Motor Systems Optimisation Expert Training

(2020 Egypt Edition)

Presented by:

Samir Khafagui & Siraj Williams

Acknowledgements

- UNIDO, Vienna
- Prof Anibal T de Almeida
- Dr Hugh Falkner
- Dr Gihan Bayoumi Attia
- Eng Siraj Williams

Course Objectives

- Why are we here?

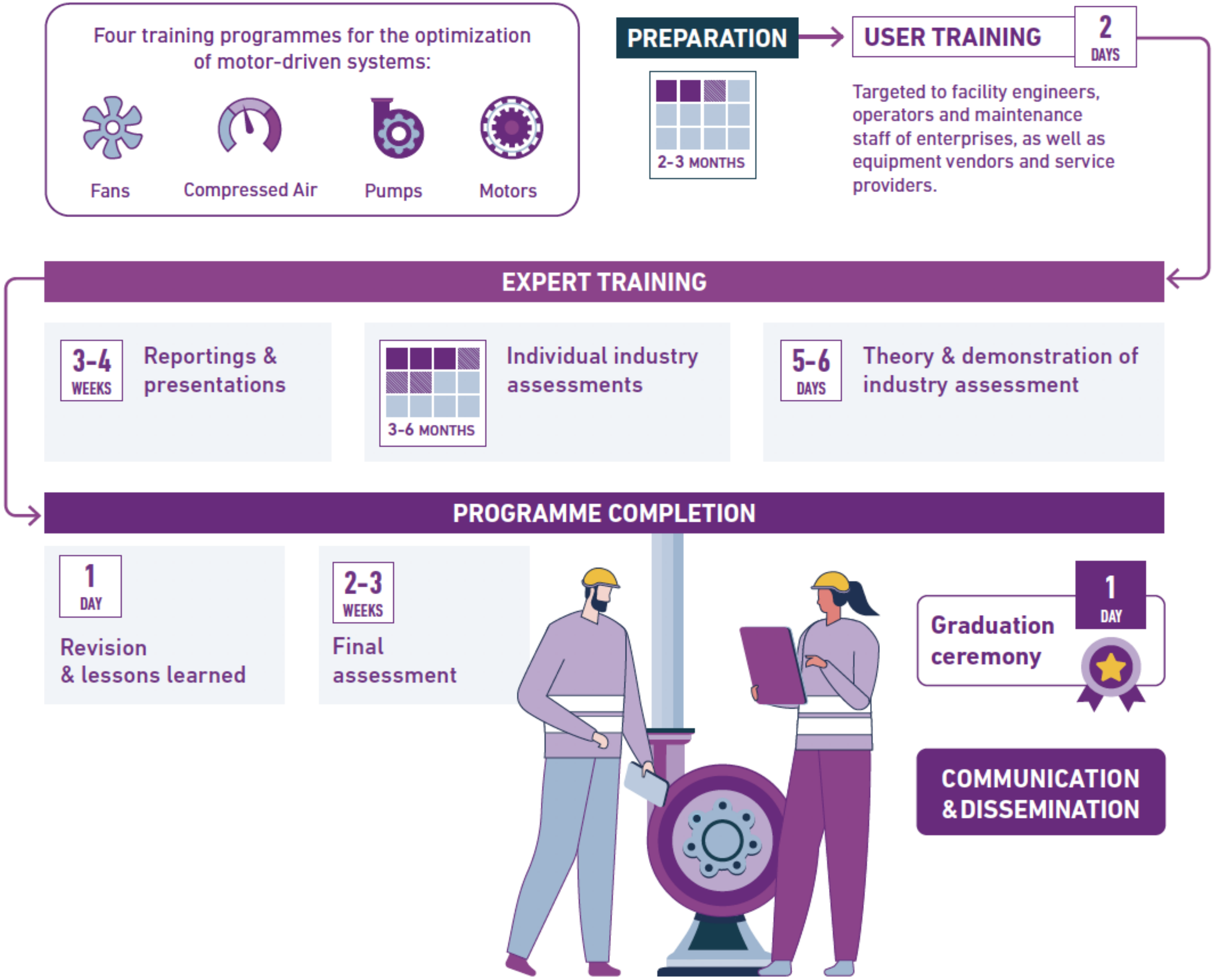
Welcome

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

The MSO Training Cycle

Key components:

1. User Training Class
2. Expert Training Class
3. Individual industry assessment
4. Final examination



Contents of this course

01. Introduction to UNIDO

Introduction

Motor Systems Optimisation (MSO) Expert Training (2020 Egypt Edition)

Samir Khafagui
Siraj Williams

Paris Agreement (2015)

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

Objective:

Reduce
global warming
by 2°
by the year 2030

Objectives of the UNIDO IEE Program

Egyptian program for promoting Industrial Motor Efficiency
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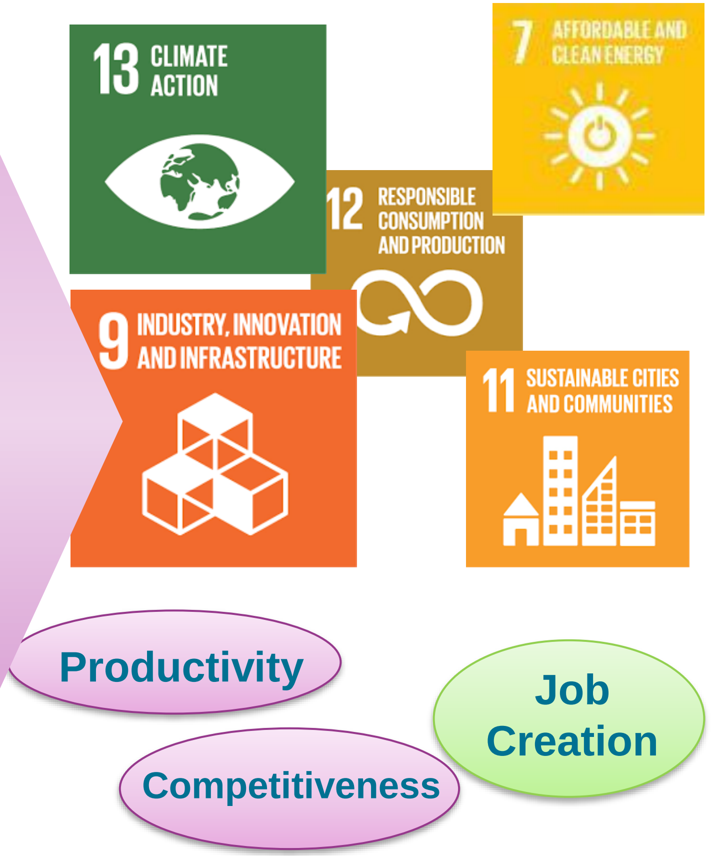
Work together with counterparts, stakeholders and partners to:

- **Strengthen policy** and regulatory frameworks for better & sustainable EE performance in industry
- **Accelerate adoption** and wide dissemination of IEE best-available practices and technologies
- **Save energy** and reduce GHG emissio of the industrial sector
- **Integrate EE** in industry daily business practices for sustainable increased productivity and competitiveness



UNIDO Industrial Energy Efficiency Portfolio

Egyptian program for promoting Industrial Motor Efficiency
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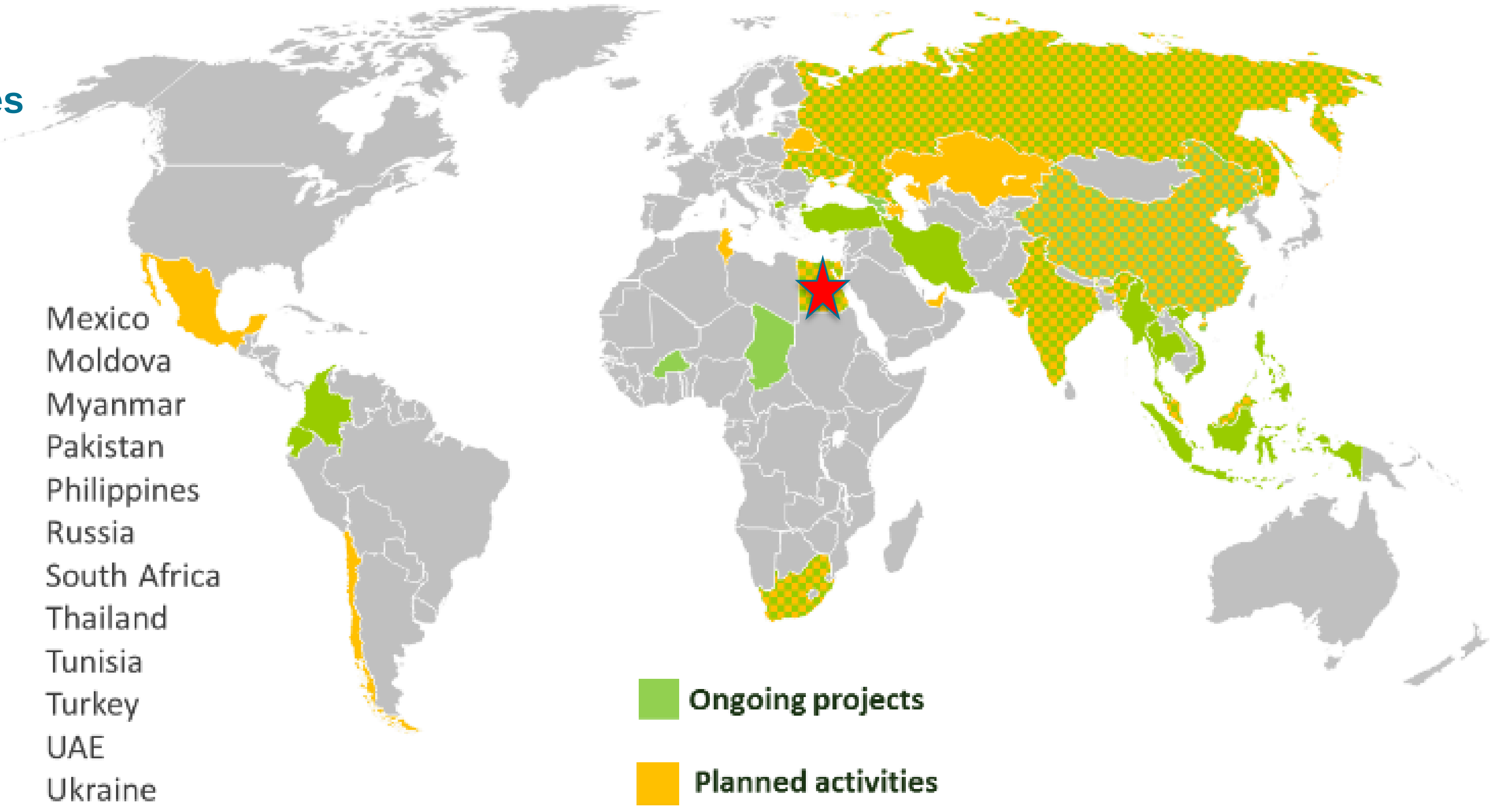
30 Countries

- Armenia
- Belarus
- Burkina Faso
- Chad
- Chile
- China
- Colombia
- Ecuador
- Egypt
- Georgia
- Kazakhstan
- India
- Indonesia
- Iran
- Macedonia
- Malaysia
- Maldives
- Mexico
- Moldova
- Myanmar
- Pakistan
- Philippines
- Russia
- South Africa
- Thailand
- Tunisia
- Turkey
- UAE
- Ukraine
- Viet Nam



02. Electric Motor Technologies

Motor Basics

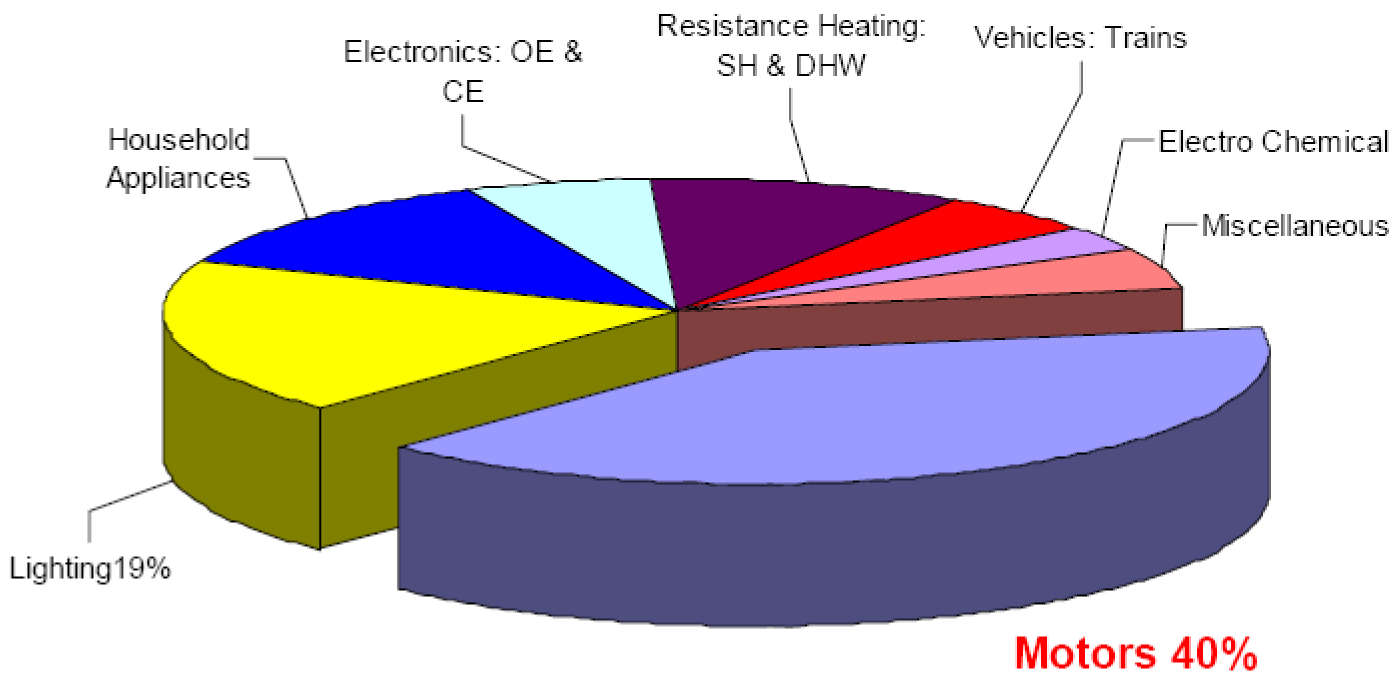
Motor Systems Optimisation (MSO) Expert Training
(2020 Egypt Edition)

Samir Khafagui
Siraj Williams

Discussed Topics

- Definition of motor system
- Types of electric motors
- Electric motor efficiency
- High efficiency electric motors

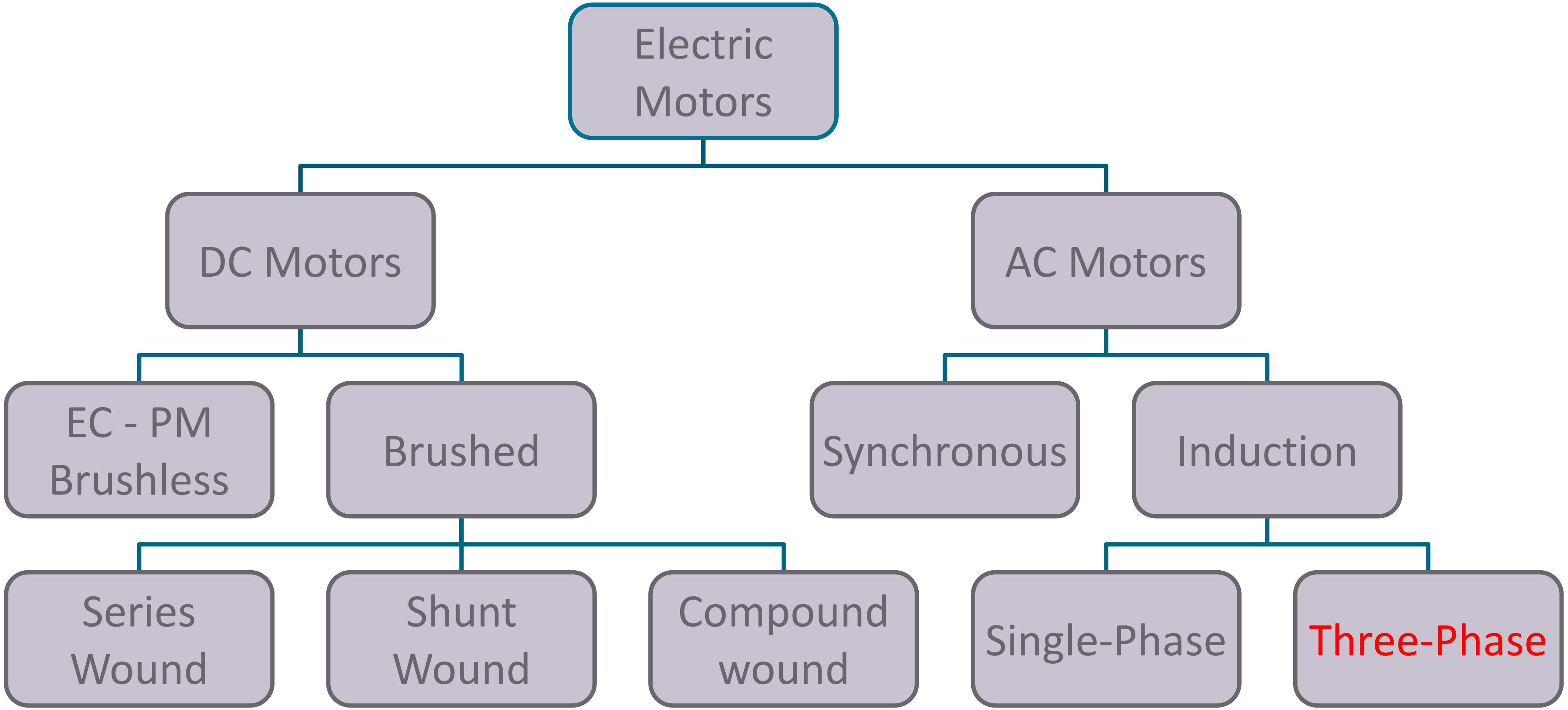
Motor Systems’ Energy Use



Global Electricity demand by end-use

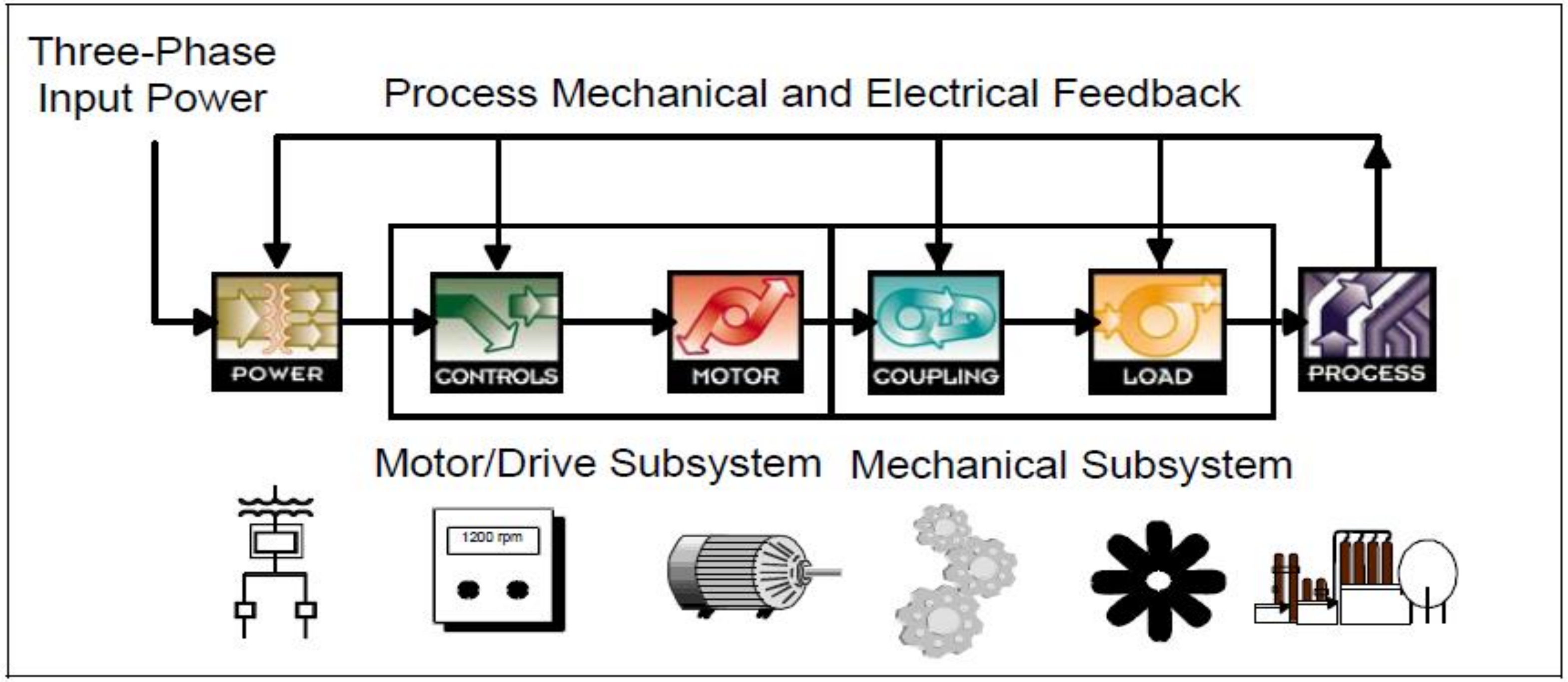
Source: A+B International 2008

Motor Types



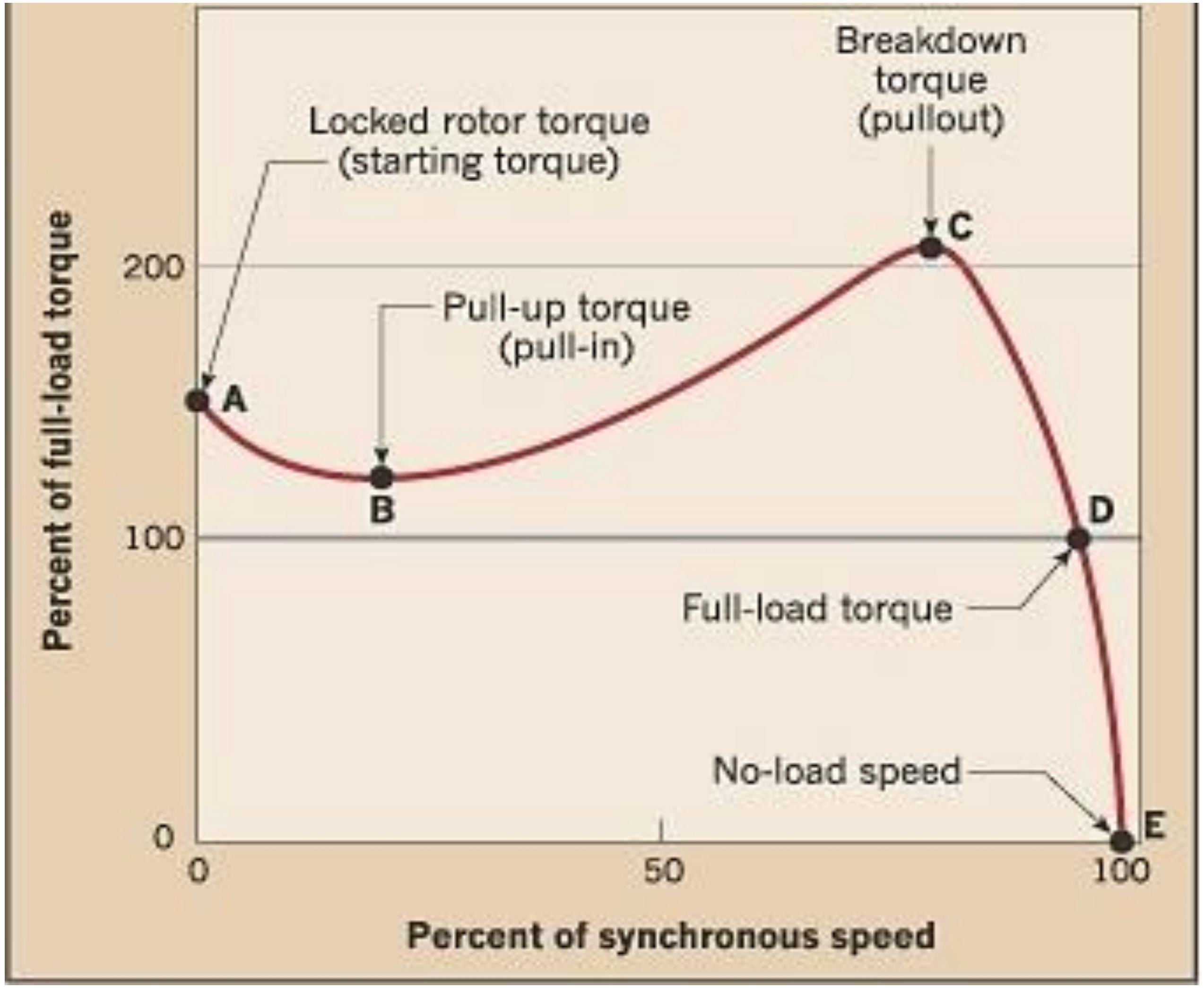
EC – Electronically Commutated
PM – Permanent Magnet

The Motor System



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

Typical Torque-speed Curve - AC Induction Motor

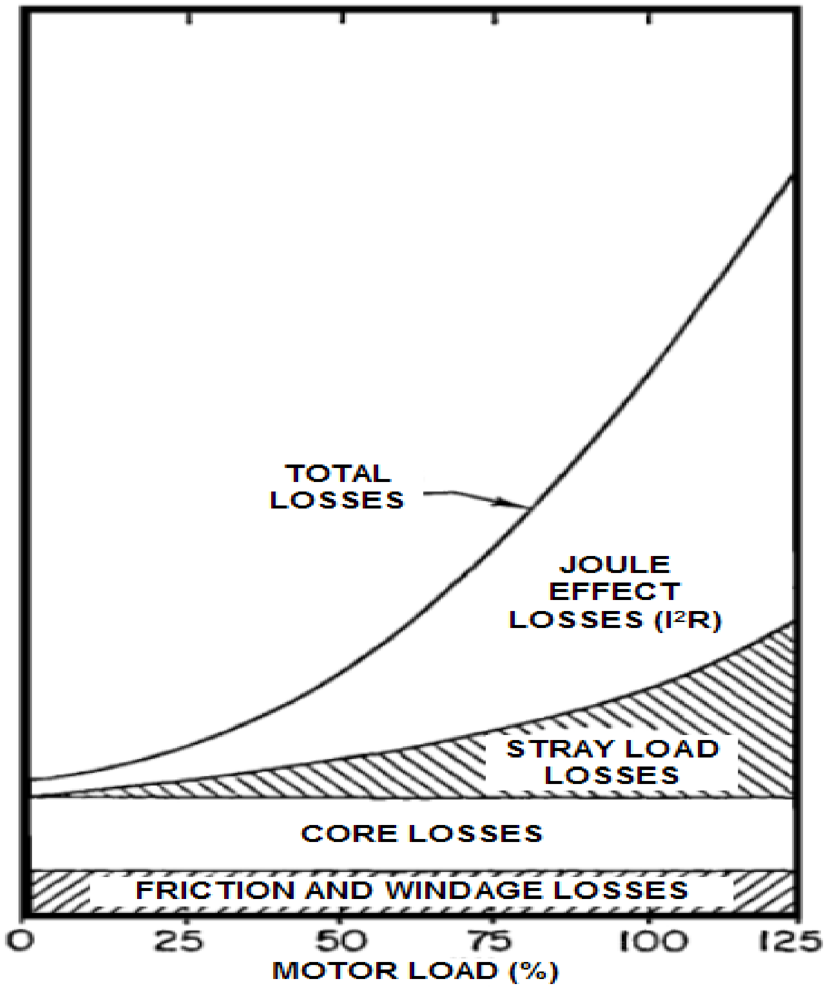


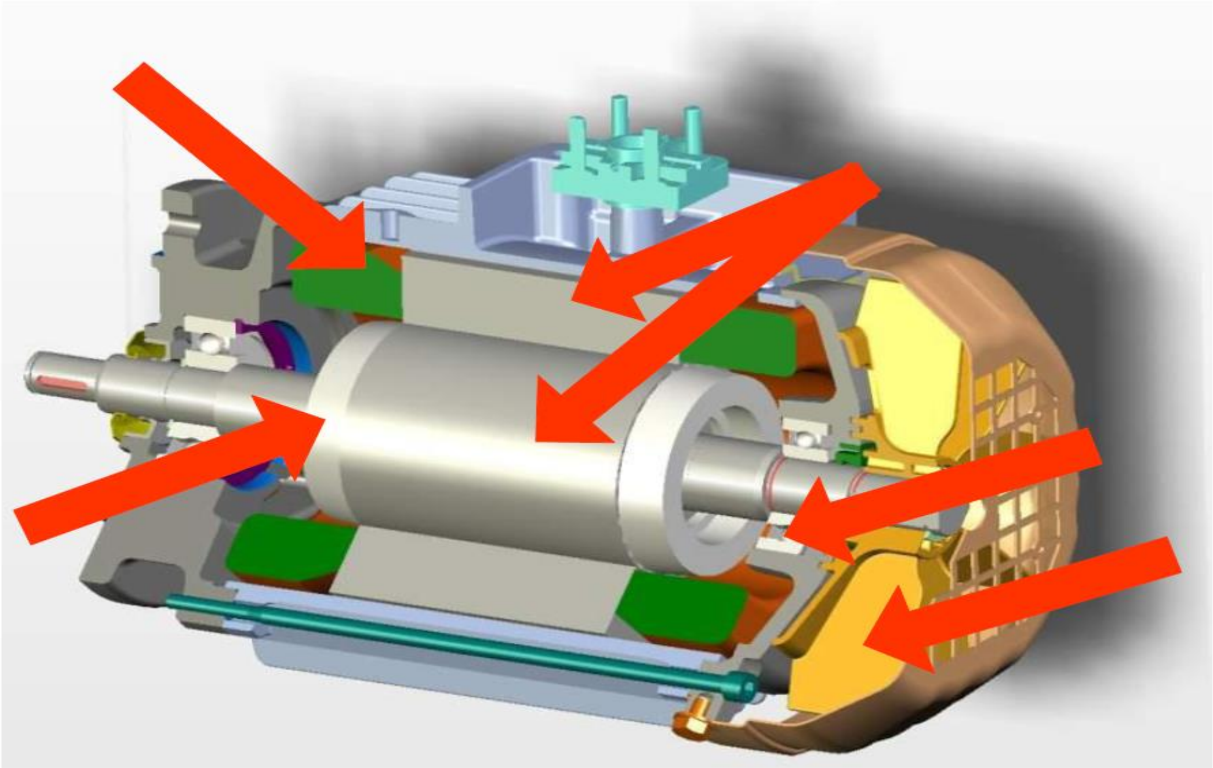
Motor Losses

- The **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.

