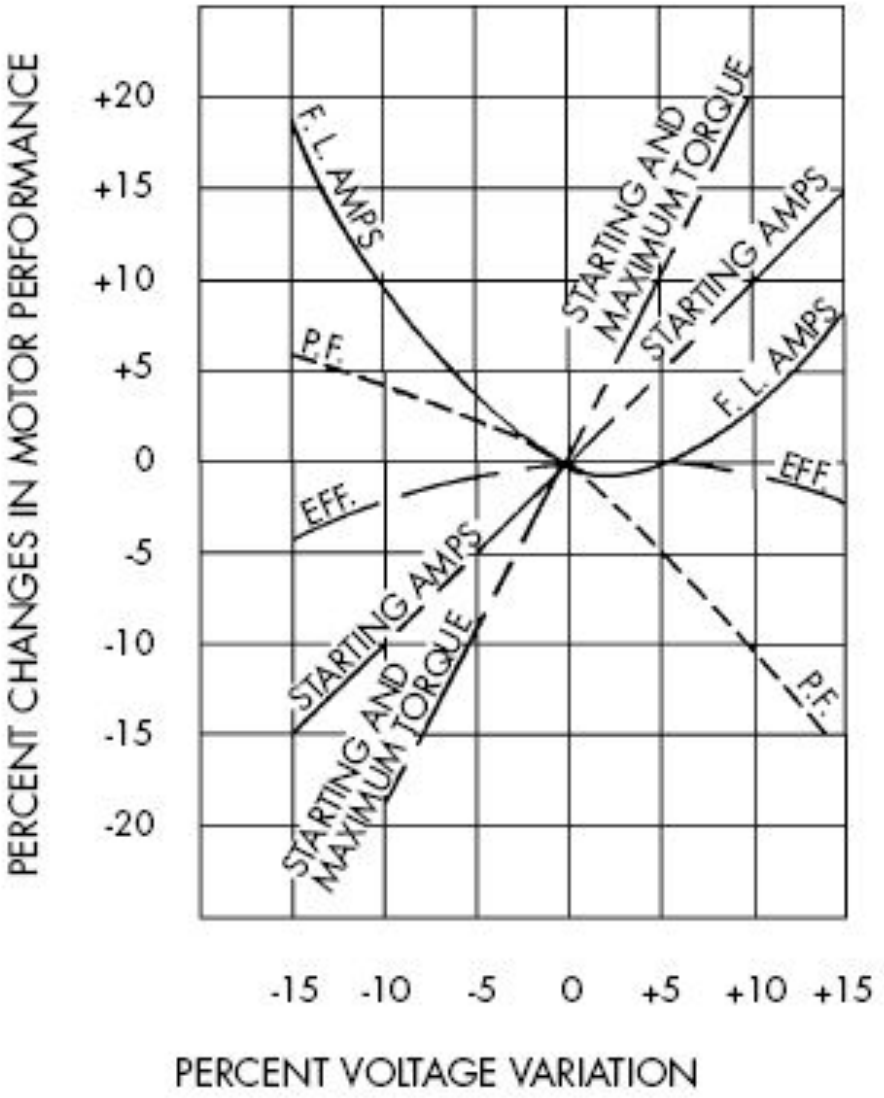


Source: Eskom Power Quality Course Notes

Voltage Variation Effect on Motor Performance

Maintain Voltage Levels

- When operating at less than 95% of design voltage, motors typically lose 2 to 4 points of efficiency.
- Running a motor above its design voltage also reduces power factor and efficiency.

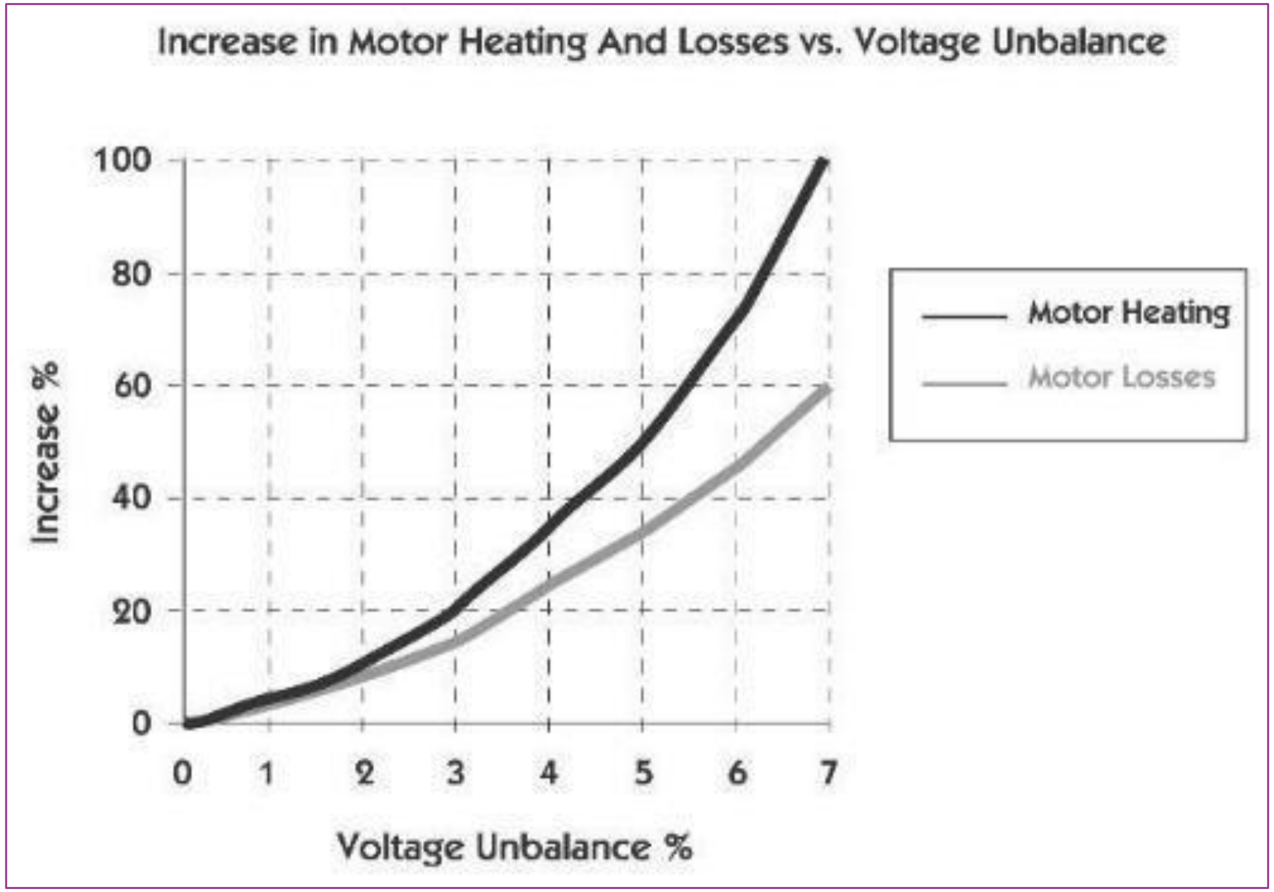


Voltage Unbalance on Motors

Effect of unbalanced voltage on winding temperature.

The increase is equal to two times the square of the unbalance %.

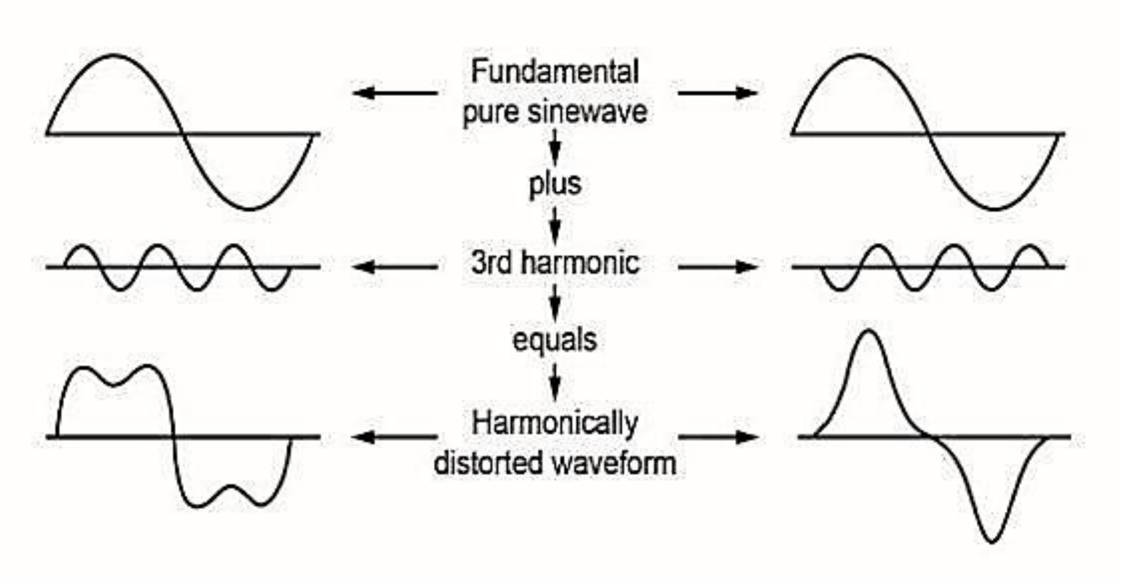
Increase = 2 x (unbalance %)^2



Source: www.pumpsandsystems.com

Harmonics

- Harmonics are waveforms with a frequency that is a full multiple (1,2,3 etc.) of the original waveform, called the **fundamental waveform.**
- When harmonics combine with the fundamental waveform, the new summated waveform is one that is distorted.



Frequency = 50 Hz

Frequency =3 x 50 Hz = 150 Hz
(3^{rd} harmonic)

Total Harmonic Distortion (THD)

Total harmonic distortion is the magnitude of the harmonic distortion in a system.

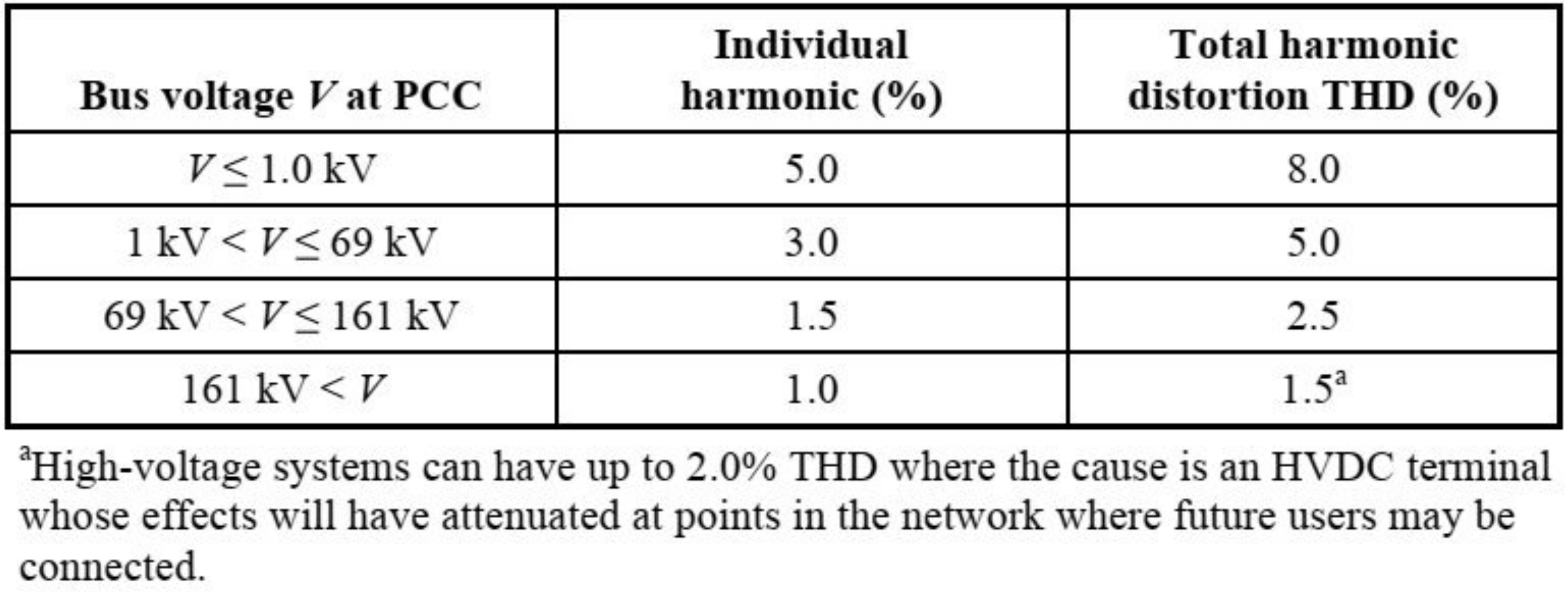
$$THD = \frac{\sqrt{V_2{}^2 + V_3{}^2 + V_4{}^2 + \ldots\ldots + V_N{}^2}}{V_1} \times 100$$

Where:

- *n* is the harmonic number
- *n=1* is the fundamental frequency of the ideal waveform

Voltage Harmonic Distortion Limits - Egypt

- Based on IEE 519 standard for requirements for harmonic control in electrical power systems



Bus voltage V at PCC	Individual harmonic (%)	Total harmonic distortion THD (%)
$V \leq 1.0$ kV	5.0	8.0
1 kV $< V \leq$ 69 kV	3.0	5.0
69 kV $< V \leq$ 161 kV	1.5	2.5
161 kV $< V$	1.0	1.5[a]

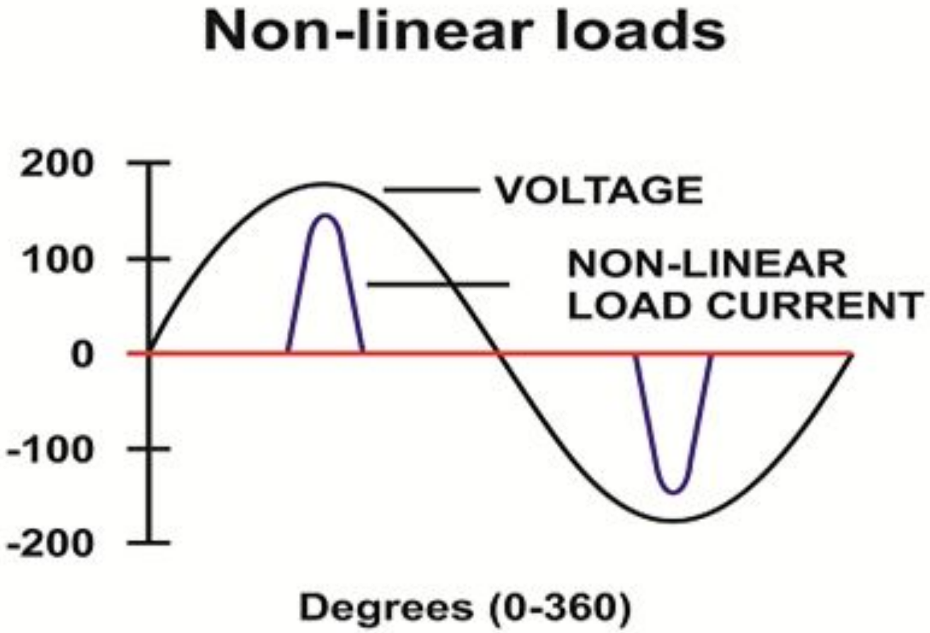
[a] High-voltage systems can have up to 2.0% THD where the cause is an HVDC terminal whose effects will have attenuated at points in the network where future users may be connected.

Source: IEE 519 – 2014

Non Linear Loads – Cause of Harmonics

- Harmonics and harmonic distortion are caused by the presence of non-linear loads
- Loads that do not exhibit a constant impedance during the sinusoidal cycle
- The voltage is not proportional to the current

- Computers
- Photocopiers
- Lighting dimmers
- VSDs
- Arc furnaces
- Welding machines
- UPS
- Battery chargers



Effect of Harmonics on Network

Harmonics cause more current to be used to do the same work. This adds energy cost, require more expensive wiring or causes overheating and damage.

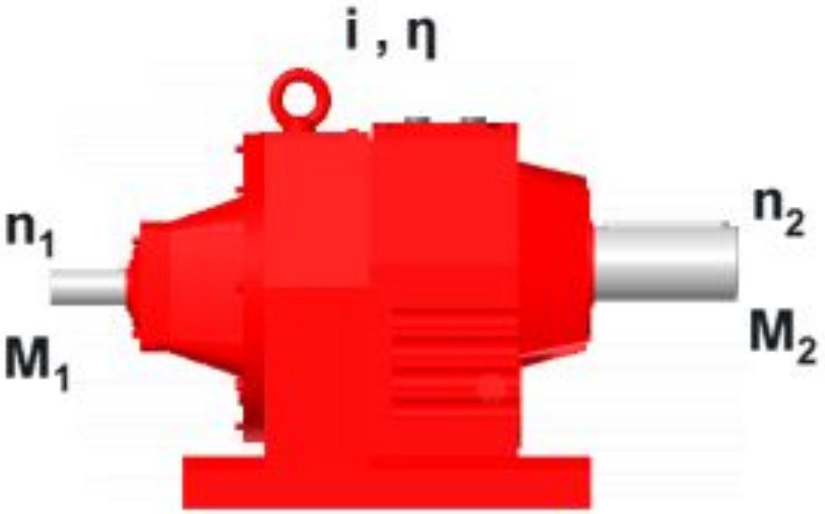
Higher frequency harmonics cause additional core losses in motors resulting in energy losses, additional energy cost and overheating of the motor core.

Higher frequency harmonics could also interfere with communication frequencies and highly sensitive electronics like avionics and medical equipment.

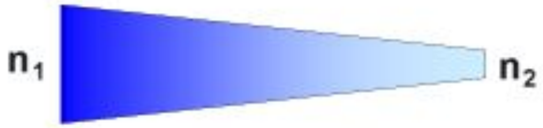
Mitigation of Harmonics

- Add linear loads to the system.
- Remove non-linear loads where possible.
- Install delta-star transformers parallel with a delta-delta transformer used for large variable speed drives.
- Install harmonic filters.

Mechanical Transmissions - Gears

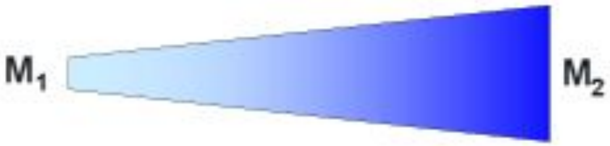


Reduce Speed



$$n_2 = \frac{n_1}{i}$$

Multiply Torque



$$M_2 = M_1 \times i \times \eta$$

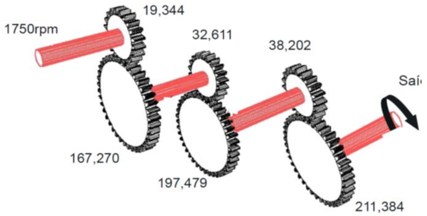
Mechanical Transmissions - Gears

- Used for low speed, high torque loads

Several types:

  - Helicoidal
  - Spur
  - Conic
  - Screw.

- Losses are related to the friction of gears and bearings, windage and lubricating viscosity



Mechanical Transmissions - Belts

- 1/3 of all transmission applications use belts
- Belts offer high flexibility of the motor in relation to the load, and speed adjustment possibility

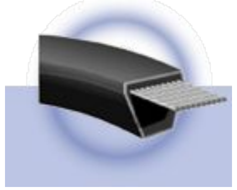
Several types:

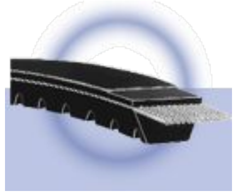
  - V-belts (with and without cogs)
  - flat belts,
  - synchronous belts

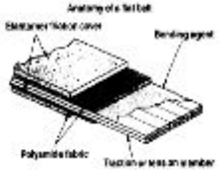
- The V-belt is the most widely used, with an efficiency of 90-96% (depending on the elasticity, tension, slip, and alignment)

- If the tension is excessive → accelerated wear of the belts and bearings
- if the tension is too little → the slip and losses increase

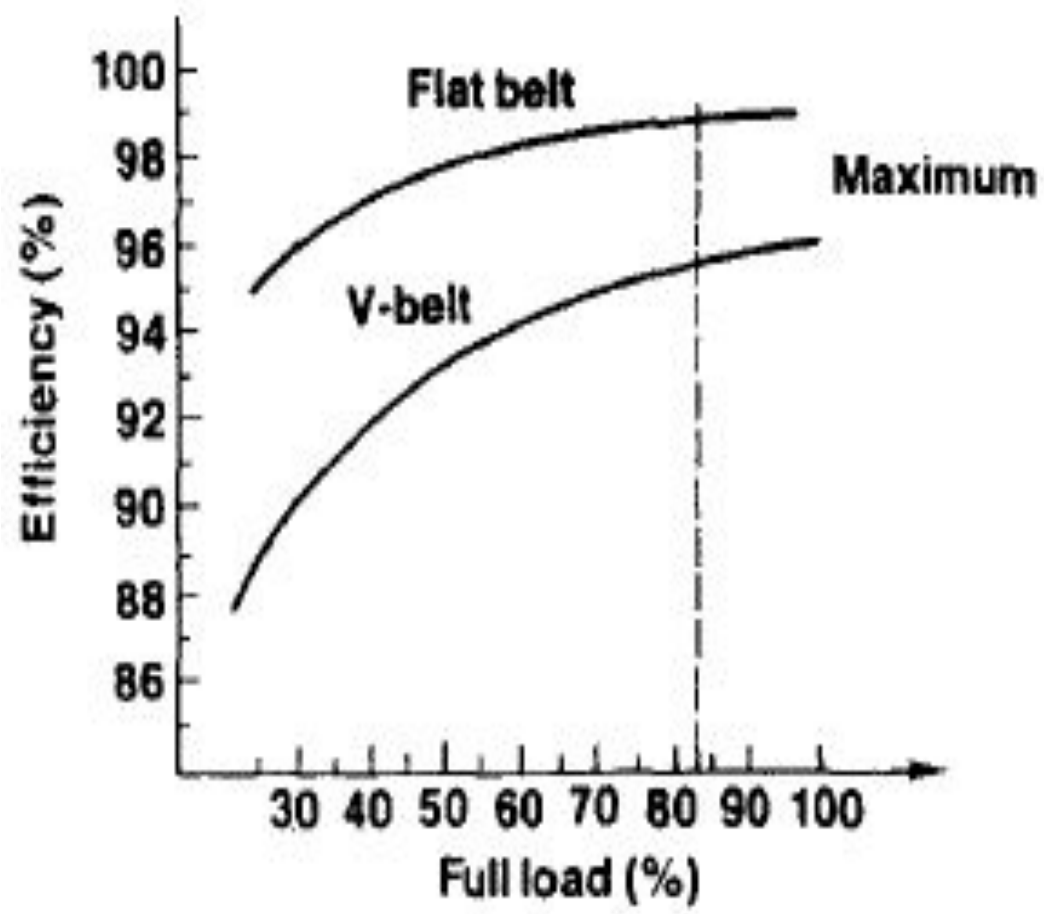
- The most efficient types are the flat and the synchronous belts. The synchronous belt has an efficiency of about 98-99%

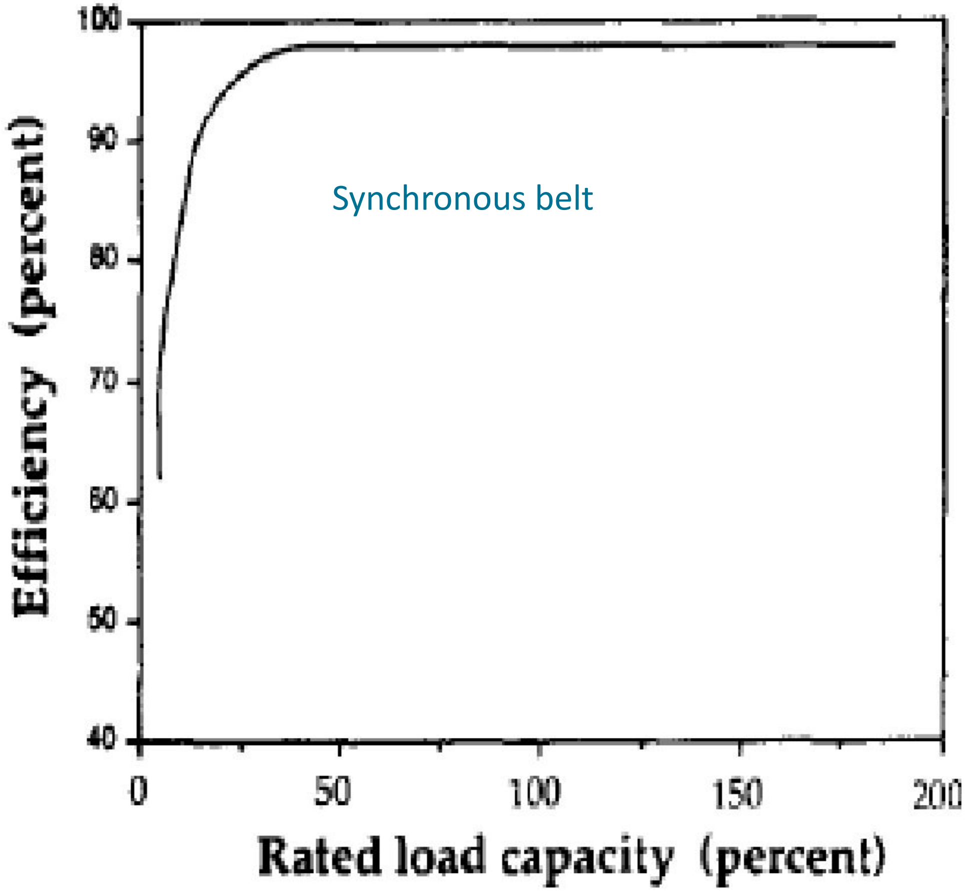






Mechanical Transmissions - Belts





Mechanical Transmissions - Belts

Comparison of the Main Characteristics of Belt Drives

	Typical Efficiency Range (%)	Suitable for Shock Loads	Periodic Mainte-nance Required	Change of Pulleys Required	Special Features
V-belts	90-98	Yes	Yes	No	Low first cost
Cogged-V-belts	95-98	Yes	Yes	No	Easy to retrofit Reduced slip
Synchro-nous Belts	97-99	No	No	Yes, with higher cost	Low-medium speed applications. No slip. Noisy

Worked Example

A continuously operating 75kW supply-air fan motor (93% efficient) operates at an average load of 75% and consumes 530,000 kWh annually.

What are the annual energy and cost savings if a 93% efficient (η_1) V-belt is replaced with a 98% efficient (η_2) synchronous belt?

(Electricity is priced at EGP 0.90 /kWh)

Energy Savings

= Annual Energy Use x (1 – η_1 / η_2)

= 530,000 kWh/year x (1 – 93/98)

= 27,000 kWh/year

Annual Cost Savings

= 27,000 kWh x EGP 0.90/kWh

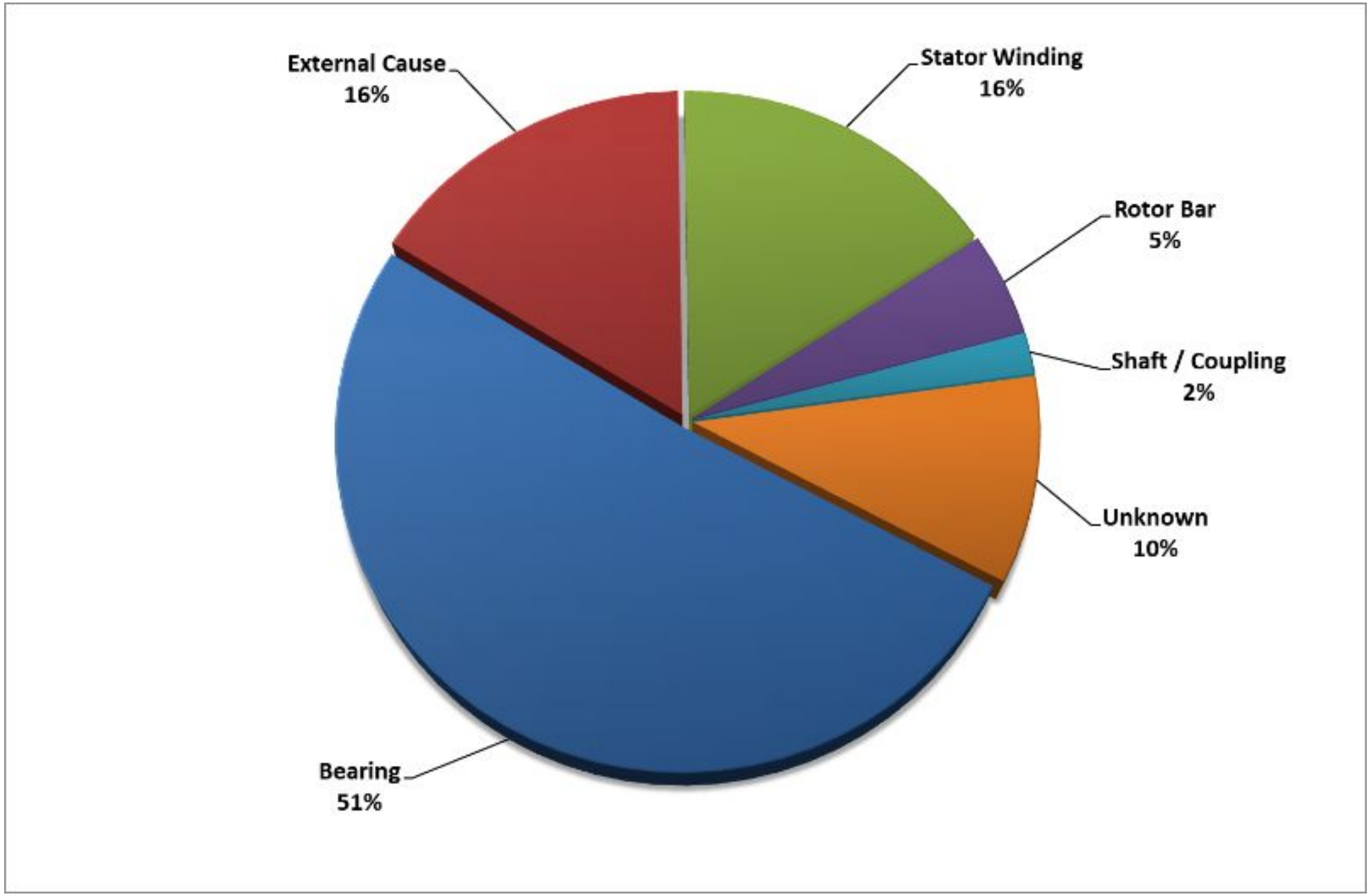
= EGP 24,300 / year

Why do motors fail?

Problems arising from:

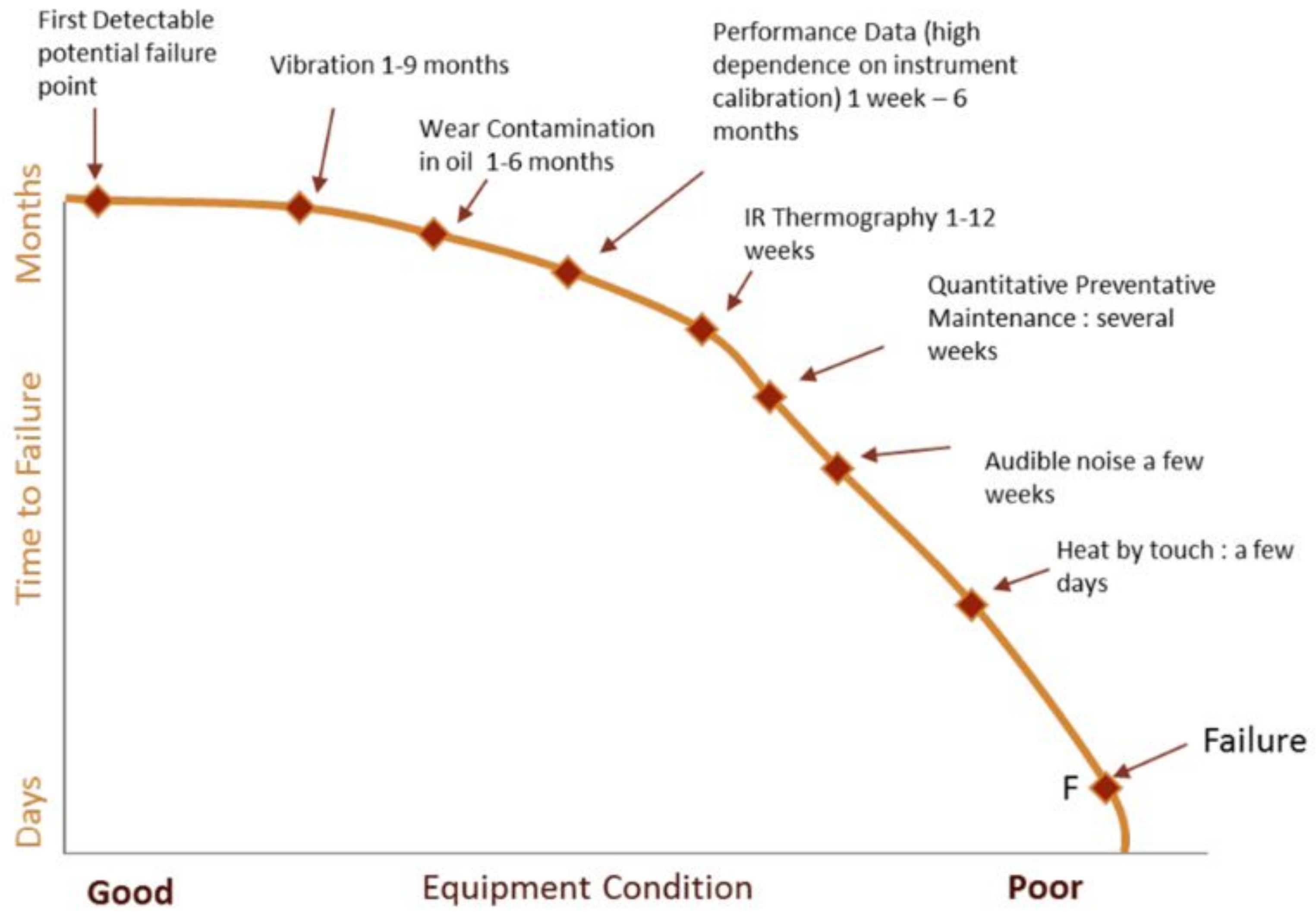
- Poor specification
- Incorrect installation
- Operating under abnormal ambient conditions
- Poor power quality
- Poor maintenance
- External mechanical damage

Failure by Motor Component



Source: EASA

Motor Failure Potential



Source: EASA

Prevention of failures

- It is usually easier to prevent a motor from failing than it is to repair or replace it.
- Failures often result in production loss – this is usually large in comparison to the motor cost

Where do we start with prevention?

- Commissioning practices
- Operating conditions
- Power quality
- Maintenance and inspection

Where Better Maintenance Saves Energy

- Shaft alignment
- Lubrication
- Dirt removal
- Ventilation
- Voltage balance
- Harmonic filtering

Conditions Affecting Motor Performance/Reliability

Frequent starts and stops

- Can cause premature motor failure

Environmental conditions

- Poor cooling due to high ambient temperatures
- Partially clogged motor vents
- Dirty/wet application

Voltage unbalance or under/over voltage

- Creates additional heat
- Increases motor internal losses
- Motor is derated for high voltage unbalance Frequent starts and stops

Operating in the service factor

- NEMA recommends that motors should be derated when operating in the service factor

Selecting a Motor Repairer

In the absence of any accreditation scheme, you are on your own.

Things to look for:

Stocks

- Do they have adequate spares inventories?
- Do they have a good range of wire gauges?

Winding removal

- Do they have an oven in good condition with good controls?

Quality control

- What evidence is there of quality control system?

Motor testing

- What tests do they do on repaired motors?

Personnel

- What experience do their staff have?

Stator Core – Burn Out Temperature

This is a critical part of the repair function.

Burnout temperature must be closely controlled

< 360°C

The core may not be clean, requiring additional cleaning and risk of mechanical damage

> 360°C

can damage organic interlaminar insulation

> 400°C

can damage inorganic interlaminar insulation

Source: Reliance Electric

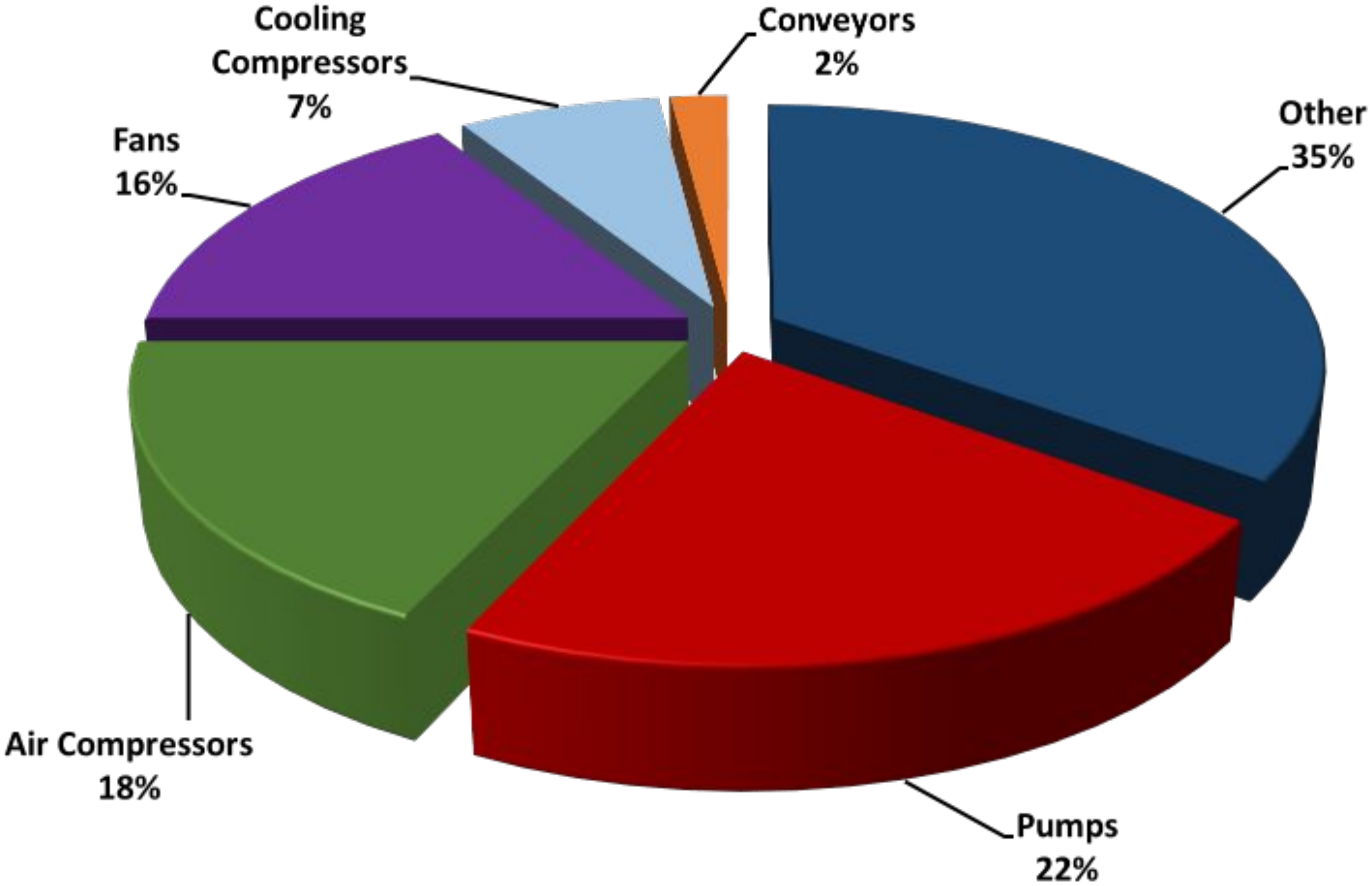
Review & Discussion

3. Motor Load Applications

Review: Electric motors in industry

Motor Systems Electricity Consumption by Application

- Pumps, fans and air compressors make up 56% of industrial applications



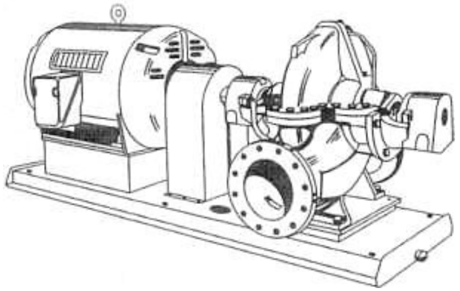
Electricity Consumption in the European Union Industrial Sector
Source: ISR – University of Coimbra (2012)

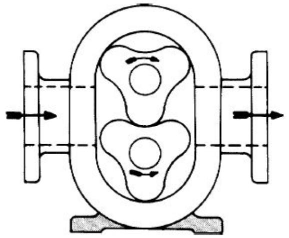
Pump Types

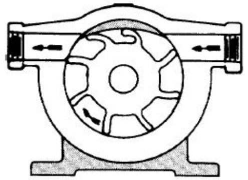
Pump Types

- **Roto-Dynamic Pumps** (Centrifugal)
  - End Suction
  - Split Case
  - Vertical Turbine
  - Special Pumps
    - Jet Pumps
    - Vortex Pumps
    - Regenerative turbines
- **Displacement Pumps**
  - Reciprocating
    - Piston
    - Diaphragm
  - Rotary
    - Peristaltic
    - Progressive Cavity
    - Multiple Gear-Lobe