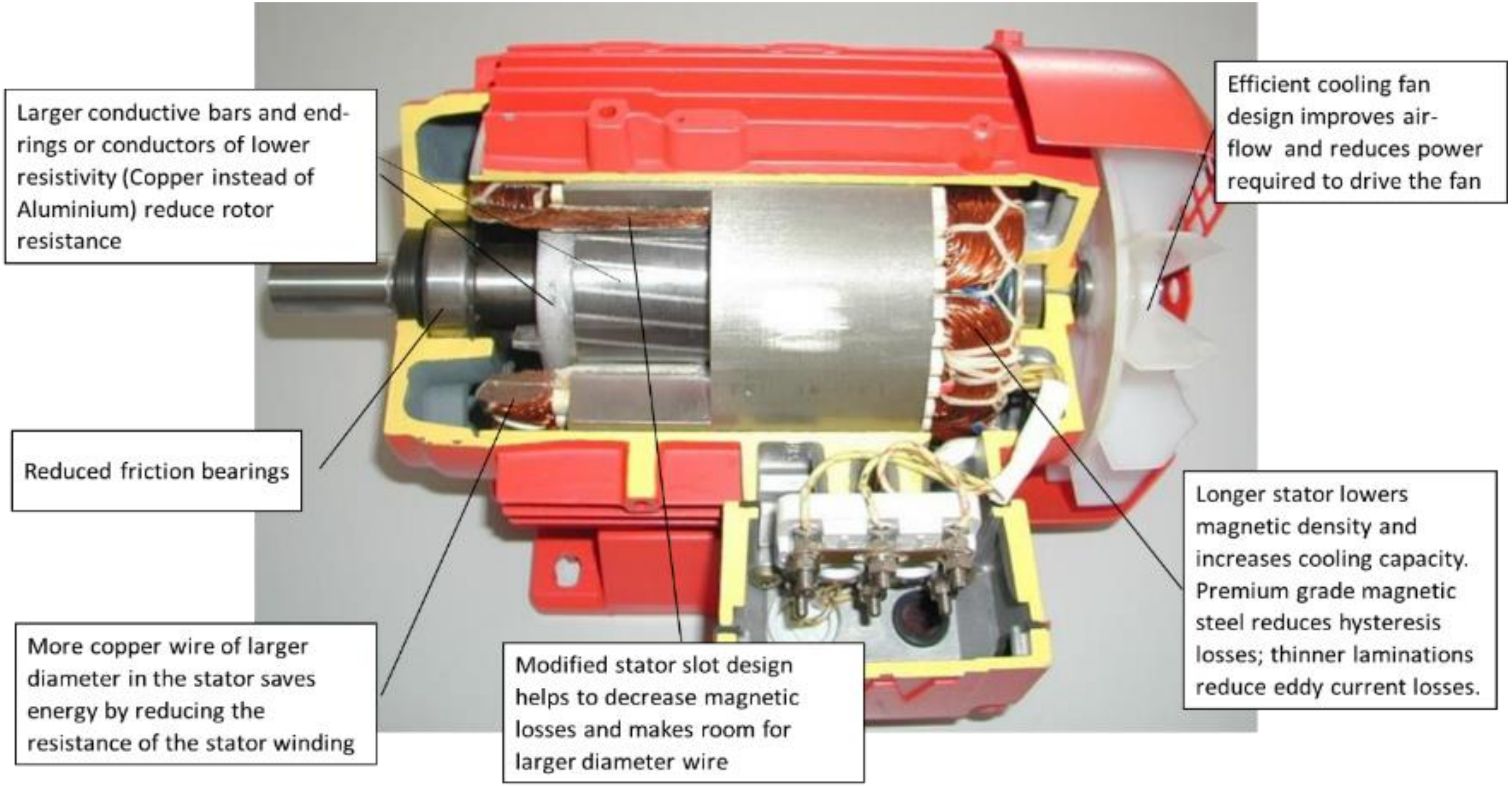
I - current; R – electric resistance

Motor Losses vs Motor Load





Features of a Premium Induction Motor

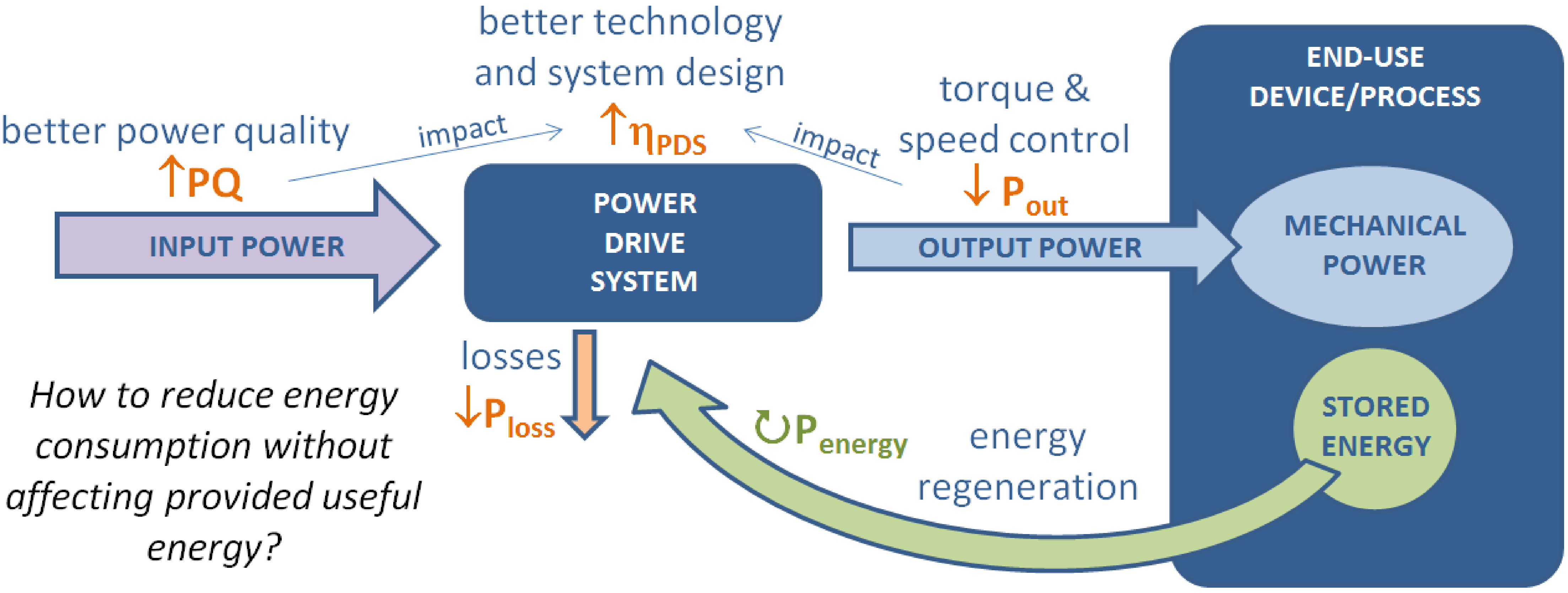


Factors Affecting Energy Efficiency

The efficiency of a motor system depends on several factors, including:

- motor efficiency
- motor speed/torque control
- proper sizing
- power supply quality
- distribution losses
- mechanical transmission
- maintenance practices
- end-use mechanical efficiency (pump, fan, compressor, etc.)

Strategies to improve electric motor system efficiency



How to reduce energy consumption without affecting provided useful energy?

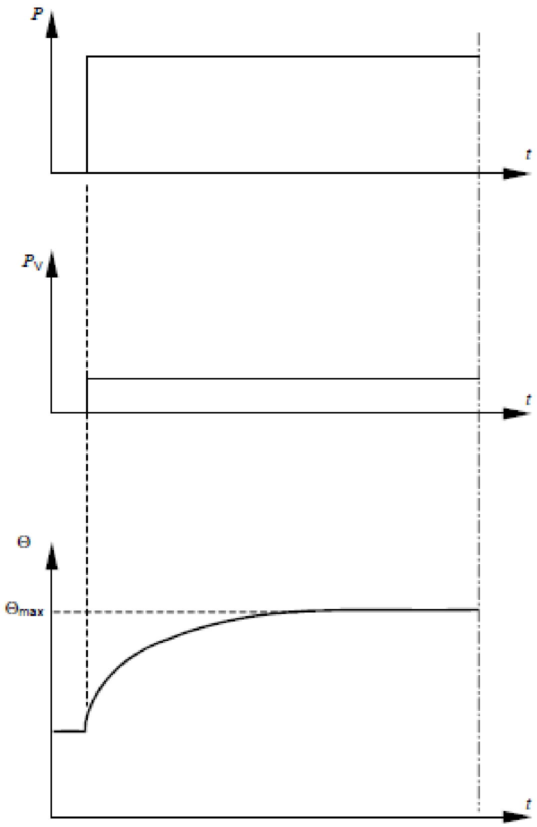
Duty Cycles (IEC Rating - IEC 60034-1)

No.	Ref.	Duty Cycle Type	Description
1	S1	Continuous running	Operation at constant load of sufficient duration to reach the thermal equilibrium.
2	S2	Short-time duty	Operation at constant load during a given time, less than required to reach the thermal equilibrium, followed by a rest enabling the machine to reach a temperature similar to that of the coolant (2 Kelvin tolerance).
3	S3	Intermittent periodic duty	A sequence of identical duty cycles, each including a period of operation at constant load and a rest (without connection to the mains). For this type of duty, the starting current does not significantly affect the temperature rise.

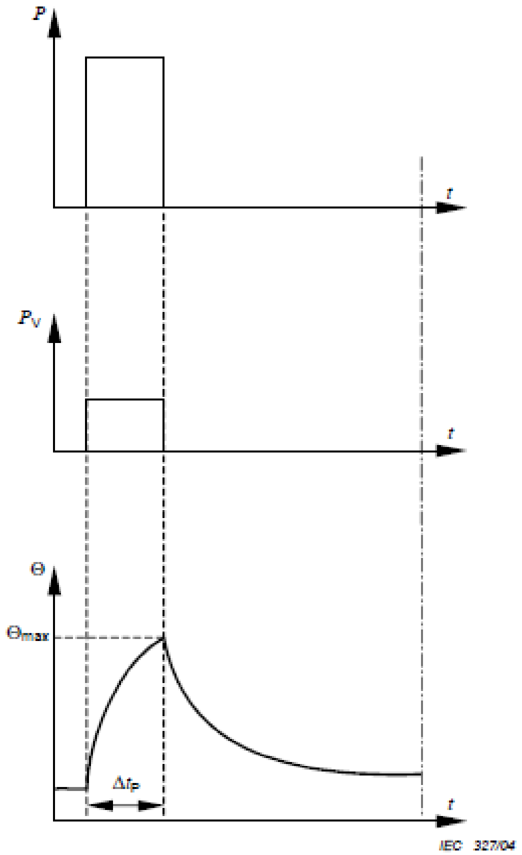
- IEC defines 10 different duty cycles.
- Only 3 shown here for illustration.
- S1 is most common for continuous duty
- Other duty cycles have a cyclic nature and are designed primarily around the ability to dissipate heat for the given duty cycle

Duty Cycles (IEC Rating - IEC 60034-1)

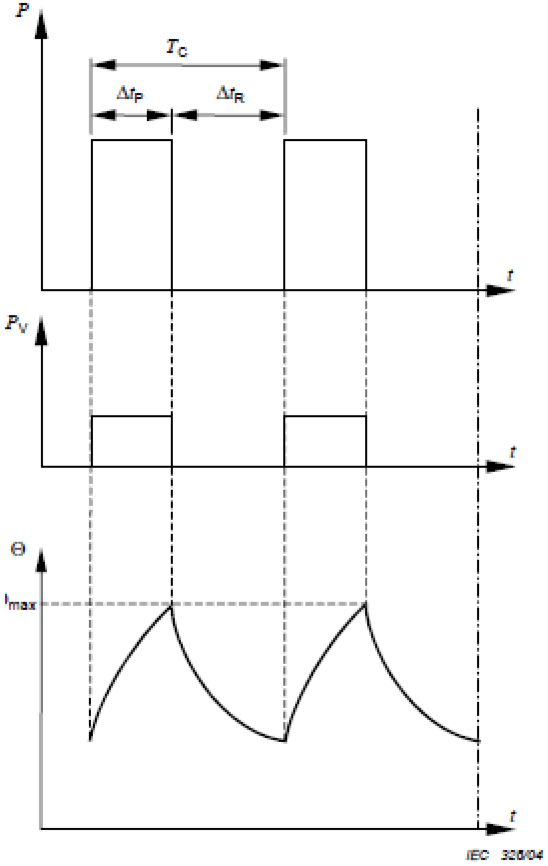
S1



S2



S3



Key

P	load
P_V	electrical losses
Θ	temperature
Θ_{max}	maximum temperature attained
t	time
Δt_P	operation time at constant load

Opportunities for Savings

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	Electrical components	Mechanical components	Application	Factory Automation	Energy Recovery
	Proper and regular maintenance				
S1 Continuous Duty	Energy-efficiency motors	Energy-efficient gearboxes, belts, …	Variable speed drive systems	Most efficient power-supply	
	Power-factor correction devices	Energy-efficient pumps, fans, compressors,…	Reducing elec. transmission losses	Low-energy mode during stand-still	
S2 Short-Time	Use most economical components				
S3…S10 Intermittent Duty	Soft-start with frequency control	Minimize rotating inertia	Variable speed drive systems	Most efficient power-supply	Regenerative braking
					DC-link coupling
			Optimized mass and flow	Low-energy mode during stand-still	Batteries, ultra-caps, fly-wheels etc.

Source: IEC60034-31

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Most induction motors have a squirrel cage made with die cast aluminium

- A copper rotor is a rotor made of electrical steel (laminations) where the slots and end rings are filled with copper instead of the traditional material (aluminium).
- The use of copper in place of aluminium can lead to improvements in motor energy efficiency due to a significant reduction in I^2R losses in the rotor.

Induction Motors – Die Cast Copper Rotor

- EXAMPLE: 1.1-kW DIE CAST COPPER ROTOR

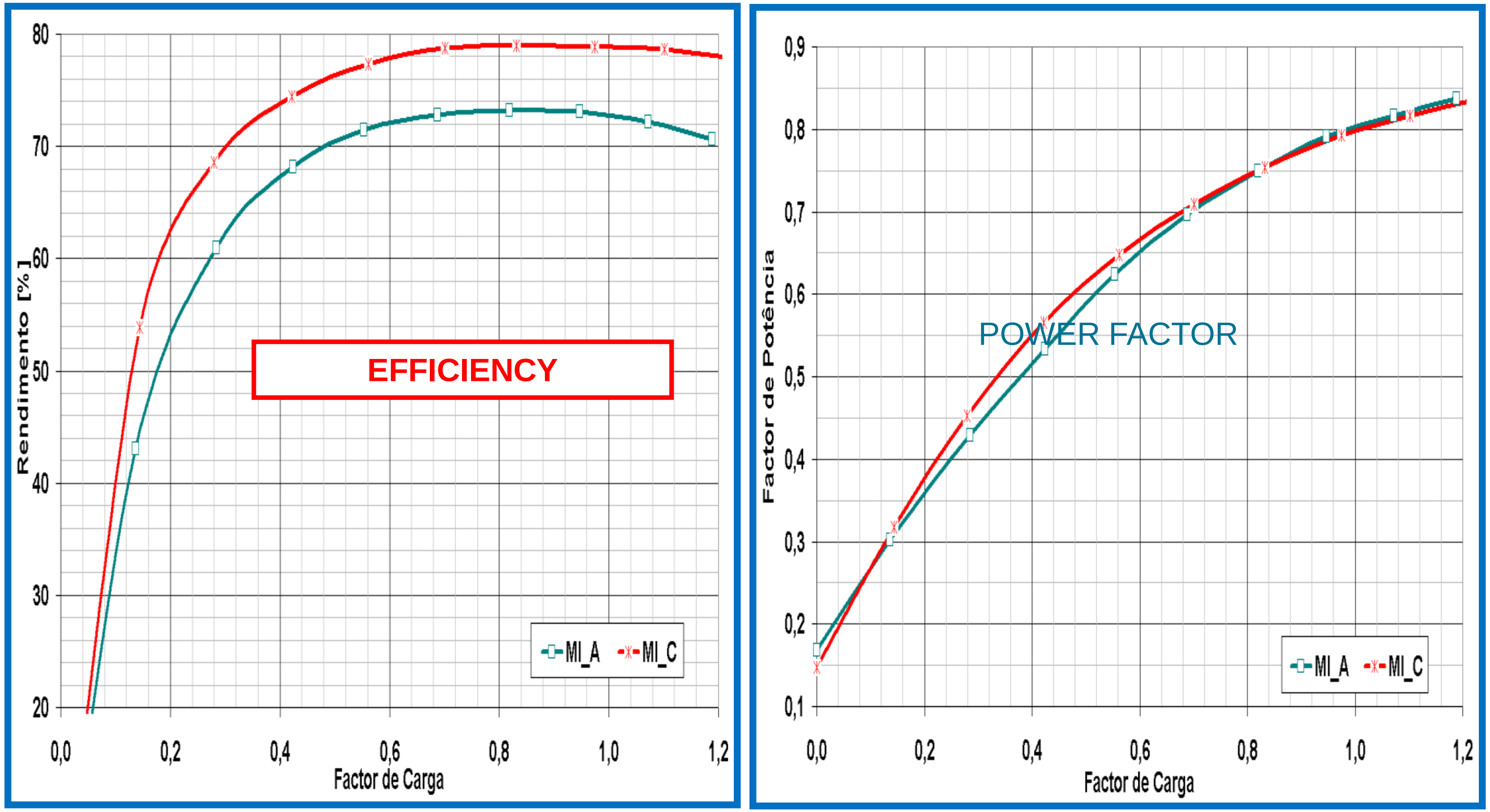
Higher efficiency and higher speed, when compared to the aluminum rotor EEMs.

Squirrel Cage	Aluminum	Copper
Efficiency Class	IE2	IE3
Enclosure	TEFC	TEFC
Nominal Voltage, U_n	400 V	400 V
Nominal Current, I_n	2.80 A	2.45 A
Nominal Speed, n_n	1410	1435
Nominal Power, P_n	1.1 kW	1.1 kW
Power Factor $\cos_{\varphi n}$	0.77	0.78

Comparison between COPPER (MI_C) and ALUMINUM (MI_A) squirrel cage motors

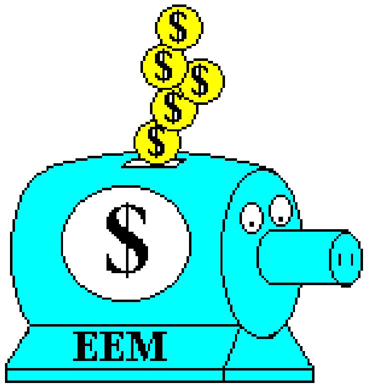
Induction Motors – Die Cast Copper Rotor

Die Cast Copper Rotor vs Aluminium Rotor (4 pole, 1.1 kW)



Energy Efficient Induction Motors

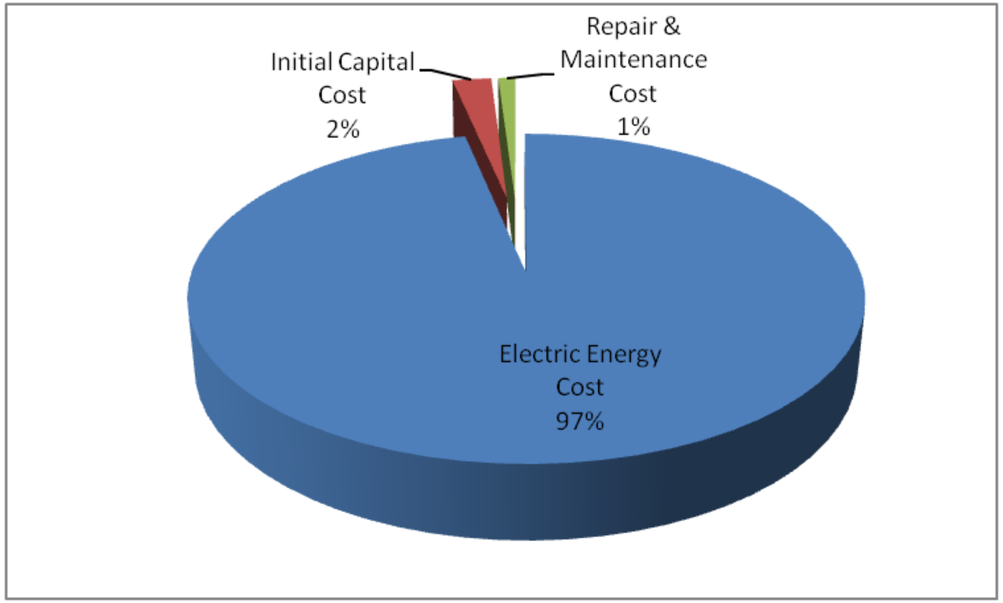
- Higher efficiency (2-10% more depending on motor power);
- They can reduce energy bills as well as the maintenance costs;
- More active materials of higher quality – more expensive (25-30%);
- Longer lifetime (due to lower operating temperature);
- Typically, lower starting torque (depends on the rotor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



Squirrel-cage Induction Motors Lifecycle Cost

- In Industry, an induction motor can consume per year an energy quantity equivalent to 5-10 times its initial cost, along all its lifetime of about 12-20 years, representing 60-200 times its initial cost.

- This fact justifies a life-cycle cost (LCC) analysis including the repair and maintenance.



11 kW IE3 Motor, 4000 operating hours per year, 15 years life cycle 1.5 EGP/kWh

Source: ISR – University of Coimbra

Permanent Magnet Synchronous Motors (PMSM)

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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

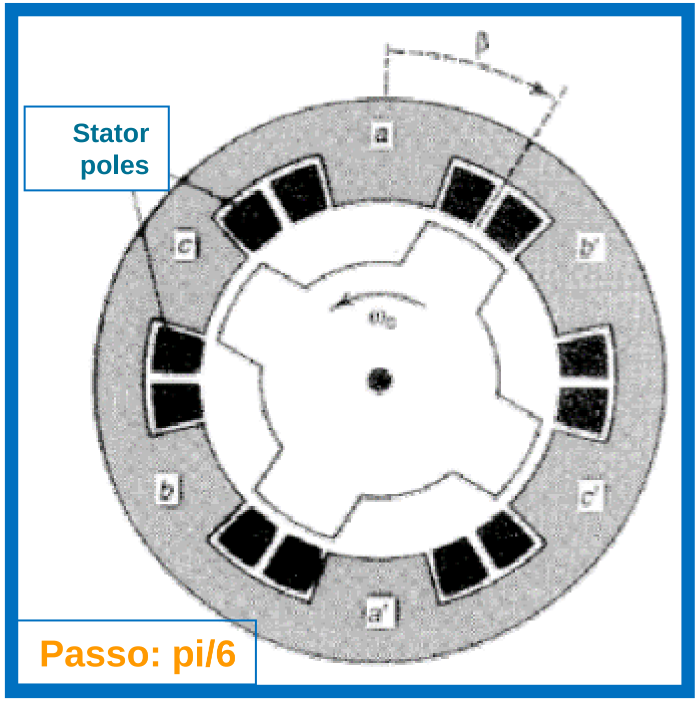
Switched Reluctance Motors (SR)

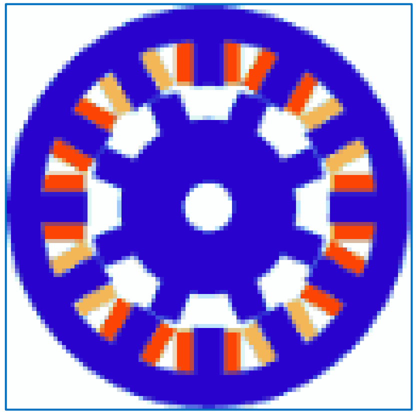
- An SR motor is a doubly salient design with phase coils mounted around diametrically opposite stator poles.
- Energisation of a phase will cause the rotor to move into alignment with the stator poles, so minimizing the reluctance of the magnetic path. As a high performance variable speed drive, the 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.

Switched Reluctance Motors

STATOR: 6 POLES (3 PHASES)

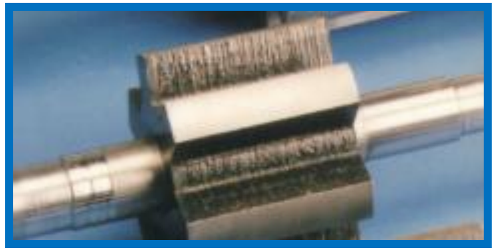
ROTOR: 4 POLES





STATOR: 8 POLES

ROTOR: 6 POLES



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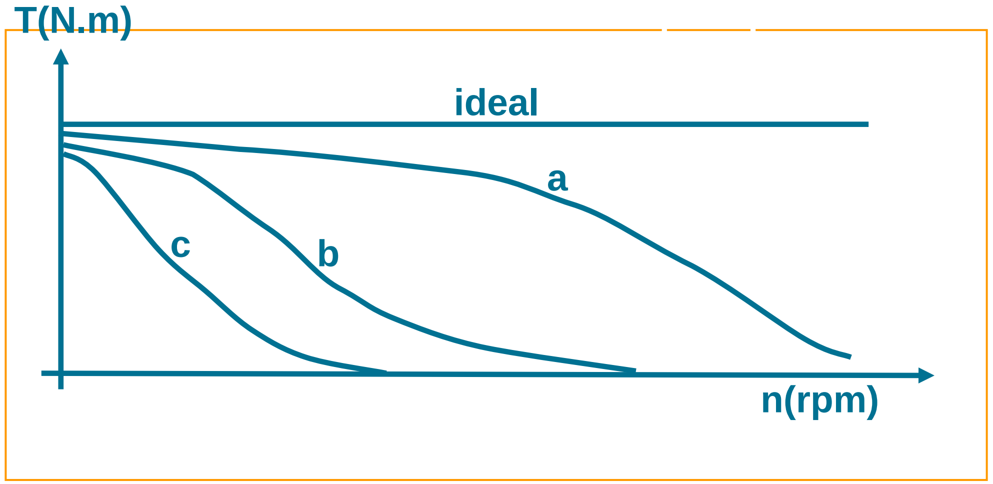
APPLICATIONS UP TO 75 kW:

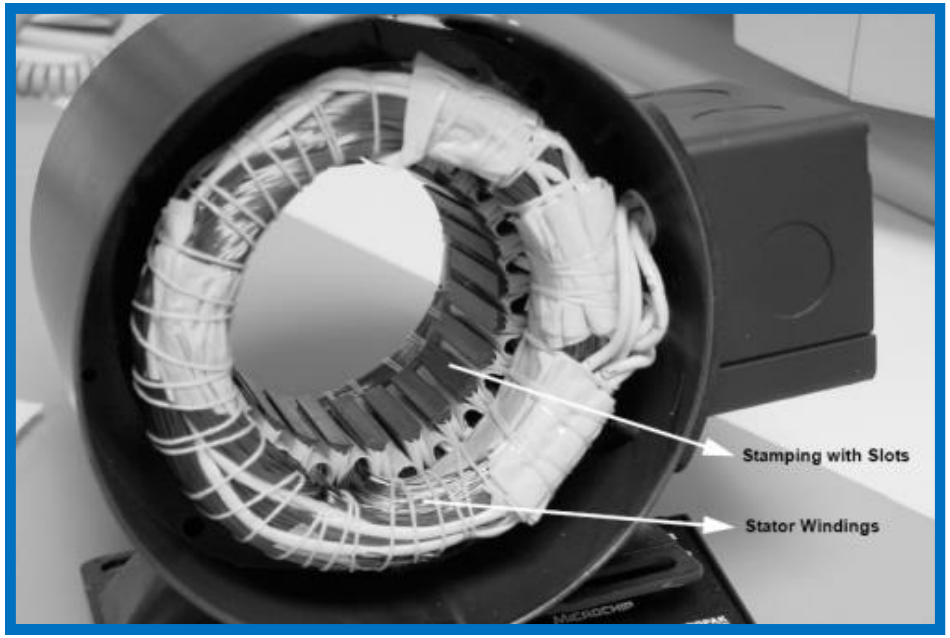
- High speed centrifugal machines
- Compressors
- Washing machines
- Vacuum cleaners
- Vacuum pumps
- HVAC**
- Variable-speed drive systems
- Machine-tools
- Automation
- Traction, etc.

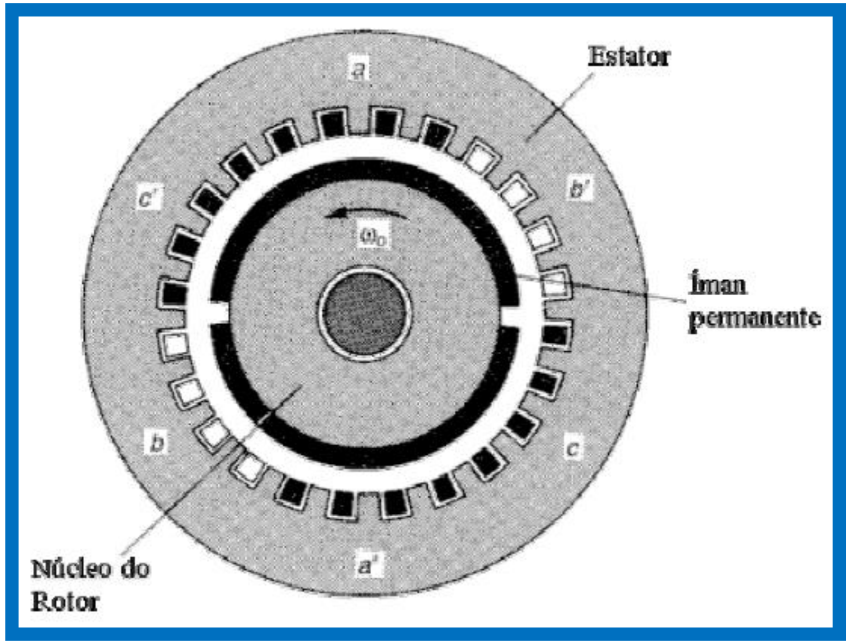


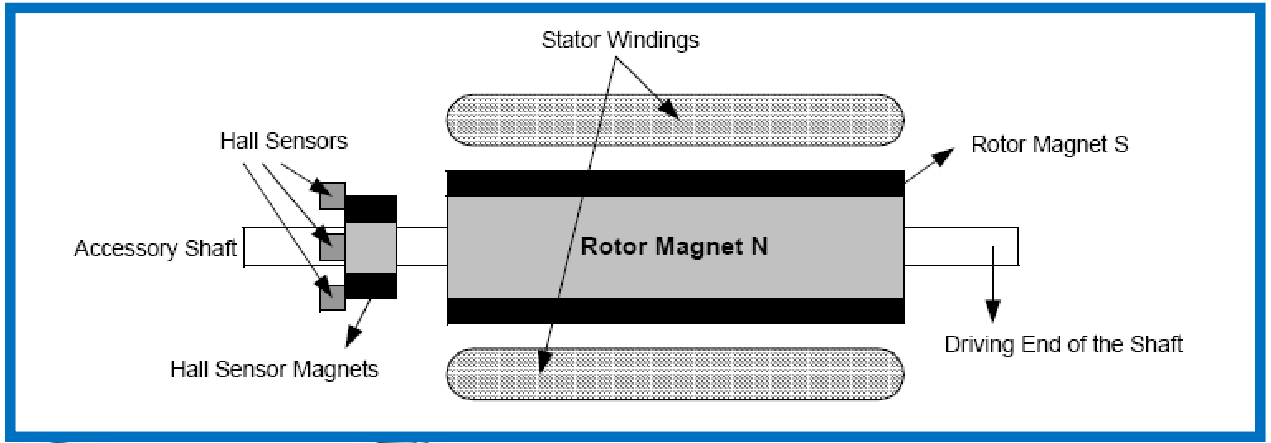
Source: ISR – University of Coimbra

** Heating, Ventilation, Air Conditioning

Permanent Magnet Synchronous Motors

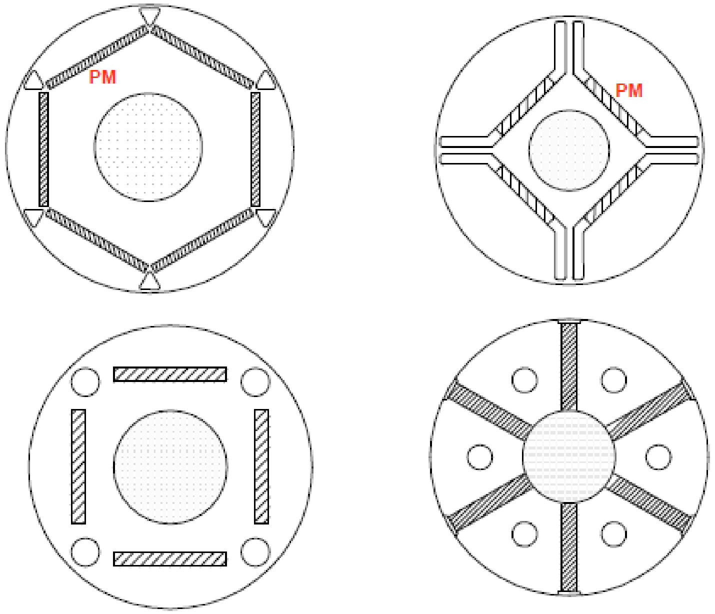


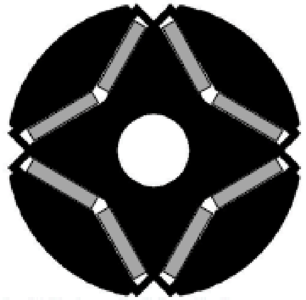




Permanent Magnet Synchronous Motors

- The rotor position is detected by hall effect or optical sensors, which is used to excite the stator windings properly.
- The electronic control circuit can be embedded in the motor
- The magnets are typically ferrite or rare-earth alloy (*neodymium (nd)+ferrite+boron (ndfeb)*).
- High currents or temperatures can demagnetize the rotor.
- Interior magnets are more robust and cheaper





V-shape PM

Permanent Magnet Synchronous Motors

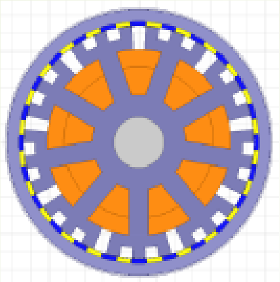
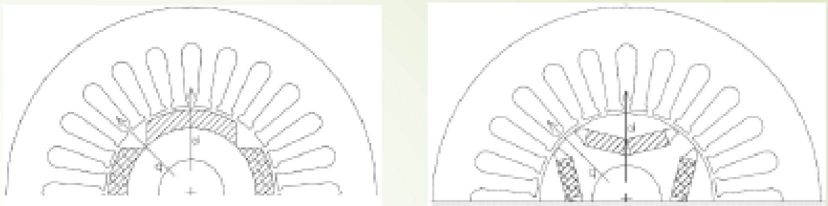


Table – 4 Qualitative comparison under harsh environment



	PMPM	*SPM*	*IPM*
Machine cost	Very High due to more magnet weight	Higher than IPM due to arc shaped magnets	Lower due to rectangular magnets
Drive cost	Higher due to poor pf and higher drive current	Lower as compared to PMPM	Lower as compared PMPM
Performance measures	Poor pf and higher Drive current, No demagnetization at higher temperatures	Demagnetization at high temperatures	Robust under high temperatures

Permanent Magnet Synchronous Motors

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- **Pole-modulated PM machine:** Higher power density and reliability under higher temperatures – Higher machine cost – Very Poor power factor – Large Drive size and cost. Lower magnet weight can reduce cost but suffers even worst power factor, which causes even higher drive cost.