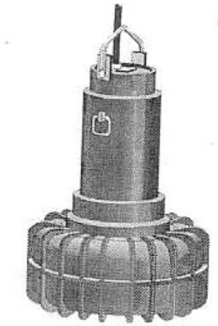
Examples of Pump Types


Split Case

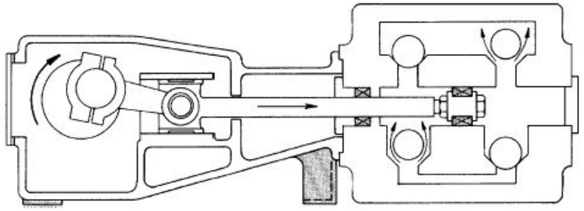

Rotary Lobe

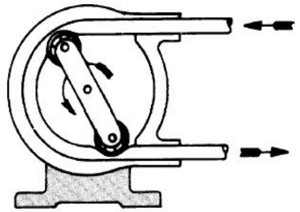

Flexible Vane

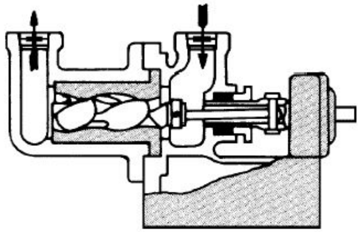

Vertical, close coupled


Submersible


End Suction

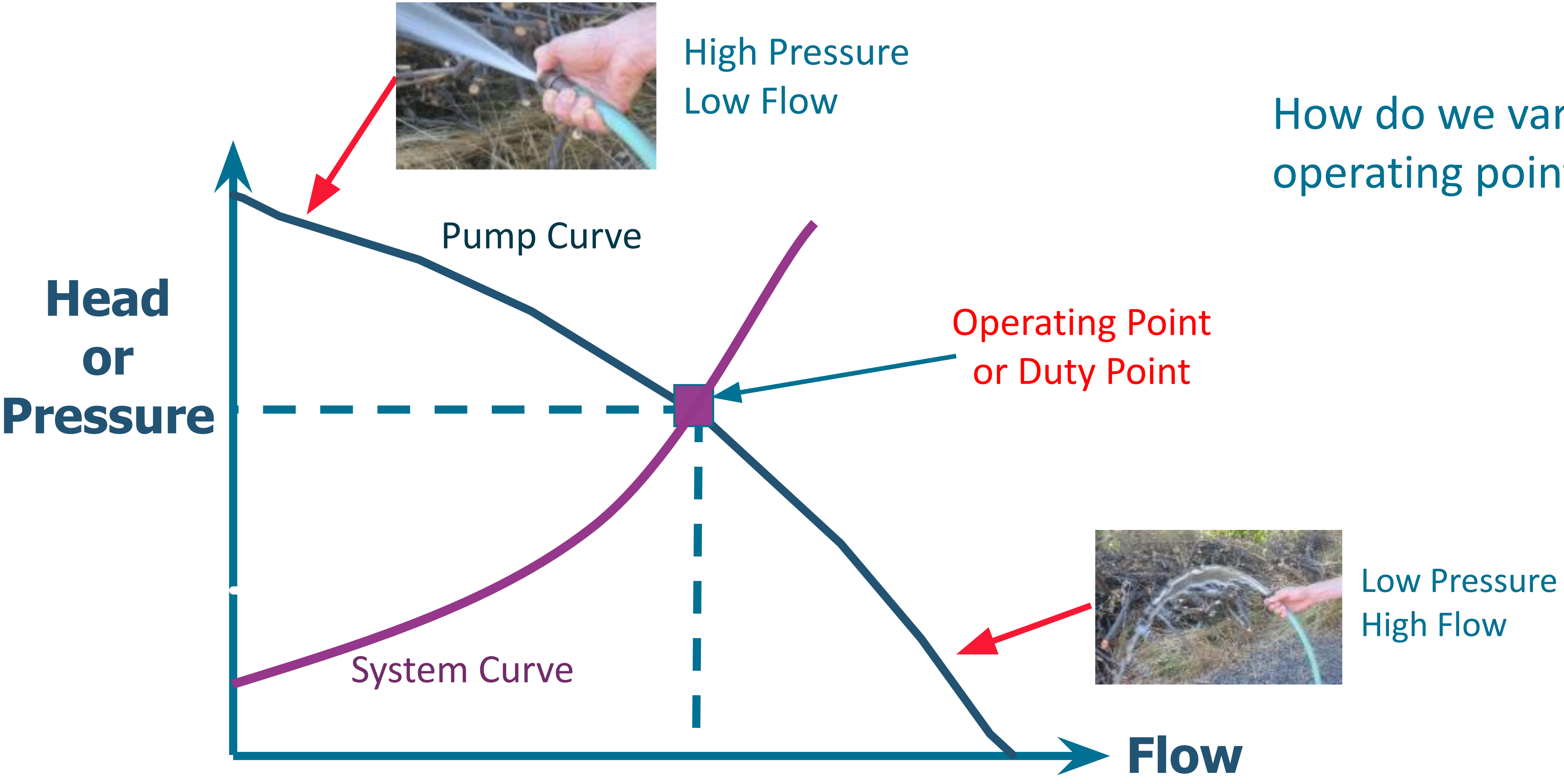

Horizontal Piston


Flexible Tube


Screw Pump

Figures: ACR Publications, Hydraulic Institute

Pump Basics – Pressure Flow Relationship

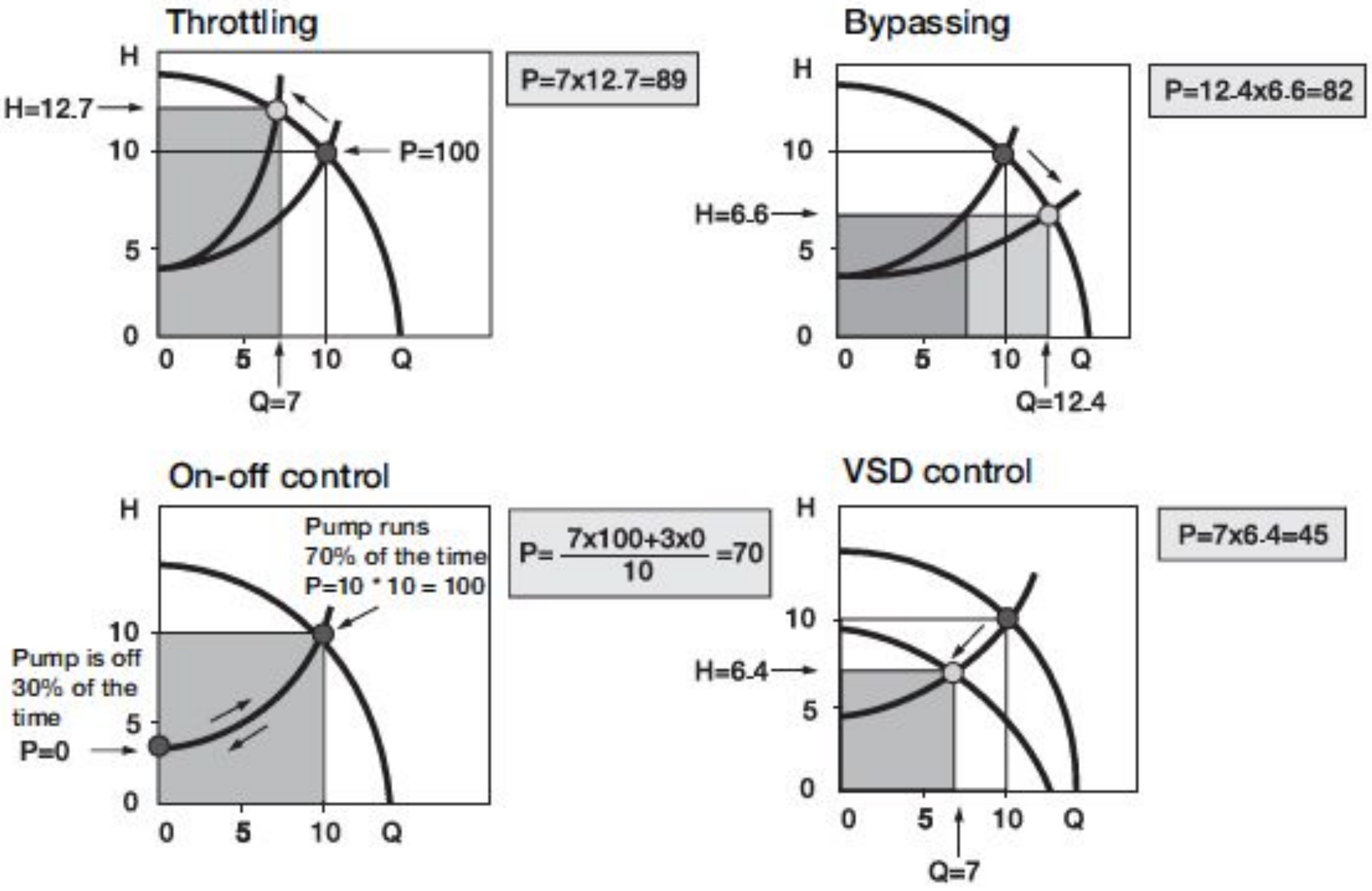


How do we vary the operating point?

Fluid Flow Control Methods

1. Bypass Lines
    - Bypass allow the fluid to flow around or past the production or system component, when the fluid flow is not required.
2. On Off Control
    - Fluid flow is controlled by switching pumps on and off . This often requires a multi pump arrangement.
3. Throttle Valves
    - A throttle valve restricts the fluid flow so that less fluid can flow through the pump, and also creating a pressure drop across the valve
4. Multispeed Pumps
    - Pumps that have been fitted two speed motors that can switch between speeds depending on the fluid flow required.
5. Impeller Trimming
    - For specific process speed requirements the pump impeller may be trimmed in order to redefine the operating point of the pump more efficiently
6. Pump Speed Control
    - Fluid flow is controlled by the actual speed of the pump and includes:
        a) Mechanical (gears, belts, fluid couplings)
        b) Electrical (VSDs)

Traditional Pump Control Methods



Relative power consumption on an average flow rate of 70% with different control methods

Control	Energy
Throttling	89
Bypassing	82
On-off control	70
VSD control	45

Affinity Laws for Pumps

Relation between

- Pump Speed (N),
- Impeller Diameter (D)
- Flow (Q)
- Head (H)
- Power (P)

- Changes to pump performance is governed by the Affinity Laws.
- These laws show how performance is affected when the pump speed is changed, or when the impeller diameter is changed.

For changes in speed

$$Q_{new} = Qold * \left(\frac{N_{new}}{N_{old}}\right)$$

$$H_{new} = H_{old} * \left(\frac{N_{new}}{N_{old}}\right)^2$$

$$P_{new} = P_{old} * \left(\frac{N_{new}}{N_{old}}\right)^3$$

For changes in diameter

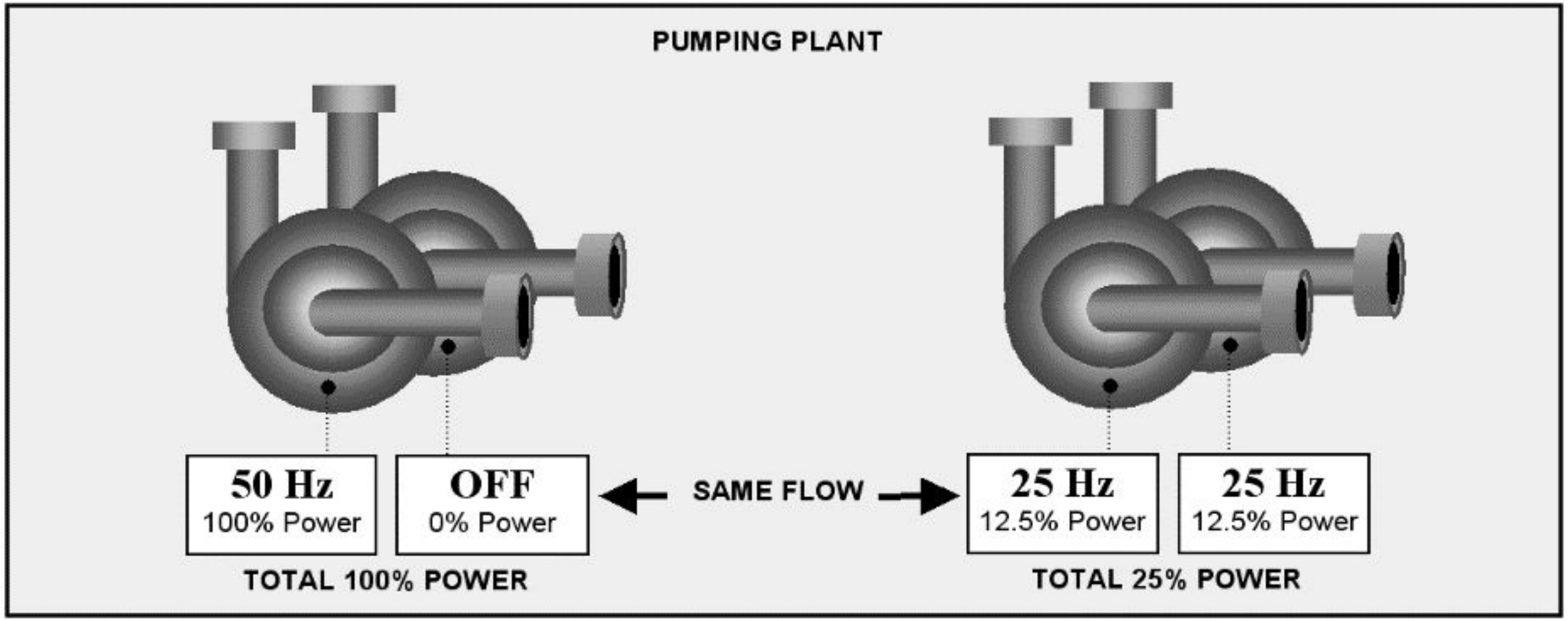
$$Q_{new} = Qold * \left(\frac{D_{new}}{D_{old}}\right)$$

$$H_{new} = H_{old} * \left(\frac{D_{new}}{D_{old}}\right)^2$$

$$P_{new} = P_{old} * \left(\frac{D_{new}}{D_{old}}\right)^3$$

Example

Pumping plant: Useful relationship to consider with closed loop circulating independent systems (two hydraulic circuits) where “static head" is not a major factor



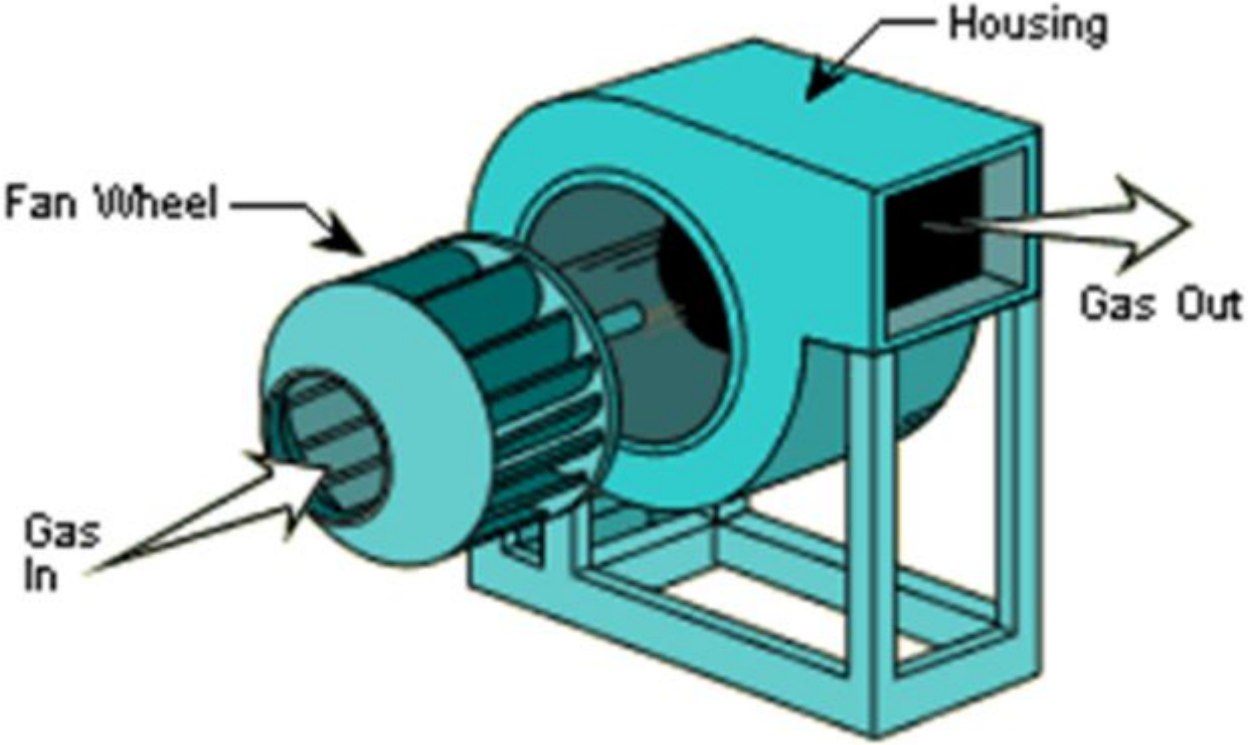
Pump Systems – Energy Strategies

- Pumps purchased based on cheapest initial price can be upgraded or replaced with higher efficiency models.
- Erosion by abrasive particles can affect clearances and efficiency.
- Special coatings can be applied to repair cavities and smooth internal surfaces to reduce friction losses.
- The suction inlet design should ensure that flow approaching the inlet is uniform and steady.
- A straight run of suction pipe of at least eight diameters in length immediately prior to the pump suction flange is recommended.

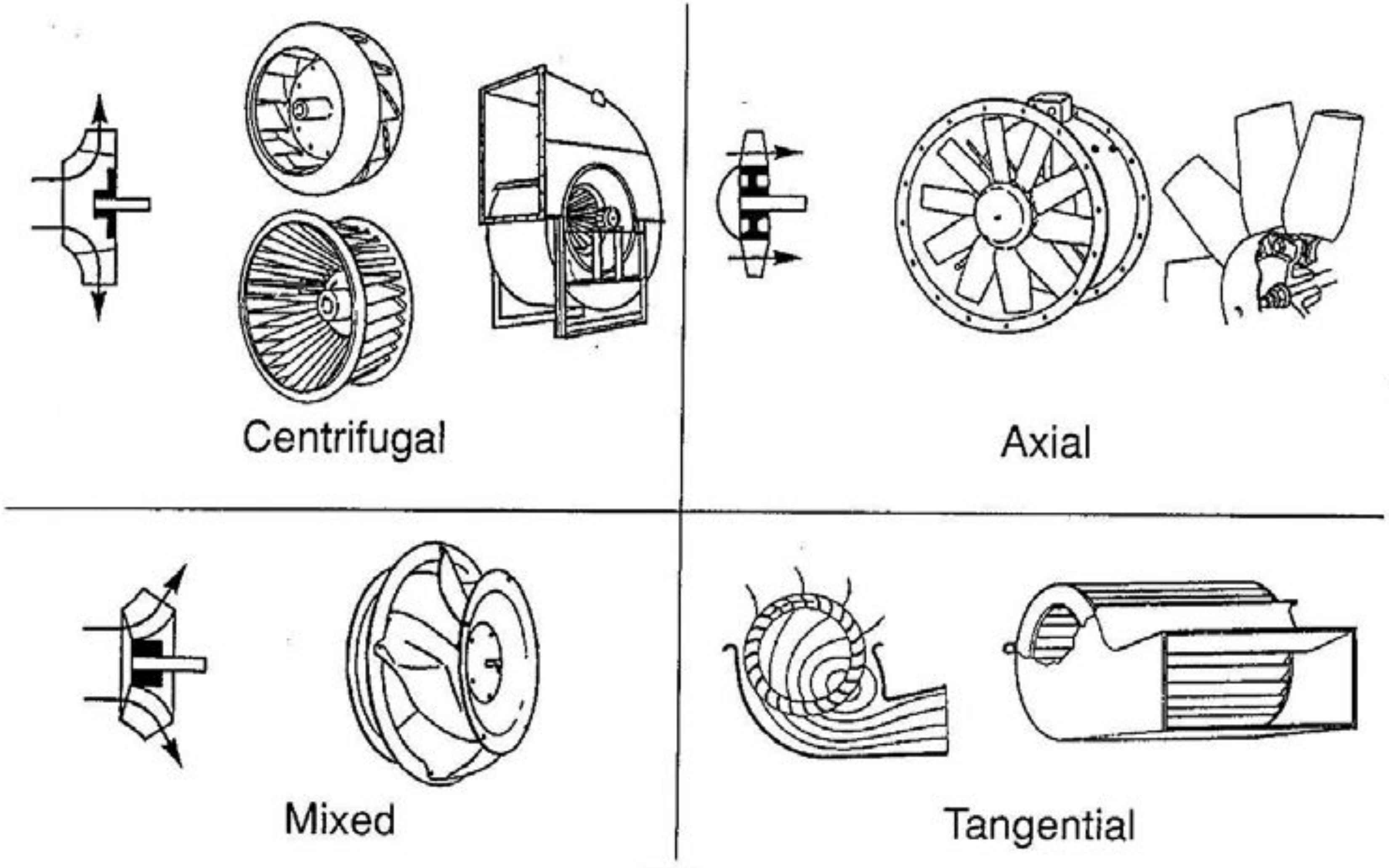
Fans

Energy performance of fans is determined by many factors:

- Type of fan (blade shape)
- Diameter of the impeller
- Width of the impeller
- Rotational speed
- Density of the fluid