- **Surface PM Machines**: Better choice for direct drive solutions - at a cost of arc shaped magnets- but are more prone to demagnetization under higher ambient temperature.

- **Interior PM Machines**: Less susceptible to demagnetization as compared to surface type PM machines - more reliable under higher temperatures and extreme operating conditions - cost of IPM machines - lower as compared to SPM and PMPM machines.

- Considering cost and demagnetization, IPM machines are the most competitive choice for low-speed direct-drive applications in demanding environments.

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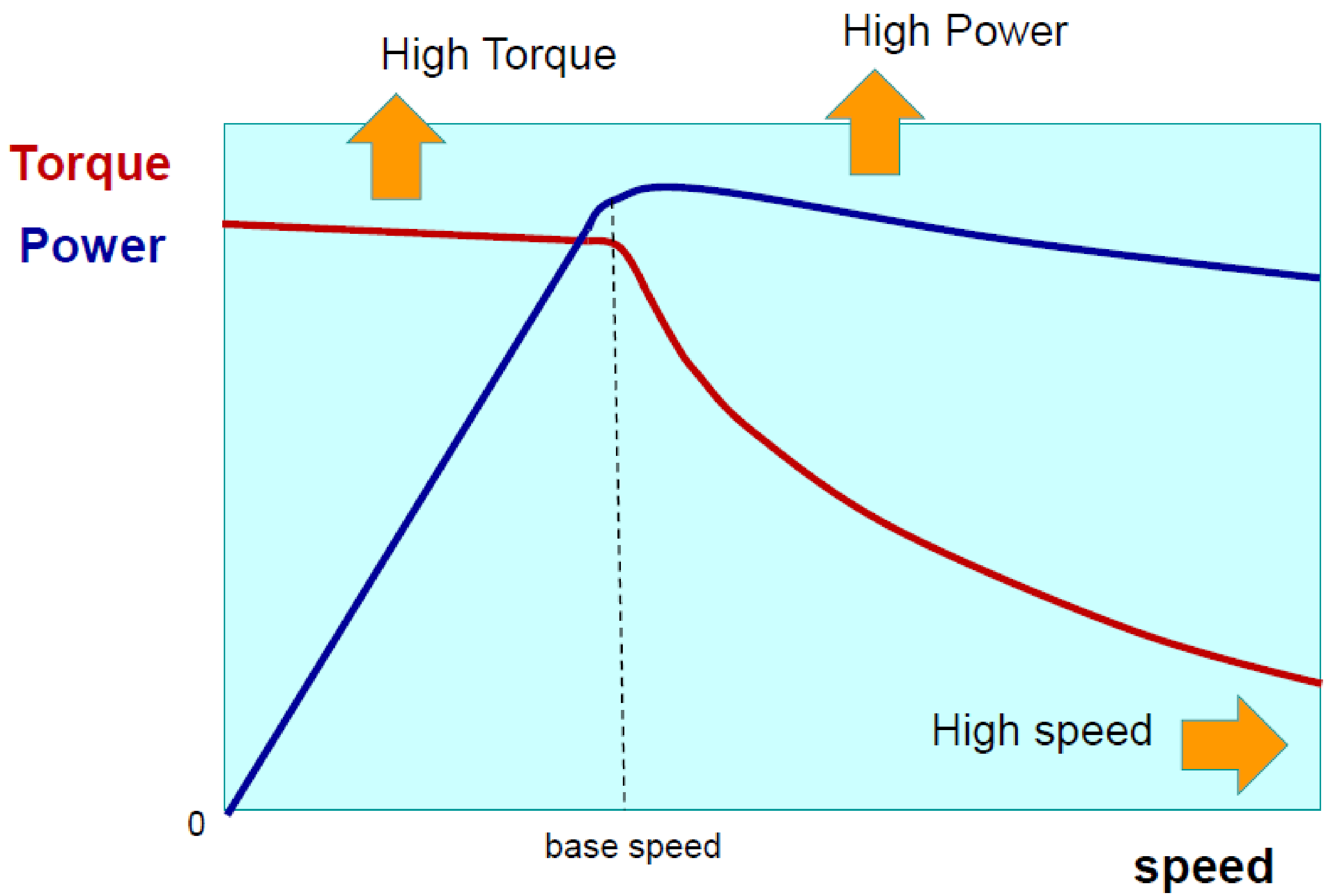
Torque Speed characteristics of PMSM



Synchronous Reluctance Motors

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- New synchronous reluctance motor (SynRM) and drive packages optimized for pump and fan applications
- The new rotor has neither magnets nor windings, and thus suffers virtually no power losses – which makes it uniquely cool.
- A standard IM fitted with a new rotor, combined with a standard drive with new software, results in a high output, high efficiency VSD system

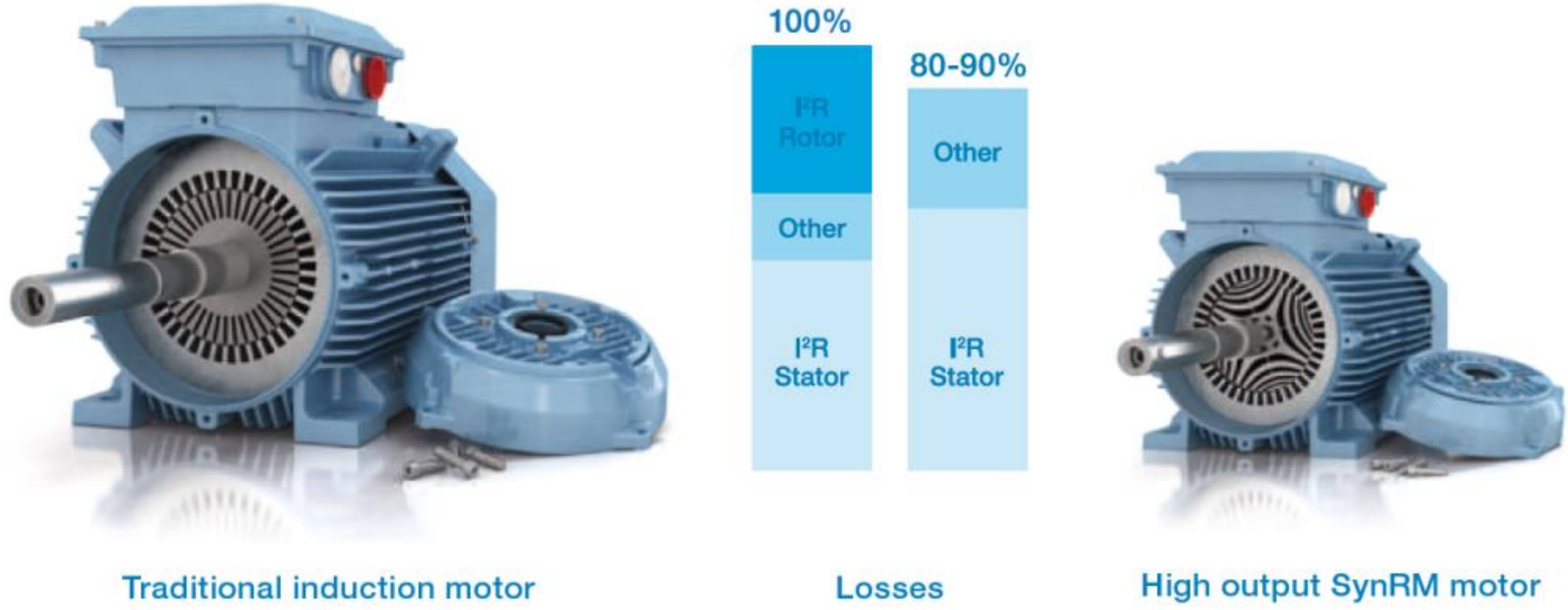
Advantages:

- No winding and PM in the rotor
- Low inertia
- Good acceleration performance
- Good flux weakening operation
- Low manufacturing cost

Disadvantages:

- Low power factor
- Torque ripple

Synchronous Reluctance Motors

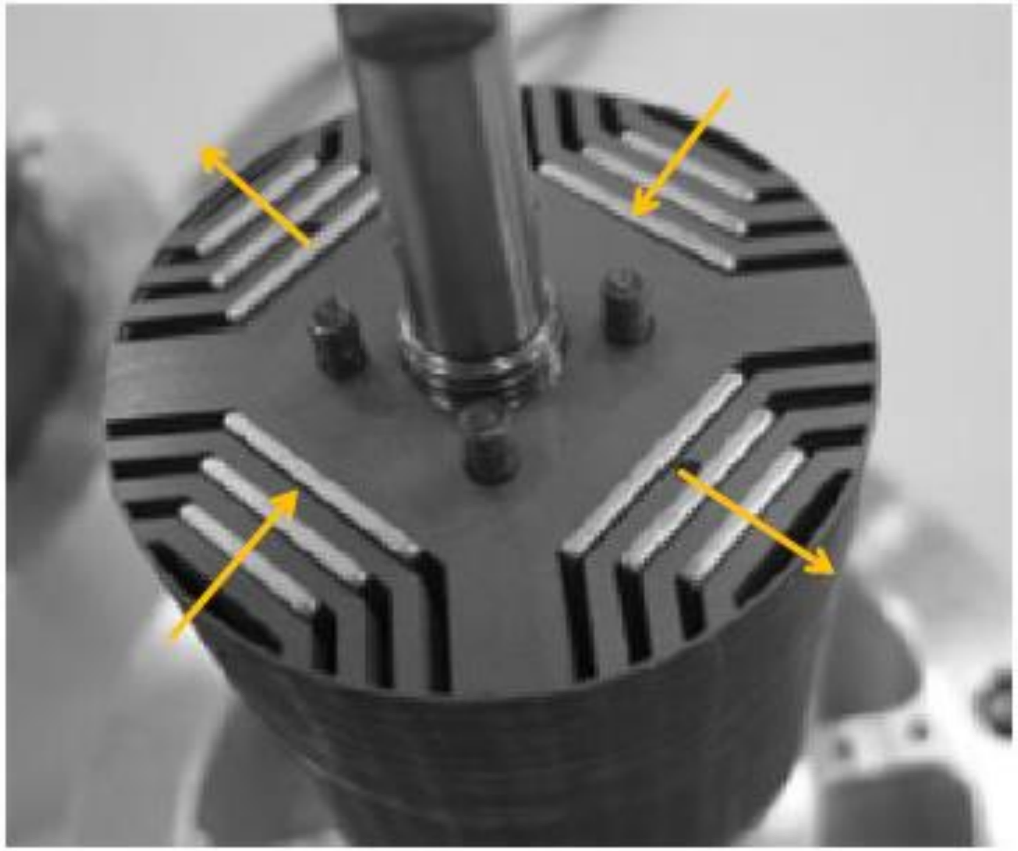


Source: ABB

PM-Assisted SynR Motors

- Low cost ferrite magnets
- Easy to handle
- High efficiency
- High power density
- Good power factor

(→impact size of the inverter)



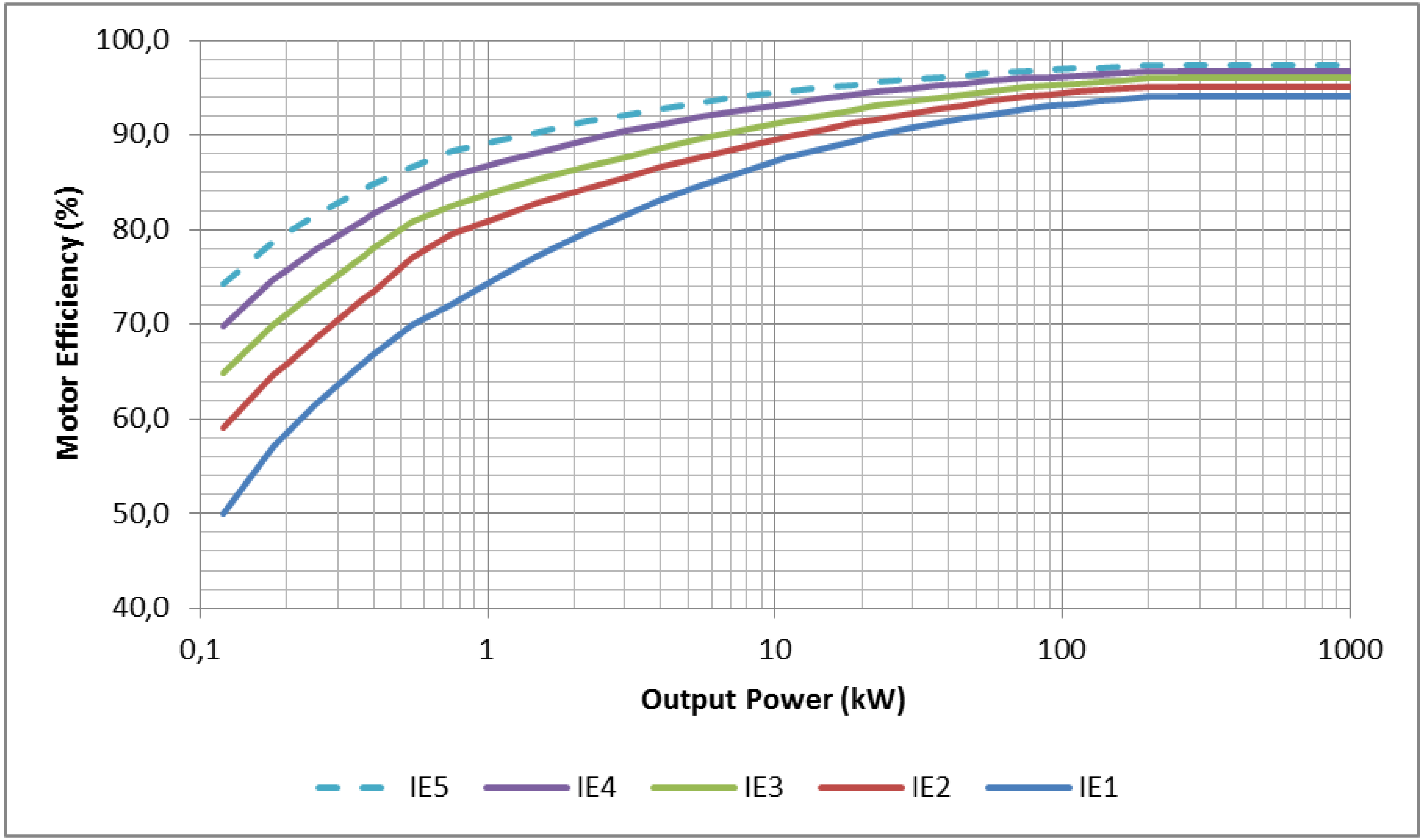
What is a Super-Premium Motor?

- IE3 have at least 15% lower losses than IE2 motors

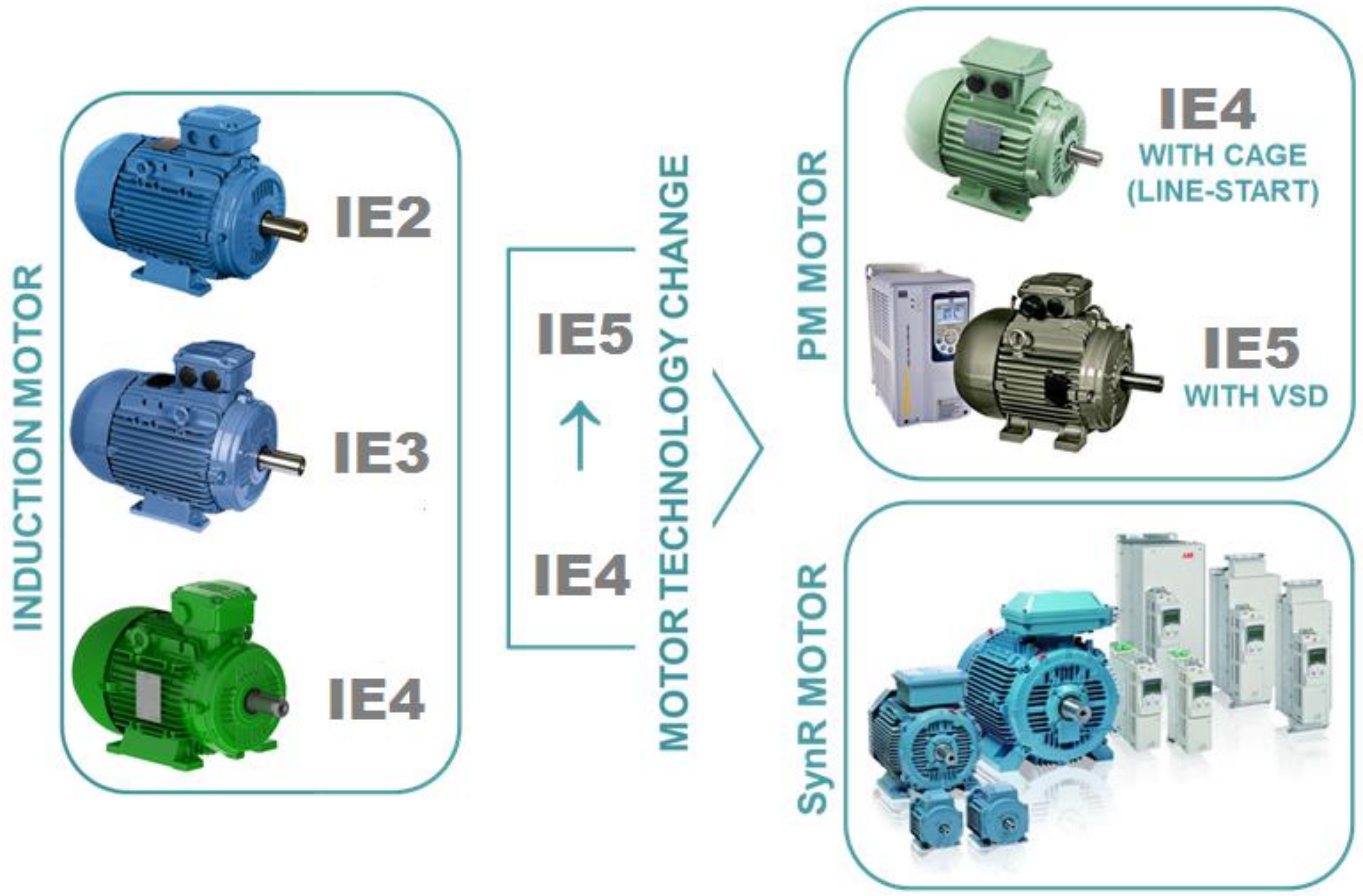
- A Super-Premium IE4 Class has at least a 15% loss difference in relation to IE3 / Premium.

- A Ultra-Premium (new IE5 Class) has at least a 15% loss difference in relation to IE4 / Super- Premium.

IM Efficiency Classification
IEC 60034-30-1 (2014)



Technologies for Higher Efficiency Motors



Review & Discussion

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03. Motor Standards

Motor Basics

Motor Systems Optimisation (MSO) Expert Training
(2020 Egypt Edition)

Samir Khafagui
Siraj Williams

Discussed Topics

- Energy efficient standards realted to motors and motror drives
- Extended systems approach
- MEPS

Key Efficiency Test and Related Standards

***IEC 60034-1 (Edition 12: 2010)*: Rating and performance**

***IEC 60034-2-1 (Edition 2.0:2014):* Standard methods for determining losses and efficiency from tests**

This standard establishes methods of determining efficiencies from tests, and also specifies methods of obtaining specific losses. It applies to DC machines and to AC synchronous and inductions machines of all sizes within the scope of IEC 60034-1.

IEC 60034-31 (Edition 1.0: 2010): Guide for the selection and application of energy-efficient motors including variable-speed applications

The standard gives technical guidelines for the application of energy-efficient motors in constant-speed and variable-speed applications. It does not cover aspects of a pure commercial nature.

IEC - International Electrotechnical Commission

Worldwide harmonisation of efficiency standards

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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**: Standard efficiency (existing Eff2)
- **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.

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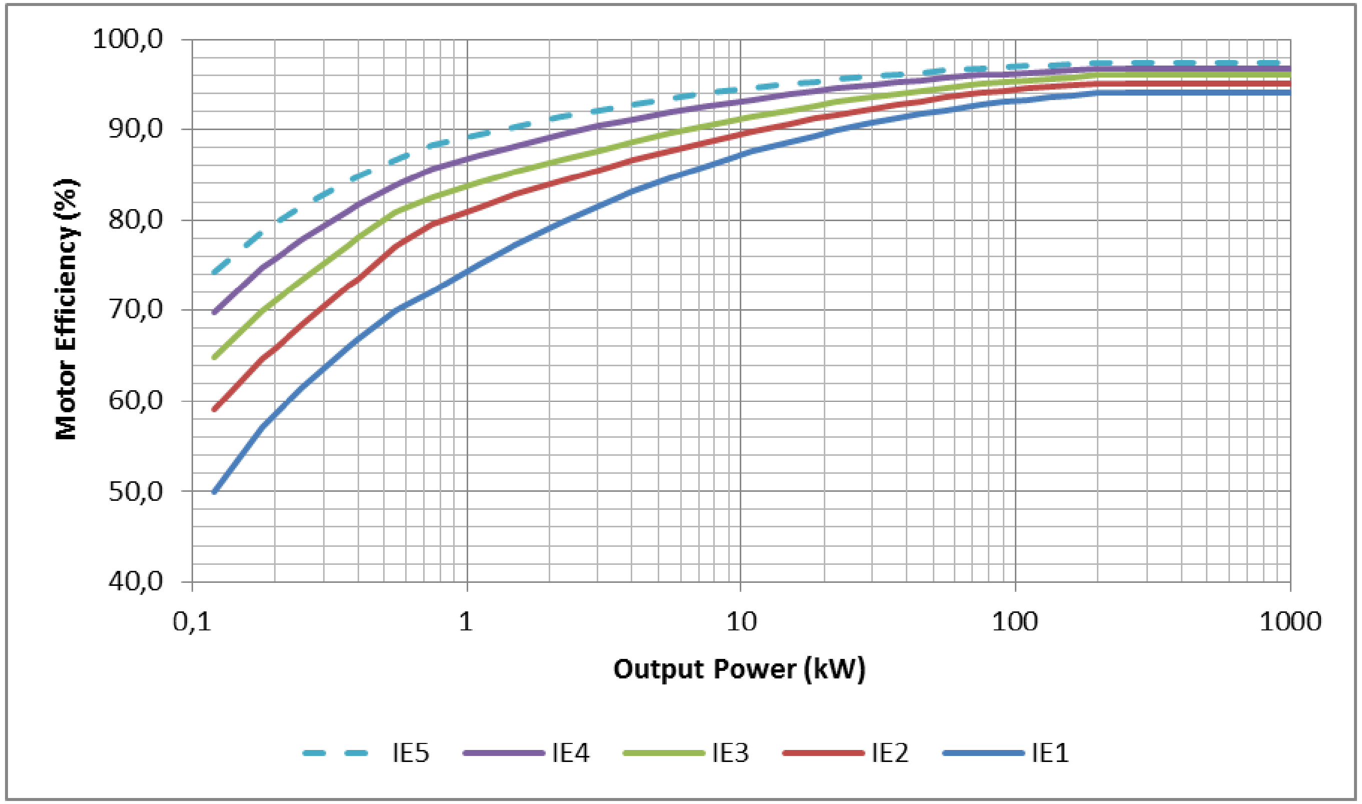
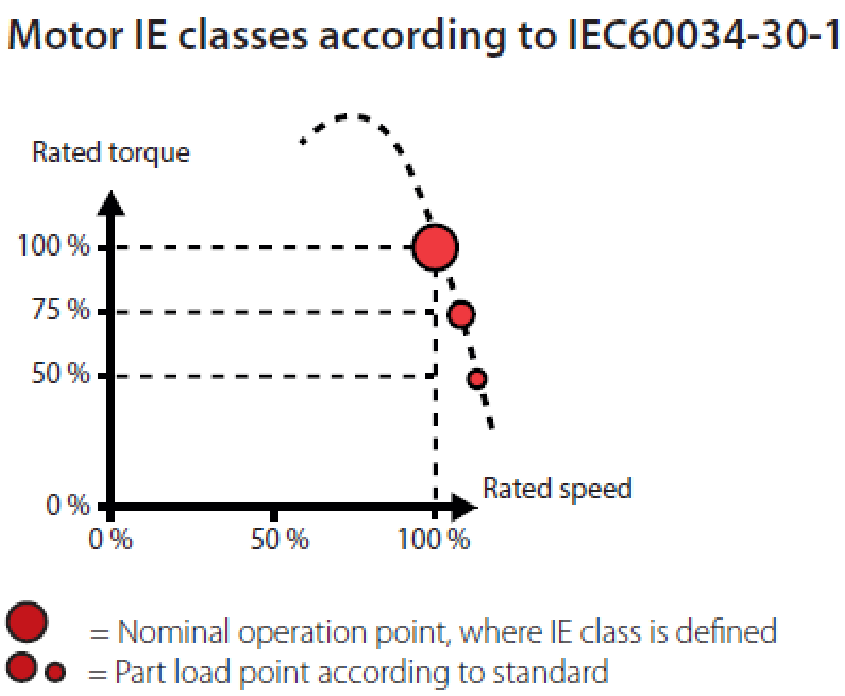
Harmonization of efficiency classification standards – IEC 60034-30-1



Curves for 50 Hz 4pole motors



Key Efficiency Test and Related Standards

- ***IEC 60034-30-2 (2016):* Efficiency classes of variable speed AC motors (IE-code)**

This standard defines efficiency classes for motors that are rated for converter operation (with a VSD). No distinction is made between motor technologies.

INCLUDED:

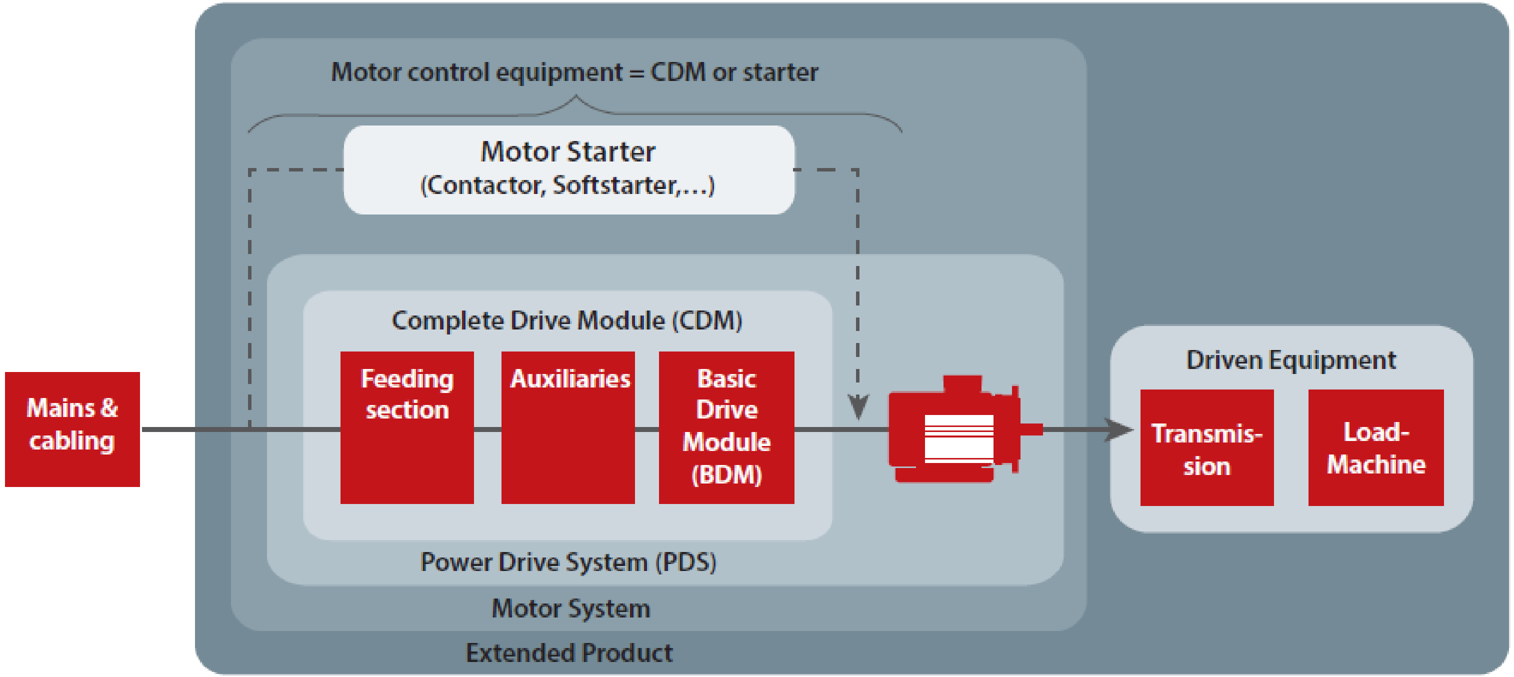
- Pumps
- Fans
- Compressors
- Conveyors

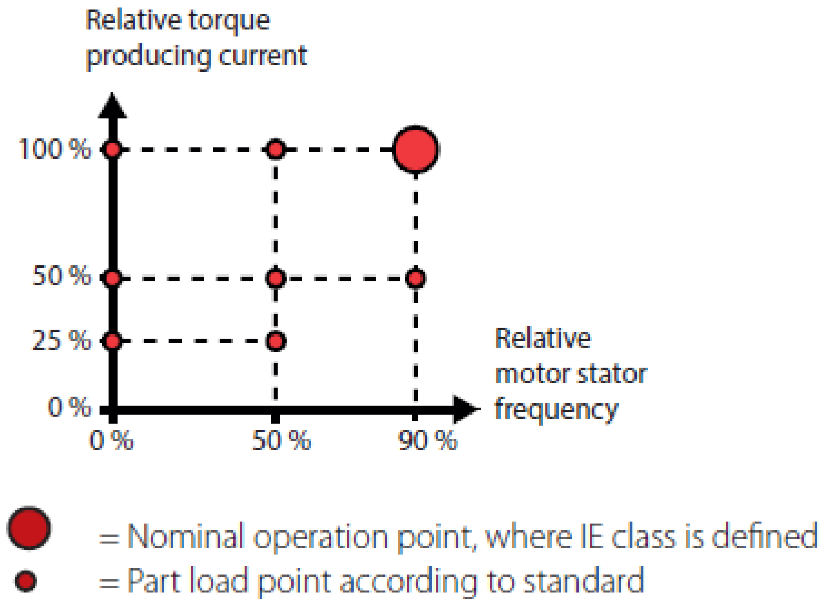
EXCLUDED:
(motion control applications)

- Robots
- Hoist Drives
- Pick-and-Place Machines
- Machine Tools
- Rack Feeders

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.



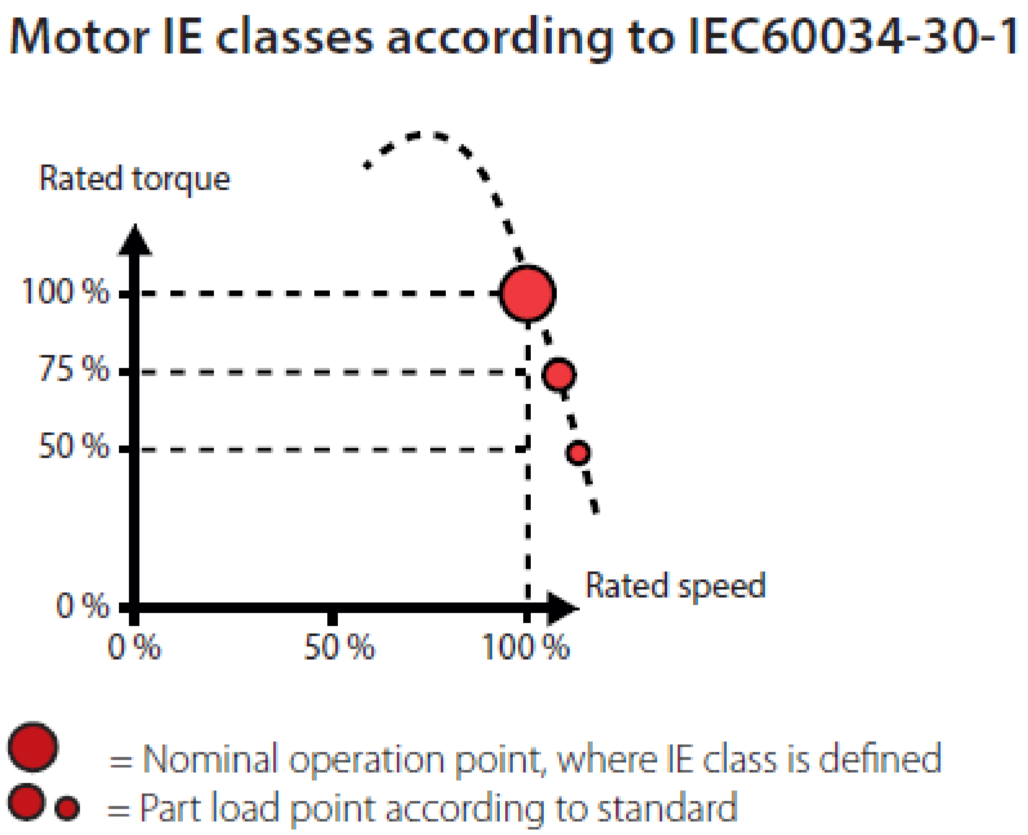


Source: Danfoss

IEC 61800-9 Series

- Enable the system energy efficiency to be determined based on defined criteria such as speed/load profiles, the duty profiles, drive topologies and architectures.
- Provide limits for the maximum losses of sub-parts or the overall losses of the motor system. It also describes the methodology of determination of losses.
- Describes the methodology to quantify the influence of system parameters like cabling, filtering and control strategy for the energy efficiency requirements of the Motor system.
- Suggests a methodology for characterization of the best Energy efficiency solution to be implemented, depending on the motor driven system architecture, the speed/load profile and the duty profiles of the application.

System Efficiency Classification - Motor

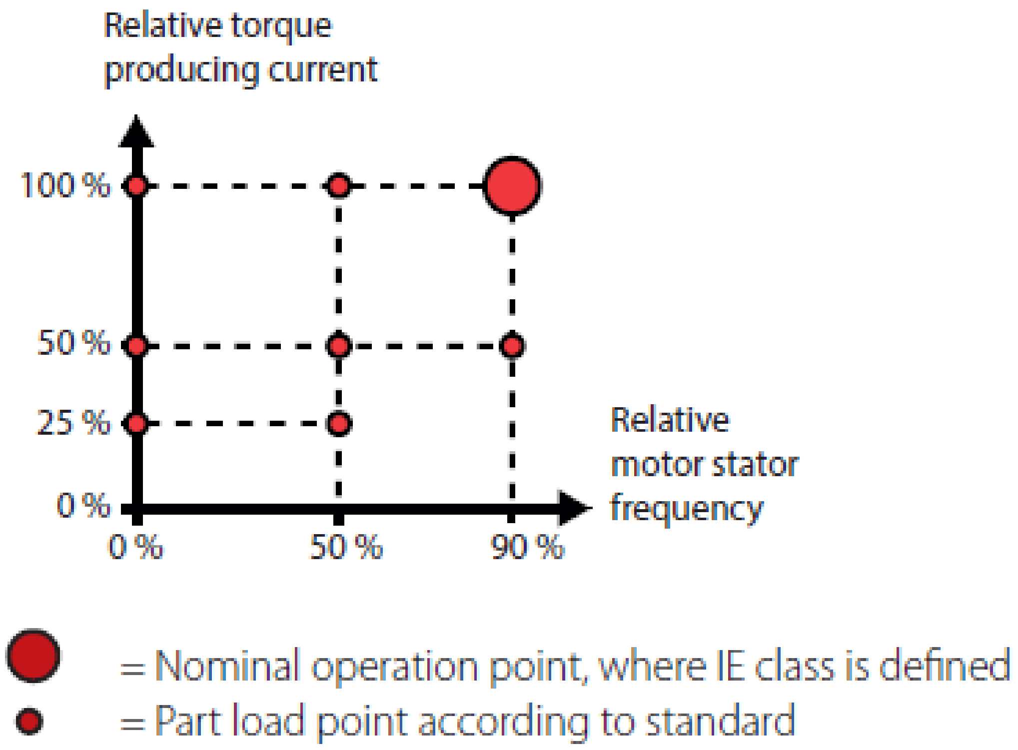


- IE classes are defined at the nominal motor load
- Efficiency levels for 50% and 75% rated torque at mains frequency need to be stated in the documentation
- The efficiency classes are defined for direct on line motors, independent of the motor technology
- Asynchronous motors with a higher efficiency typically run at a higher speed (RPM). Consider this in retrofit applications.
- Mechanical dimensions can vary depending on motor technology and IE class

Source: Danfoss

System Efficiency Classification – CDM/VSD

IE classes for frequency converters according to EN 50598-2 / IEC 61800-9-2

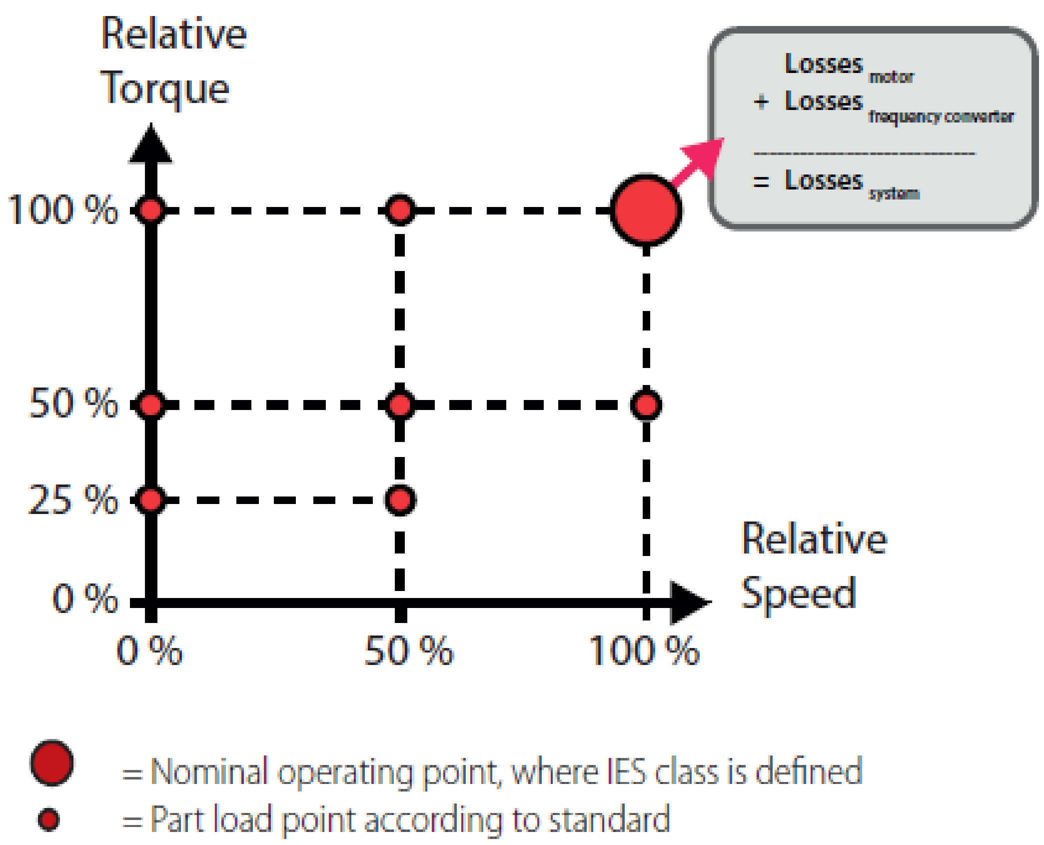


- The IE class is defined at an operating point of 90% frequency and 100% torque-producing current.
- Special test settings are not permitted.
- The classification for the frequency converter includes integrated options.
- Losses in options that are not built in (for example, EMC filters or chokes) are not included in the efficiency class but need to be documented if they
  - Comprise more than 0.1% of the rated frequency converter power, and
  - Are greater than 5 W.
- Losses at partial load can be documented by the manufacturer.

Source: Danfoss

System Efficiency Classification - PDS

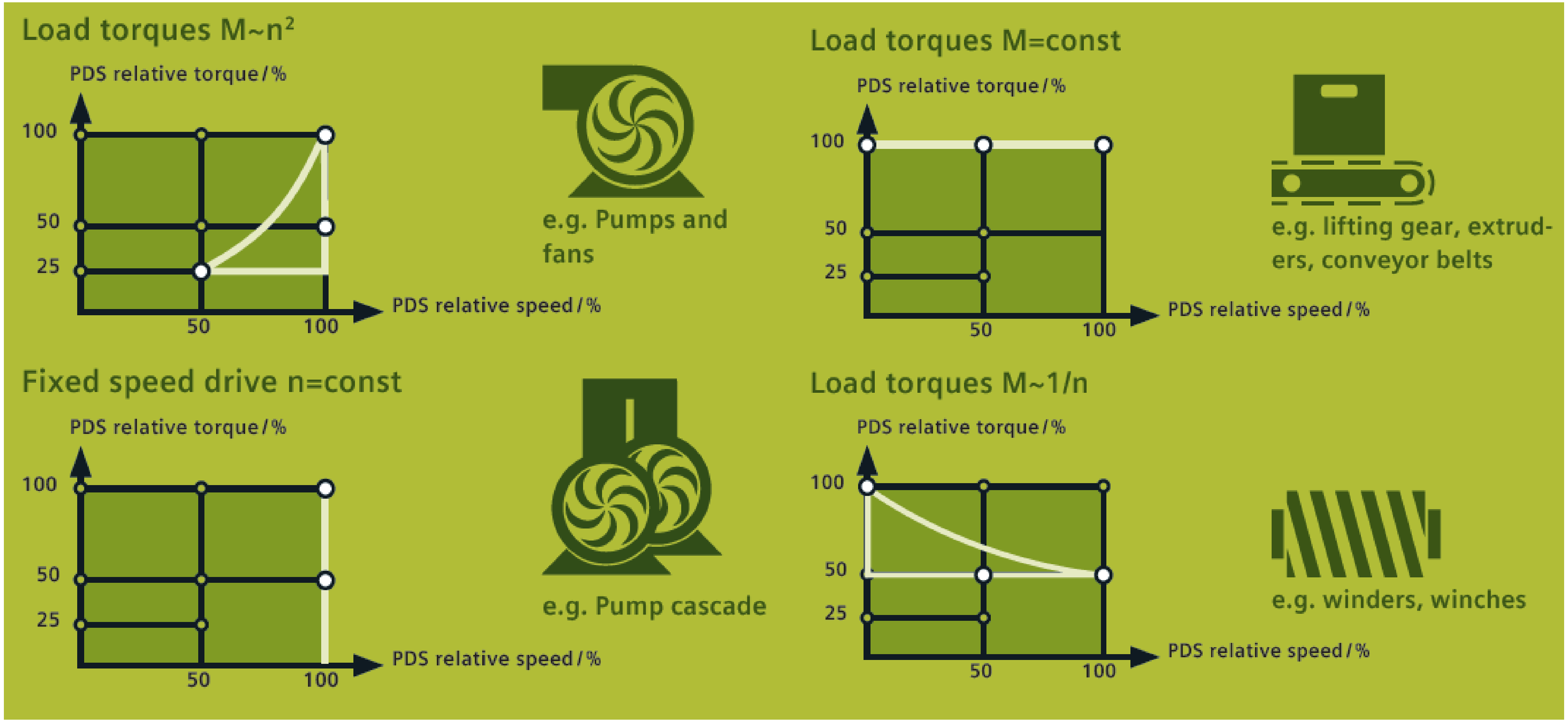
IES classes for power drive systems according to EN 50598-2 / IEC 61800-9-2



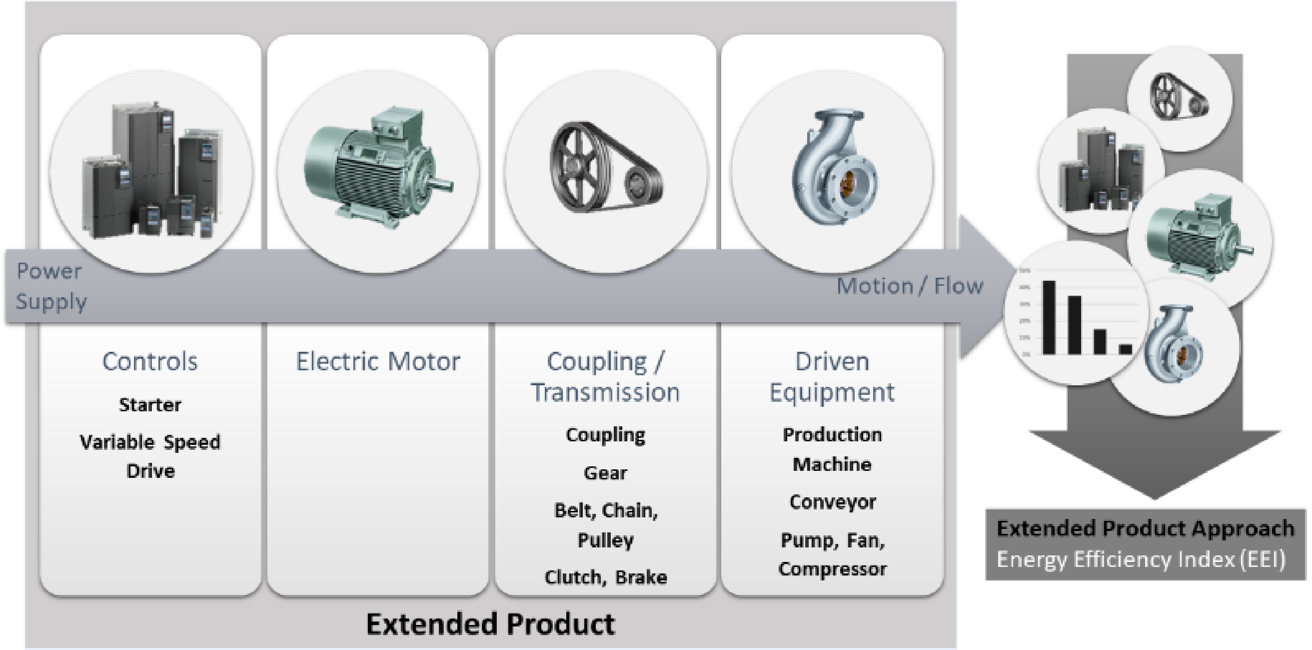
- The IES class applies for frequency converter – motor systems
- The IES class is defined at 100% speed and 100% torque
- The cable length between frequency converter and motor is defined.
- Deviations from the standard cable length or switching frequency are permitted, but must be documented
- Losses at partial load are documented by the manufacturer

Source: Danfoss

Examples for Different Applications



The Extended Product Approach



- The method can be used to determine the energy efficiency of the motor system for a particular application, taking into account the time spent at the different operating points (speed-torque).

- Using a relative weighting system, the overall energy efficiency index (EEI) is determined for the actual operating conditions encountered.

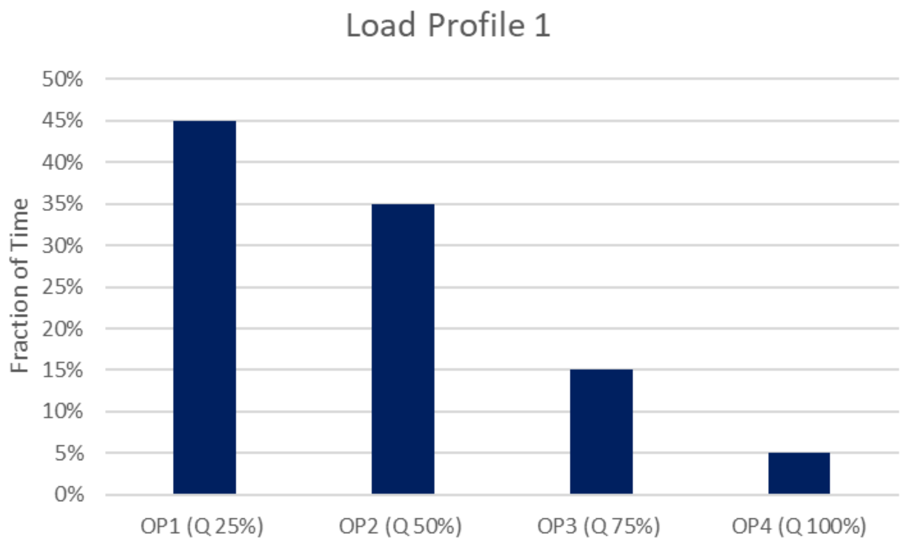
The Extended Product Approach

The method can be used to determine the energy efficiency of the motor system for a particular application, taking into account the time spent at the different operating points (speed-torque). To calculate the EEI, the following inputs need to be known:

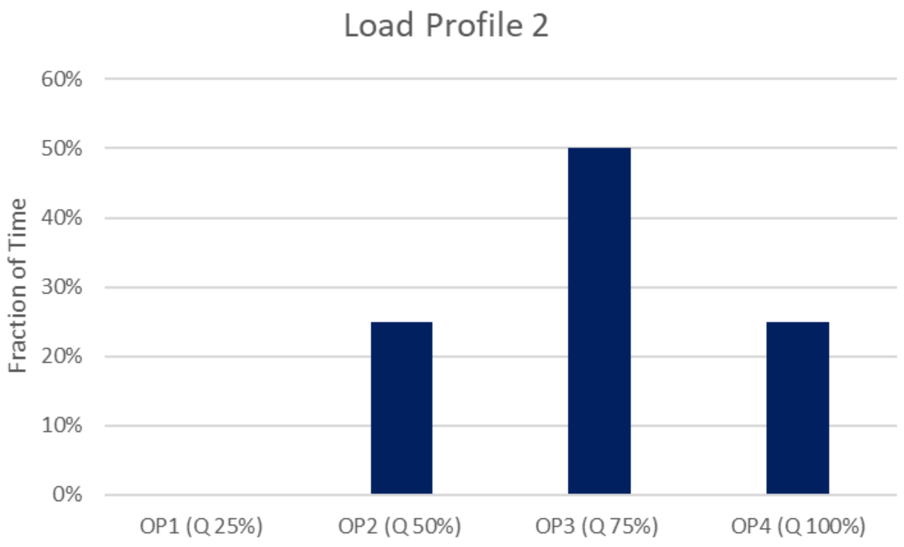
- Characteristics of the application load, namely, the torque or power as a function of shaft rotational speed, and the working time or fraction of time of each operating point (duty cycle), including standby mode.
- Power losses of components (Motor, CDM, end-use equipment, auxiliaries) at the operating points required by the application. Power losses are used instead of efficiency because they take into account particular conditions such as standby consumption (no-load condition, in which the efficiency is zero).

Comparison between two typical pumping applications

Knowing the values of the PDS losses in the eight operating points defined in standard IEC61800-9 allows users to evaluate the performance (both energy- and economic-wise) of any application for which typical operating points are known.



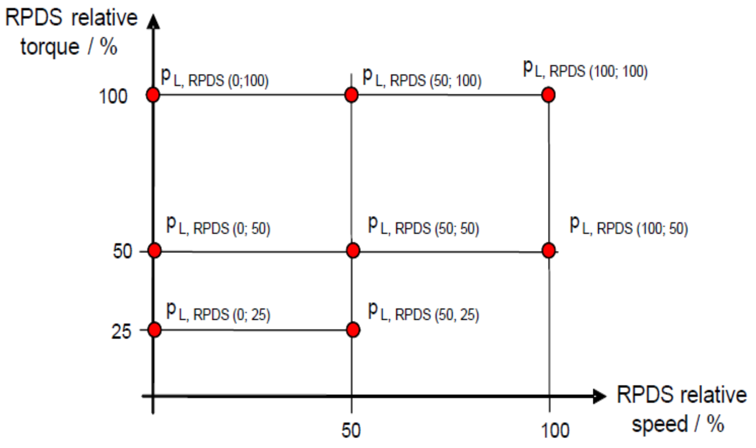
A typical HVAC application

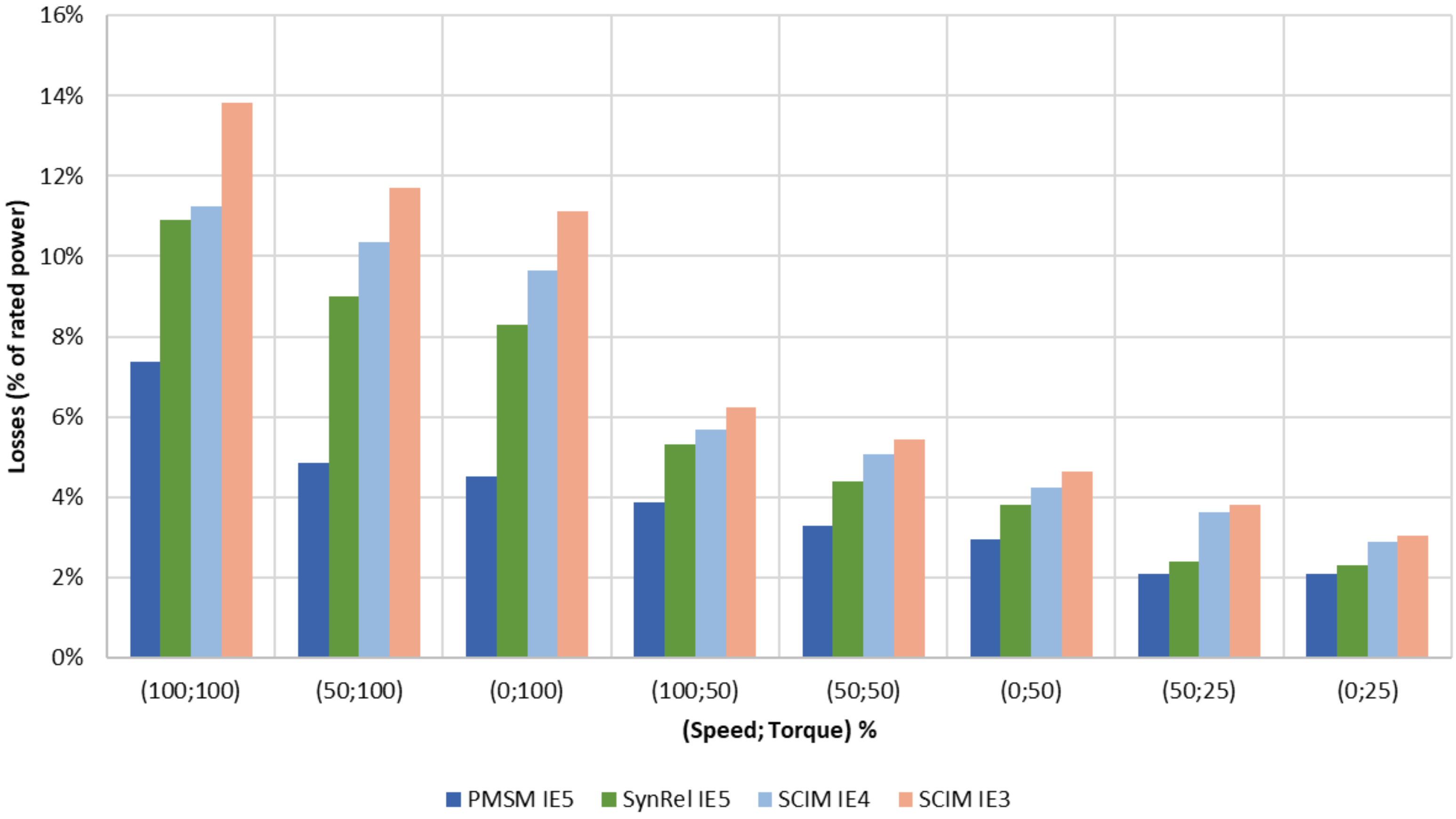


Fresh water pumping application

PDS losses as a percentage of the output rated power

7.5 kW Motor + Drive

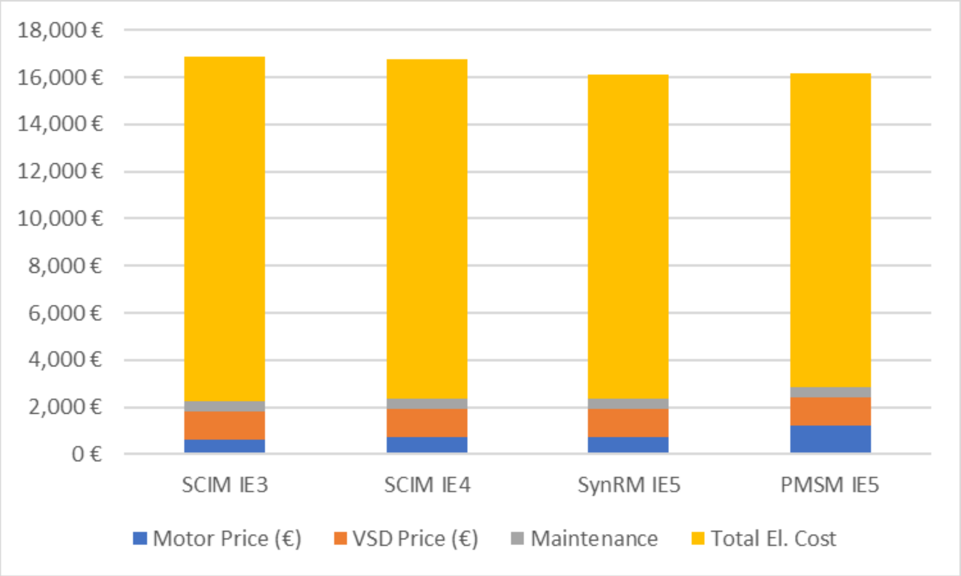




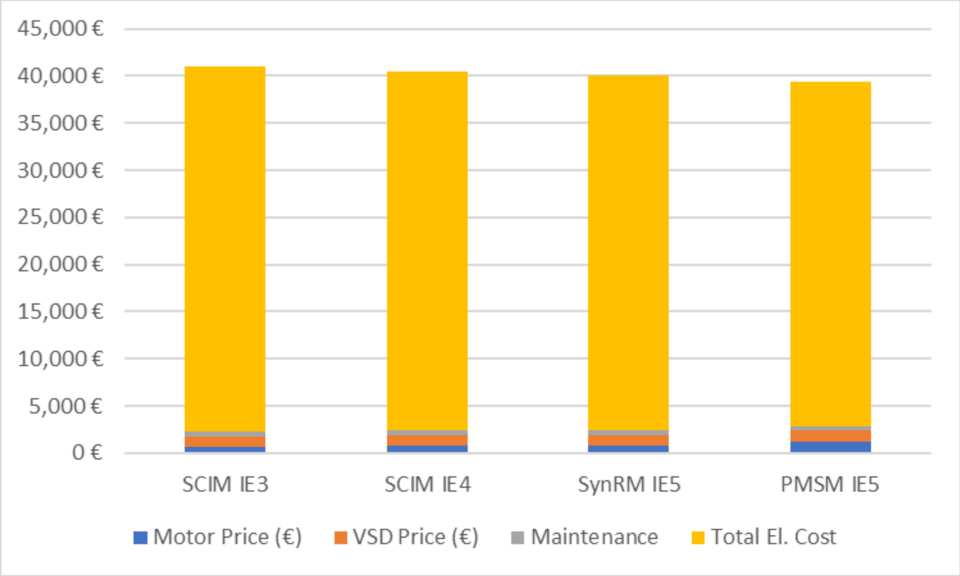
Results from tests carried out at the ISR-UC Lab

Total Cost of Ownership (4000 operating h/year)

Load Profile 1



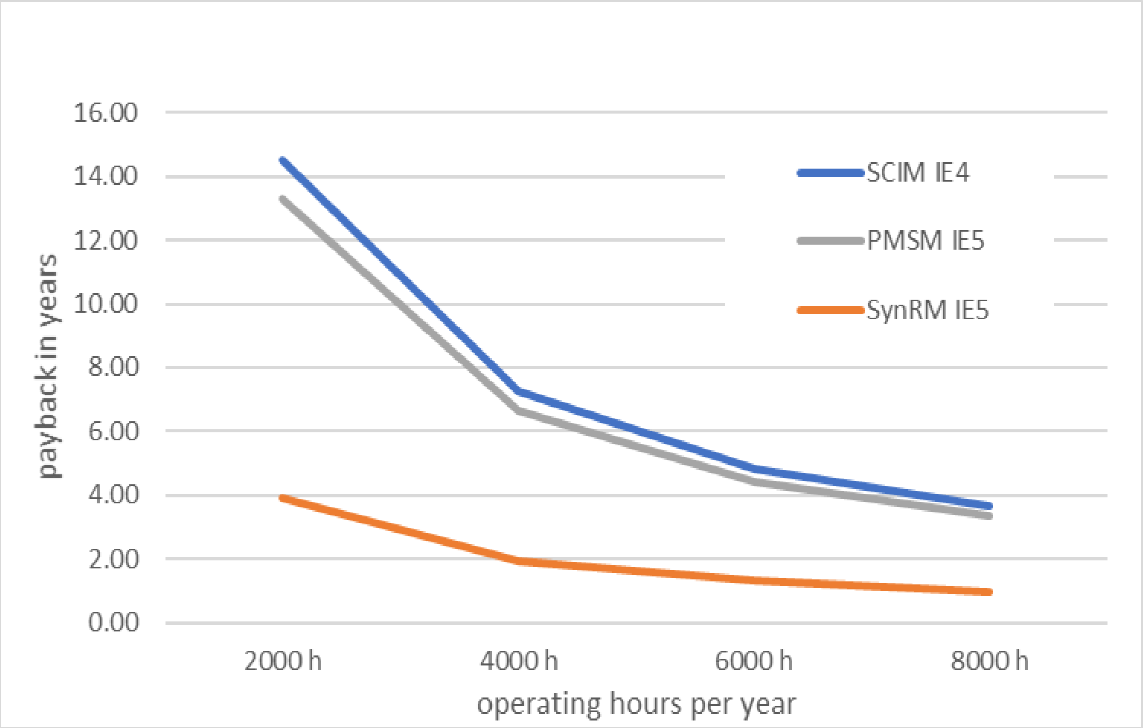
Load Profile 2



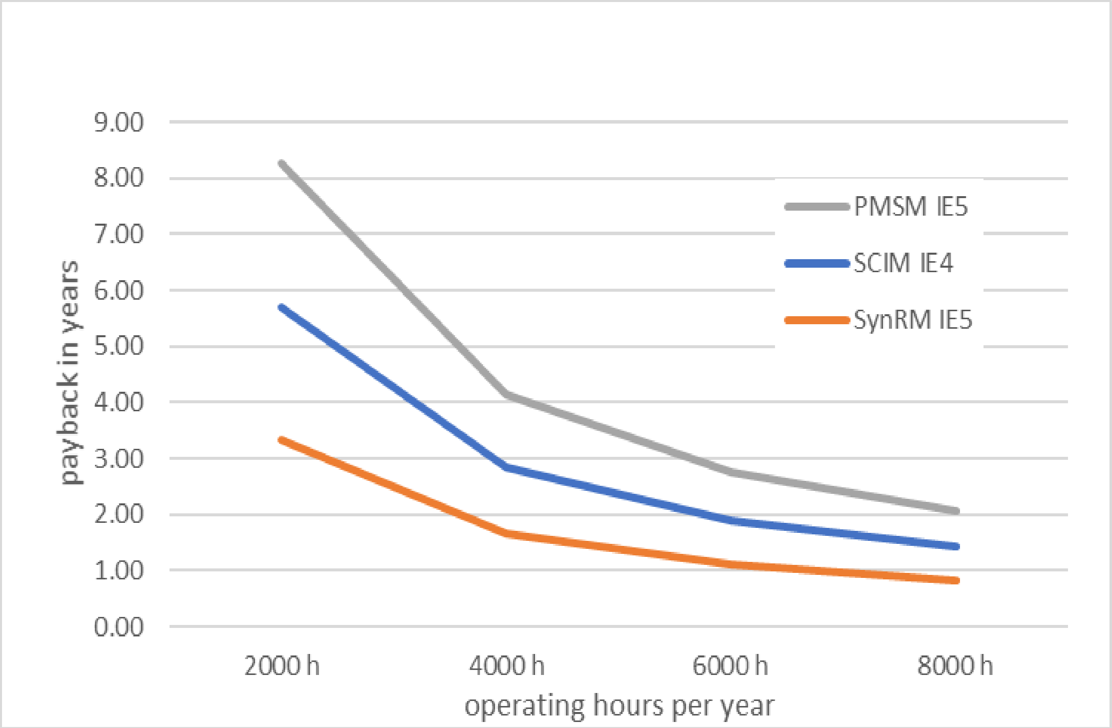
Motor Technology	Motor Price	VSD Price	Maintenance[1] (4000 h/year)	Lifetime
SCIM IE3	600 €	1200 €	450 €	15 years
SCIM IE4	720 €	1200 €	450 €	15 years
SynRM IE5	720 €	1200 €	450 €	15 years
PMSM IE5	1200 €	1200 €	450 €	15 years