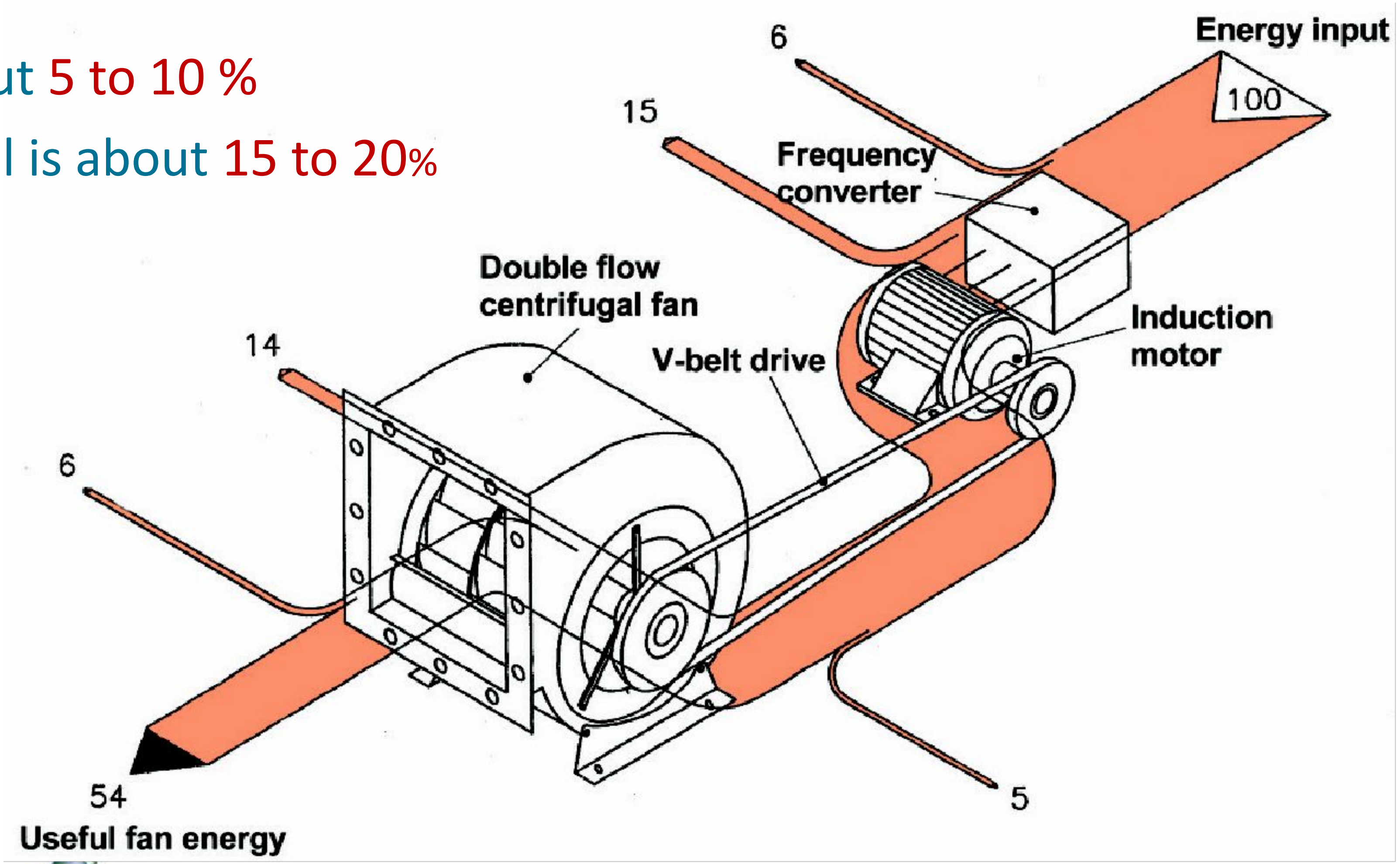
Types of Fans



Fan Systems

Systems approach:

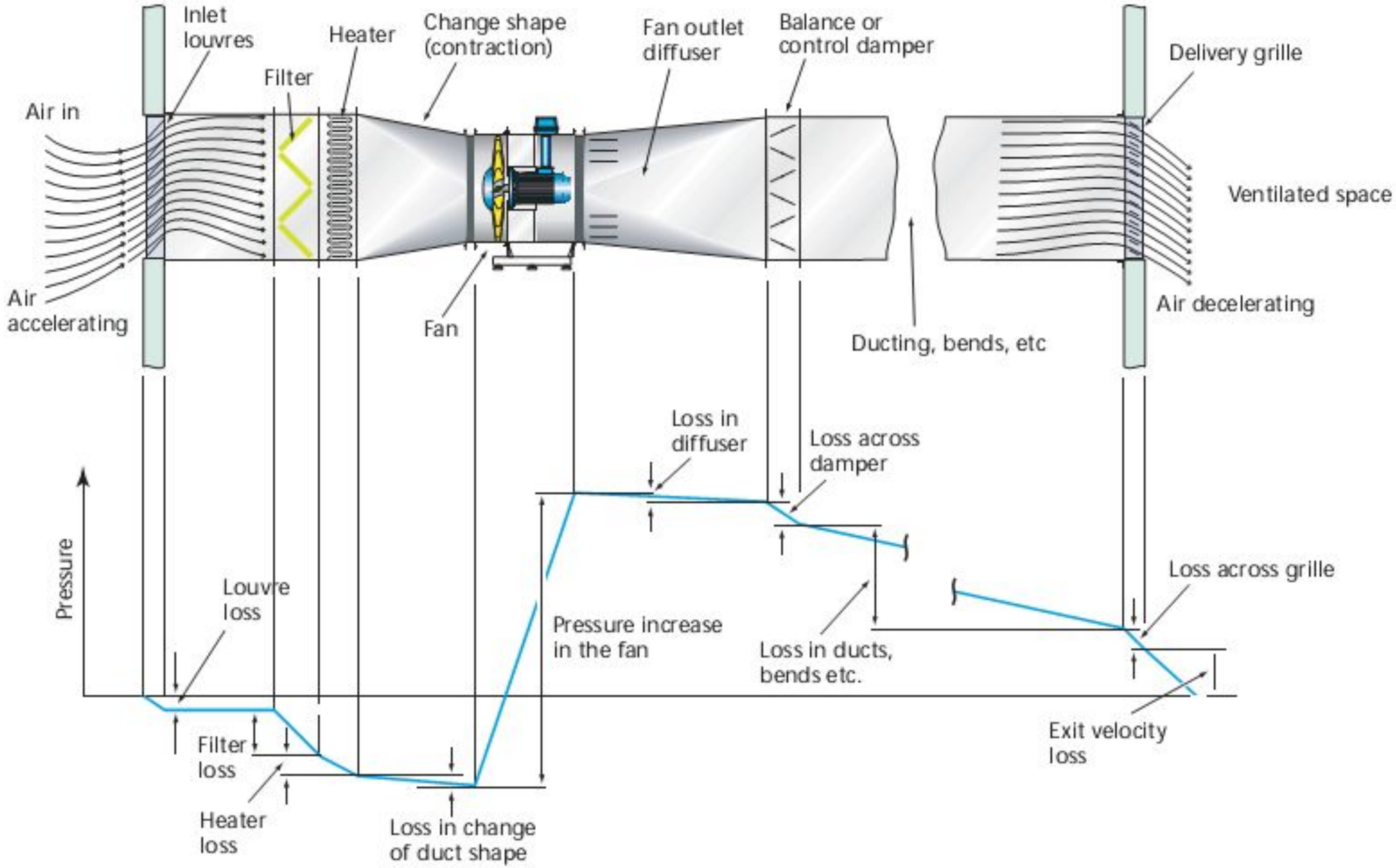
- Fan Saving Potential is about 5 to 10 %
- Fan System Saving Potential is about 15 to 20%



Fan Flow Control Methods

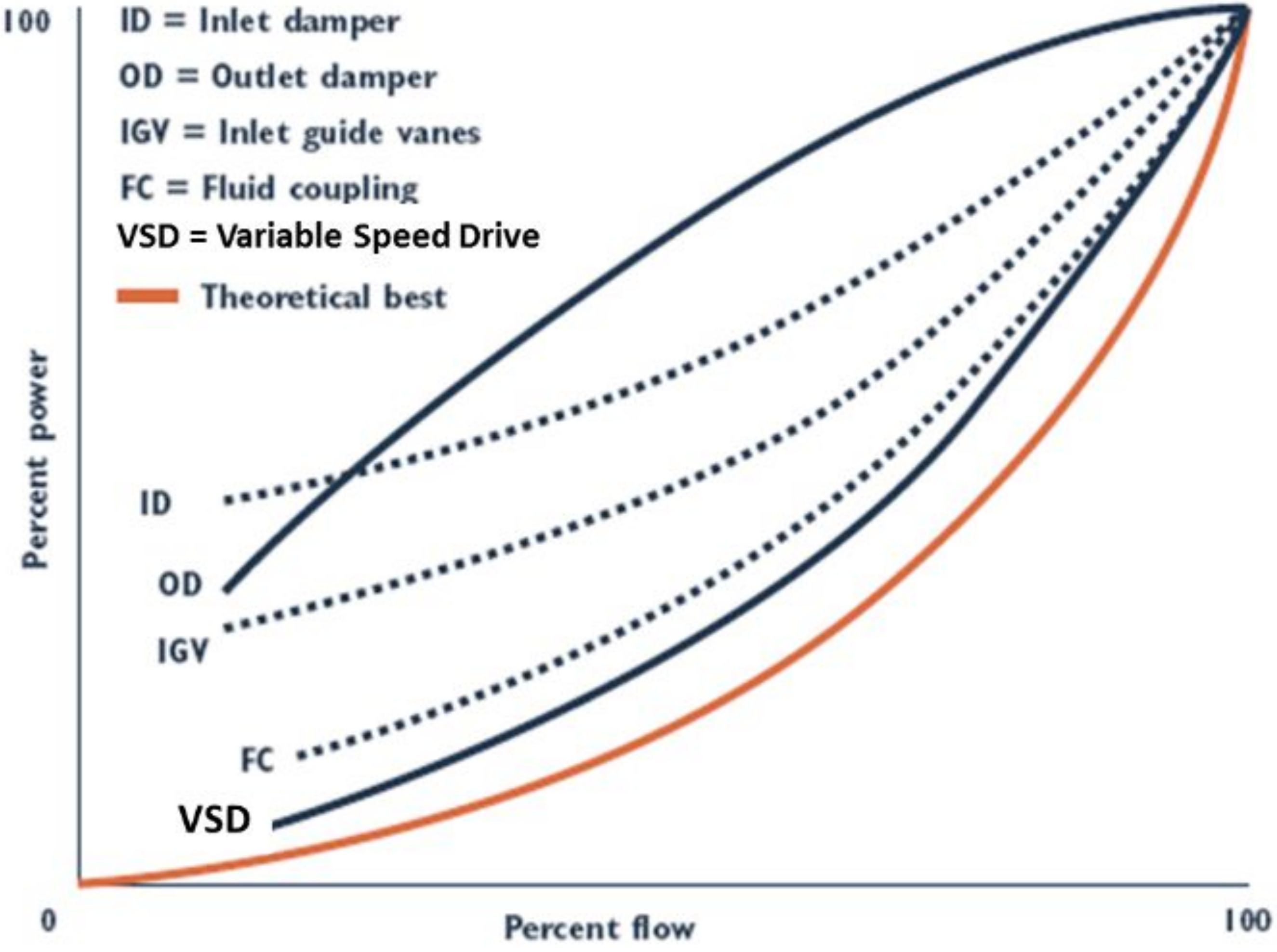
1. On Off Control
    - Fluid flow is controlled by switching fans on and off . This often requires a multi fan arrangement.
2. Inlet and Outlet Dampers
    - A valve positioned before or after the fan restricts the fluid flow so that less fluid flows through the fan, and also creating a pressure drop across the damper
3. Variable Inlet Guide Vanes
    - Variable pitch vanes that control the direction and volume of flow a the inlet to the fan.
4. Multispeed Fans
    - Fans that have been fitted with two speed motors that can switch between speeds depending on the fluid flow required.
5. Impeller Trimming
    - For specific process speed requirements the fan impeller may be trimmed in order to redefine the operating point of the pump more efficiently
6. Fan Speed Control
    - Fluid flow is controlled by the actual speed of the fan and includes:
        a) Mechanical (gears, belts, fluid couplings)
        b) Electrical (VSDs)

Losses Across a Typical Fan System



Source: CIBSE Fan Application Guide

Fan Control Methods



Fan Systems – Energy Strategies

- Fans originally purchased based on cheapest initial price can be upgraded or replaced with higher efficiency models
- Variable speed drive (VSD) control provides superior savings over the full range of flow
- Causes of high system resistance include dirty screens, filters and coils
- Flow that is lost due to leakage is a waste of energy
- Fan systems are susceptible to developing leaks in flexible connections, at loose or distorted flanges and due to deteriorated gaskets

Spotting Fan Savings

Look for

- Variable demand
- Changes in demand since system installed
- Old control technologies
- Poorly controlled systems

But it is harder to identify or resolve these other types of problems:

- Poorly specified fans (wrong size or type)
- System design problems (ducting, filters, etc)

Compressed air - Why do we use it in industry?

Power

As an energy source to perform work

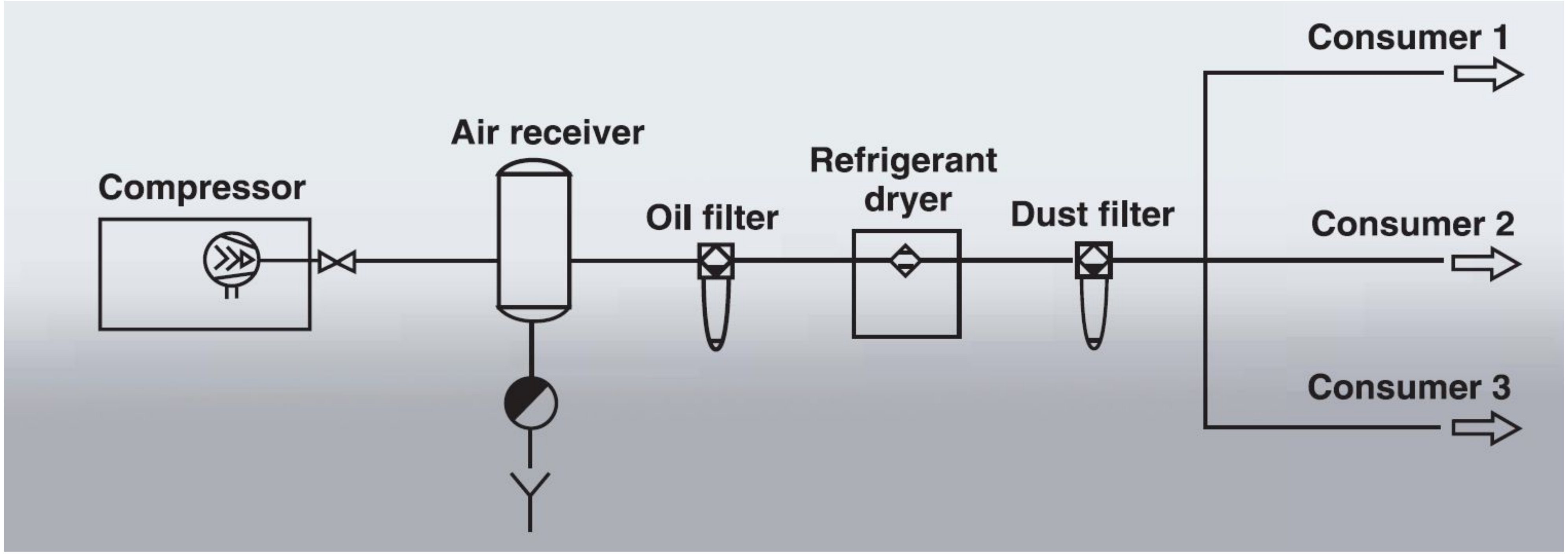
Process

Air becomes part of a process

Control

To stop, start or regulate the operation of a machine

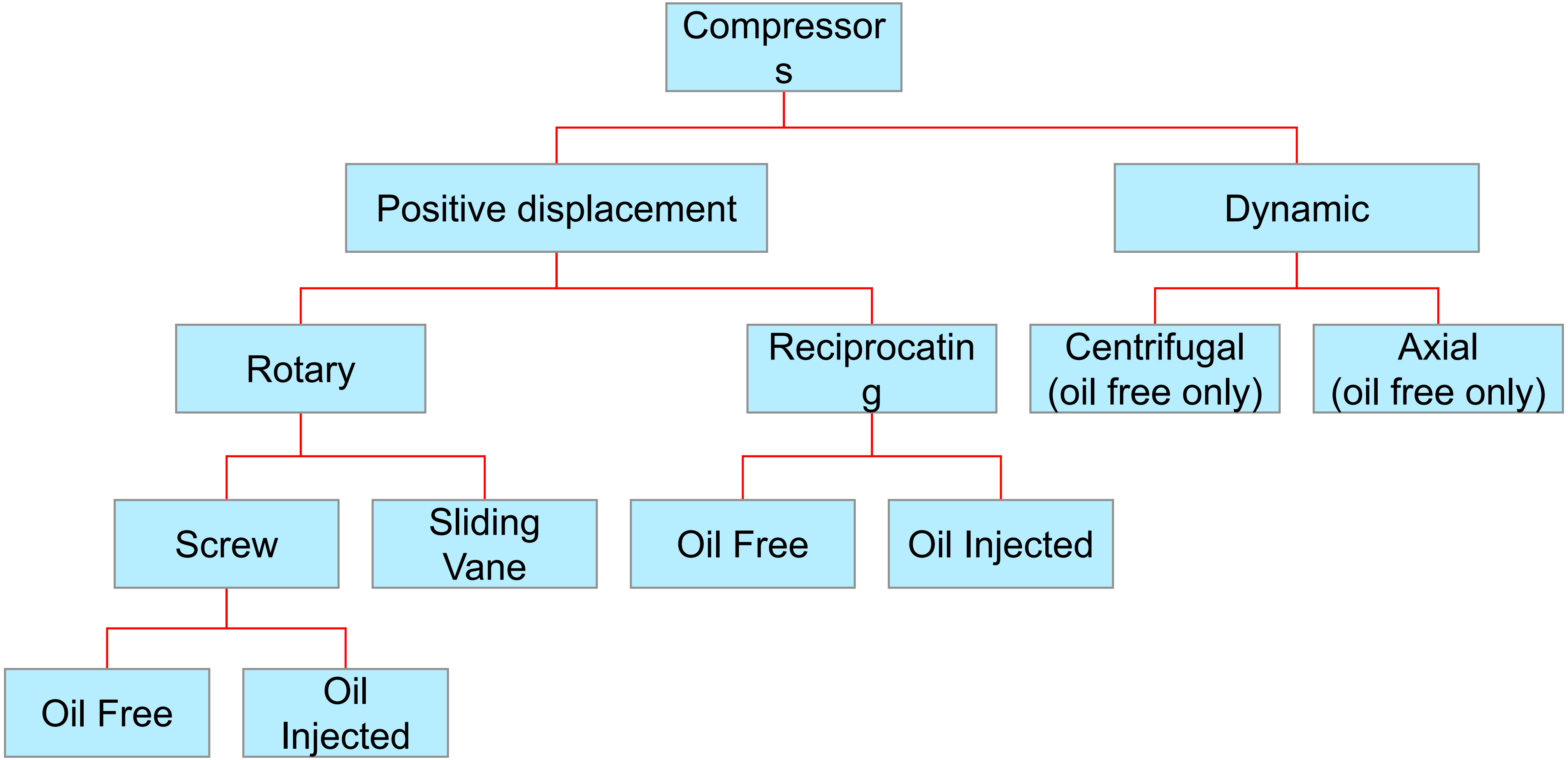
Typical Compressed Air System



Where does the energy come from?

What drives the compressor?

The Compressor Family



Compressors

Positive displacement

Dynamic

Rotary

Reciprocating

Centrifugal (oil free only)

Axial (oil free only)

Screw

Sliding Vane

Oil Free

Oil Injected

Oil Free

Oil Injected

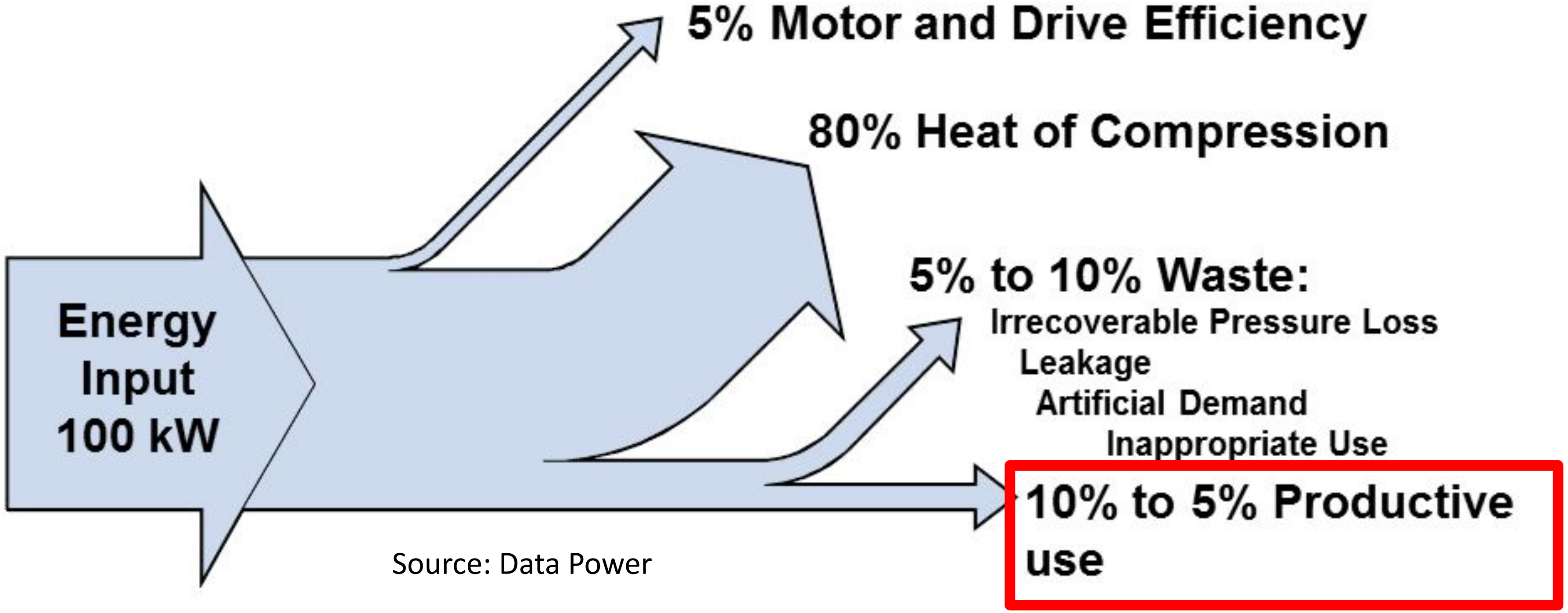
Why compressed air offers rich pickings?