Payback time for SCIM IE4, SynRM IE5, and PMSM IE5, in relation to SCIM IE3

Load Profile 1

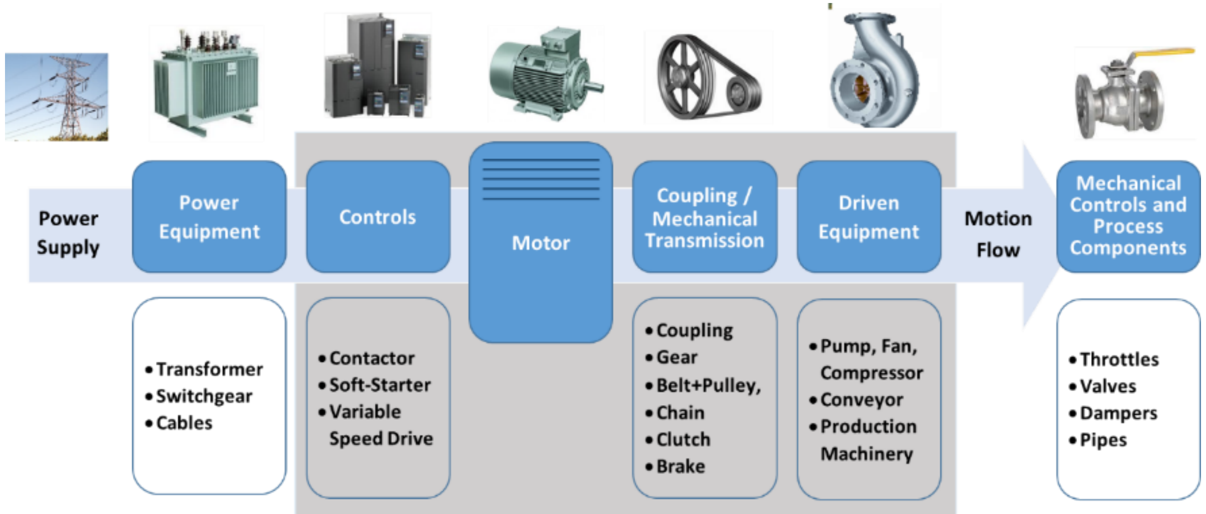


Load Profile 2



Standardisation Bodies

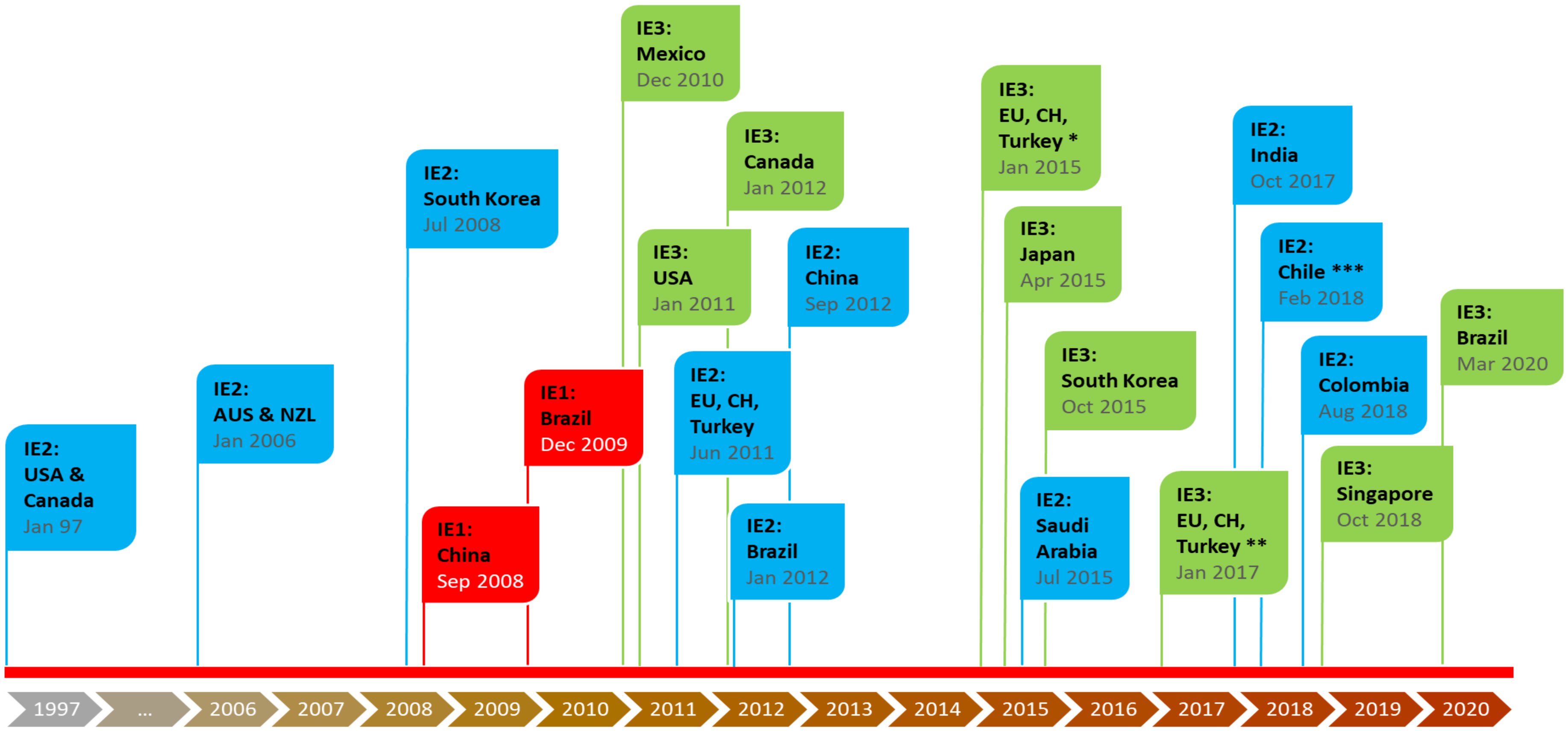
Standardisation bodies that cover different parts of motor systems



Motor control		Motor	Mechanical equipment		Driven equipment			
IEC TC 121	IEC TC 22 SC 22G	IEC TC 2	ISO TC 41	ISO TC 60	ISO TC115	ISO TC 117	ISO TC 86	ISO TC 118
Switchgear & controlgear	Adjustable speed drive	Rotating machinery	Pulleys & belts	Gears	Pumps	Fans	Cooling-Com-pressors	Air-Com-pressors
1927	1934	1911	1947	1947	1964	1964	1957	1965

Group Standard

MEPS Timeline



* 7,5 kW – 375 kW or IE2 + VSD
** 0,75 kW – 375 kW or IE2 + VSD
*** 0,75 kW – 7,5 kW

MEPS Worldwide

Egyptian program for promoting Industrial Motor Efficiency
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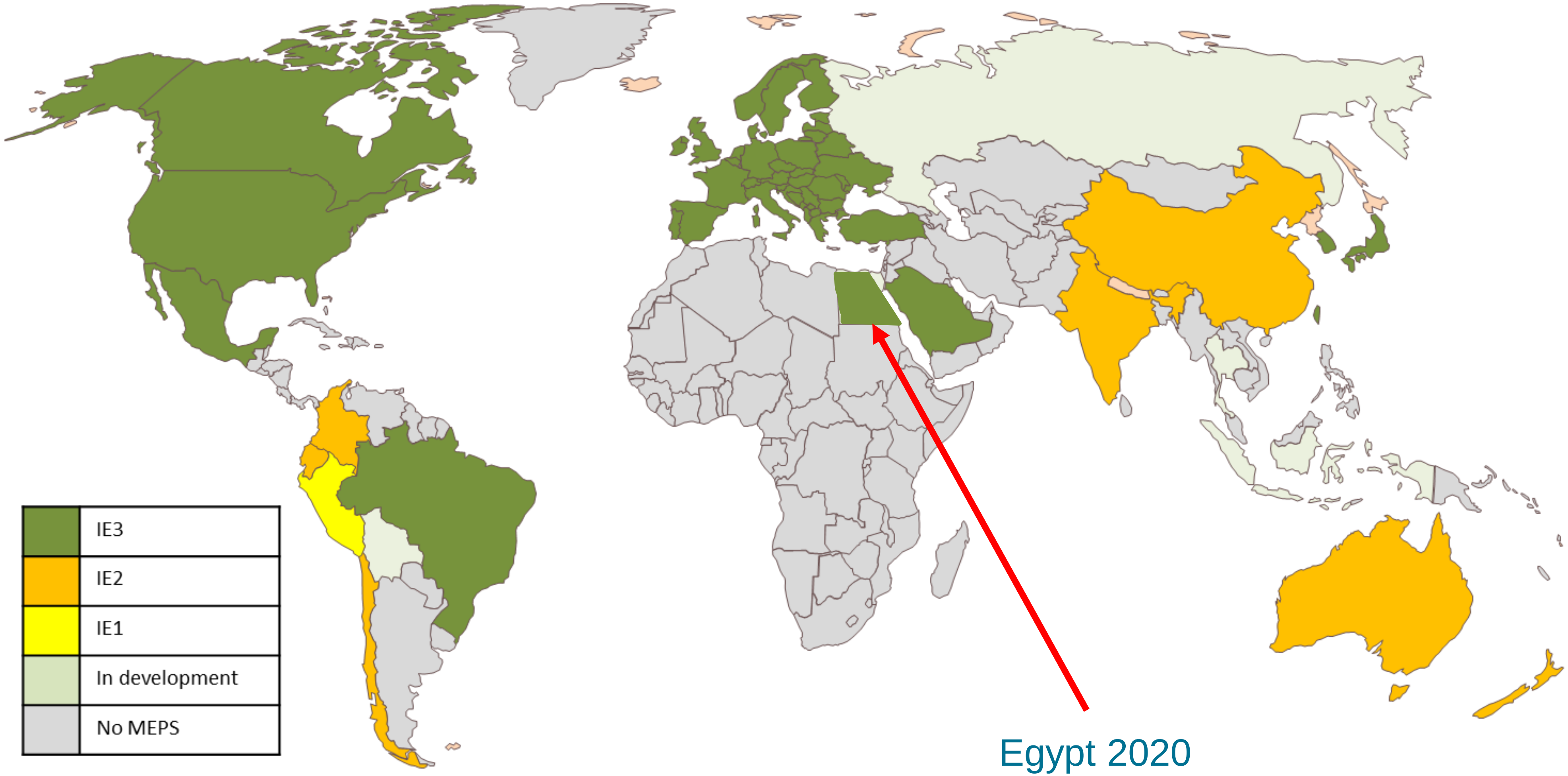
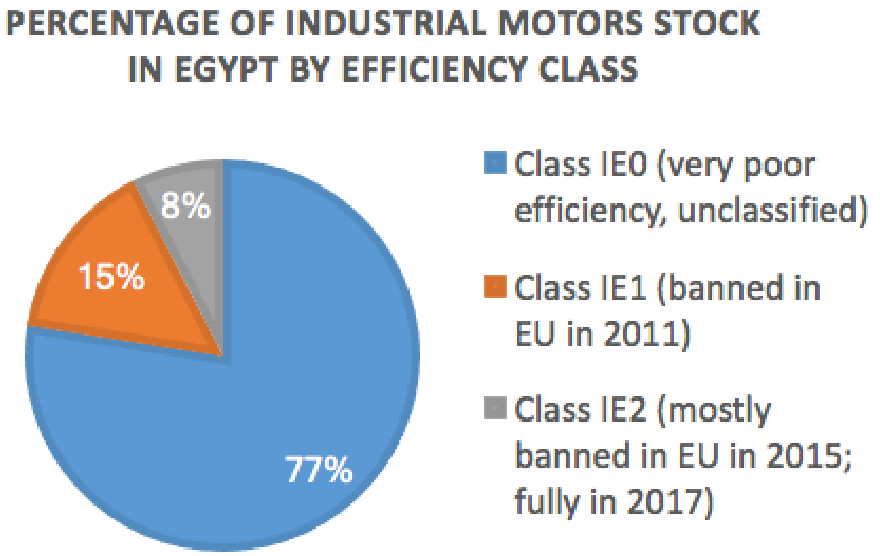


Egypt – Existing Motor Market

- Over three quarters of industrial motors in operation now in Egypt are of low efficiency
- At least half are over 10 years old
- A large proportion of motors have been rewound
- Delivery of high efficiency motors (IE3) takes between 2 weeks and 2 months
- Suppliers still have existing stocks of lower efficiency class motors



- There is a big market for grey imports of cheap and 'no-brand' motors routed from China and other parts of Asia via the EU.
- Businesses often use old procurement specifications that do not specify energy efficiency;

Egypt – Introduction of MEPS

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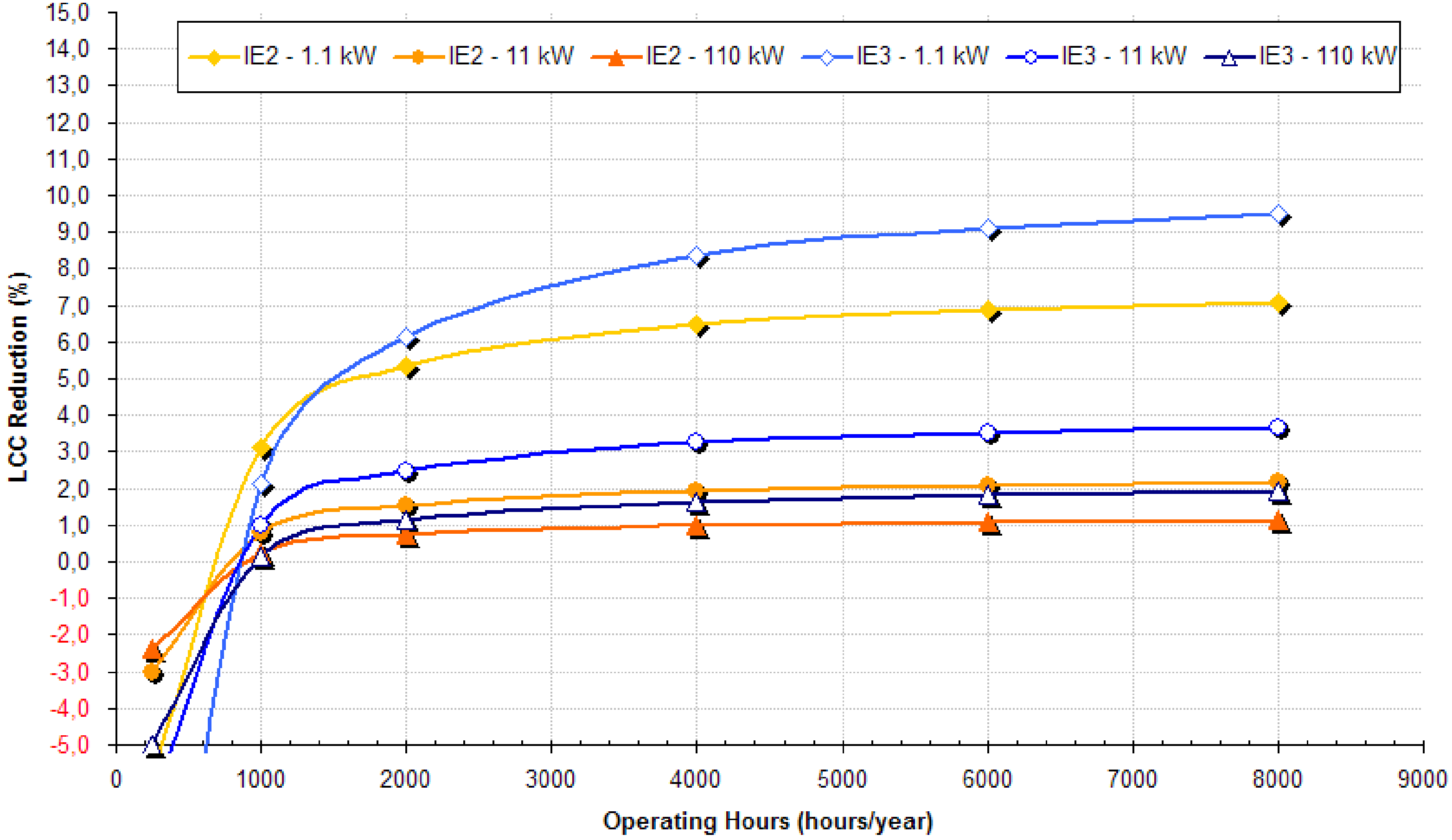
Policy makers in Egypt decided to move directly to IE3 MEPS in 2020 for all motors, taking into account that:

- 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.

Potential Energy Savings Achieved Through MEPS



LCC reduction as a function of the number of operating hours (0,075 €/kWh), BAT vs. Base Case

Source: ISR – University of Coimbra

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04. Motor Selection

Motor Basics

Motor Systems Optimisation (MSO) Expert Training
(2020 Egypt Edition)

Siraj Williams
Samir Khafagui

Discussed Topics

- Review of key concepts
- Wound rotor induction motors

Motor Selection Criteria - 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)

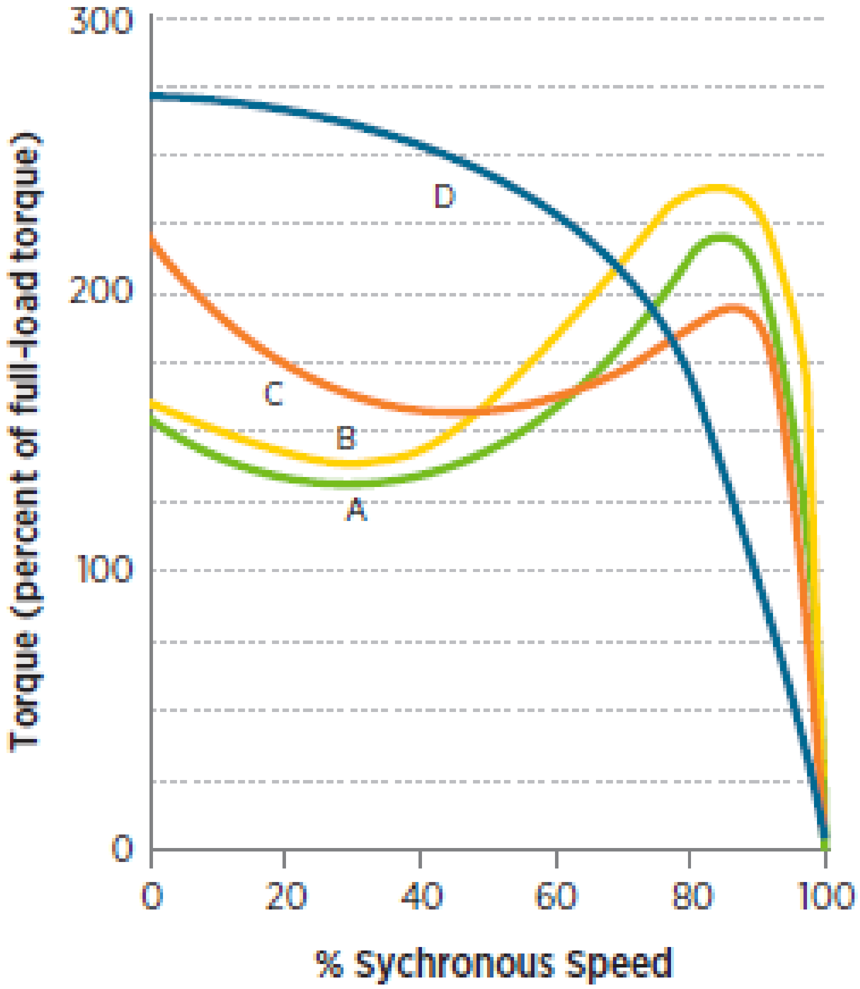
Motor Selection

- Induction motors – used in most industrial applications, robust and reliable, easily available, minimum control requirements
- Synchronous motors – very large motors (>1000kW) because more efficient than induction motors, exact speed requirement, power factor correction
- DC Motors - where precise speed control is required, very high starting torques, easy to control, appropriate for battery powered systems

Typical speed/torque curves of induction motors

In most cases, the motor selected will be an induction motor:

- Design B (NEMA motors) and **Design N** (IEC Motors) are similar and the most common due to higher efficiency
- Design D (NEMA motors) and **Design H** (IEC Motors) are similar and used in high starting torque applications



Synchronous Motor Selection

Speed:

- Synchronous motors operate at synchronous speed with no speed drop over the load range. They should be selected if exact speed is required.

Power Factor Correction:

- Synchronous motors can generate reactive power to correct poor supply system power factor while delivering mechanical power. When supplying reactive power they are said to be operating at a leading power factor.

Lower Operating Costs:

- Synchronous motors are often more energy efficient than induction motors, especially in the very large horsepower ranges (above 1000 hp).

Direct Current Motor Selection

- DC motors are often selected where precise speed control is required, as DC speed control is simpler, less costly and spans a greater range than AC speed control systems.
- Where very high starting torque and/or high over-torque capability is required, DC motors are often selected.
- They are also appropriate where equipment is battery powered.

Disadvantages of DC motors:

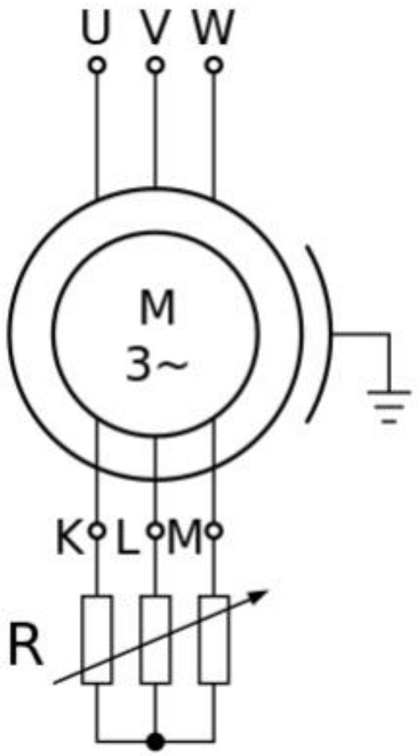
- High initial cost, since the rotor is more complex and expensive
- Increased operation and maintenance cost due to presence of commutator and brush gear
- Cannot operate in explosive and hazard conditions due to sparking occur at the brush-commutator interface

AC motors with similar control capabilities with the use of high performance speed drives and offer much higher reliability, are taking over

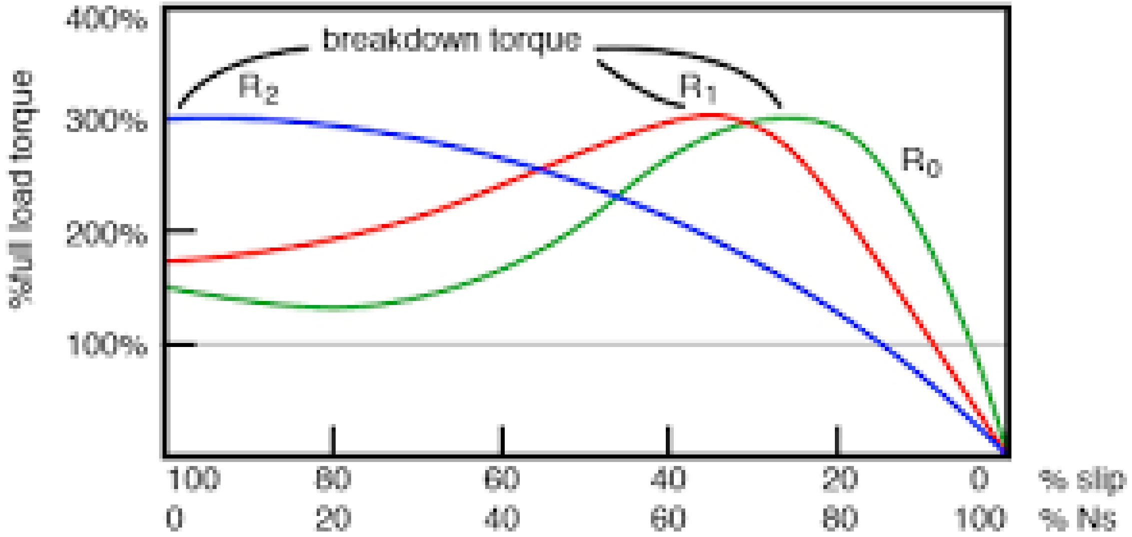
Wound Rotor Induction Motor Selection

When should we use them?

- Wound rotor induction motors (WRIMs) are useful in some applications (above 250 kW) because the resistance of the rotor circuits can be altered to control the desired starting torque and current, or running characteristics.
- WRIMs were used before variable speed drives became widely available at a moderate cost.
- In new installations variable speed drives coupled with squirrel cage induction motors (SCIMs) allow higher performance in relation to WRIMs
- More expensive (about 50%) and more maintenance than SCIMs due
- to brushes and slip rings



WRIMs Use a Variable External Resistor to Control Starting Current and Starting Torque



Motor Selection Criteria - Operation

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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.

Motor Selection Criteria - Load

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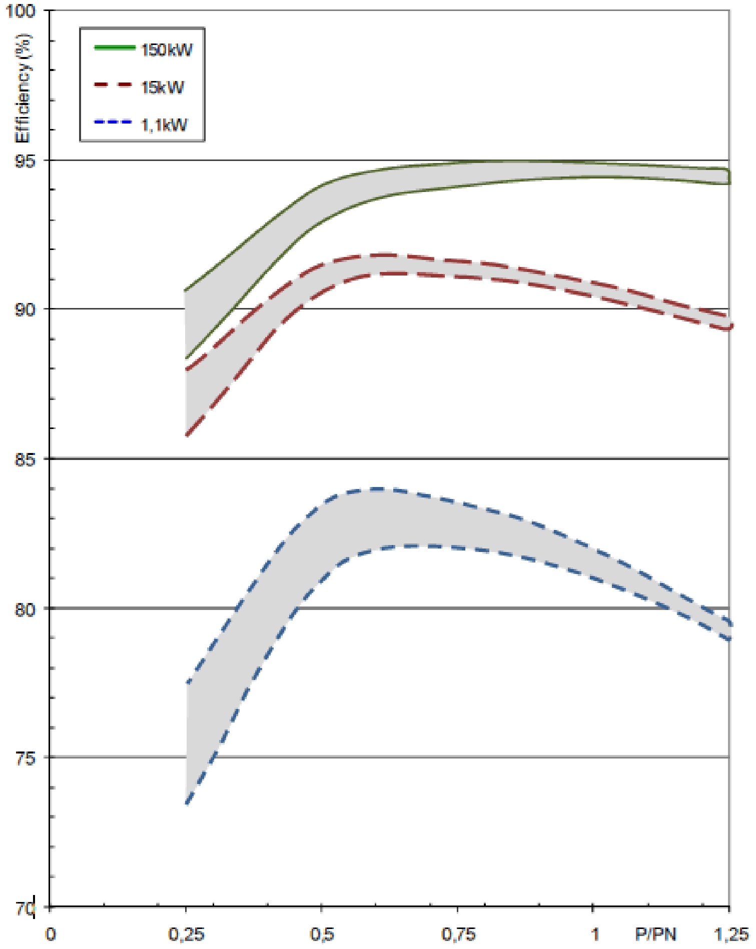
Motor Load

- 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.

Efficiency vs. Load



IEC 60034-31

Motor Selection Criteria - Temperature

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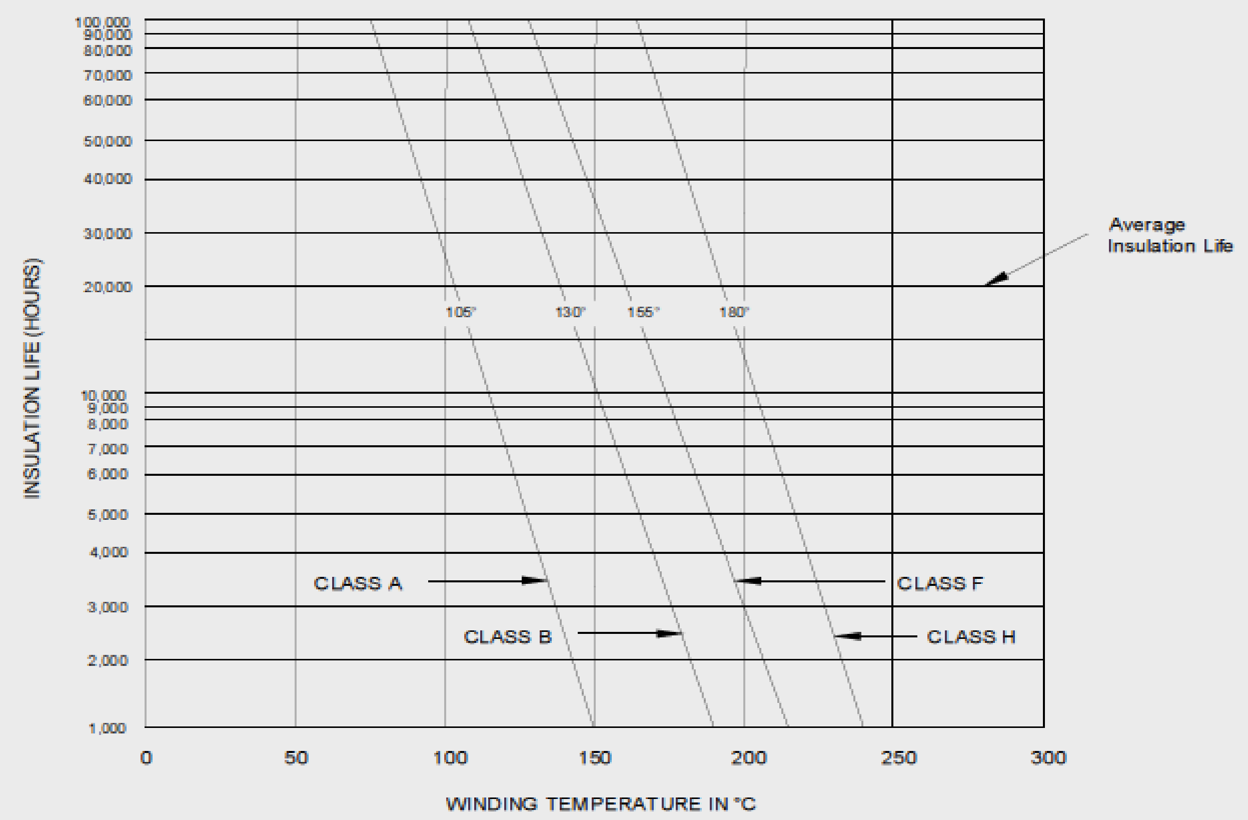
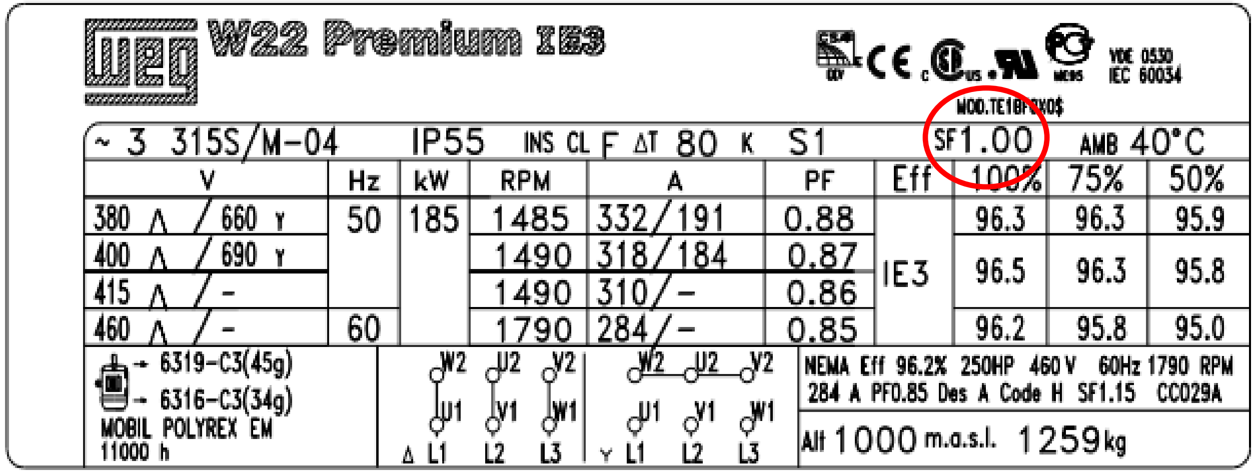
- Motors that run hotter have shorter operating lives (thermal degradation of insulating materials).
- Rule of thumb is that the service life expectancy of winding insulation is reduced by one half for each 10°C increase in operating temperature.
- Winding insulation life is affected by conditions such as number of starts, voltage surges and sags, undervoltage operation, and voltage unbalance.