Most compressed air systems are initially designed with:

- The assumption that “more” is better, where supply is concerned
- Little or no thought is given to system efficiency
- There is no plan for increases or decreases in system demand
- Purchase the lowest initial capital cost system
- An initial demand very different from how things have evolved

And… they also need regular maintenance

Compressed Air Energy Conversion


Energy Input 100 kW

5% Motor and Drive Efficiency

80% Heat of Compression

5% to 10% Waste:
Irrecoverable Pressure Loss
Leakage
Artificial Demand
Inappropriate Use

10% to 5% Productive use

Source: Data Power

Approximately 15% of the electrical input energy is converted into compressed air energy, a ratio of ~7 to 1.

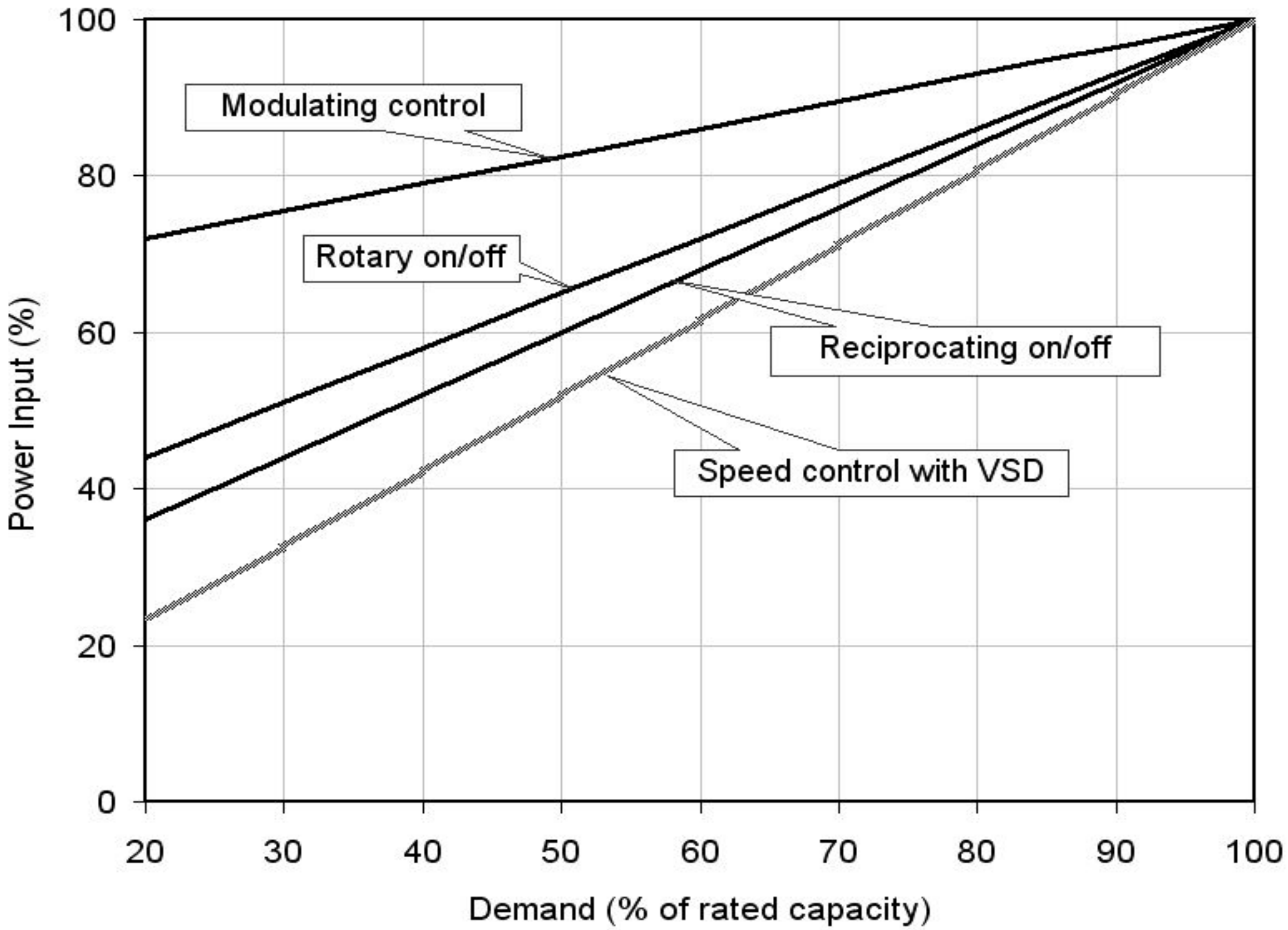
Effectively compressed air energy **costs 7 times as much as electricity**!

Typical Compressor Operating Cost

Item:	Typical 160 kW air cooled screw compressor
Duty:	Fully loaded at 7.5 bar, 4,200 hr/y, Unloaded 4,000 hr/y
Rate:	$ 0.13 / kWh
Power at full load:	182.5 kW
Flow:	30.3 m^3 / m
Specific Power:	6.02 kW / m^3/m
Energy Cost:	kW x hours x rate
Energy Cost :	$ 134,000 per year

Compare with Purchase Price = $ 126,000

Compressor Control Methods



Energy can be saved by using a VSD on a rotary screw air compressor, but low cost energy savings are often found in the application of compressed air in the plant

Optimisation of Compressed Air

1. Use less air
2. Optimise generation and compressor control
3. Improve quality of air to process
4. Recover energy from heat of compression

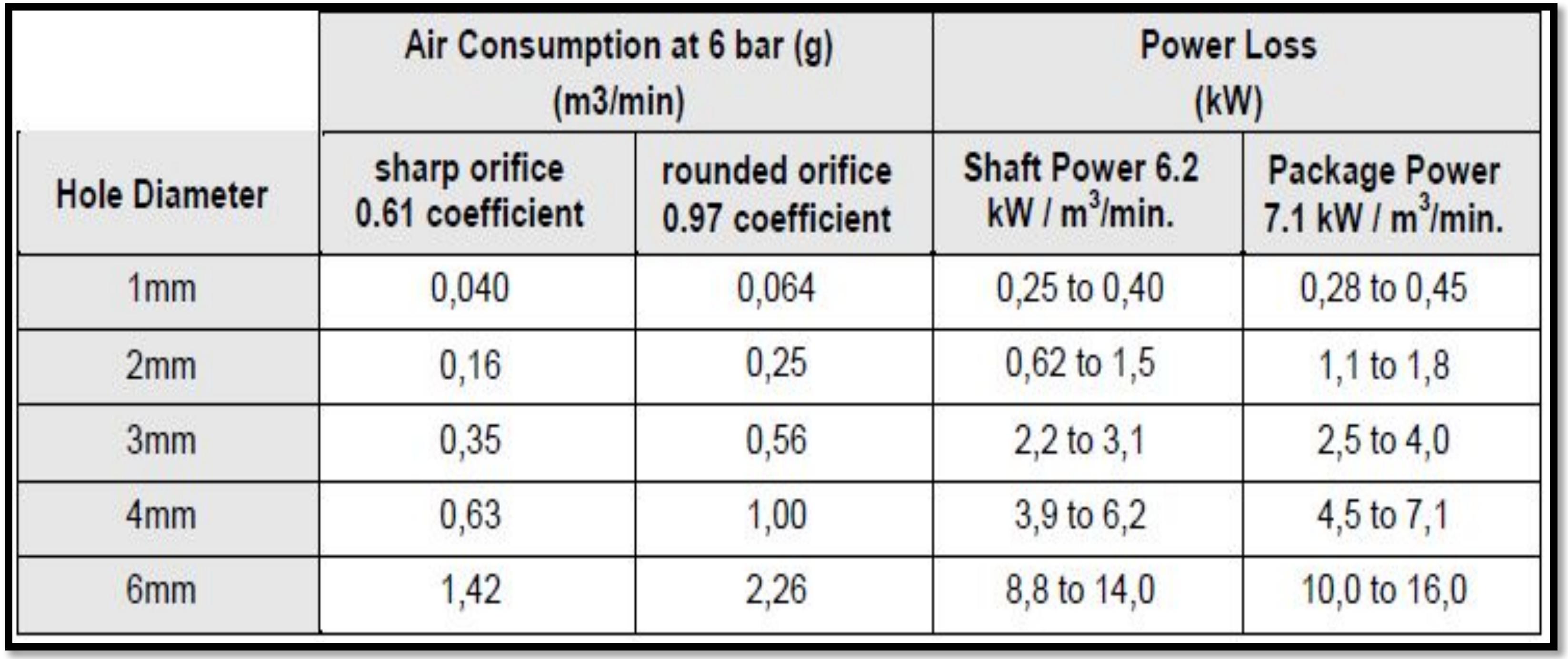
Compressed Air Systems – Energy Strategies

- Leakage is the largest single waste of energy associated with compressed air usage.
- Consider alternate methods for low-pressure applications such as agitation, part ejection, cleaning, cooling and fume removal – this can be effectively done at greatly reduced cost by blowers or air amplifiers.
- Use the lowest system pressure possible - every 1bar increase in system pressure requires an additional 7% power.
- Pipe pressure loss is proportional to pipe length and inversely proportional to diameter - Keep air velocities below 9 m/s.

Compressed Air Systems – Energy Strategies

- Install intakes in locations providing the cleanest, driest and coolest air possible – outdoors if possible.
- Compressors charge the system to the preset pressure and maintain it by various methods including recirculation, venting, stop/start and speed control with variable speed drives - optimize the control to meet requirements.
- Choose filter systems with the lowest pressure drop.
- Compressor systems give off high volumes of low-grade waste heat, which can be used efficiently by some industrial processes, boiler feed water, heating or ventilation systems.

Leakage Losses

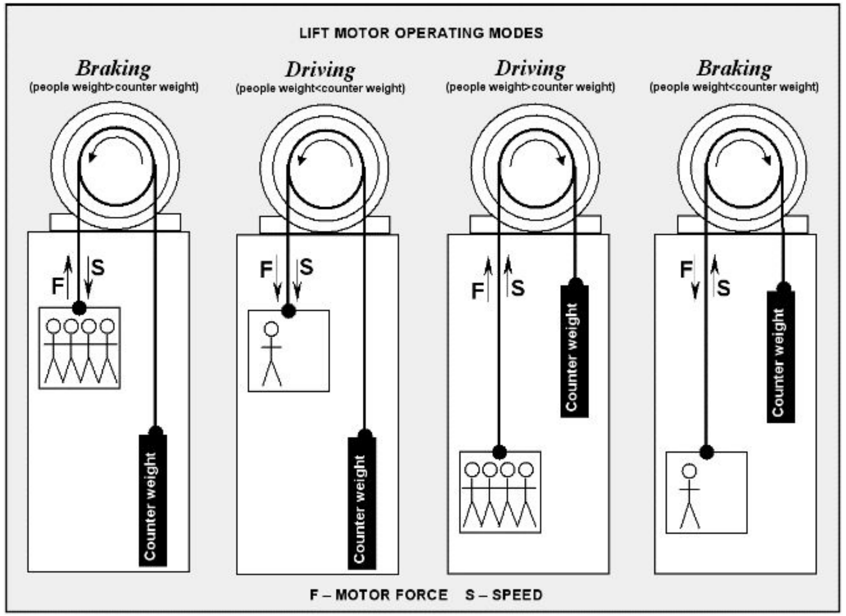


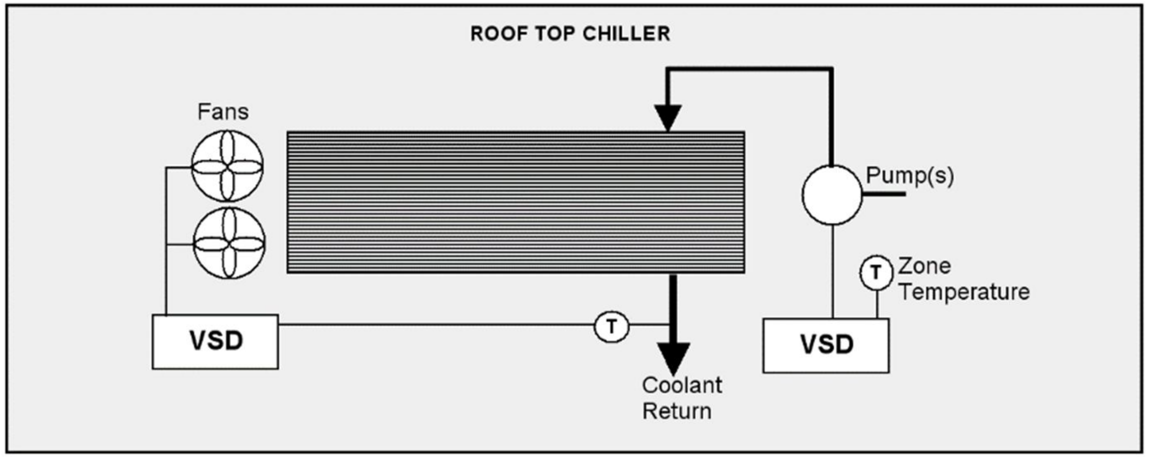
	Air Consumption at 6 bar (g) (m3/min)		Power Loss (kW)	
Hole Diameter	sharp orifice 0.61 coefficient	rounded orifice 0.97 coefficient	Shaft Power 6.2 kW / m^3/min.	Package Power 7.1 kW / m^3/min.
1mm	0,040	0,064	0,25 to 0,40	0,28 to 0,45
2mm	0,16	0,25	0,62 to 1,5	1,1 to 1,8
3mm	0,35	0,56	2,2 to 3,1	2,5 to 4,0
4mm	0,63	1,00	3,9 to 6,2	4,5 to 7,1
6mm	1,42	2,26	8,8 to 14,0	10,0 to 16,0

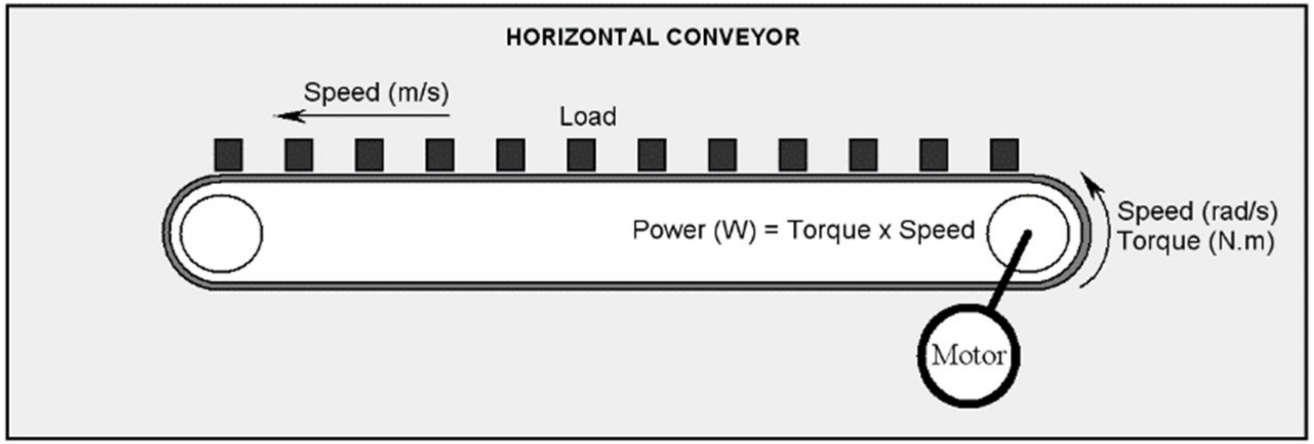
At EGP 0.80/kWh, a 6mm leak costs over EGP 90,000 per year in power plus additional service on the compressed air equipment.

One audible leak (±3mm) will cost EGP20,000 per year!

Other VSD Applications

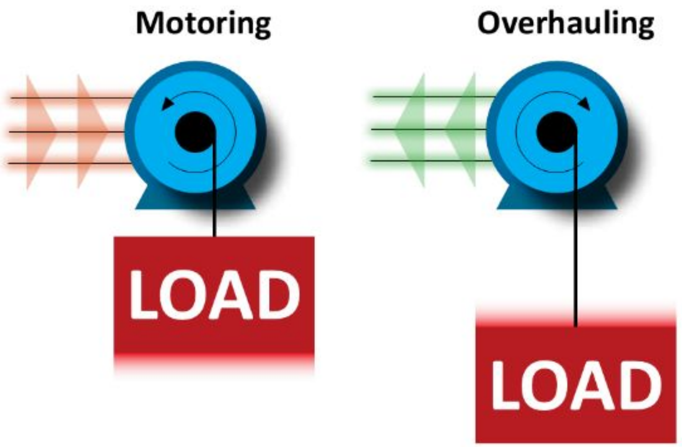






Regeneration Using Electric Motors

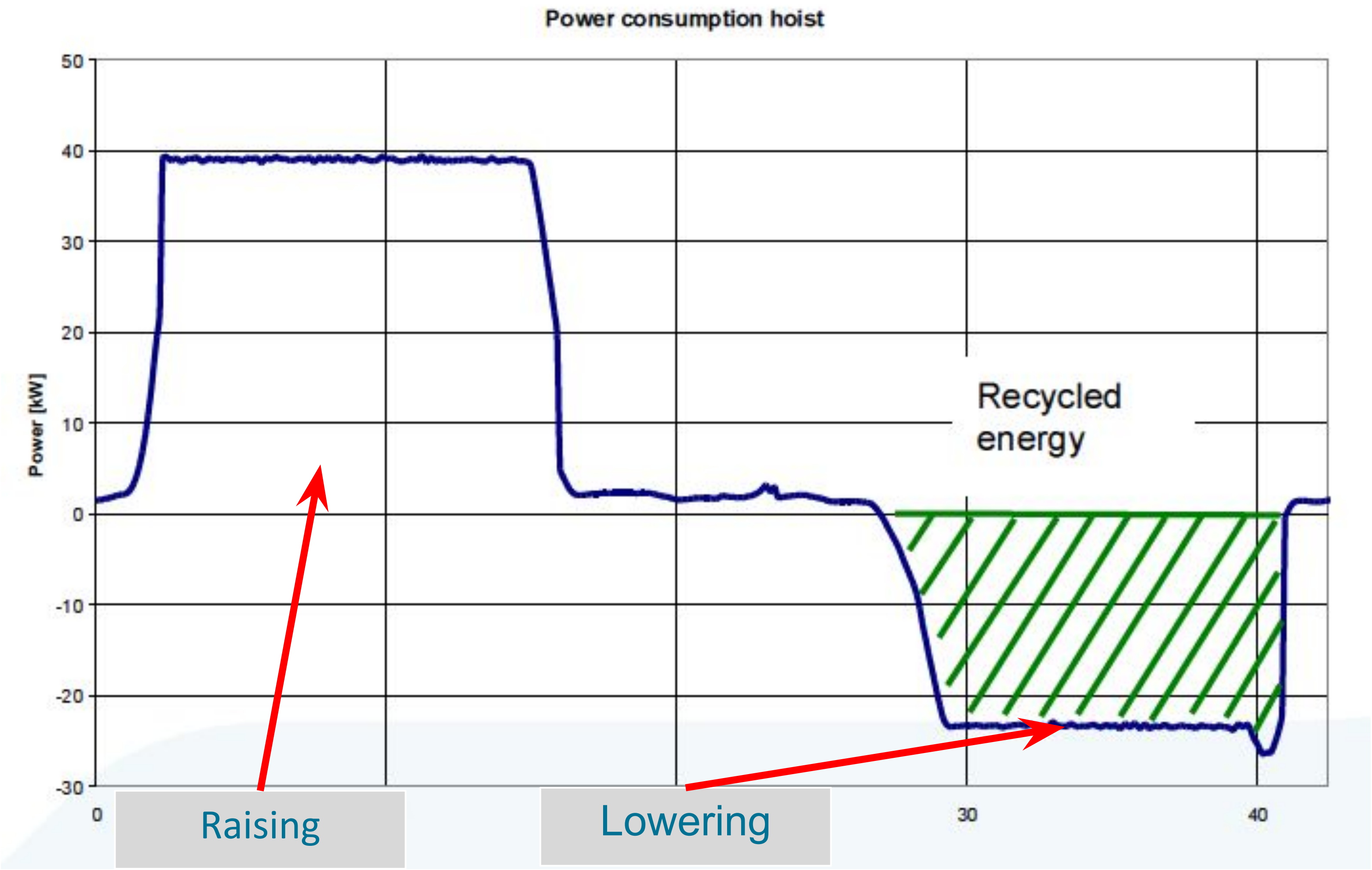
- Regeneration represents a good opportunity for energy saving in many applications of material handling loads.
- The opportunity for regeneration exists where the mechanical load is driving the motor. This is called **overhauling**.
- A VSD with an active front end is required to allow for energy to flow in the reverse direction, i.e. from the motor (acting as a generator) to the electrical supply network.