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

Motor Selection Criteria – 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.
- E.g. A 10 hp motor operating under rated conditions with a 1.15 service factor should be able to deliver 11.5 hp without exceeding the NEMA allowable temperature rise for its insulation system.
- A motor operating continuously at a service factor greater than 1 will have a reduced life expectancy (insulation and bearings).
- Motor efficiency is usually reduced during operation at the service factor rating.



Motor Selection Criteria – Strategies

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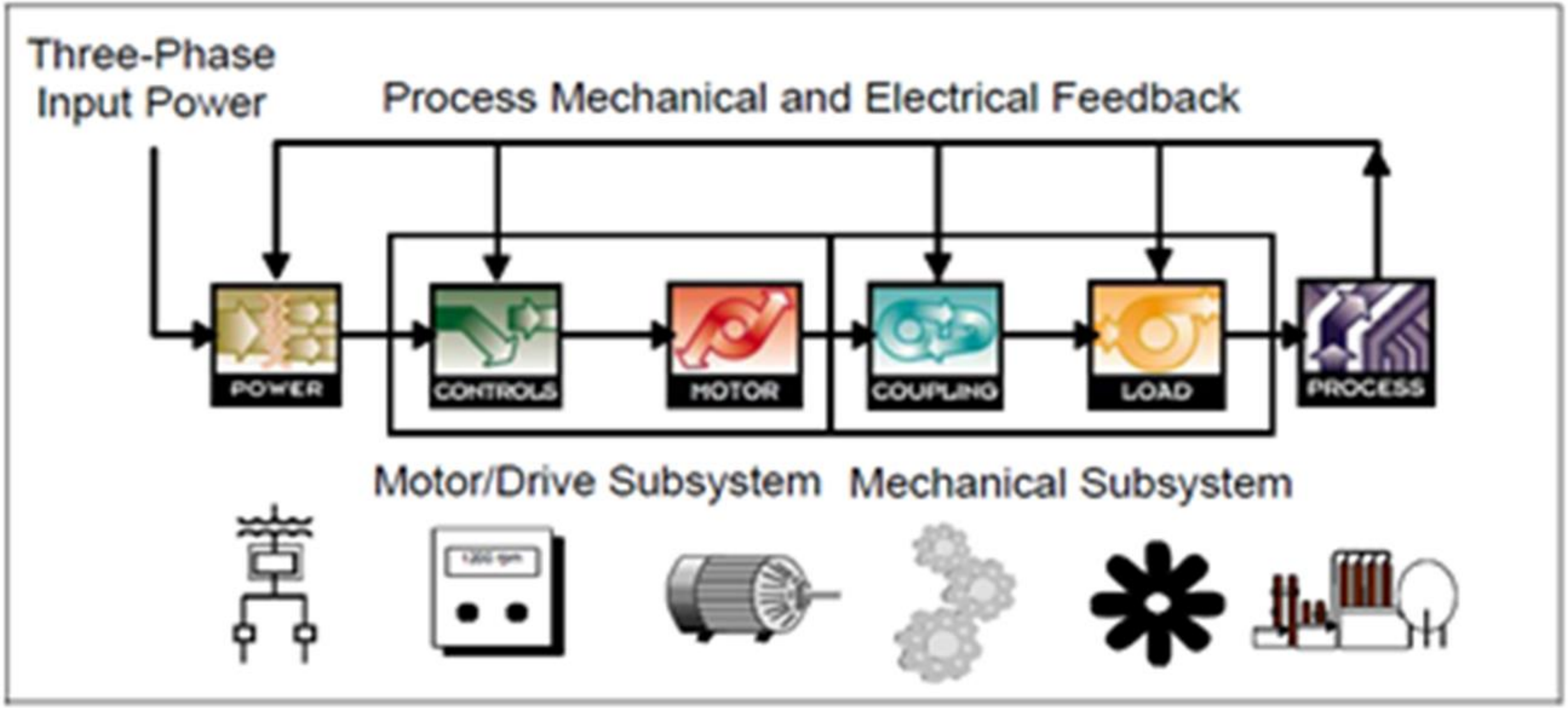
- Choose a replacement motor BEFORE the in service motor fails. Sometimes in trying to get a motor back into service as quickly as possible, decisions are made that satisfy the short-term goal but negatively impact long-term efficiency and motor life.

- Derate the motor operation at high altitude (above 1000m) and high ambient temperature (above 40° C) rise for its insulation system.

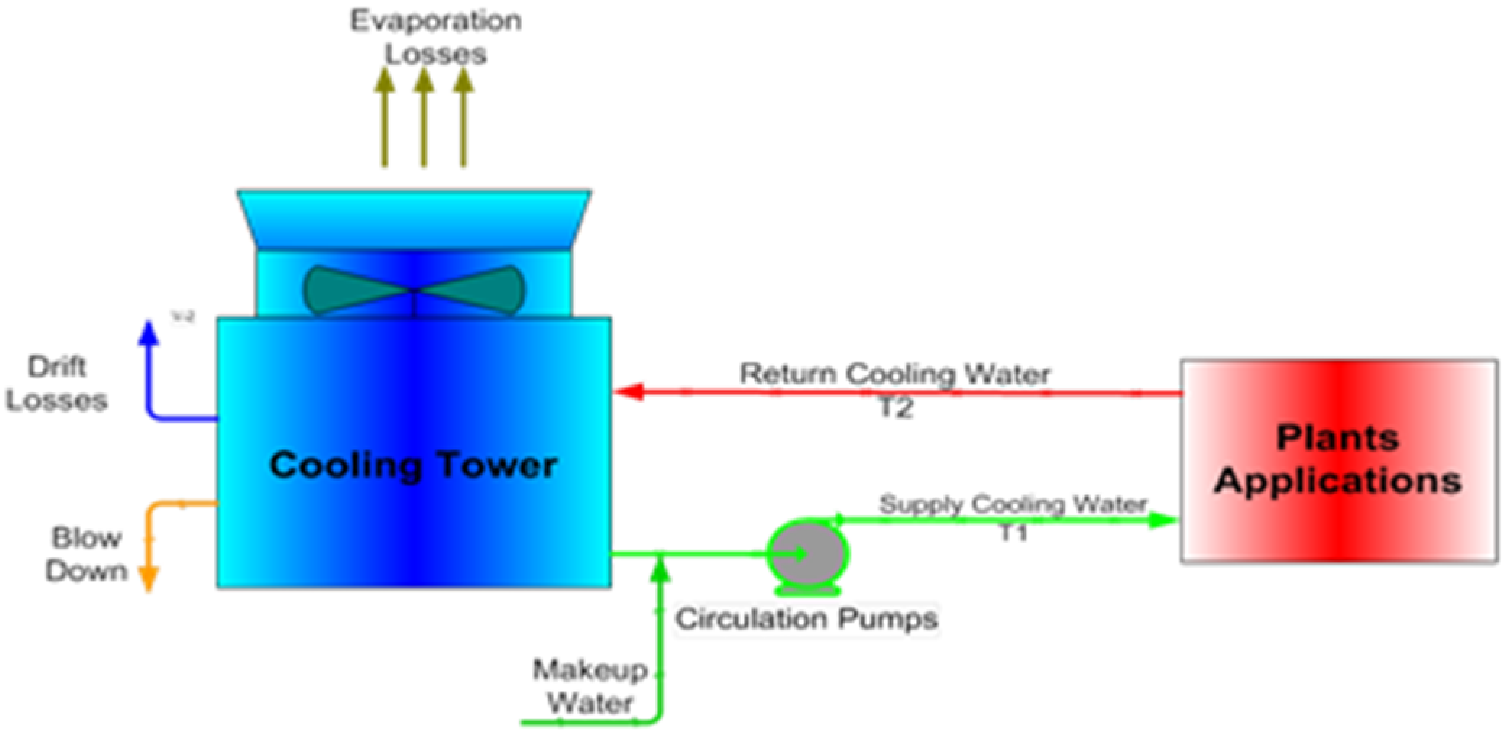
- Match Motor Operating Speeds: In general, motors with higher efficiency have a higher operating speed i.e. a reduced slip compared to motors of lower efficiency. On average, the slip is reduced by some 20 to 30% per next higher efficiency class for motors of the same rated output power. , increasing operating speed by 2% can increase the power required to drive the system by 8%. This can easily offset the savings expected by the replacement of a motor with a more efficient one.

- The motor should be sized for the peak load expected. Oversized motors can significantly increase costs since all electrical components must be sized to the motor rating.

The Motor System

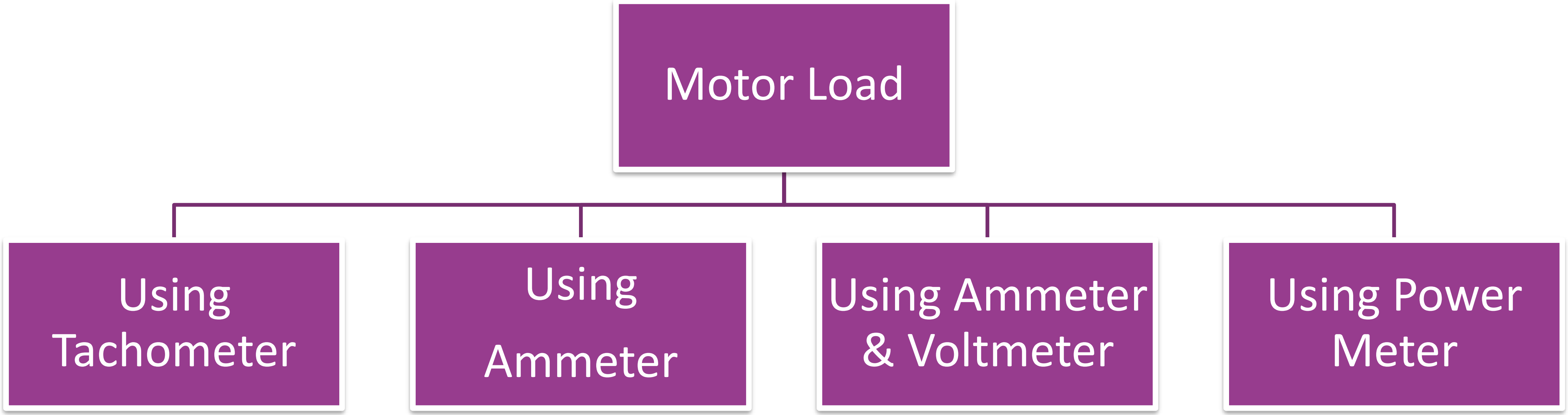


Motor Selection Criteria – Load Estimation



Source: Sidpec

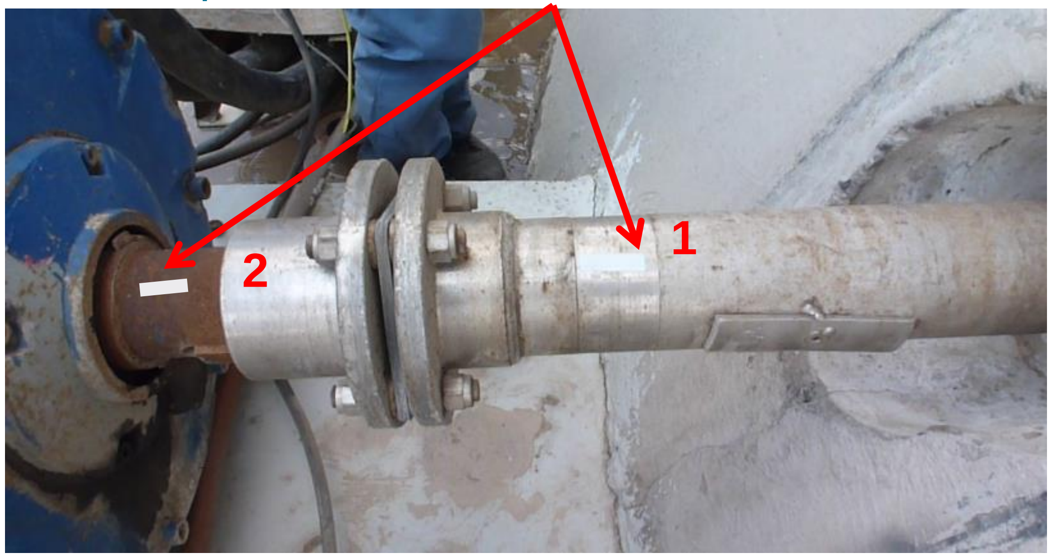
Estimation or Calculation of Motor Load



Load Estimation – Using Tachometer

- Motor nameplate details:
  - Rated power - 110 kW
  - Rated speed - 1488 rpm
  - Rated current - 209 A
  - Rated voltage - 380 V
  - Rated power factor - 0.85

Marker tape to allow strobe effect for Tachometer



- Readings taken during site visit:
  - **Actual speed** - 1490 rpm (using Tachometer)
  - **Actual voltage** - 390 V (from control panel)

Load Estimation – Using Tachometer

- Load Estimate

$$Load\ (\%) = \frac{Slip}{(S_{synch} - S_{nameplate}) \times \left(\frac{V_n}{V_{measured}}\right)^2} \times 100$$

$$Load\ (\%) = \frac{1500 - 1490}{(1500 - 1488) \times \left(\frac{380}{390}\right)^2} \times 100 = \mathbf{87.8\%}$$

Load Estimation – Using Ammeter

- Nameplate ratings:
  - Rated Power - 110 kW
  - Rated Speed - 1488 rpm
  - Rated Current - 209 A
  - Rated Voltage - 380 V
  - Rated power factor - 0.85

- Measured Values:
  - **Actual Current - 188 A**

$$Load\ (\%) = \frac{I_{measured}}{I_{rated}}$$

$$Load\ (\%) = \frac{188}{209} = \mathbf{90.0\%}$$

Load Estimation – Using Ammeter & Voltmeter

- Nameplate ratings:
  - Rated Power - 110 kW
  - Rated Speed - 1488 rpm
  - Rated Current - 209 A
  - Rated Voltage - 380 V
  - Rated power factor - 0.85

- Measured Values:
  - Actual Current - **188 A**
  - Actual Voltage - **390 V**

$$Load\ (\%) = \frac{V_{measured} \times I_{measured}}{V_{rated} \times I_{rated}}$$

$$Load\ (\%) = \frac{390 \times 188}{380 \times 209} = \mathbf{92.3\%}$$

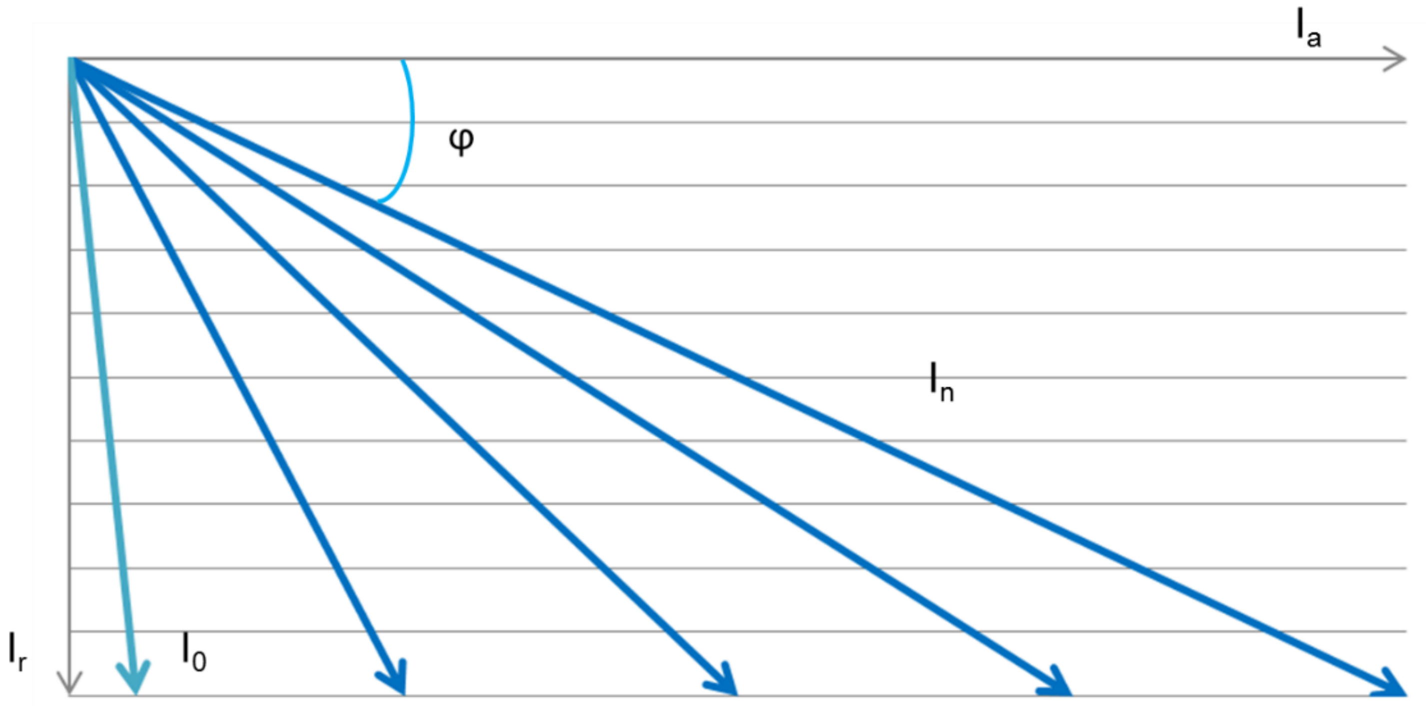
Load Estimation – Using Power Meter

- Measured Values:
  - Actual Power = 103.5 kW
  - Actual Power Factor = 0.81

$$Load\ \% = \frac{P_{actual}}{P_{rated}} = \frac{P_{measured}}{\sqrt{3} \times V \times I \times pf}$$

$$Load\ \% = \frac{103.5}{\sqrt{3} \times 380\ \times 209 \times 0.85} = \mathbf{88.5\%}$$

Current Phasor Variation with Load



$$I_0 \cong I_n \sin\varphi$$

I_a – Active Current
I_r – Reactive Current
I_0 – No load Current
I_n – Nominal Current
Cos φ – Full Load Power Factor (nameplate rating)

Load Estimation Methods

Instrument	Value	Accuracy
Tachometer	79.1 %	Fair, but large variance
Ammeter	90.0%	OK, not good below 50% load
Voltmeter Ammeter	92.3 %	OK, not good below 50% load
Power	88.5 %	Good for all load conditions

Estimating Motor Efficiency in the Field

When evaluating the replacement of an existing motor with a Premium or a Super-Premium solution it is important to know the efficiency of the existing motor.

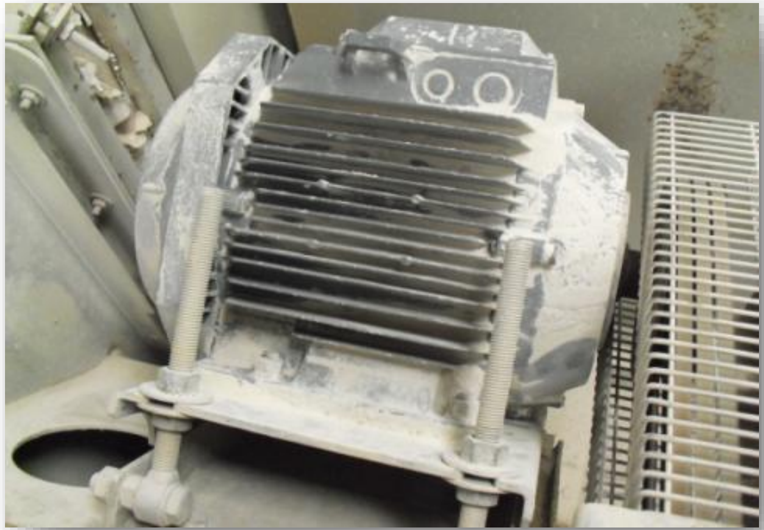
- **Speed** measurement is easy and fast
- **Torque** measurement is difficult and would need uncoupling the motor from the load to install a torque sensor

The most common methods used are:

- Loss accounting methods (Typical errors around 1 to 3%)
- Software tools (Oak Ridge National Laboratory developed the Oak Ridge Motor Efficiency and Load -ORMEL)
- New standards (IEC 61800-9 Series) assisting with PDS efficiency estimation

Case Study - Super-Premium Retrofitting

As an example of retrofitting, an IE0-Class Equivalent, 5.5-kW, 4-pole, Induction Motor driving a fan in an industrial facility, has been replaced by an IE4-Class Line-Start Permanent Magnet Motor (LSPM).



(a) IE0 SCIM

(b) IE4 LSPMSM

Photos of the replaced and replacing motors: (a) Brand A, 132S, IP55, Cl. F, 5.5 kW, 380-420V, 11.5 A, 1450 r/min, PF=0.83, Eff.=83.2% (IE0/EFF3 Class); (b) Brand B, 132S, IP55, Cl. F, 5.5 kW, 380-420V, 9.34 A, 1500 r/min, PF=0.93, Eff.=92.5% (IE4 Class).

Summary of the Motor Performance for the SCIM and LSPM

	Before Replacement	After Replacement
Motor Type	SCIM	LSPM
Efficiency Class	IE0/EFF3	IE4
Rated Efficiency	**83.2%**	**92.5%**
Rated Power	5.5 kW	5.5 kW
Rated Voltage	400 V, 50 Hz	400 V, 50 Hz
Rated Current	11.5 A	9.34 A
Rated Power Factor	0.83	0.93
Rated Speed	**1450 r/min**	**1500 r/min**
Actual Voltage	≈ 400 V	≈ 400 V
Actual Current	≈ 7,5 A	≈ 5,5 A
Actual Power Factor	0,75	0,90
Actual Input Real Power	3750 W	3500 W
Actual Input App. Power	5100 VA	4000 VA
Actual Speed	1472 r/min	1500 r/min
Estimated Load	< 57%	< 59%

The original motor was oversized (load lower than 57%) and, therefore, a 4-kW LSPM would be enough for this application, but the user decided to maintain the rated power. Moreover, since the new 5.5-kW LSPM has a load lower than 60%, it can benefit in terms of efficiency and power factor from voltage regulation.

Savings & Payback

$$Electricity\ Savings\left[kWh / year\right] = Hr \times LF \times \left(\frac{P}{\eta_1} - \frac{P}{\eta_2} \right)$$

$$Electricity\ Savings\left[kWh / year\right] = 4000 \times 0.59 \times \left(\frac{5.5}{0.832} - \frac{5.5}{0.925} \right)$$

$$= 1557.6\ \text{kWh/year}$$

Hr – Number of Operating Hours per year
LF – Load Factor
P – Motor mechanical output power
η – Motor Efficiency

Savings & Payback

$$Simple\ Payback = \frac{Cost\ \ of\ \ new\,motor\,(US\$)}{Energy\ Savings(kWh\,/\,year) \times Electricity\ Cost(US\$\,/\,kWh)}$$

$$Simple\ Payback\ = \frac{\$300}{1557.6 \times \$0{,}10}$$

$$= 1.92\ years$$

Hr – 4000 hours
LF – 0,59
P – 5.5 kW
η_1 – 83.2%
η_2 – 92.5%

05. Pumps

Motor Applications

Motor Systems Optimisation (MSO) Expert Training (2020 Egypt Edition)

Samir Khafagui
Siraj Williams

Discussed Topics

- Pump Basics
- Pump Control
- Pump Optimisation
- Pump Flow Profiles
- Multiple Pump Configurations
- Typical Pump Problems
- Top Industrial Energy Saving Opportunities

Egyptian program for promoting Industrial Motor Efficiency
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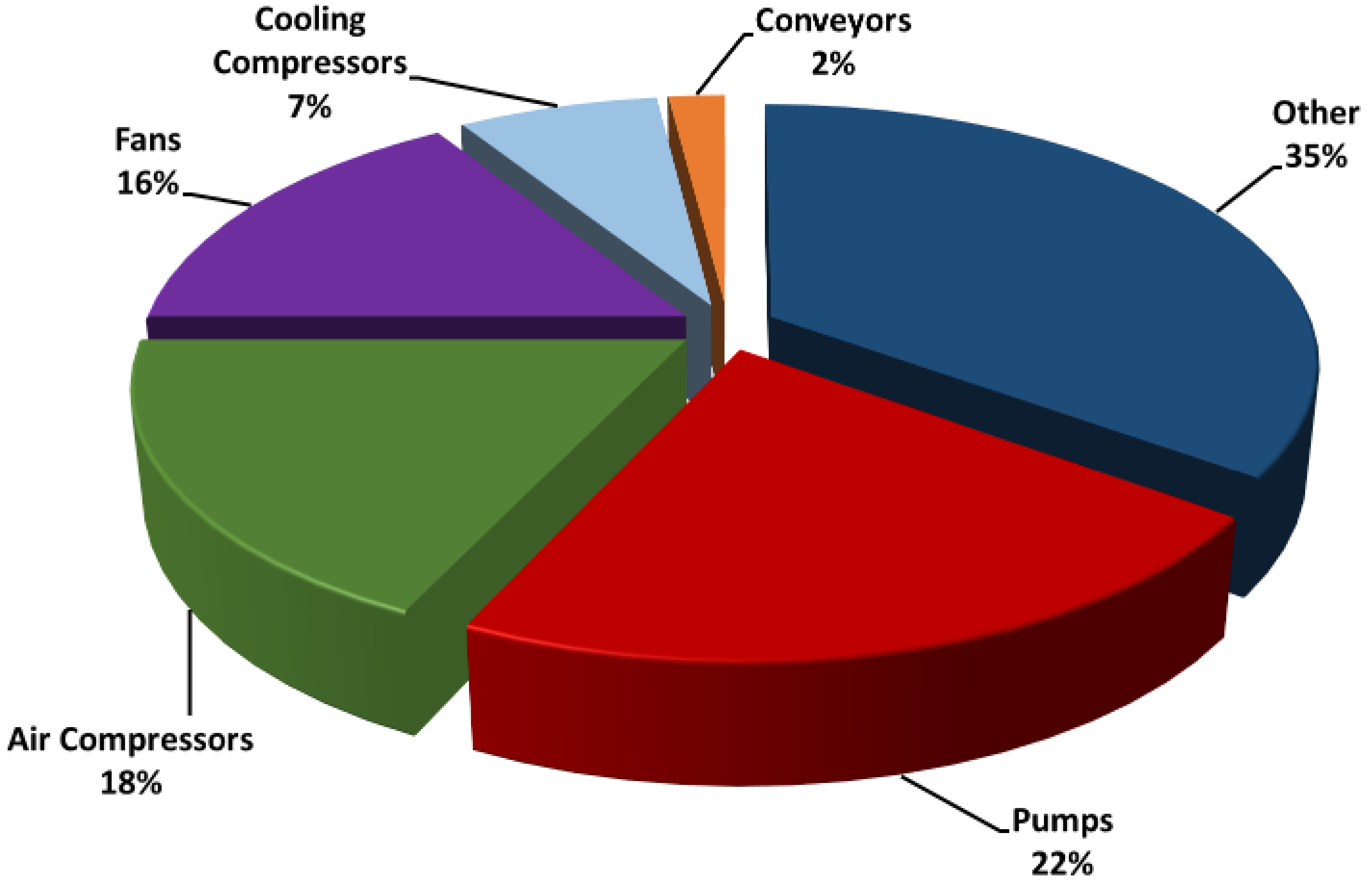
Motor Systems Electricity Consumption by Application

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



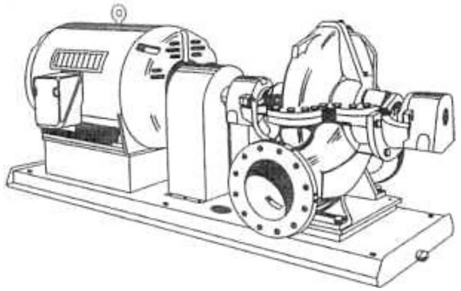
Electricity Consumption in the European Union Industrial Sector
Source: ISR – University of Coimbra (2012)

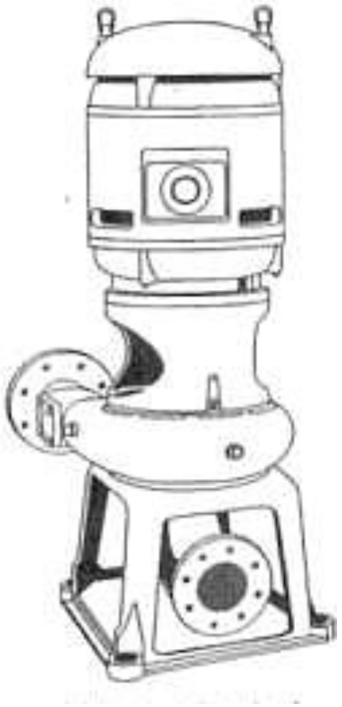
Pump Types

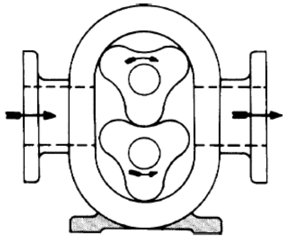
Pump Types

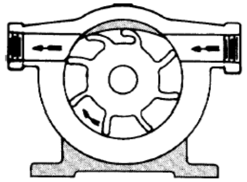
- **Roto-Dynamic Pumps** (Centrifugal)
  - End Suction
  - Split Case
  - Vertical Turbine
  - Special Pumps
    - Jet Pumps
    - Vortex Pumps
    - Regenerative turbines
- **Displacement Pumps**
  - Reciprocating
    - Piston
    - Diaphragm
  - Rotary
    - Peristaltic
    - Progressive Cavity
  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

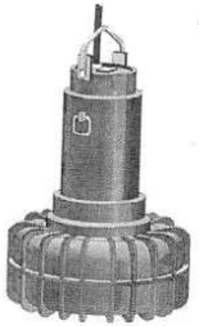
Examples of Pump Types


Split Case

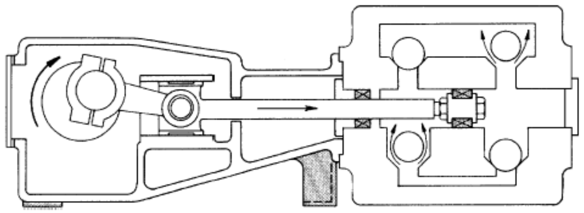

Vertical, close coupled

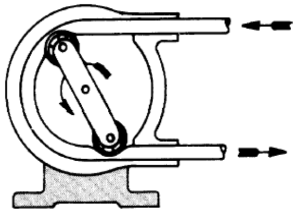

Rotary Lobe

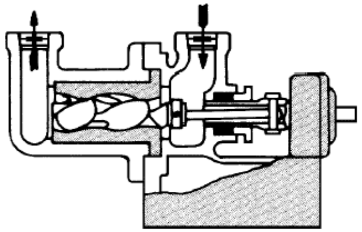

Flexible Vane


Submersible


End Suction


Horizontal Piston


Flexible Tube


Screw Pump

Figures: ACR Publications, Hydraulic Institute

Pump Basics – Pressure Flow Relationship

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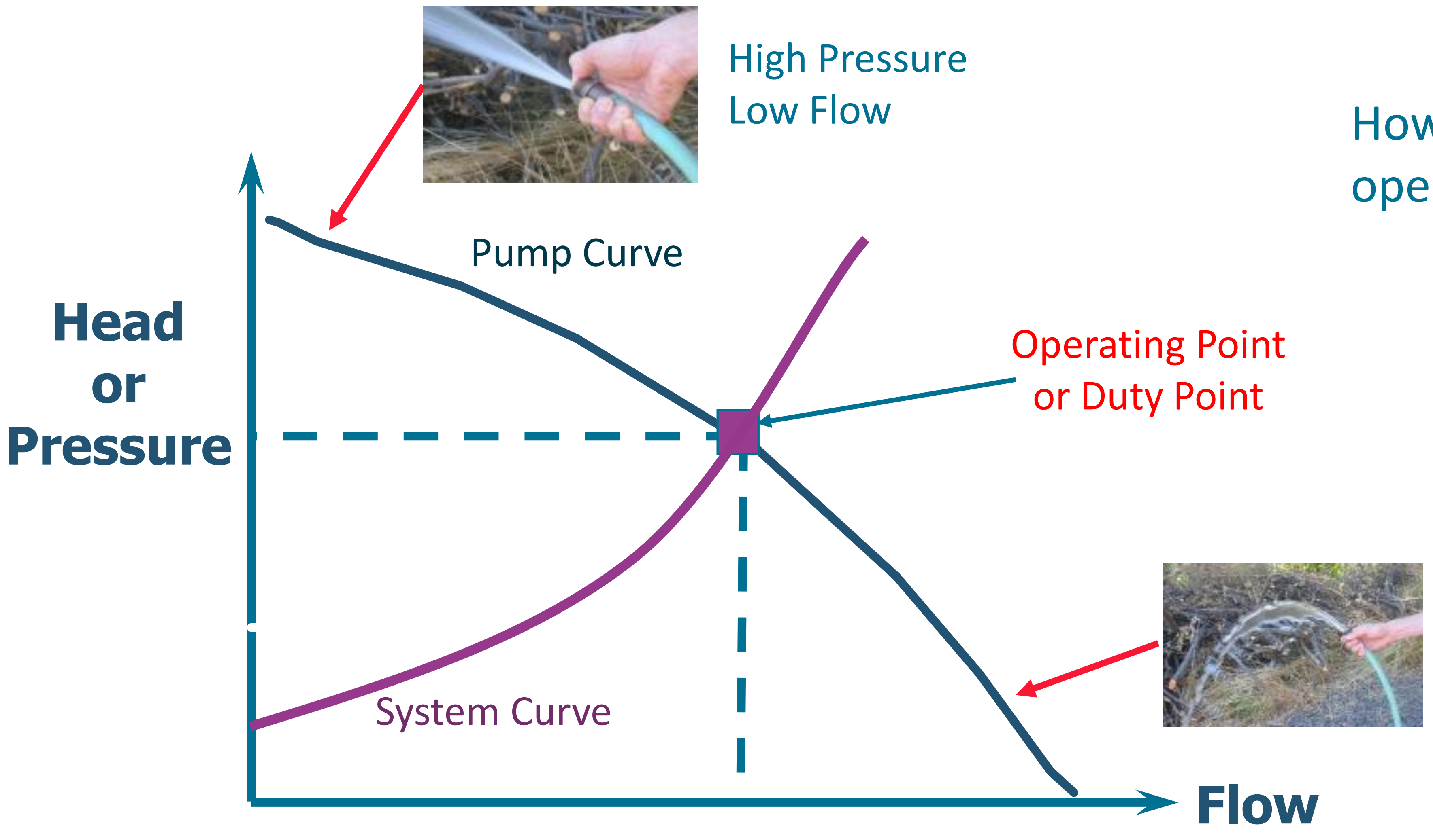


Low Pressure
High Flow

How do we vary the operating point?