Source: www.bonitron.com

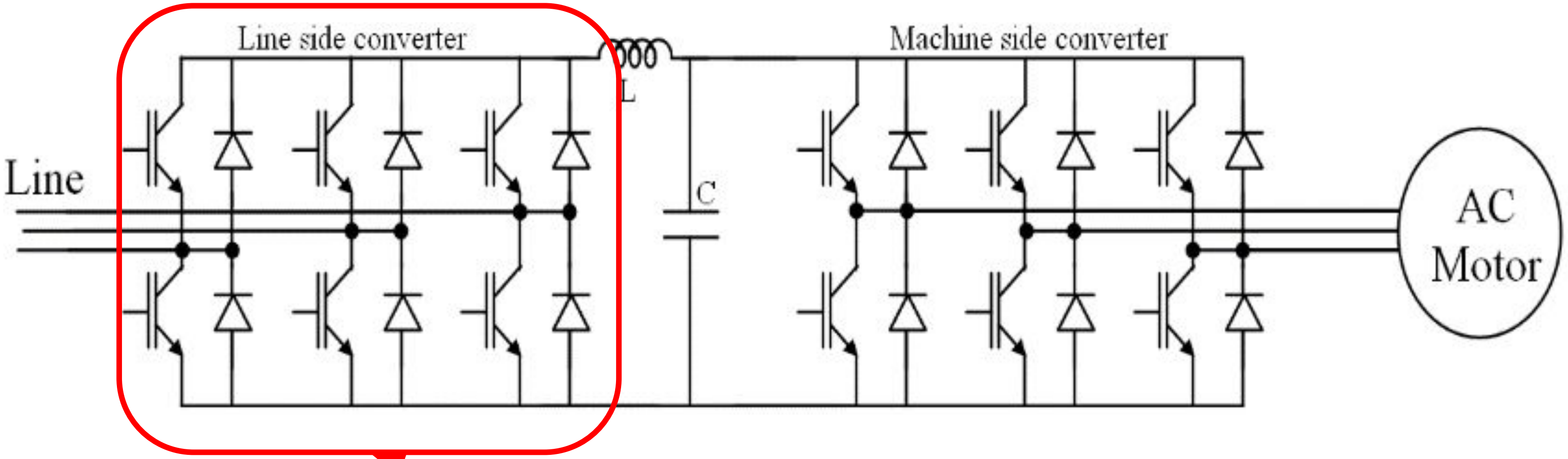
Typical RTG Crane at Shipping Port

Recycled Energy from Hoist (Y-axis)



VSD with Bidirectional Power Flow

- Four quadrant drive control allows for regenration of electrical energy from the motor when operating in generating mode



“Active Front End”

Common Energy Saving VSD Applications

1

Centrifugal pumps, fans and compressors in which torque increases with the square of the rotating speed of the motor
The electric power sharply increases with the speed (up to the cube) and a small adaptation to the process need can lead to large savings

2

Conveyors, escalators, hoists, cranes and similar types of equipment where the torque is more or less independent from speed
The cost and energy efficiency benefits are smaller compared to the first group of applications because the change of input power is only linear with the speed.
Regenerative braking can lead to additional savings

Common Energy Saving VSD Applications

3

Changes in load and speed can benefit from a VSD in other ways like process control, soft starting and stopping, as well as the requirement of an especially high starting torque or of regenerative braking

The cost and energy efficiency benefits are small compared to the first two groups. VSDs allow for voltage optimization to improve motor efficiency if the torque changes

4

Motion Control – AC drives can now provide high performance torque/speed control, similar to motor servo drives

Benefits of VSD Applications

- Large energy & cost savings (20% – 70% possible)

Better match of machine to process requirements

- Increased flexibility
- Better process control
- Better throughput

- Better start & stop control
- Reduced starting currents
- Reduced stresses on the system = reduced maintenance & longer life

VSD Applications

Do not use when

- Cost savings are not financially viable
- Little opportunity to reduce speed
- Little variation in process demand
- Associated equipment does not allow speed changes
- A large static head exists in a pumping system
- If other equipment is sensitive to harmonics

Review & Discussion

- Any questions?

4. The Motor System Assessment

Why Motor Systems Energy Assessments?

Why do we need it?

- Energy cost money
- Equipment costs money
- Reducing operating costs will improve profits for the same volume of production
- Opportunities for saving DO exist

What benefits?

- Save money
- Cultural behavioural shift (management more willing to spend on energy projects, operational staff become accustomed to reducing waste)

Why Motor System Energy Assessments?

70 % → of industrial electric load is consumed by motor systems

Opportunities to reduce energy use include:

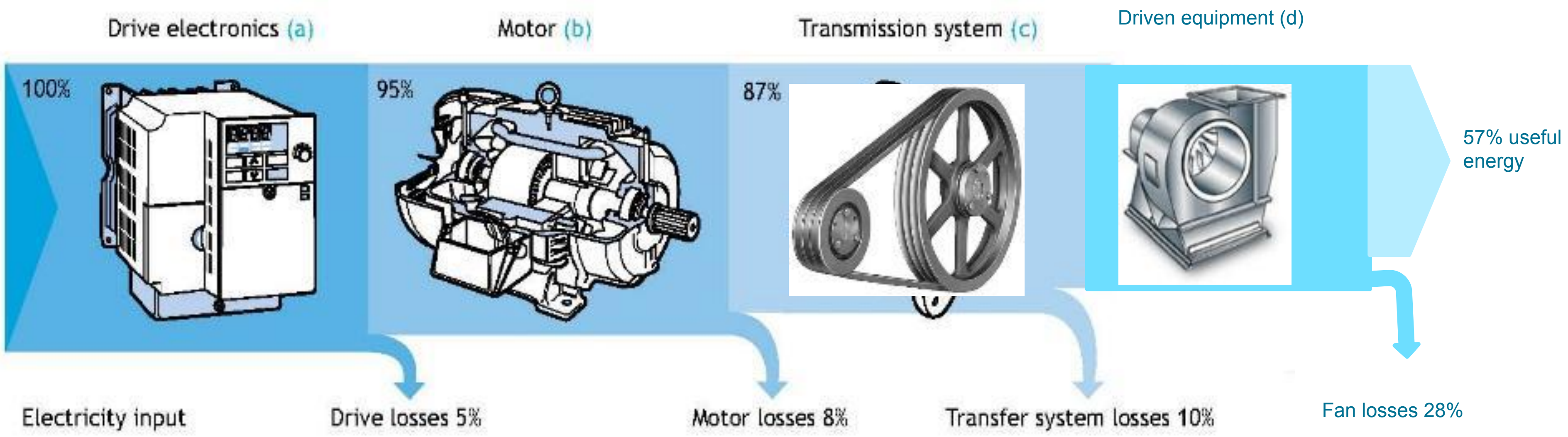
- Old control technologies
- Changing operating conditions
- Varying production needs

Although system efficiency can be around 60% or higher, → it often falls below 50% and even as low as 15%-20%

Start with the end use…

Egyptian program for promoting Industrial Motor Efficiency
SAVE TODAY ... POWER TOMORROW

Start at the process where the final energy is required and work backwords towards the source



Energy losses occur at each stage. Identify the losses and look for the best opportunities to improve

INDUSTRIAL MODERNISATION CENTRE
gef
www.theGEF.org

Ask the Big Questions

1. What is the system trying to achieve?
2. What are the settings – how were these settings determined?
3. Is it the best way of doing it?
4. Do we really need it all the time?

Pick the Top 20 Motor Systems

Ideally end up with a list of 10-20 motor systems to look at

Allow 30 - 60 minutes per system for review and prioritisation

Motor System Review

- Determine the type of motor and load application
- Determine the system requirements
- Establish the operating hours and costs
- Calculate the annual cost of operation
- Check on the method of operation and management
- Draft a system diagram showing all components
- Determine the motor control method
- Establish where any inefficiencies may occur
- Calculate the losses where possible
- Estimate the possible savings

What Actions Can Be Taken?

Motor upgrades

Switch off options

System optimisation

VSD opportunities

Identify systems that could do with more in depth investigation – FSO, PSO, CASO

Opportunities: Motor Upgrades

Develop a Motor Management Policy to enable a systematic approach to motor upgrades

Look for

- Large motors that run all the time
- Motor that fail often or tend to have short life cycles
- Motors running much less than full load (< 50%)

Opportunities: Switch Off

When

- Tea breaks
- Out of hours
- Review switch on/off times
- Time switches / BMS controls
- Tool changes
- Between batches

Beware of

Switching frequency limits – motors can only be switched on and off a certain number of times per hour

Opportunities: Transmissions

Look for

- Loose transmission belts
- Motor shaft alignment problems
- Motor bearing failures
- Oil leaks under gearbox or transmission

Listen for

- Noisy gearboxes
- Screeching pulleys

Opportunities: VSDs

Look for

- Pumps and fans driving processes and loads with variable demand
- Motors running much less than full load
- Closed loop systems with low static head
- Existing system with parallel equipment (eg multiple pumps in a cooling system)

Consider

- Review of existing operating parameters for systems
- Installation of new motors to enable VSD control

Worked Example: VSD Saving Opportunity

Existing pumping system:

- Motor runs at 2900 rpm, Electrical power in: 22 kW, Pressure: 4 bar
- Opportunity to reduce flow rate by 15%

- New speed (rpm): 2900 x 0.85 = 2465 rpm
- New pressure (bar): 4 x (0.85)2 = 4 x 0.72 = 2.9 Bar
- New power (kW): 22 x (0.85)3 = 22 x 0.614 = 13.5 kW

- Discount saving by 5% to account for additional losses due to VSD
- Savings potential = ((22kW – 13.5kW) x 95%) = 8.075kW

- ***Conclude:*** 15% flow (speed) reduction = 37% power reduction

Site Assessment - Where to Look First

- Large equipment with high and frequent usage
- Equipment that fail often and result in long down times
- Systems with varying duties or outputs
- Auxiliary equipment that is not critical to the production process
- Problem equipment and systems with high failure rates

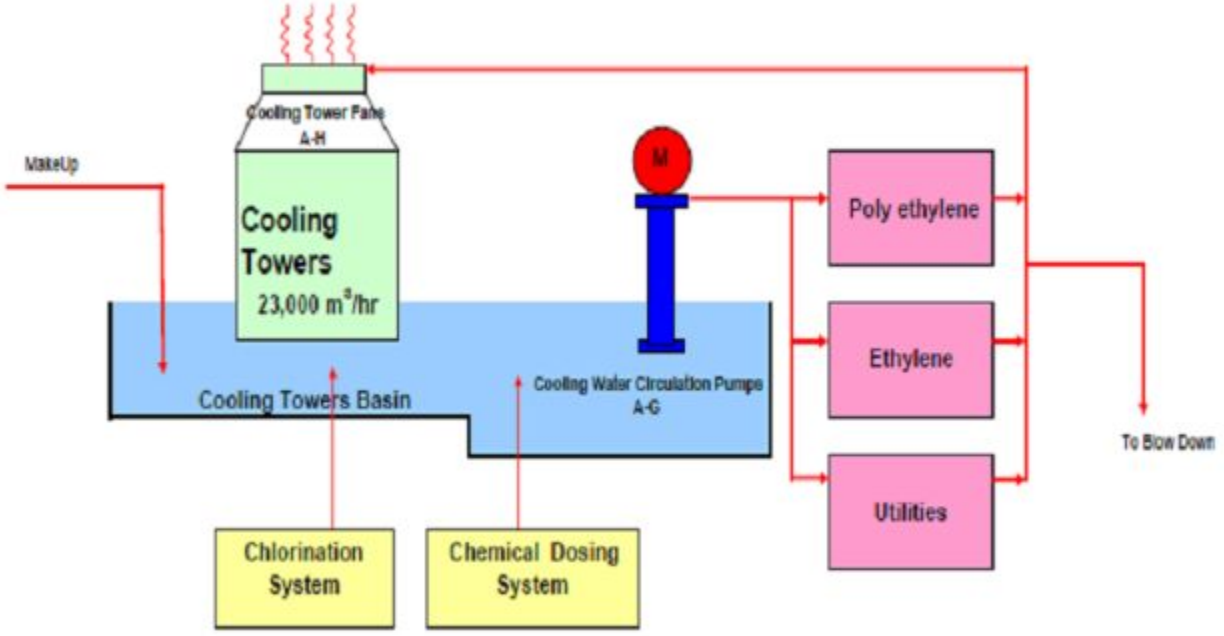
MSO Business Case Reports

Key elements of a business case report:

- Executive summary
- Objectives of study
- Plant process overview
- Plant electricity network and costs
- Motor system selection
- Motor system overview
- Motor system overview
- Measurements and findings
- Analysis of motor system results
- Energy saving opportunities
- Opportunities summary
- Recommendations

Motor System Overview

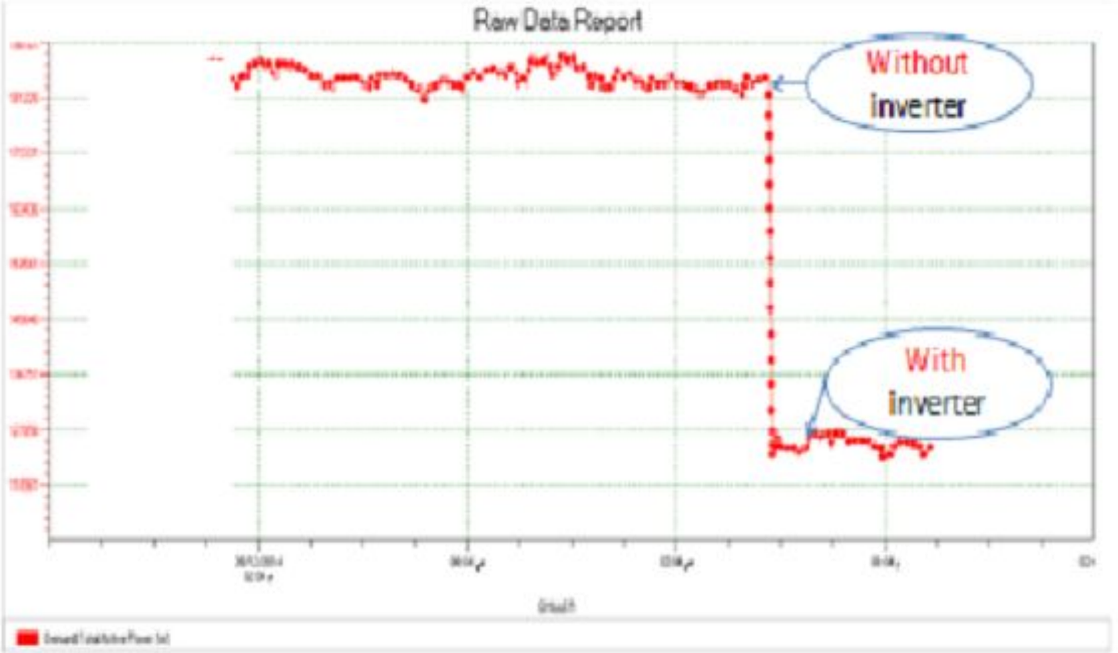
- Overview of motor system being assessed
- Simple block diagram
- Include process parameters
- Construct energy balance
- Identify opportunities along the energy supply chain



SOURCE: SIDPEC

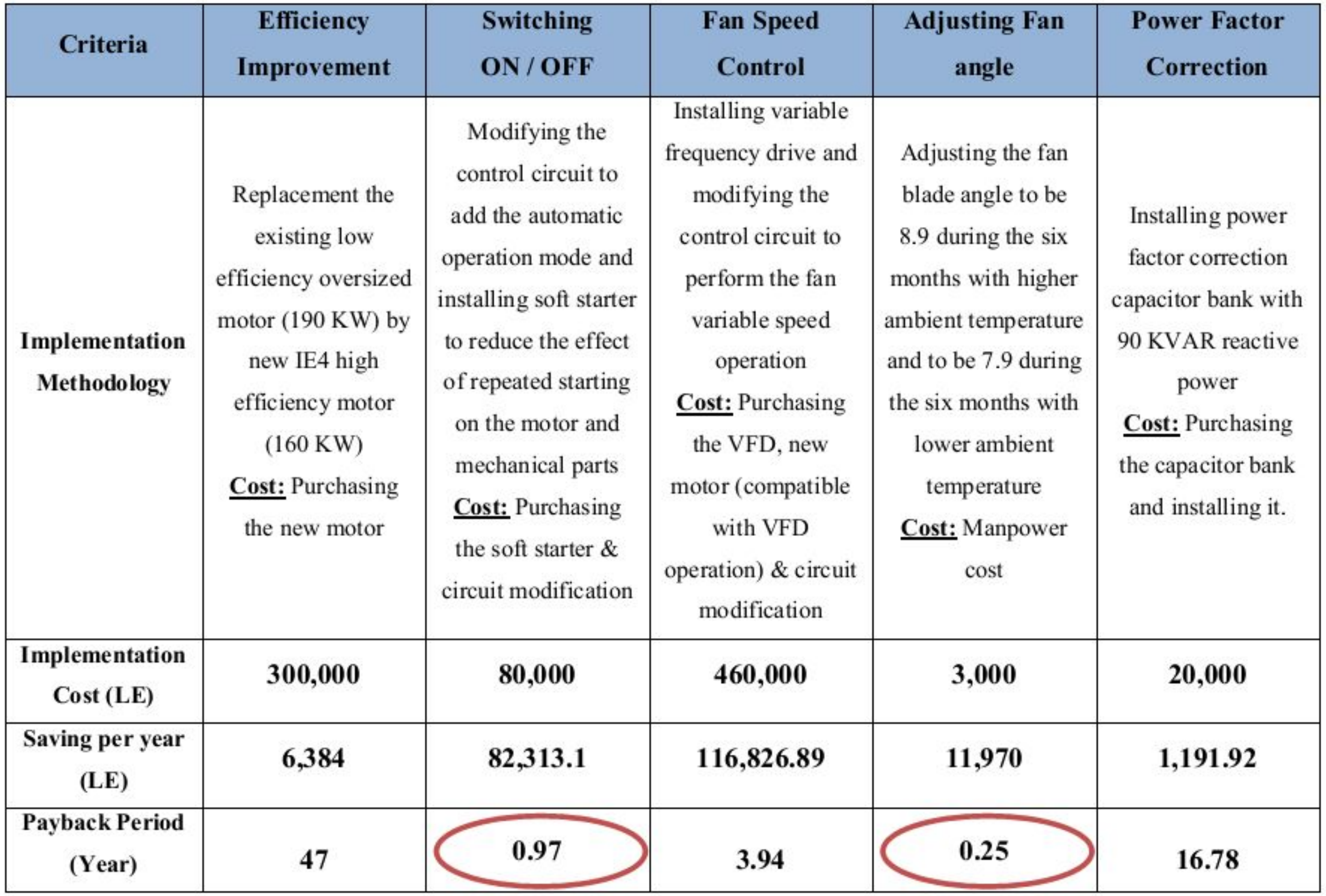
Analysis

- Must include baseline (initial energy consumption) calculation
- Must include an analysis of all elements of the motor system
- Include any assumptions (eg. costs, operating parameters) that were used to calculate energy consumption.



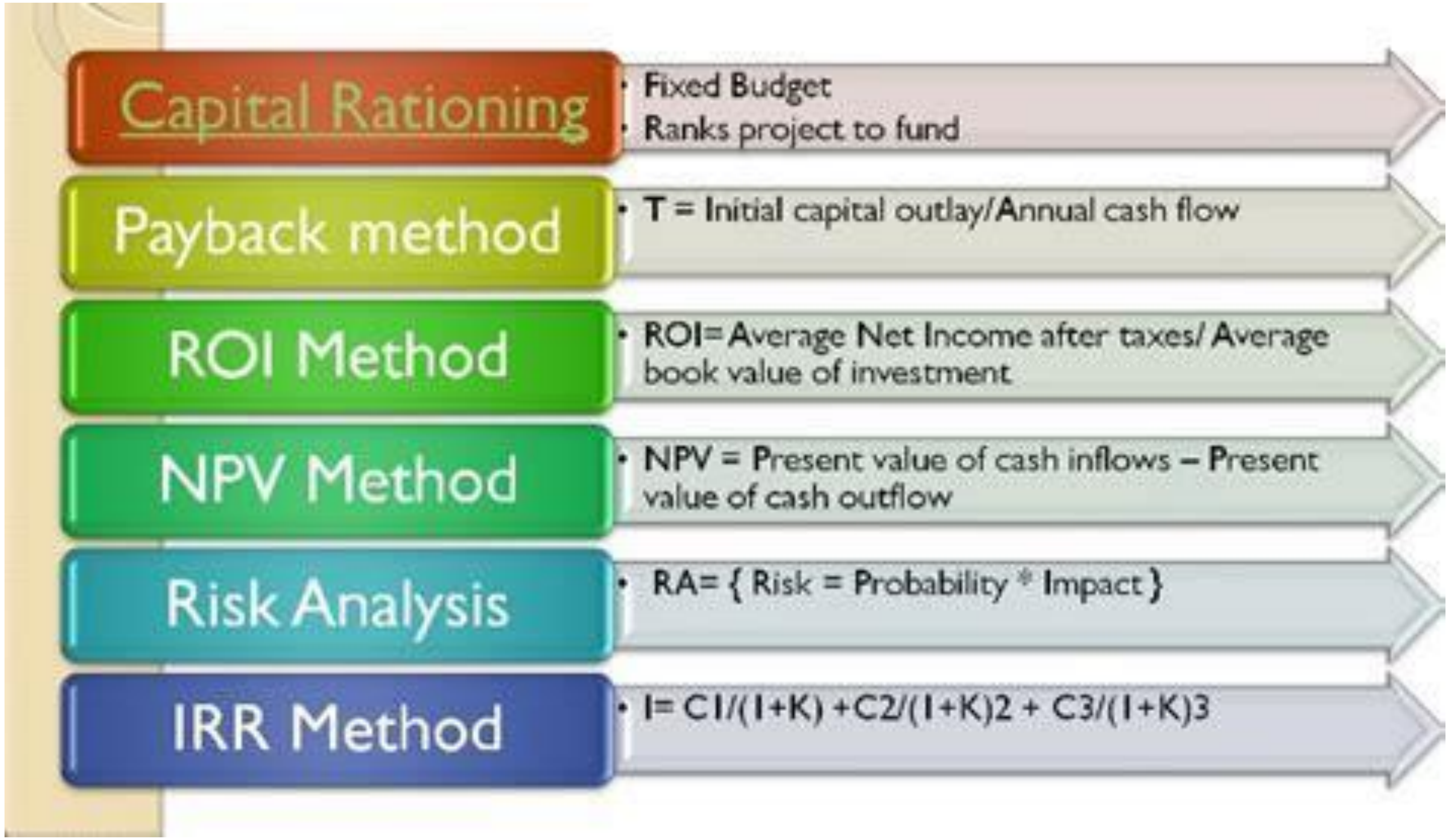
Opportunities Summary

- After analysis and identification of opportunities
- Summary table or diagram to highlight key numbers and options
- Good to remind the reader of all the opportunities in a table on one page



Criteria	Efficiency Improvement	Switching ON / OFF	Fan Speed Control	Adjusting Fan angle	Power Factor Correction
Implementation Methodology	Replacement the existing low efficiency oversized motor (190 KW) by new IE4 high efficiency motor (160 KW) **Cost:** Purchasing the new motor	Modifying the control circuit to add the automatic operation mode and installing soft starter to reduce the effect of repeated starting on the motor and mechanical parts **Cost:** Purchasing the soft starter & circuit modification	Installing variable frequency drive and modifying the control circuit to perform the fan variable speed operation **Cost:** Purchasing the VFD, new motor (compatible with VFD operation) & circuit modification	Adjusting the fan blade angle to be 8.9 during the six months with higher ambient temperature and to be 7.9 during the six months with lower ambient temperature **Cost:** Manpower cost	Installing power factor correction capacitor bank with 90 KVAR reactive power **Cost:** Purchasing the capacitor bank and installing it.
Implementation Cost (LE)	**300,000**	**80,000**	**460,000**	**3,000**	**20,000**
Saving per year (LE)	**6,384**	**82,313.1**	**116,826.89**	**11,970**	**1,191.92**
Payback Period (Year)	**47**	**0.97**	**3.94**	**0.25**	**16.78**

Common Methods of Financial Appraisal



Capital Rationing
- Fixed Budget
- Ranks project to fund

Payback method
- T = Initial capital outlay/Annual cash flow

ROI Method
- ROI=Average Net Income after taxes/ Average book value of investment

NPV Method
- NPV = Present value of cash inflows – Present value of cash outflow

Risk Analysis
- RA= { Risk = Probability * Impact }

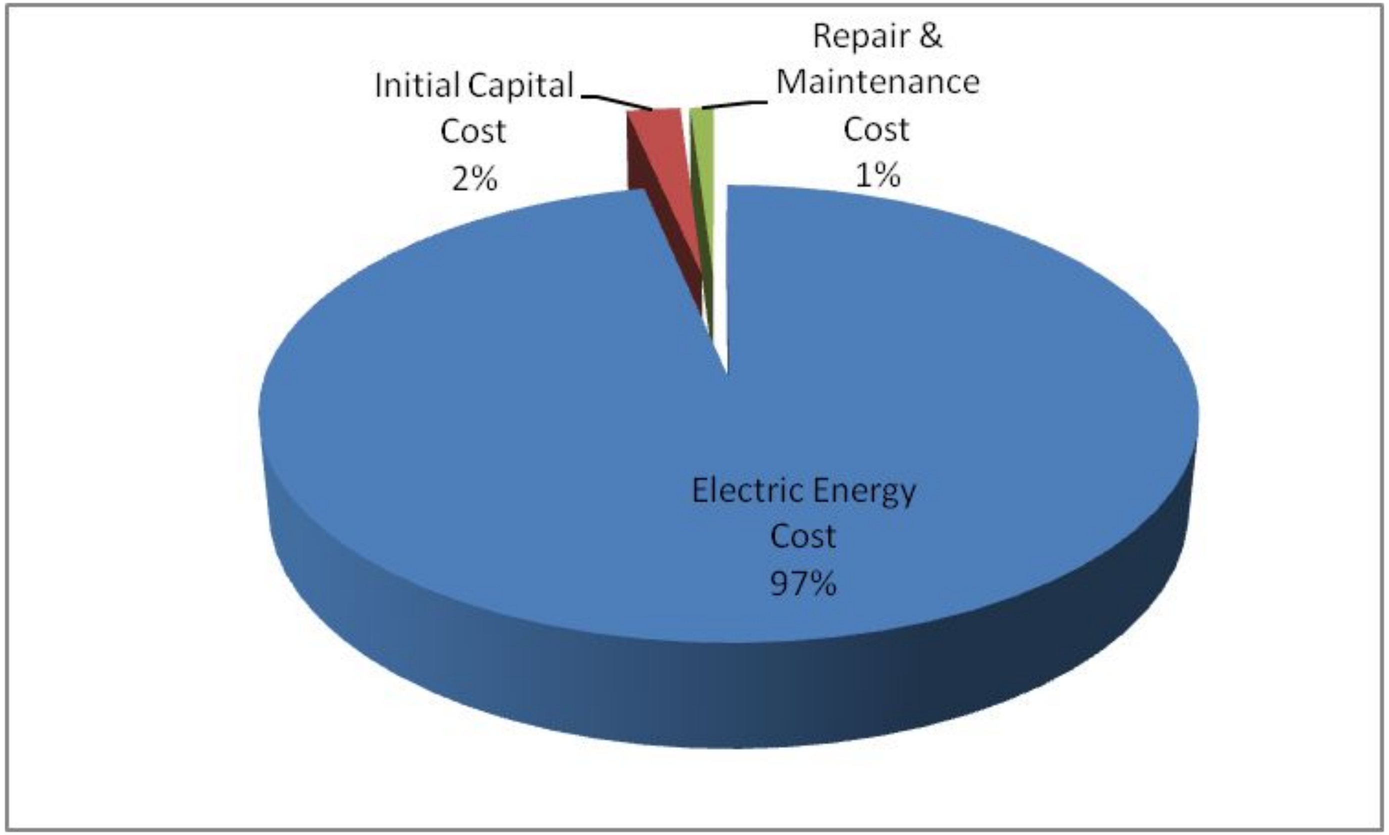
IRR Method
- I= C1/(1+K) +C2/(1+K)2 + C3/(1+K)3

Source: www.slideshare.net

Life Cycle Cost (LCC)

- LCC is used to compare which of 2 or more projects will have a lower total cost over its life cycle.
- All cash flows are negative because they are expenditures.
- In comparison, NPV is used to compare which of 2 or more projects will yield a better return.

Why use Life Cycle Costing?



11 kW IE3 Motor
4000 operating hours per year,
15 years life cycle
0.0754 €/kWh

Source: ISR – University of Coimbra

Why good projects don't happen?

Energy Efficiency is perceived as:

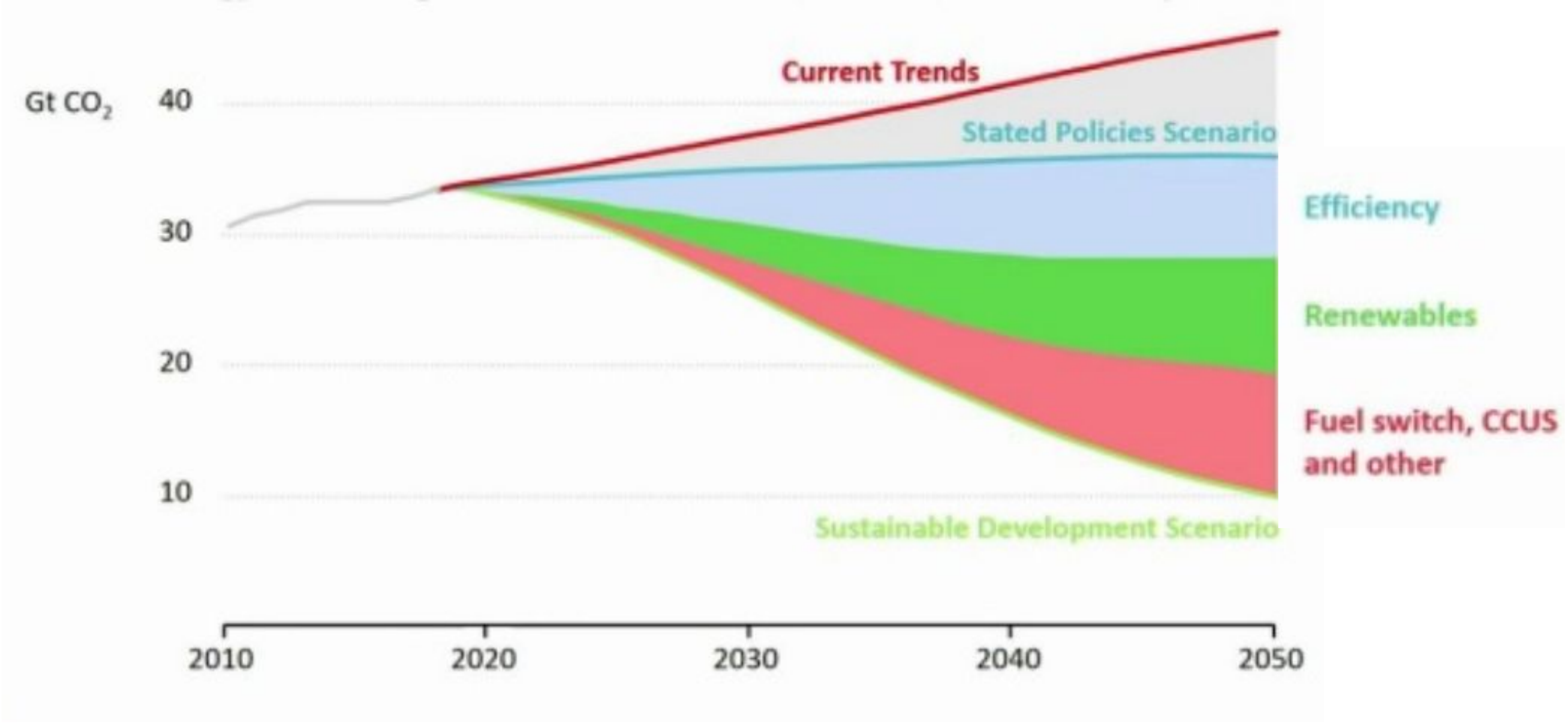
- Discretionary
- Less important because it is regarded as small scale
- Technically risky
- Optional, with no legal drivers
- Costly

Review & Discussion

- Any questions?

5. Latest Motor Applications

IEA – 2050 Sustainable Development Scenario



Electric Vehicles – Not a new thing!

- 1801–1900 EVs Enter the Marketplace
- 1901–1950 EV Production inks
- 1951–1999 High Oil Prices—Renewed Interest in EVs
- Since 2000 Increased Interest in EVs

1900 Lohner Porsche car with electric motors integrated into the wheels (Wienkötter, 2018).

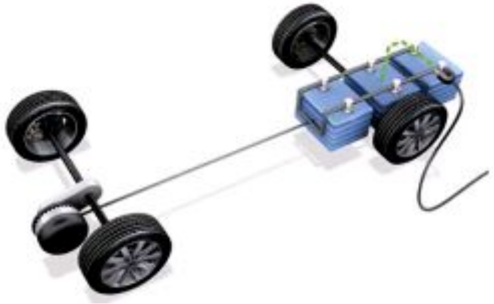
Electric Vehicle Architecture (1)

Hybrid Electric Vehicle (HEV)

- Integration of an electric motor/generator (MG) connected to a controller and battery, in parallel with the Internal Combustion Engine ICE.

Plug in Hybrid Electric Vehicle (PHEV)

- Capable of being recharged from the grid.
- Can be driven in an exclusively electric mode with good dynamic performance



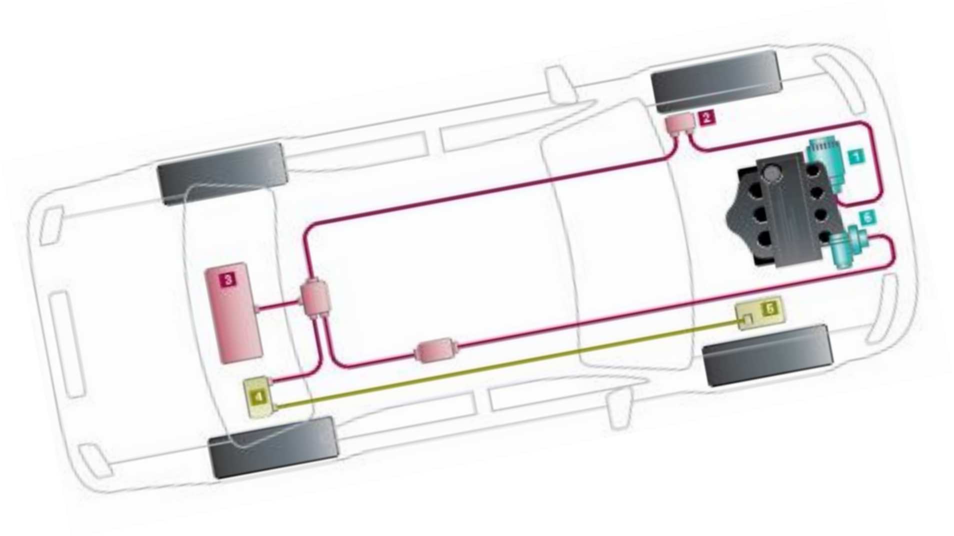
Battery Electric Vehicle (BEV)

- Equipped with a recharge system on board, a large capacity battery with values already reaching 100 kWh in some models, controllers and one or more electric motors per vehicle, axle or wheel.
- No Internal Combustion Engine

Electric Vehicle Architecture (2)

Mild Hybrid Vehicles

1. Electric Starter Generator
2. AC/DC converter
3. 48 volt lithium ion battery
4. DC/DC Converter
5. 12 volt lead acid battery
6. Electrical supercharger

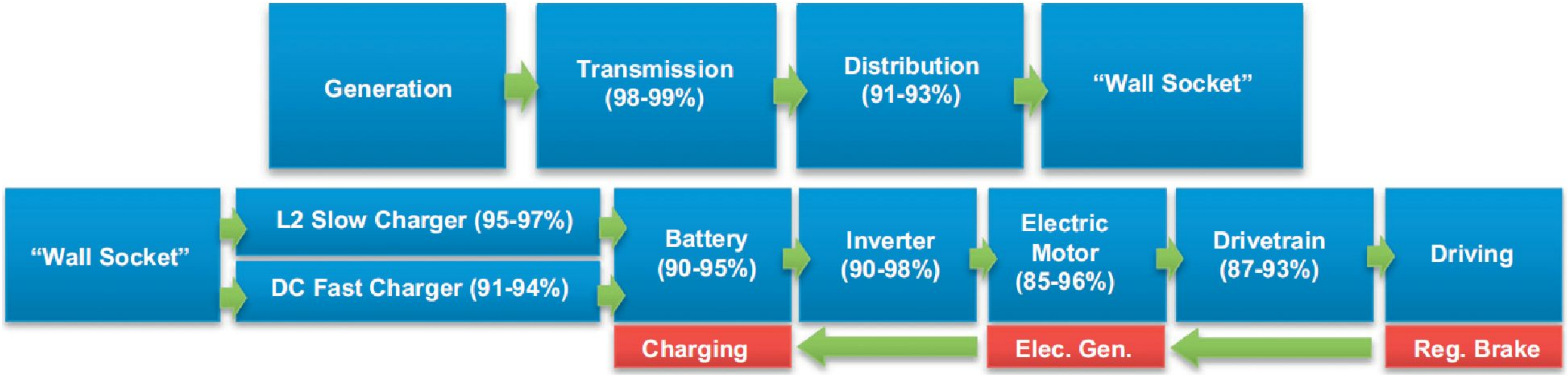


10 kW (or higher) starter motor/generator:

- It can boost the engine to increase the vehicle's acceleration performance and manage engine load to reduce fuel consumption (motoring).
- when the vehicle is cruising or decelerating/stopping the starter generator can recover electrical energy back to the battery (generating).

The electric supercharger eliminates the turbo lag limitation of the traditional turbocharger. Its primary purpose is to increase the air/fuel mixture density that goes into the cylinder of the engine.

Energy Efficiency of EVs



Generation

Transmission (98-99%)

Distribution (91-93%)

"Wall Socket"

"Wall Socket"

L2 Slow Charger (95-97%)

DC Fast Charger (91-94%)

Battery (90-95%)

Inverter (90-98%)

Electric Motor (85-96%)

Drivetrain (87-93%)

Driving

Charging

Elec. Gen.

Reg. Brake

Range of efficiency of the different components in the energy path of an EV

Comparison of Motor Technologies for EVs

Egyptian program for promoting Industrial Motor Efficiency
SAVE TODAY ... POWER TOMORROW

Characteristics	Motor type		
	IM	PM	SynRM
Power density	Medium	Very high	High
Efficiency	Medium	Very high	High
Controllability	Very high	High	Medium
Reliability	Very high	High	Very high
Technological maturity	Very high	High	High
Cost	Very low	High	Low
Used by:	Tesla S, Tesla X	Toyota Prius, Nissan Leaf, BMW i3, Chevrolet Bolt	Tesla 3 (with internal permanent Magnets)

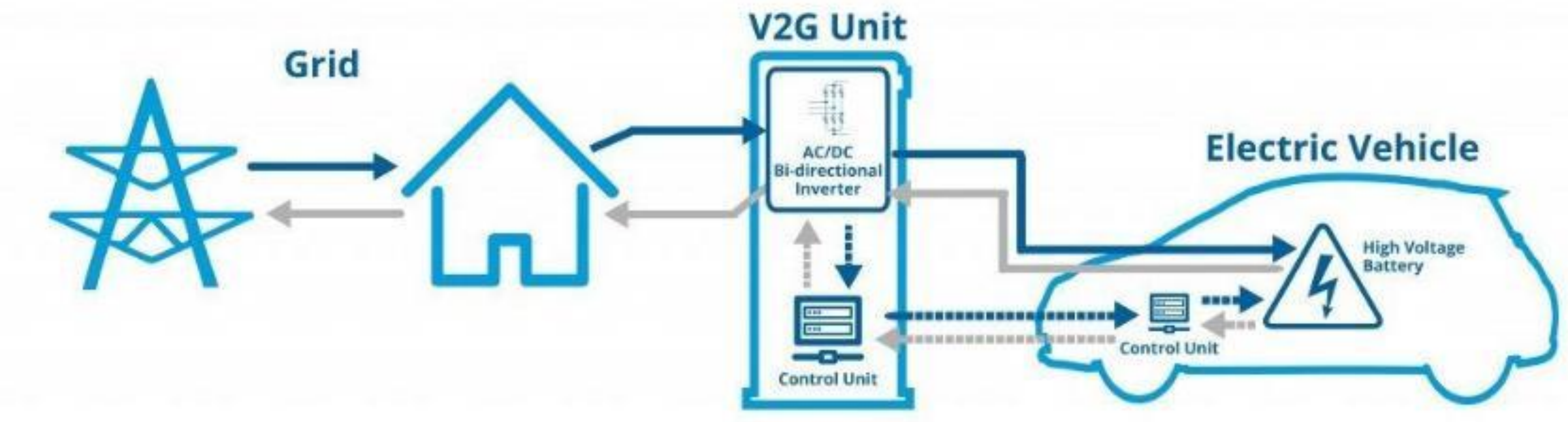
Choosing a technology is a compromise

EVs and the Smart Power System

- EV has the potential of providing flexibility as mobile load and source of energy storage
- Renewables may be complementary to electric vehicle charging
- Mass-market EV electrification requires an intelligent connection between the vehicle and the grid
- Smart charging is a cornerstone in the smart grid development benefiting the power system, EV drivers, consumers & society

Vehicle to Grid (V2G)

- Electric Vehicles can put their battery at the service of the balance between the generation and demand, functioning as a buffer that stores energy when there is generation surplus in the grid and the releases when there is a deficit, in an operation mode called Vehicle to Grid (V2G).
- Each EV will actively contribute to the stabilization of the electrical grid and the further penetration of renewable energy sources.



Source: CENEX

Electric Buses – Made in Uganda

A good example for other countries to follow

Carrying Capacity:	90 (49 seated, 41 standing)
Maximum Motor Power:	245 kW
Torque:	3,300 Nm
Range on single charge:	300 km
Battery bank energy capacity:	301 kWh

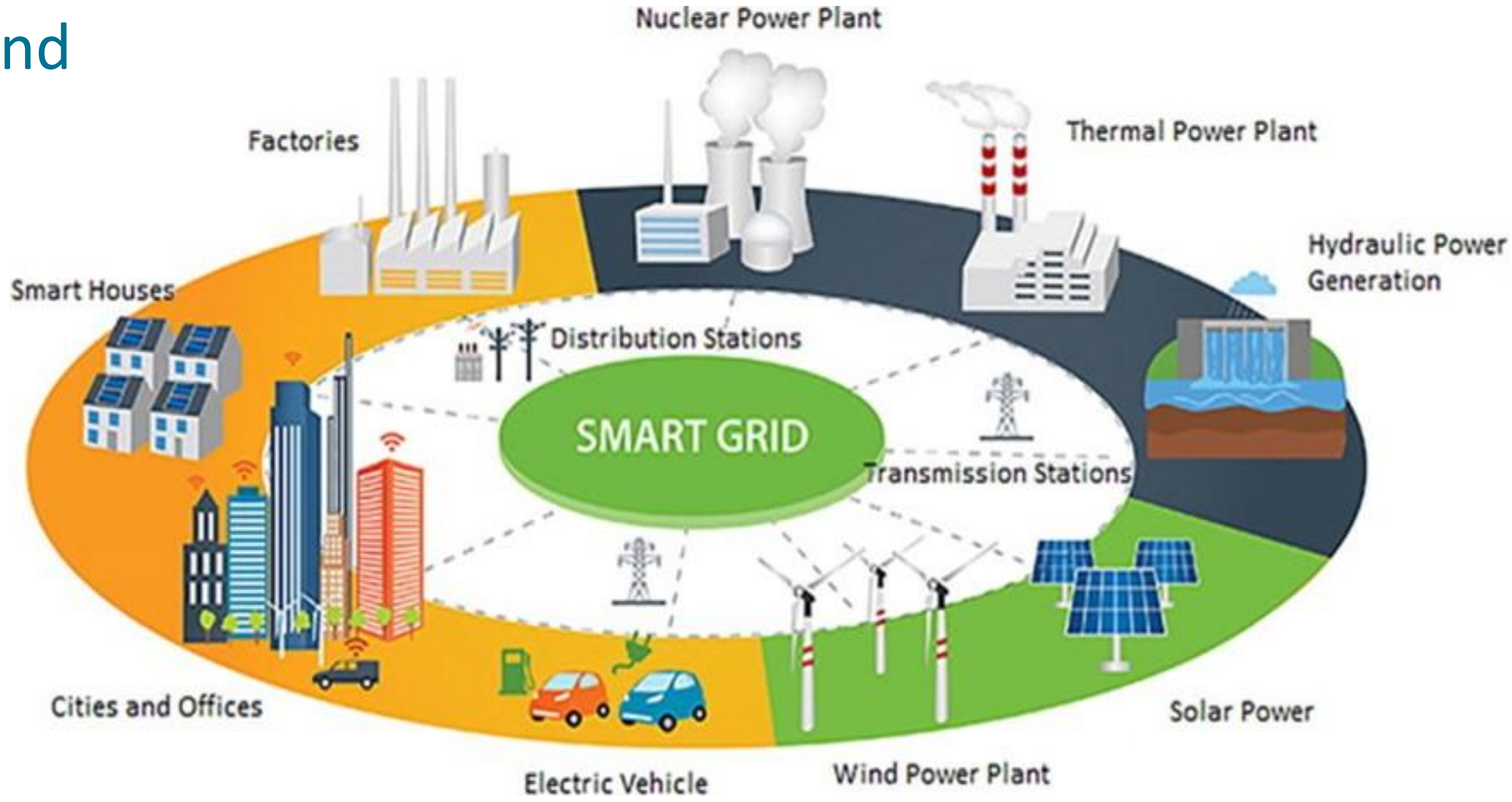
Electric Buses

Beyond improvements in air quality, there are other factors that will further help to push the adoption of e-buses:

- Lower total costs of ownership (TCO): in a growing number of configurations the e-buses have lower TCO than comparable diesel or compressed natural gas (CNG) buses. Operational savings were one of the more important arguments supporting e-buses introduction in many cities.
- Noise reduction and reduced downtime: e-buses run more quietly than diesel or CNG buses, which reduce noise pollution. E-buses also require almost no maintenance.
- Industrial policy considerations: some governments may see an opportunity to build a domestic industry around the electrification of transport. Job creation linked to e-bus production and setting up a charging infrastructure can be a very positive argument for e-buses.