Affinity Laws – Centrifugal Pumps

- Relation between Pump Speed (N), Impeller Diameter (D), Flow (Q), Head (H) and 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

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

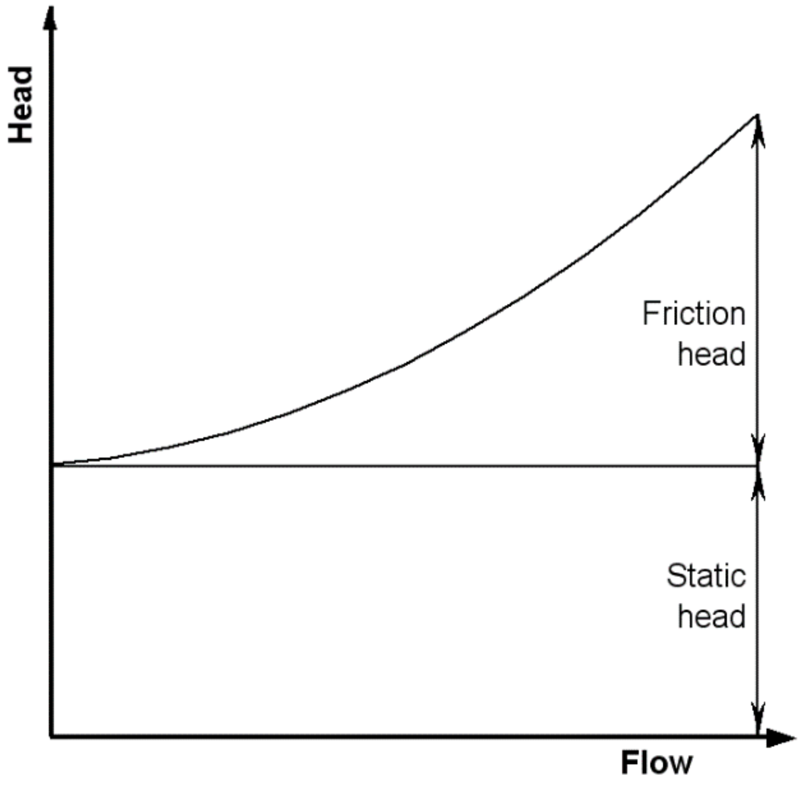
$$H_{new} = H_{old} * \left(\frac{D_{new}}{D_{old}}\right)^2$$

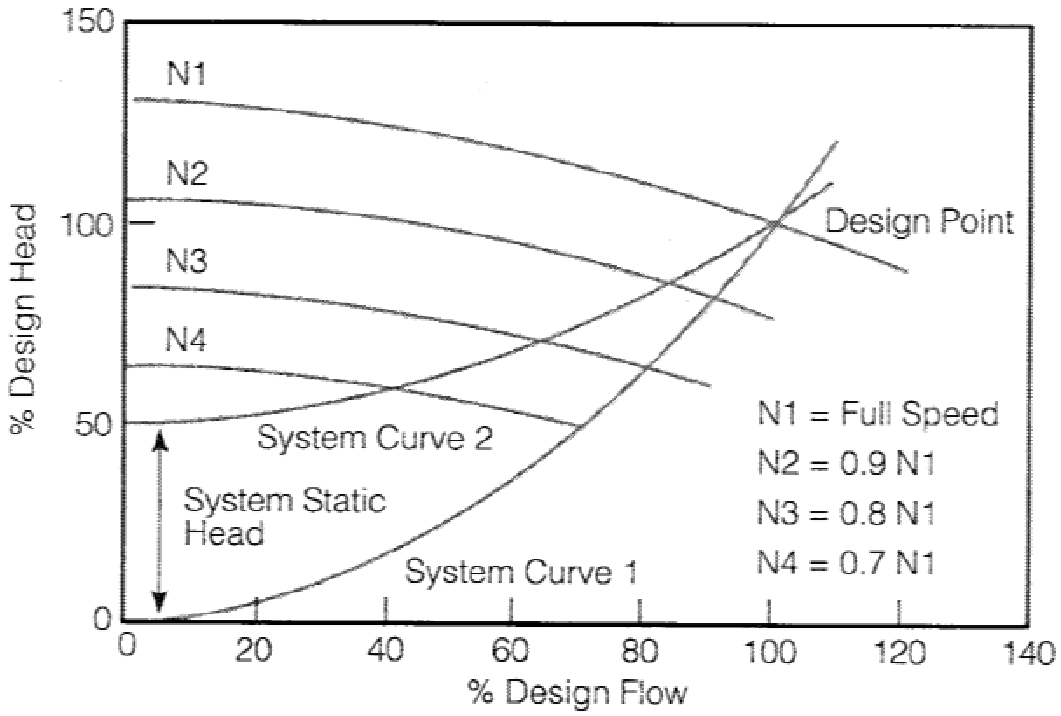
$$P_{new} = P_{old} * \left(\frac{D_{new}}{D_{old}}\right)^3$$

Affinity Laws

Affinity laws only apply to the friction losses.

Static losses are constant at different speeds.



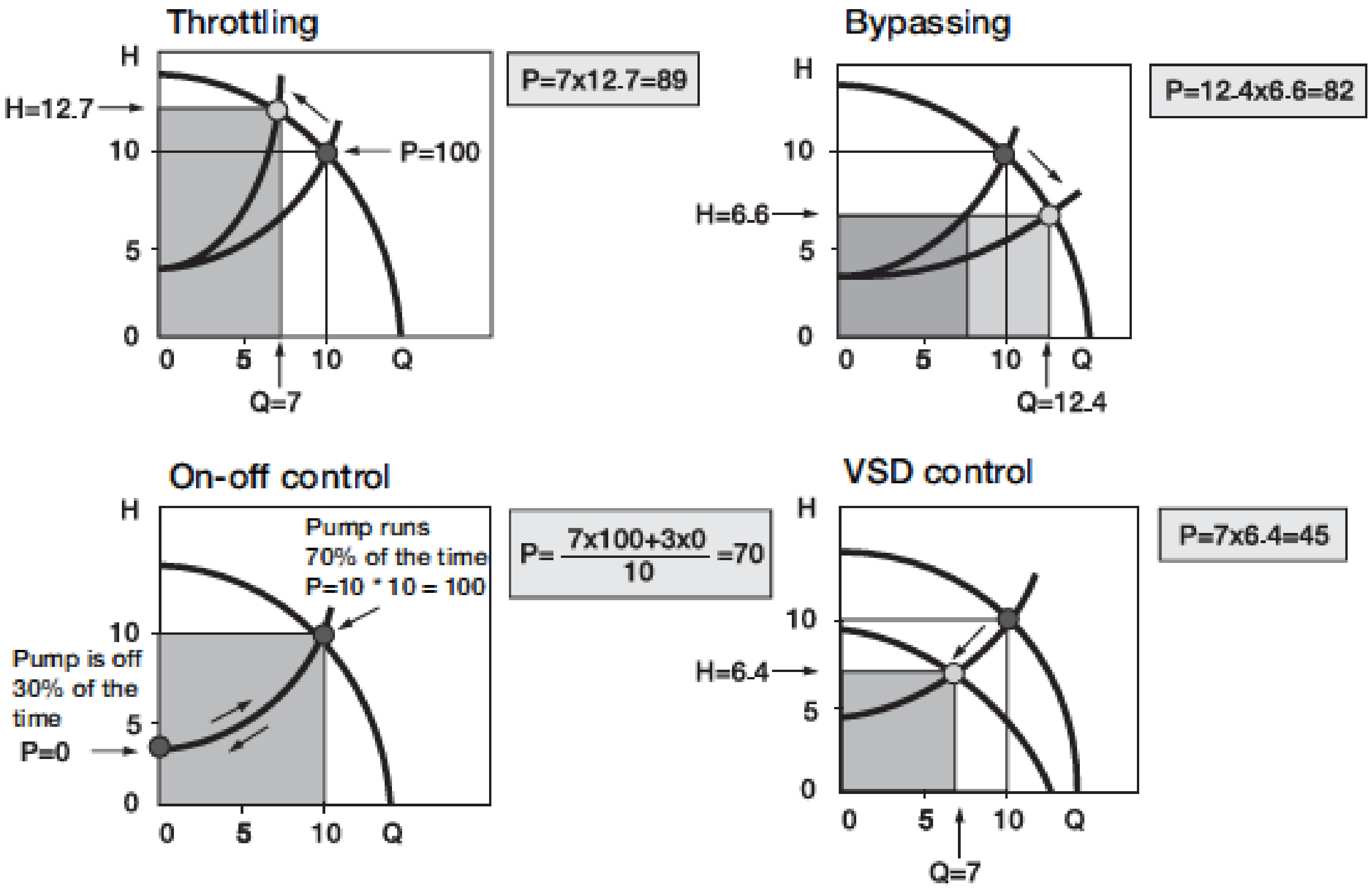


Therefore, systems with low static head tend to be better candidates for VSDs and thus for energy savings.

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)

Comparison of Flow Control Methods

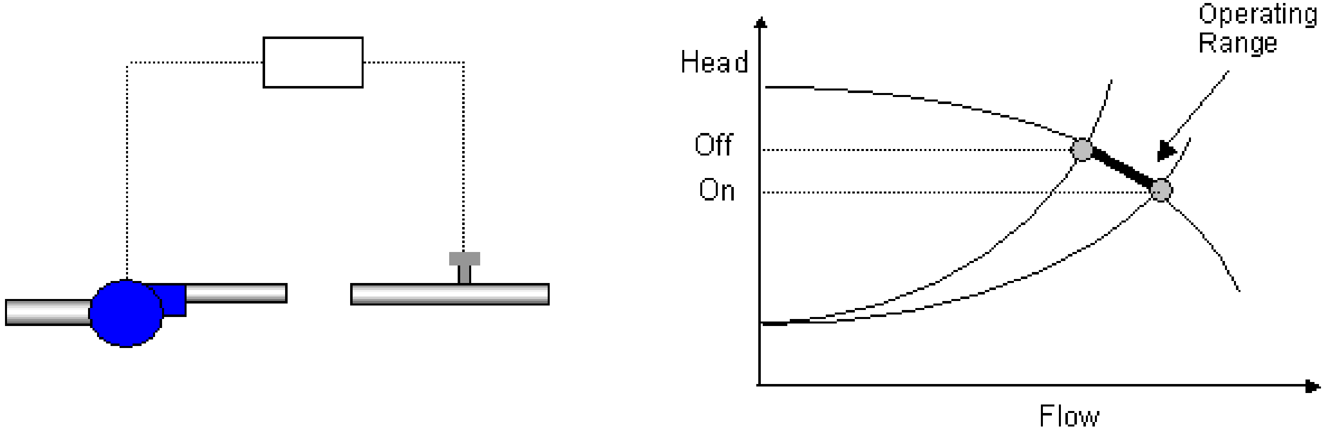


Relative power consumption on an average flow rate of 70% with different control methods

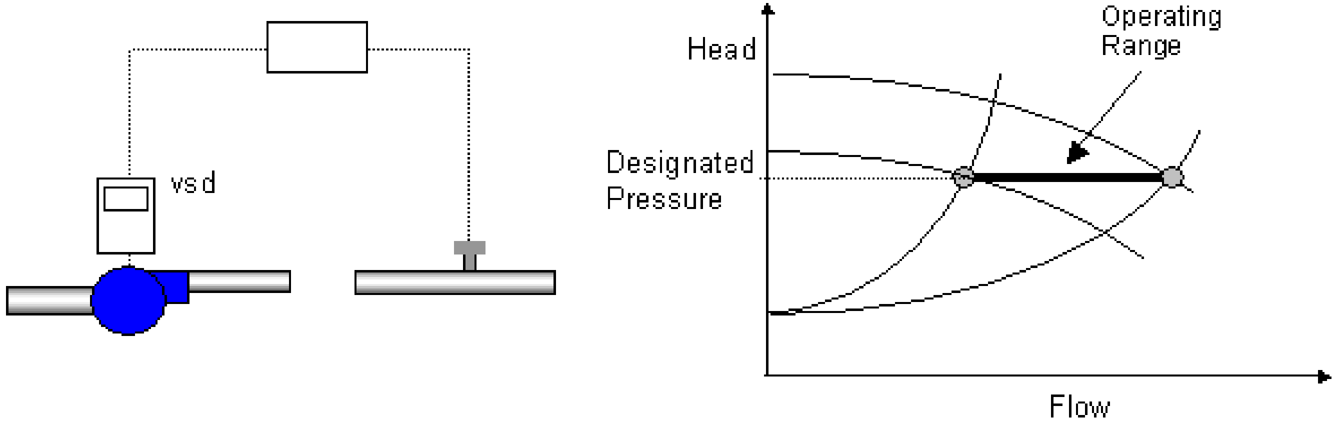
Control	Energy
Throttling	89
Bypassing	82
On-off control	70
VSD control	45

Closed Loop Pressure Control: Using a VSD

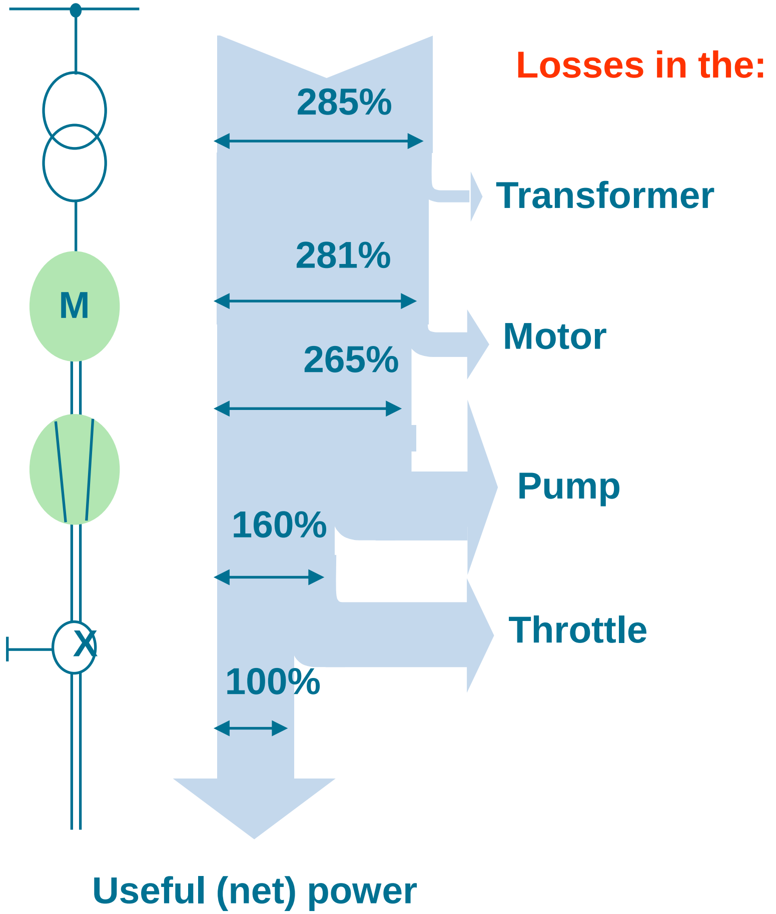
Without VSD



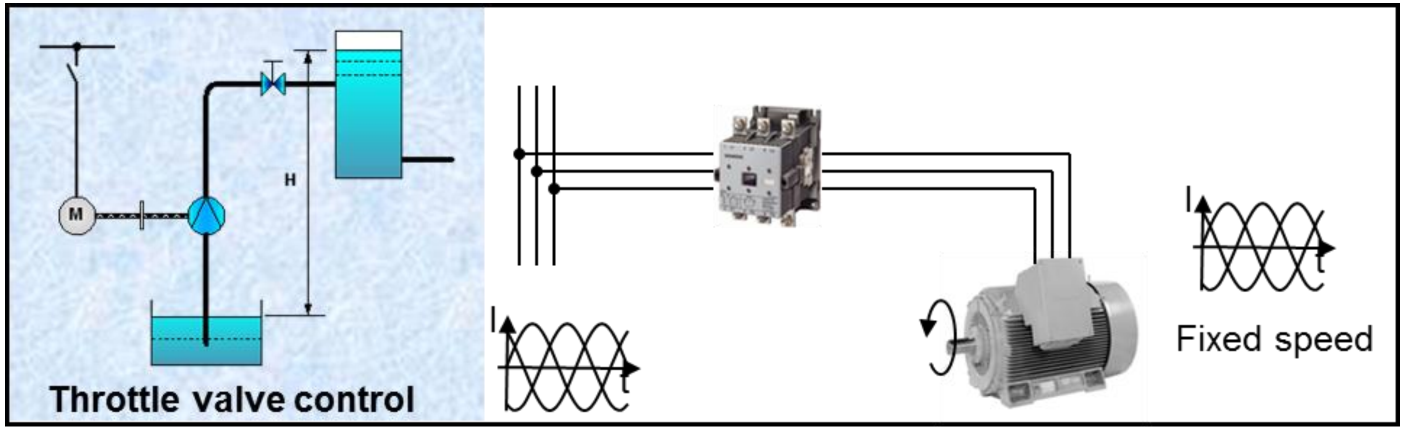
With VSD



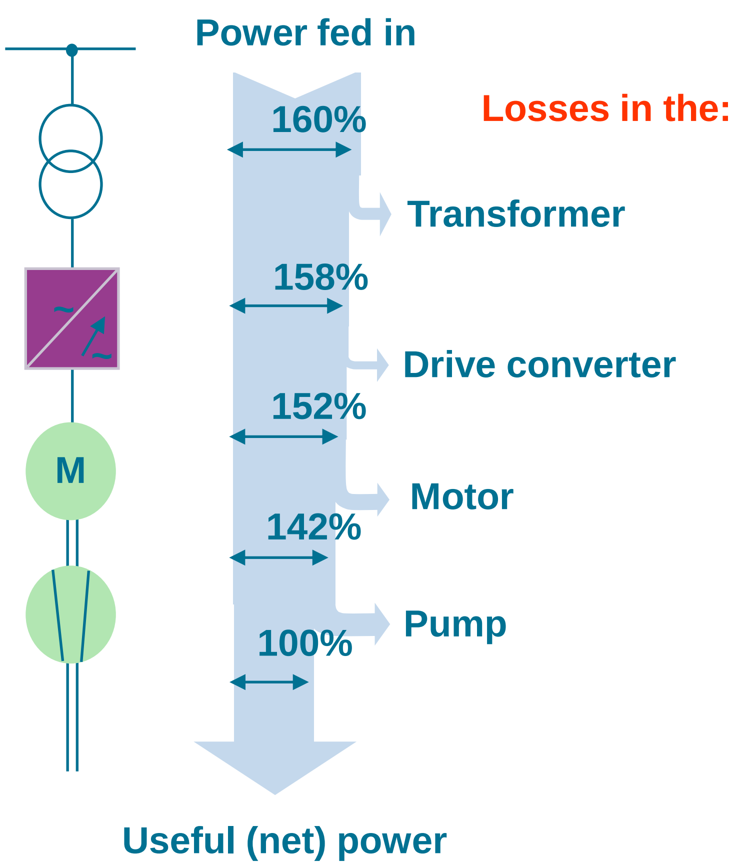
Worked Example: DOL with Throttle



The drive process represents the main energy saving potential!
Example:
For a conventional fixed-speed drive with flow control using a throttle, 285 % of the power used is supplied in the form of electrical energy. The energy balance of a pump, operated at constant speed, becomes increasingly more unfavorable, the lower the quantity of medium to be pumped.

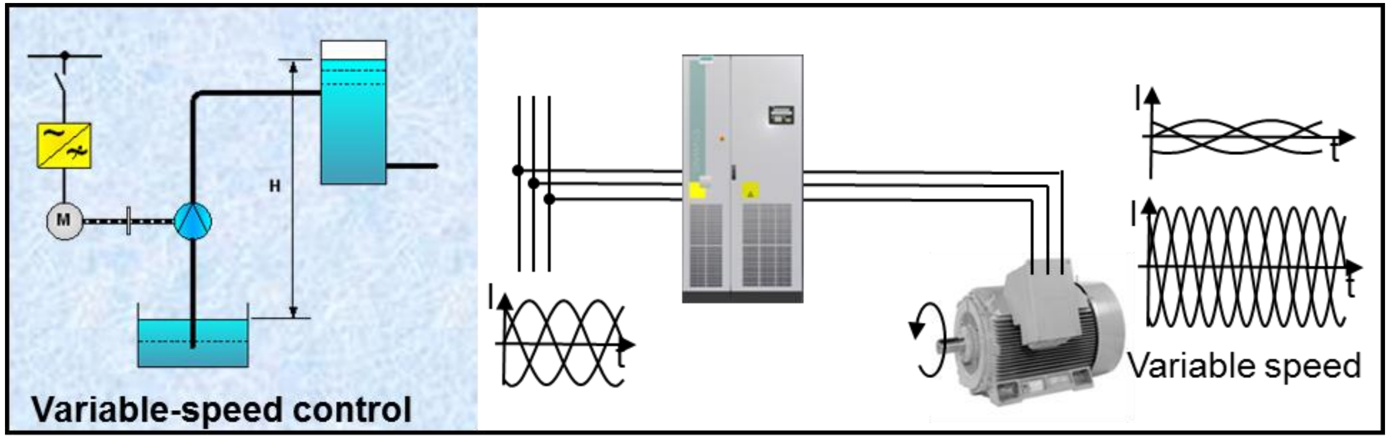


Worked Example: VSD with No Throttle Valve

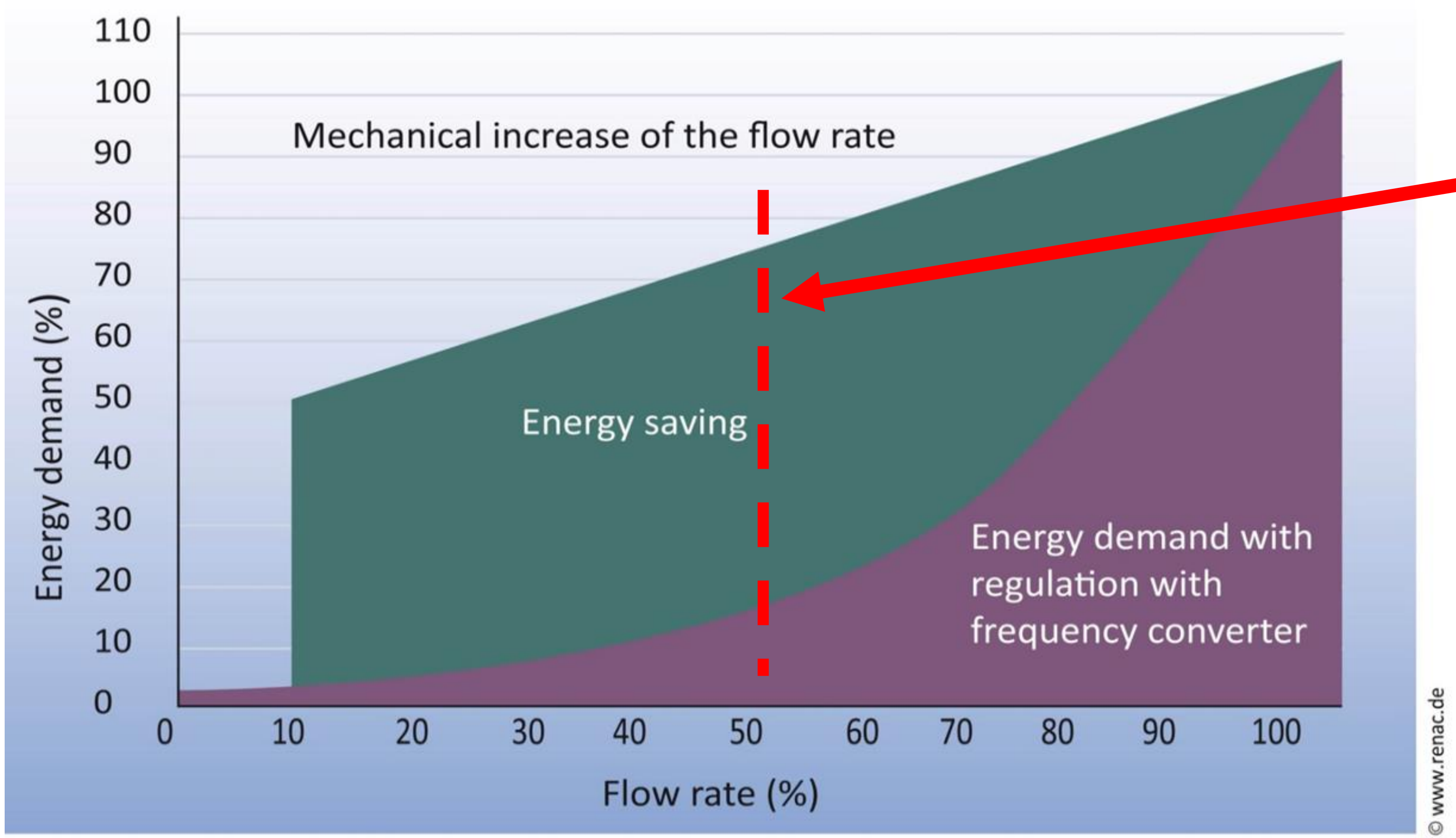


The drive process represents the main energy saving potential!
Example:
With electronic speed control, the power fed in is only 160% of the power required to pump the medium and the total losses are reduced to 1/3.

The process quality is also improved.



Centrifugal Pumps: Throttle vs VSD



Note:
- Most of the savings are made with just a 50% reduction.
- VSDs rarely run below this point.
- Bypass systems are even worse!

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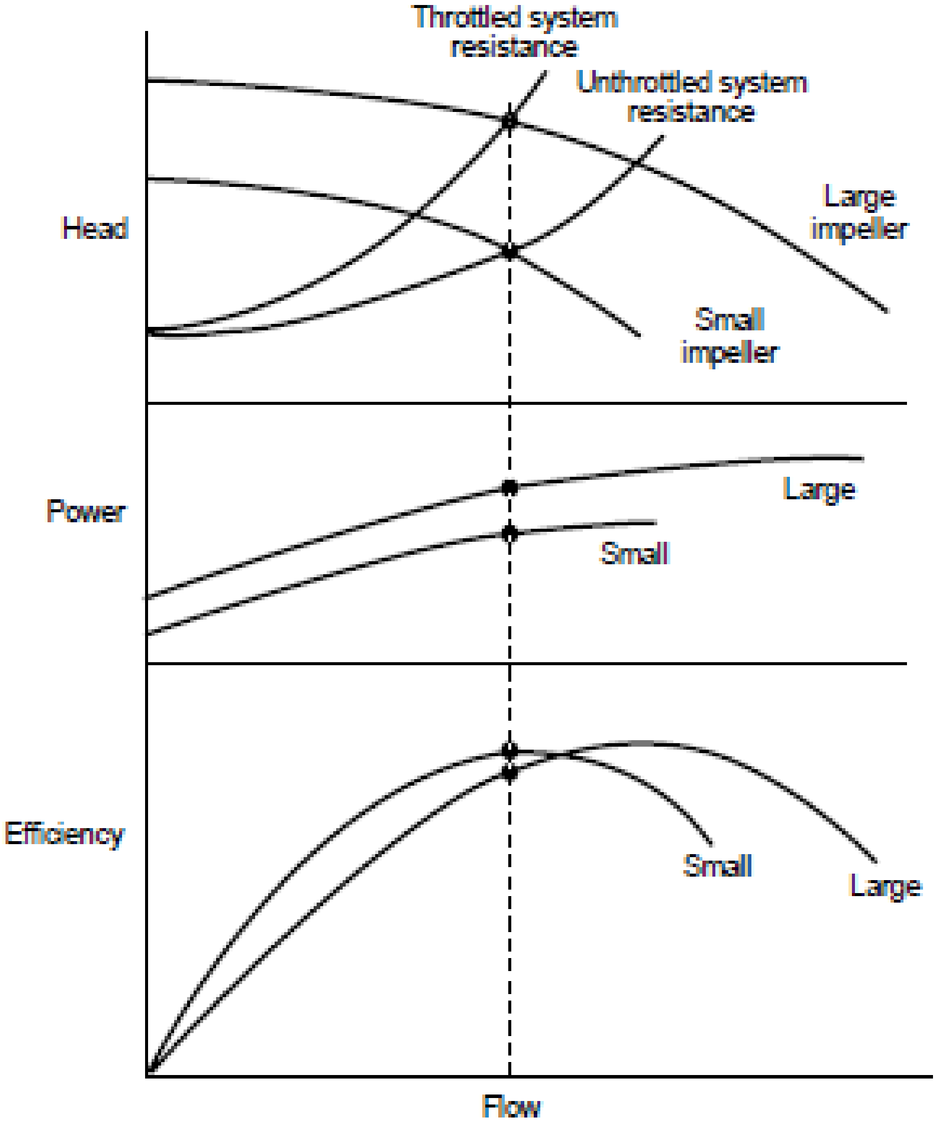
Source: RENAC

Impeller Trimming

- Pump impeller will be most efficient close to maximum diameter.
- A smaller impeller will be less efficient, but the system energy savings will be large.
- Replacing or trimming an impeller is an option, usually for fixed load applications



Impeller Trimming Case Study

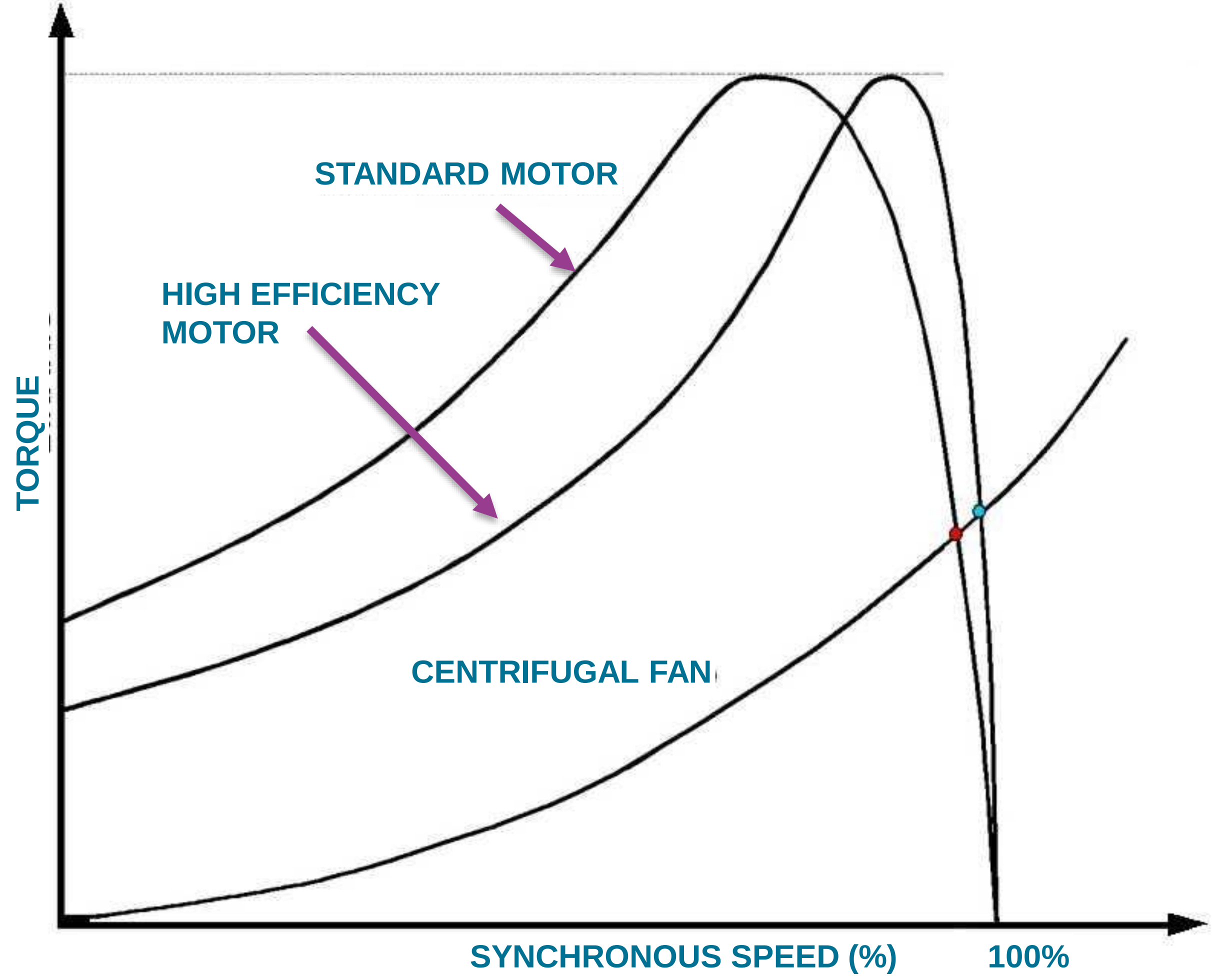
- A brine pump at salt works condensate distribution system was oversized and causing maintenance problems.
- The impeller was trimmed.
- Motor power required to drive the new pump configuration was reduced from 110kW to 75kW.
- Payback in 11 days.