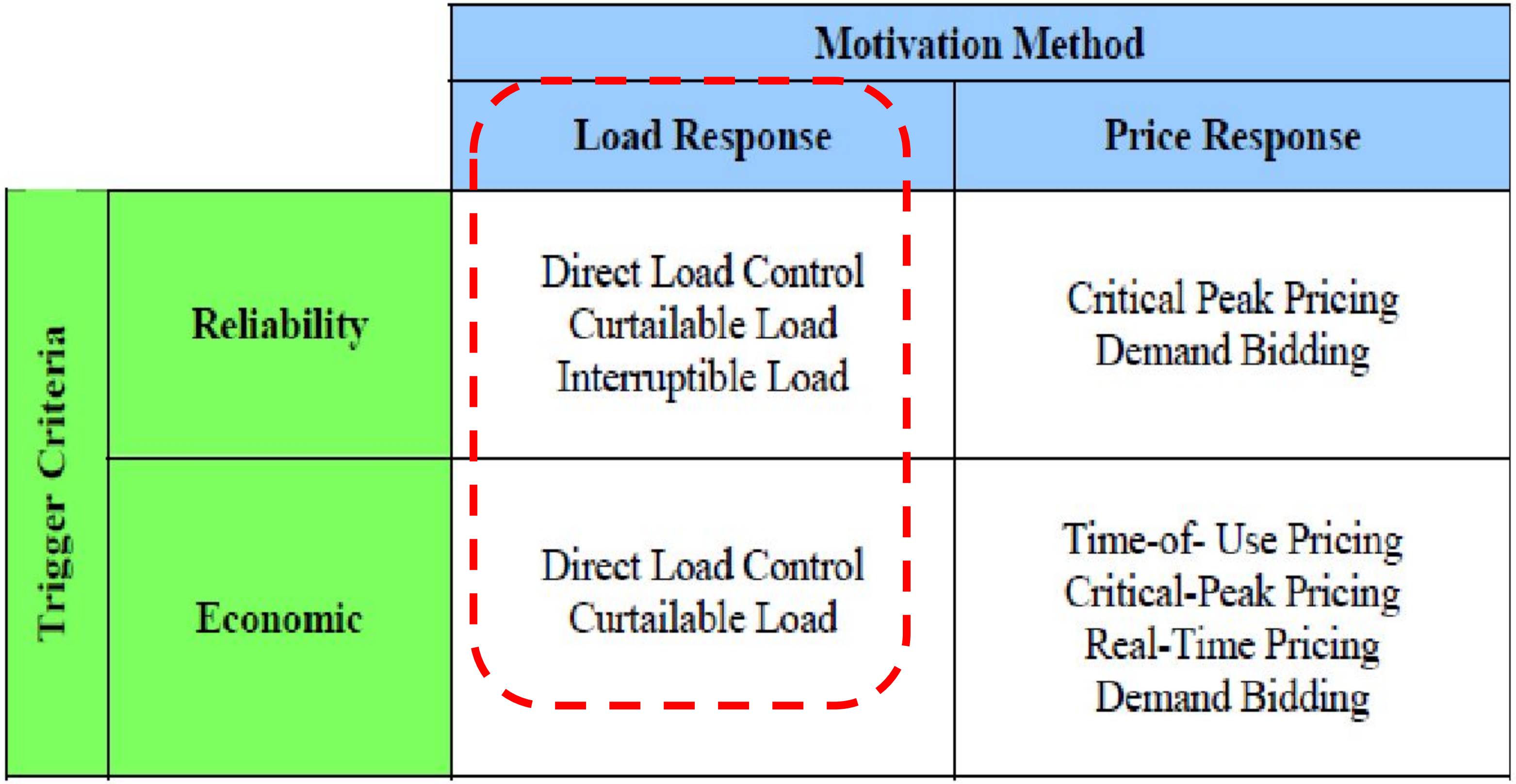
Smart Grids

Integration of renewable energies and flexible loads



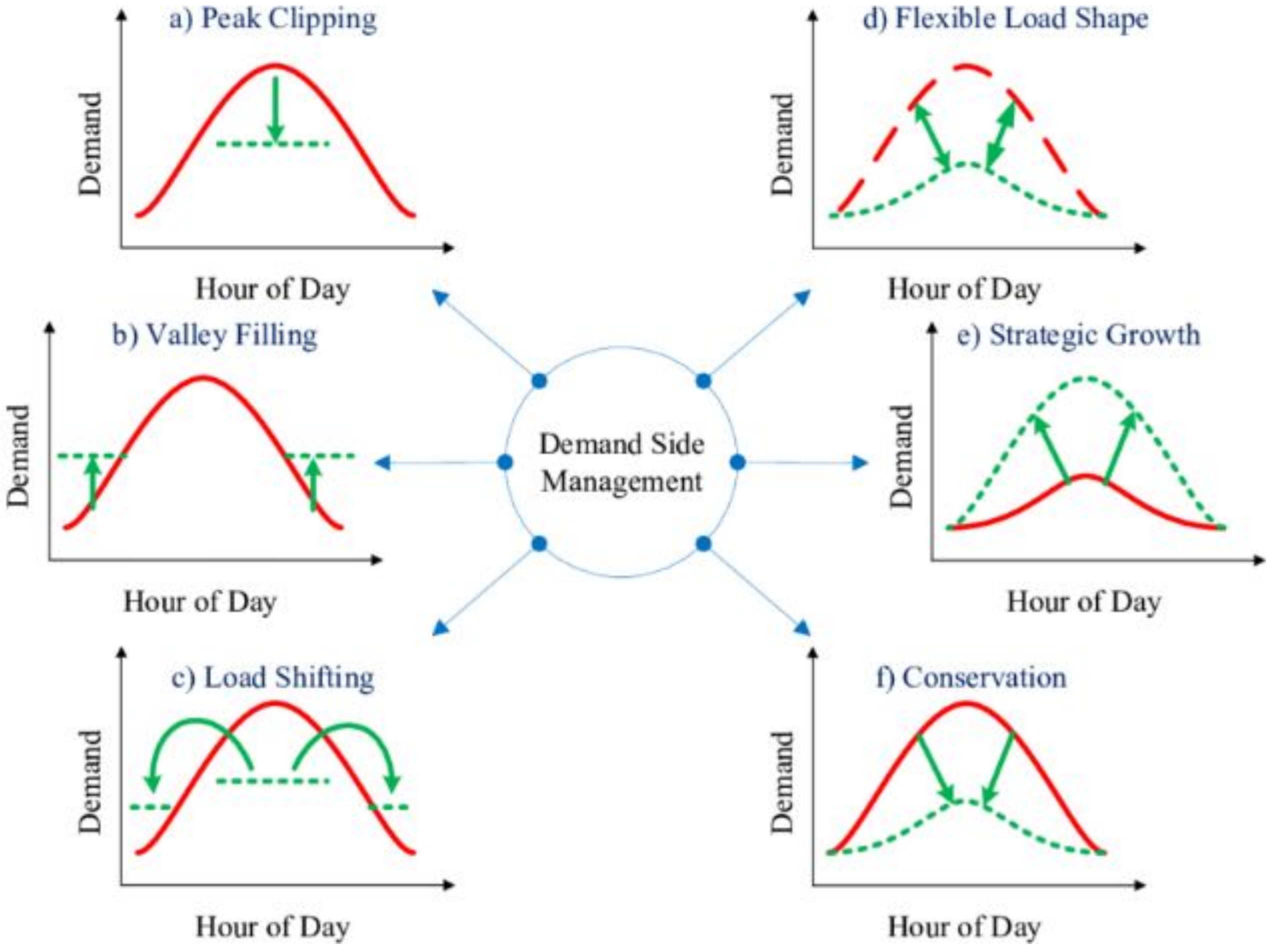
Demand Response Programs

Reliability and economic impacts of demand response programmes:



		Motivation Method	
		Load Response	Price Response
Trigger Criteria	Reliability	Direct Load Control Curtailable Load Interruptible Load	Critical Peak Pricing Demand Bidding
	Economic	Direct Load Control Curtailable Load	Time-of- Use Pricing Critical-Peak Pricing Real-Time Pricing Demand Bidding

Demand-Side Managment Strategies

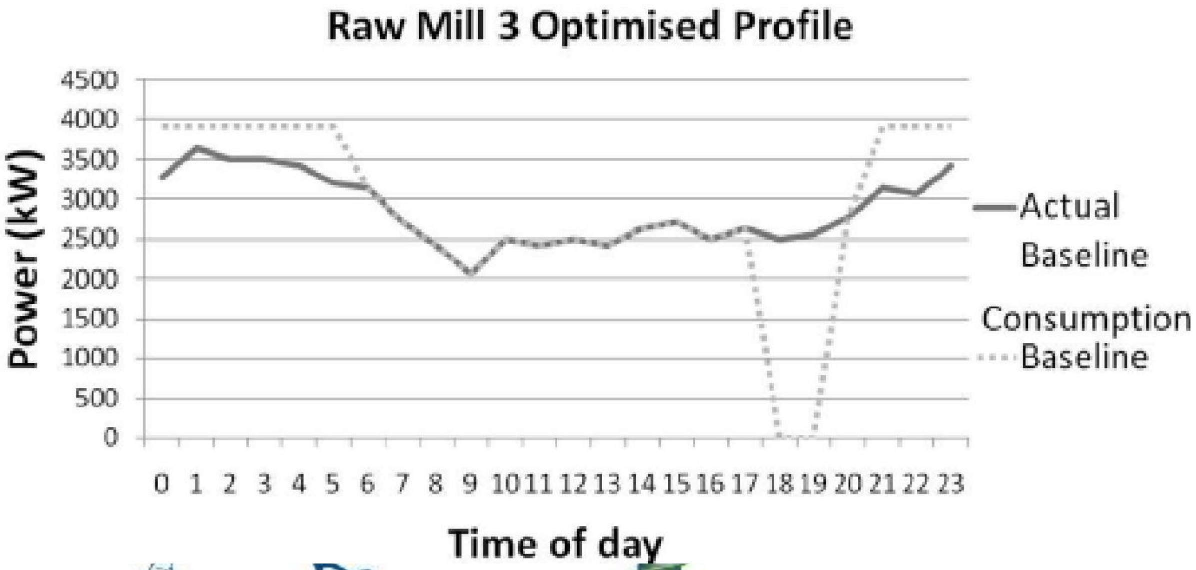


- The existing energy supply constraint will trigger the appropriate demand response
- For example:
- Various strategies will be det

Large Flexible Motor Loads

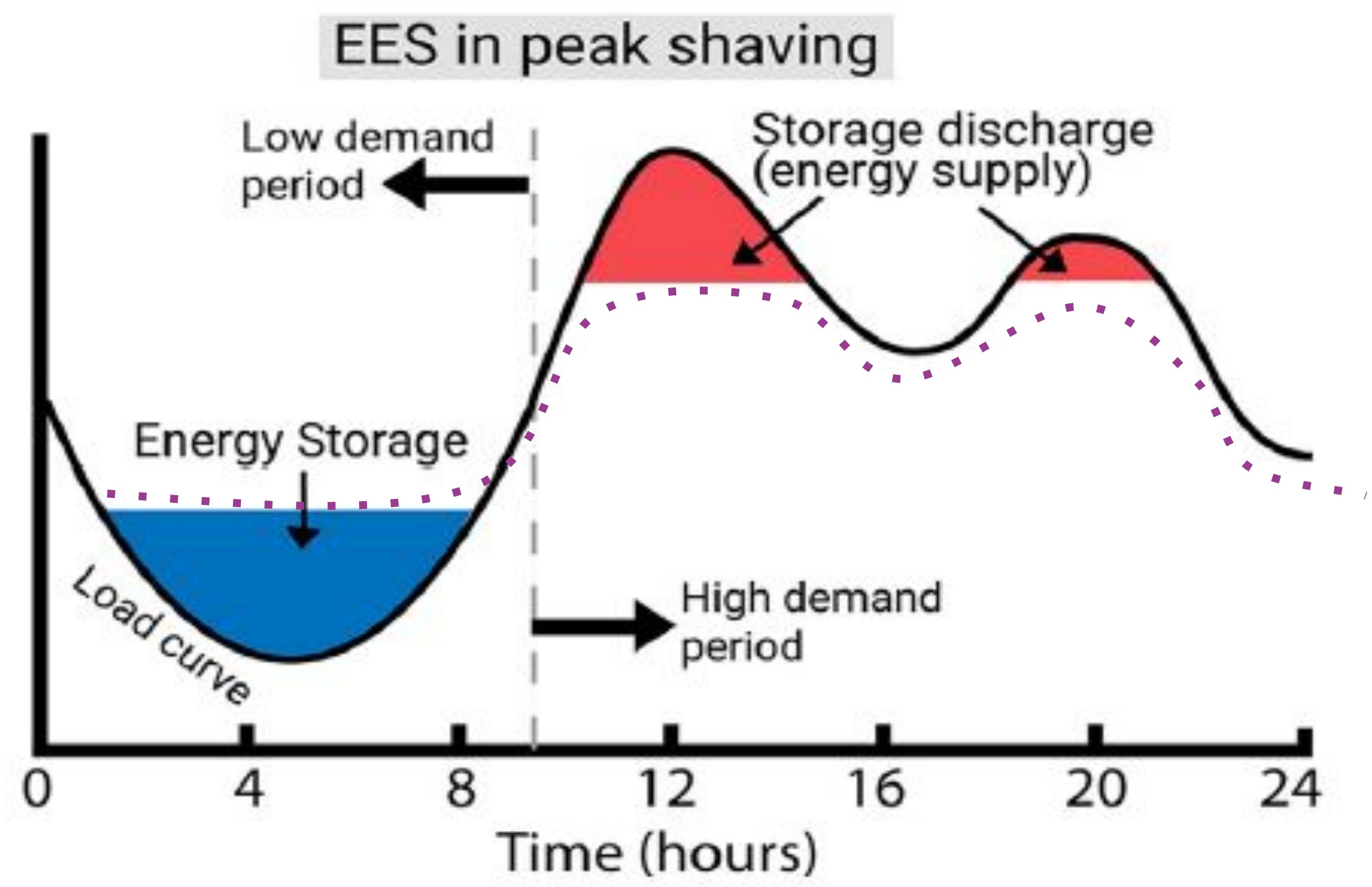
- Materials processing in industry (e.g. cement mills, mining industry)
- Refrigeration wharehouses
- Air conditioning loads with cool storage
- Large data centres
- Irrigation, namely to take advantage of solar power
- Sea water desalination, namely to take advantage of solar power, using water reservoirs
- **Electric vehicles (cars, buses, trucks) – charging can me made off-peak or with solar electricity**

Cement Mill Load Shifting



Period	Hour	Operation
Off-peak	0	Primary operation
	1	
	2	
	3	
	4	
	5	
	6	
Morning Peak	7	If silos are close to maximum cpacity the mills can be turned off
	8	
	9	
	10	
Standard Time	11	Ensure that the silos full enough to be shut down during evening peak
	12	
	13	
	14	
	15	
	16	
	17	
Evening Peak	18	No operation
	19	
	20	
Off-peak	21	Primary operation
	22	
	23	

Energy Storage for Load Profile Peak Shaving



- Storage can be achieved with electricity or through a service, like cold storage, water supply storage, materials processing in industry, etc.
- Result is a aflatter more regular demand profile with lower overall peak demands

Desalination with Water Storage

Egyptian program for promoting Industrial Motor Efficiency
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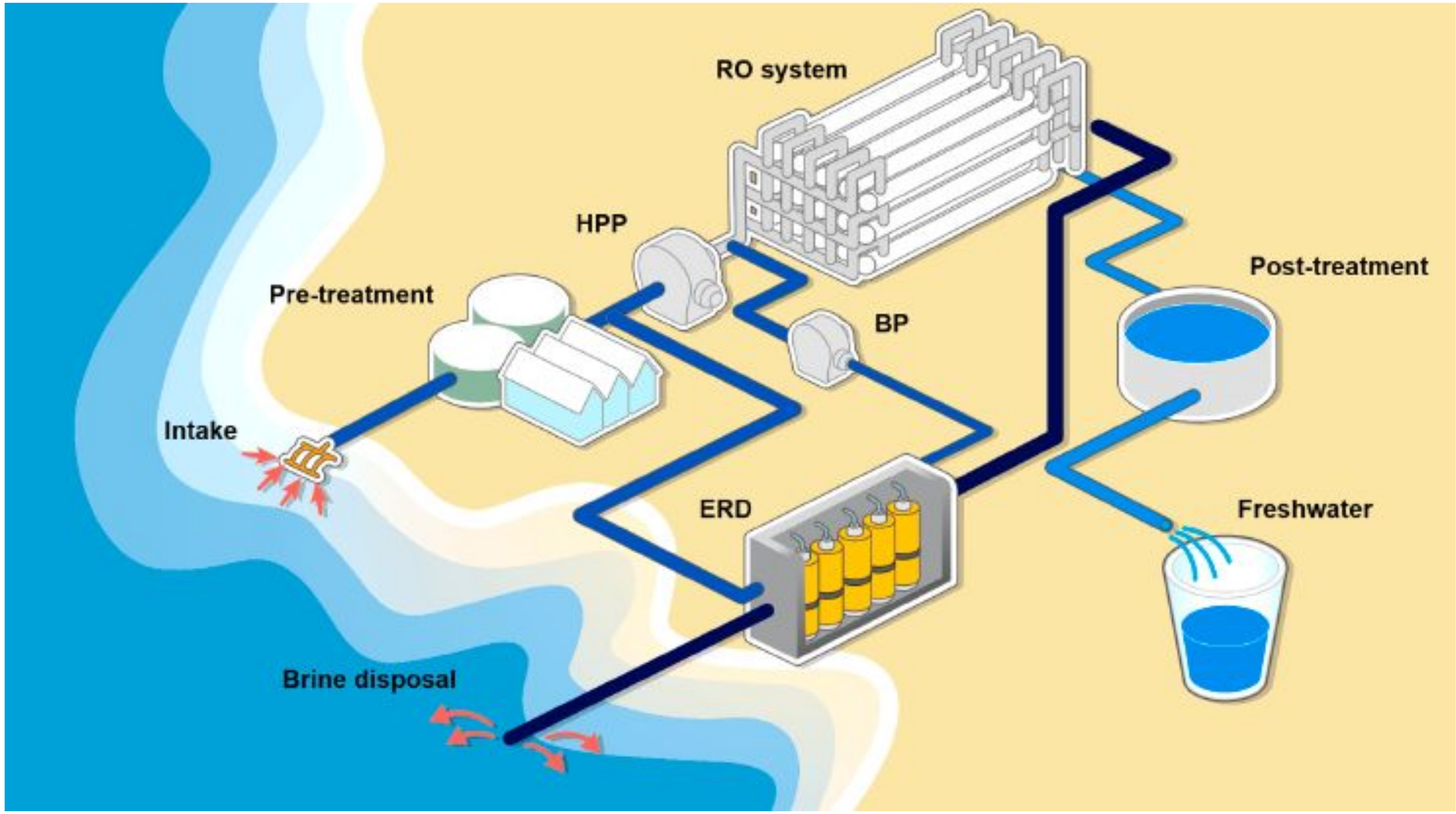
- Main load is high pressure water pump
- Water production from grid and solar depending on time of day
- No production during peak periods



Review & Discussion

- Any questions?

End of Course

Thank you for your participation

Please complete the course evaluation

Contact Details

Taymour Ibrahim
Egypt PMU

tibrahim@unido.org

Samir Khafagui
Facilitator

Samir@debeers-engineering.com

Siraj Williams
Facilitator

Siraj@triplepoint.co.za