Source: UK EEBPP GPCS300 Energy savings by reducing the size of a pump impeller

New motors – effect on pumping system

- More efficient motors will have lower slip and hence higher speed.
- For many pumps, More efficiency, but more energy.
- But for low frictional head (and high static head), the effect will be minimal.
- It is not material if the pump is controlled properly.

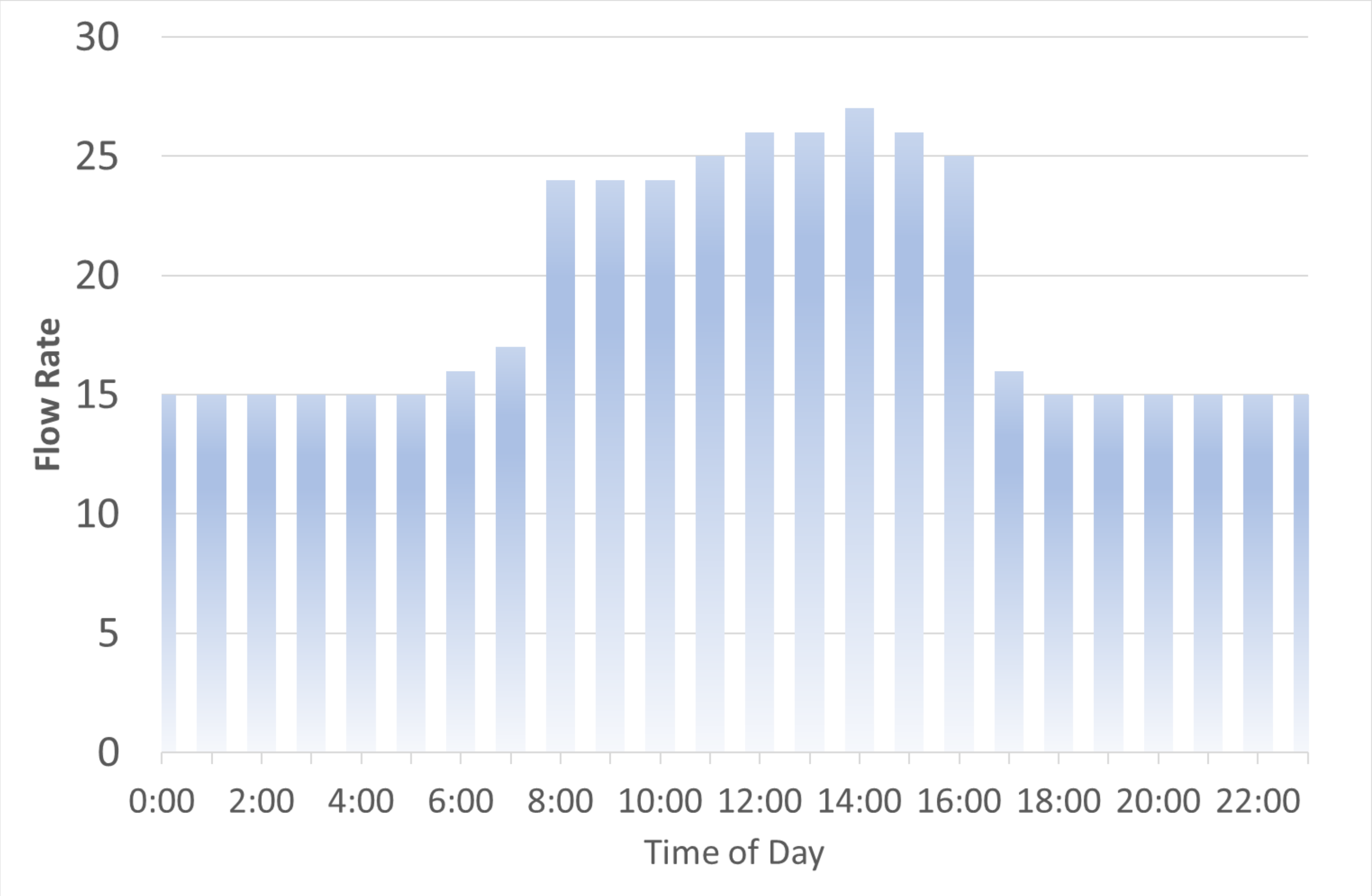
Match Higher Efficiency Motor Operating Speed



Pump Flow Profiles

- Can be useful in understanding energy requirements of the motor system.
- Recording period of flow profile is dependent on production and other operating requirements.
- Also, consider the available data and whether additional metering or measurements need to be installed.

Daily Flow Fluctuation Example



Annual Flow Fluctuation Example

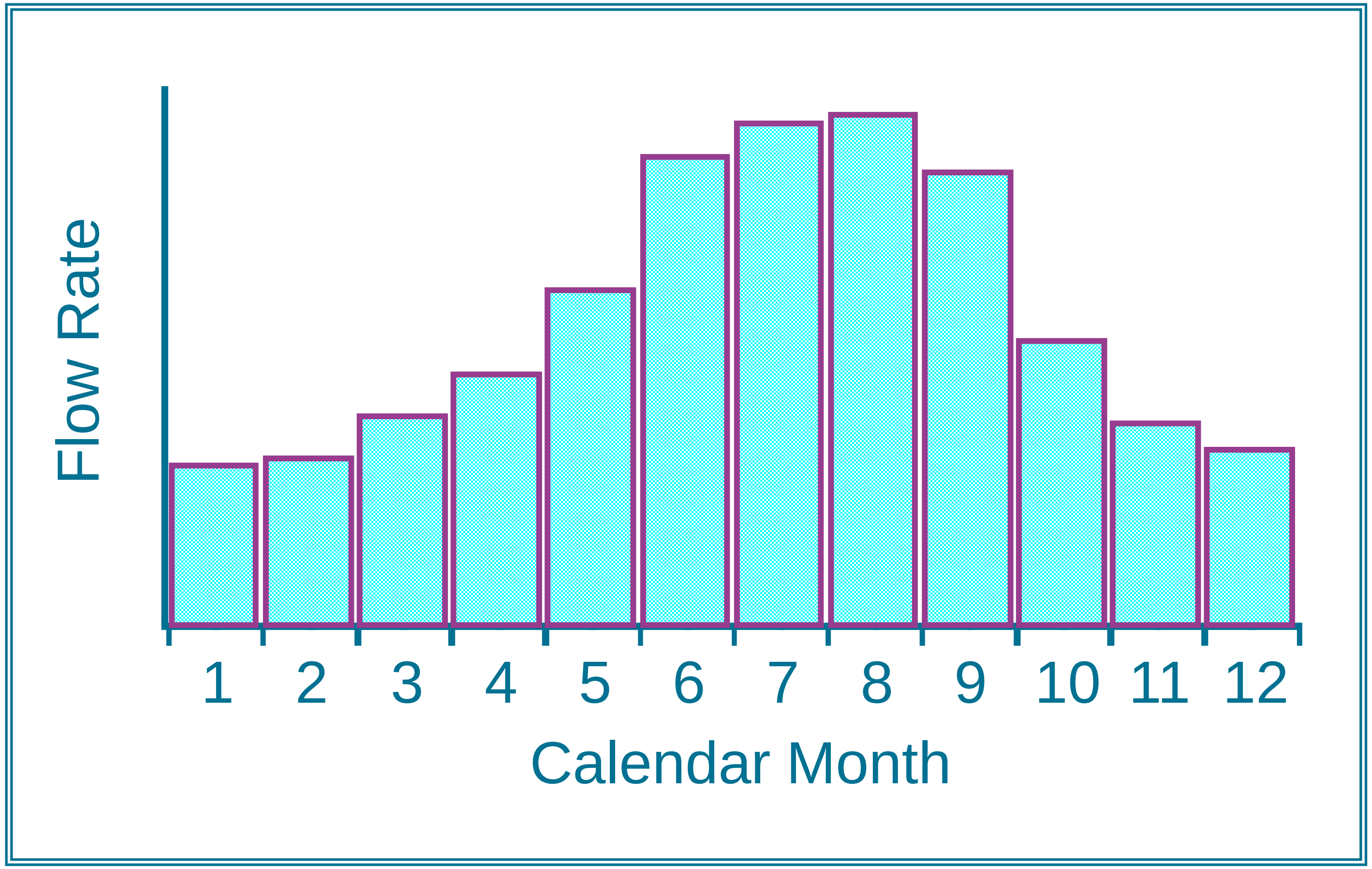
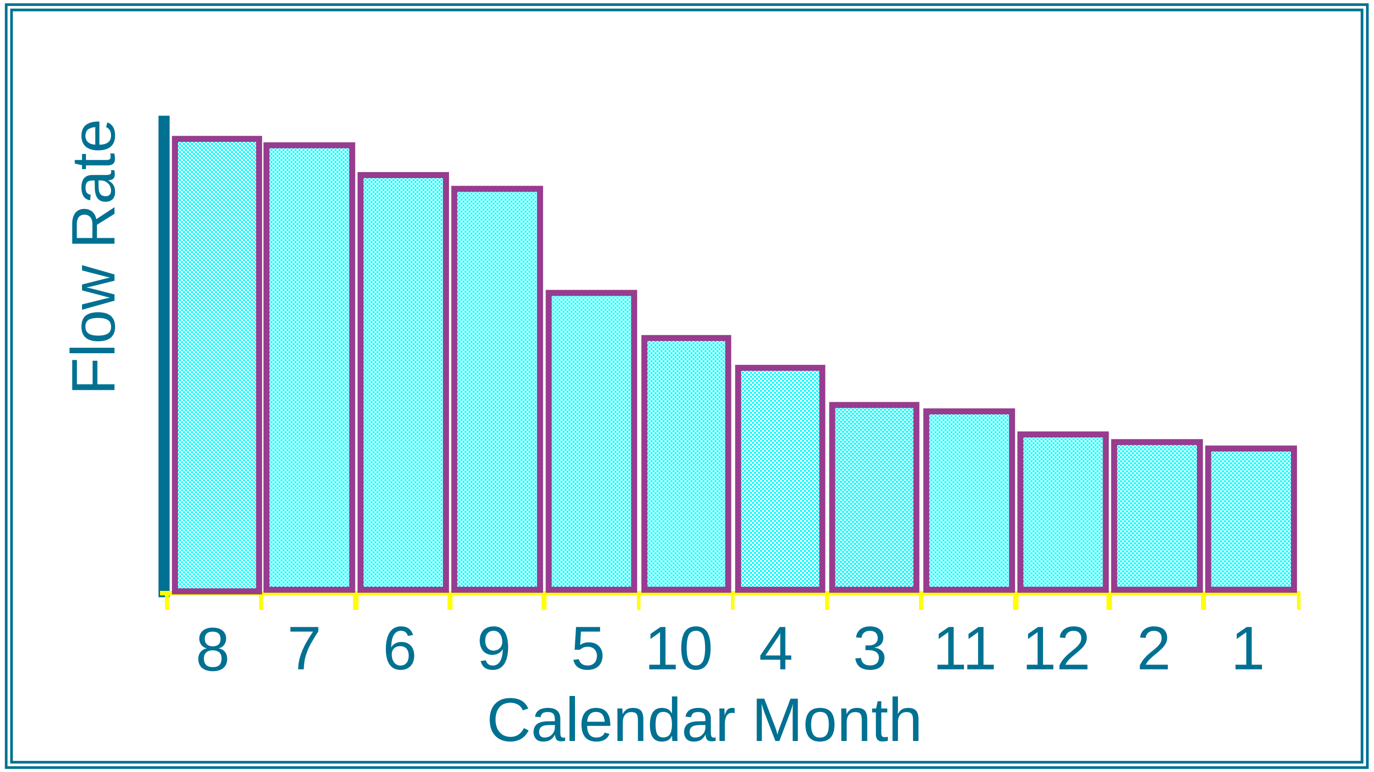
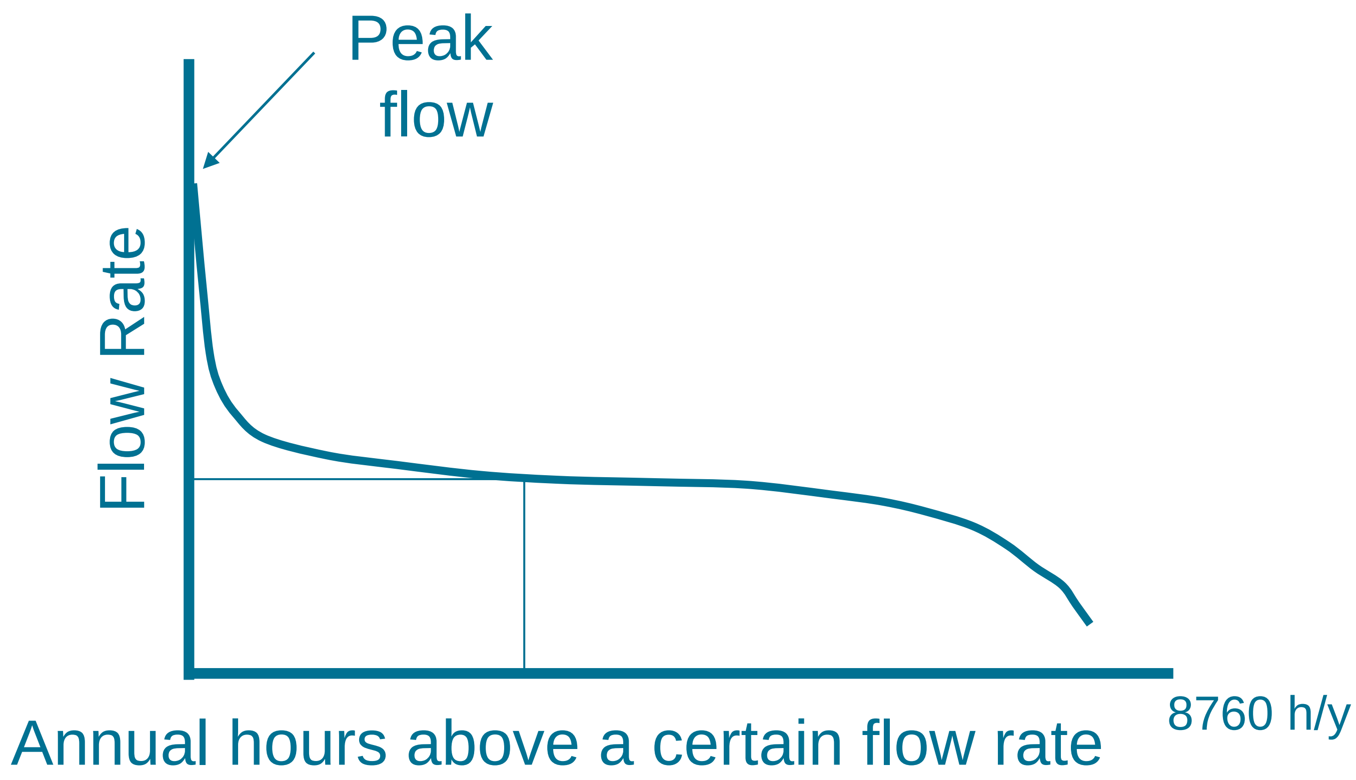


Figure Courtesy of Oak Ridge National Laboratory

Sorting the Months by Highest Flow Rate

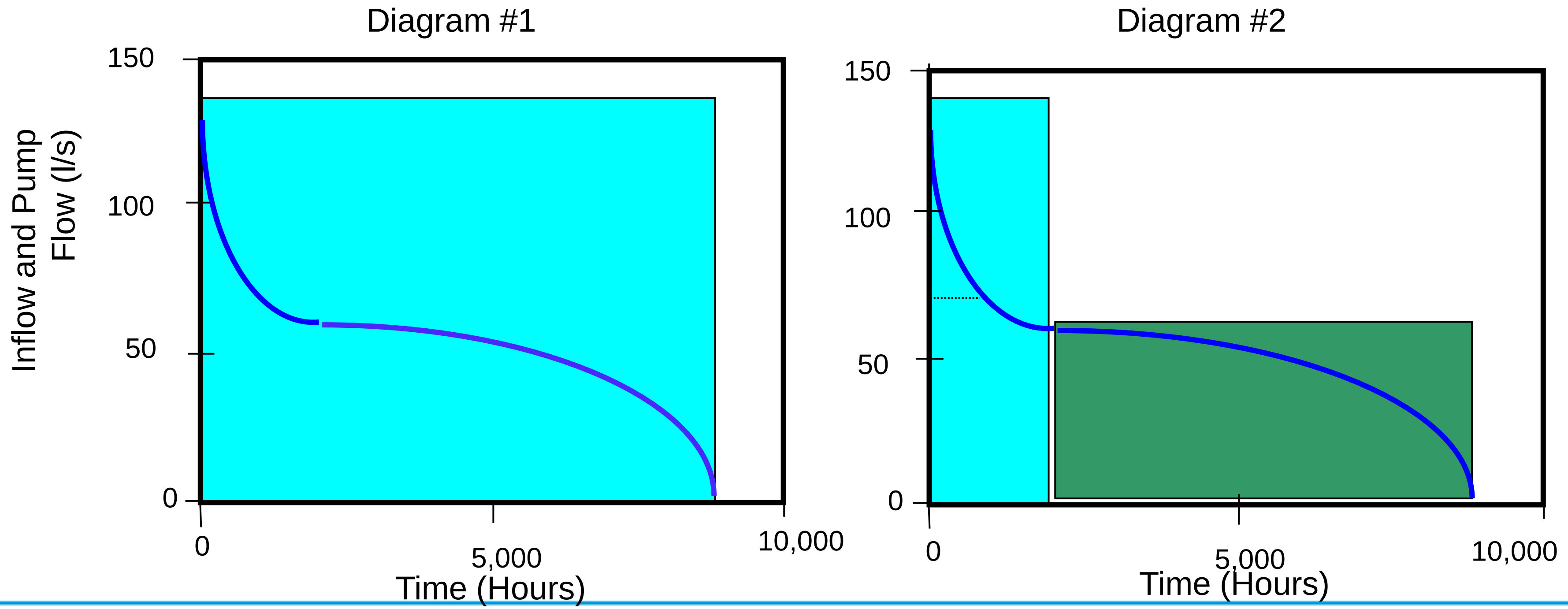


- By tracking flow rate over time, a "flow duration" curve is developed
- Understanding how the flow requirements varies over time is a crucial element in optimizing fluid systems



Using Smaller Pumps to Handle Low Flows

- Diagram #1 shows a large pump operating for 8760 hours per year at a flow rate of 140 l/s – total flow is represented by the area under the curve.
- Diagram #2 shows the same total flow pumped by two pumps. The 140 l/s pump only operates 2000 hours per year and a smaller pump rated for 60 l/s operates for 6760 hours



Worked Example: Low Flow

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- 85kW pump, rated at 270 l/s at 2 bar.
- Pump operates at full power with excess water flowing through a bypass. Actual process requires:
  - 260 l/s for 3 months per year
  - 160 l/s for 9 months per year
- What is the energy cost of the pump if the electricity cost is EGP 0.5/kWh? (Ignore motor losses)

Opportunity

- The maintenance engineer has found a spare motor in store (55kW, rated at 170 l/s at 2 bar)
- What will be the total energy cost operating if you install this pump to operate 9 months per year?

Solution

Existing Case:

- 85kW x 8760h x EGP 0.5 = EGP 372,300

New case:

- 55kW x (3/4) x 8760h x EGP 0.5 = EGP 180,678
- 85kW x (1/4) x 8760h x EGP 0.5 = EGP 93,750
- Total: EGP 273,750

- Saving = EGP 98,550

Worked Example: Throttled Flow

- 85kW pump, rated at 270 l/s at 2 bar.
- Actual process requires 200 l/s 8760 hours per year.
- Currently pump operates with throttle to restrict flow to 200 l/s.

- What is the energy saving if the throttle is replaced with a VSD? (Assume the electricity cost is EGP 0.5/kWh and the VSD losses are 5%)

Solution

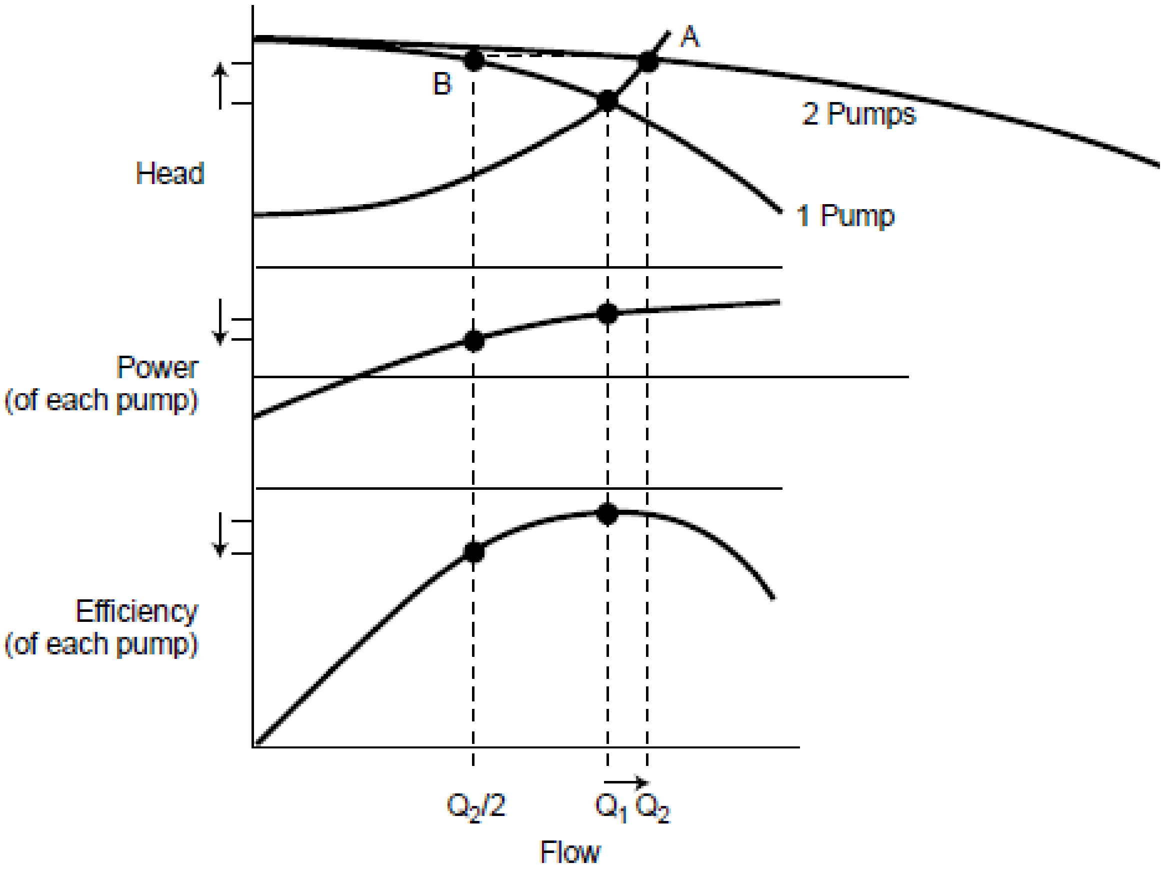
- Throttle Case:
- 85kW x 8760h x EGP 0.5 = EGP 372,300

- VSD case:
- (200/270)^3 x 85kW x 8760h x (1/0.95) x EGP 0.5
- = EGP 159,282

- Saving = EGP 213,018

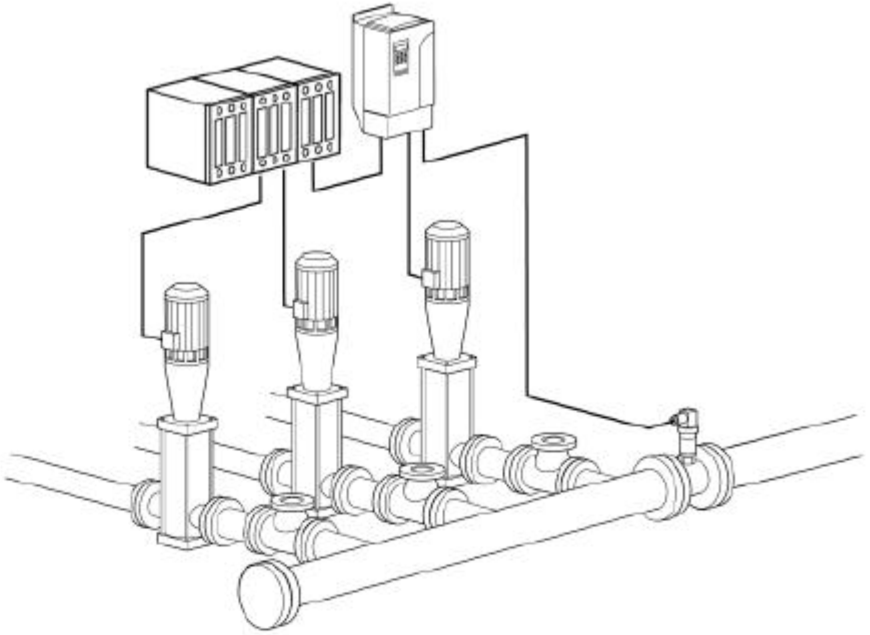
Multiple Pumps in Parallel

- Usually installed to provide redundancy, allowing rotation of pumps and maintenance.
- Can offer better matching of flow with process.
- Allows flexibility to changing requirements.
- Often a good opportunity for energy savings.
- Parallel systems are usually optimised for a specific number of pumps. Operating away from this could have severe power consequences.

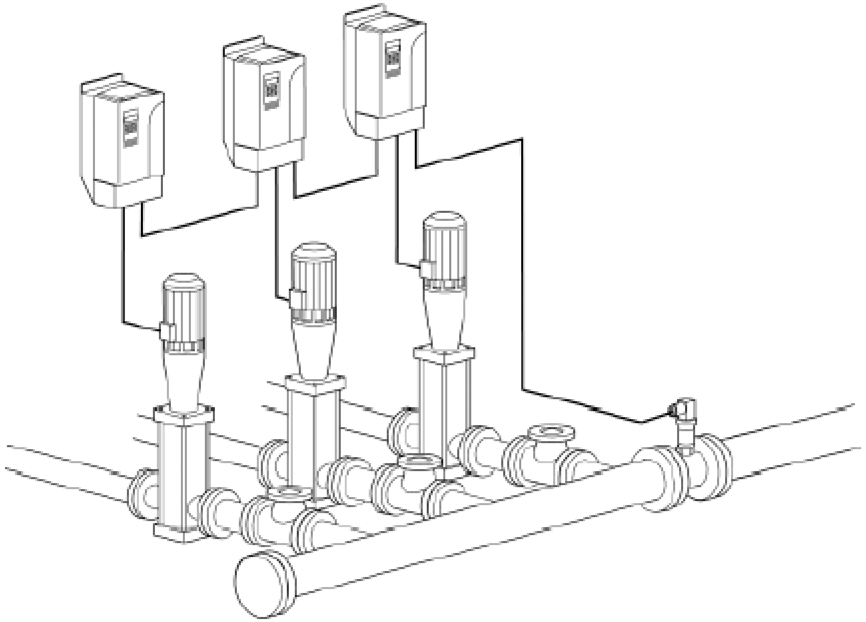


VSDs on Multiple Pump Systems

Using VSDs to control pressure reduces the electrical energy requirements by reducing the amount of hydraulic energy actually produced.



Pumping system with one VSD



Pumping system with three VSDs

Drives share information such as status of the drive, priority, running time, process feedback, etc.

Typical Problems - Pump Oversizing

- Symptoms: Highly throttled, excessive bypass, low duty cycle, excessive noise, frequent bearing/seal replacement
- Cause: Design, change in production requirements, replaced with bigger unit after failure
- Result: Excessive energy consumption, higher maintenance cost
- Solutions: Replace with appropriate size pump, trim impeller, install VSD, install smaller “jockey” pump

Typical Problems - Cavitation

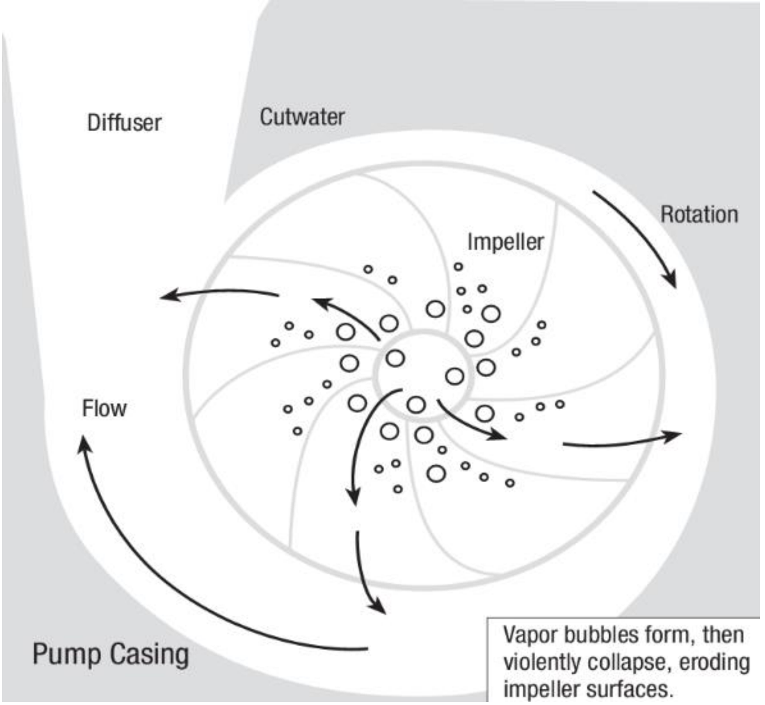
Symptom: Gravelly noise

Cause: Pressure at suction is too low ($NPSH_{actual} < NPSH_{required}$)

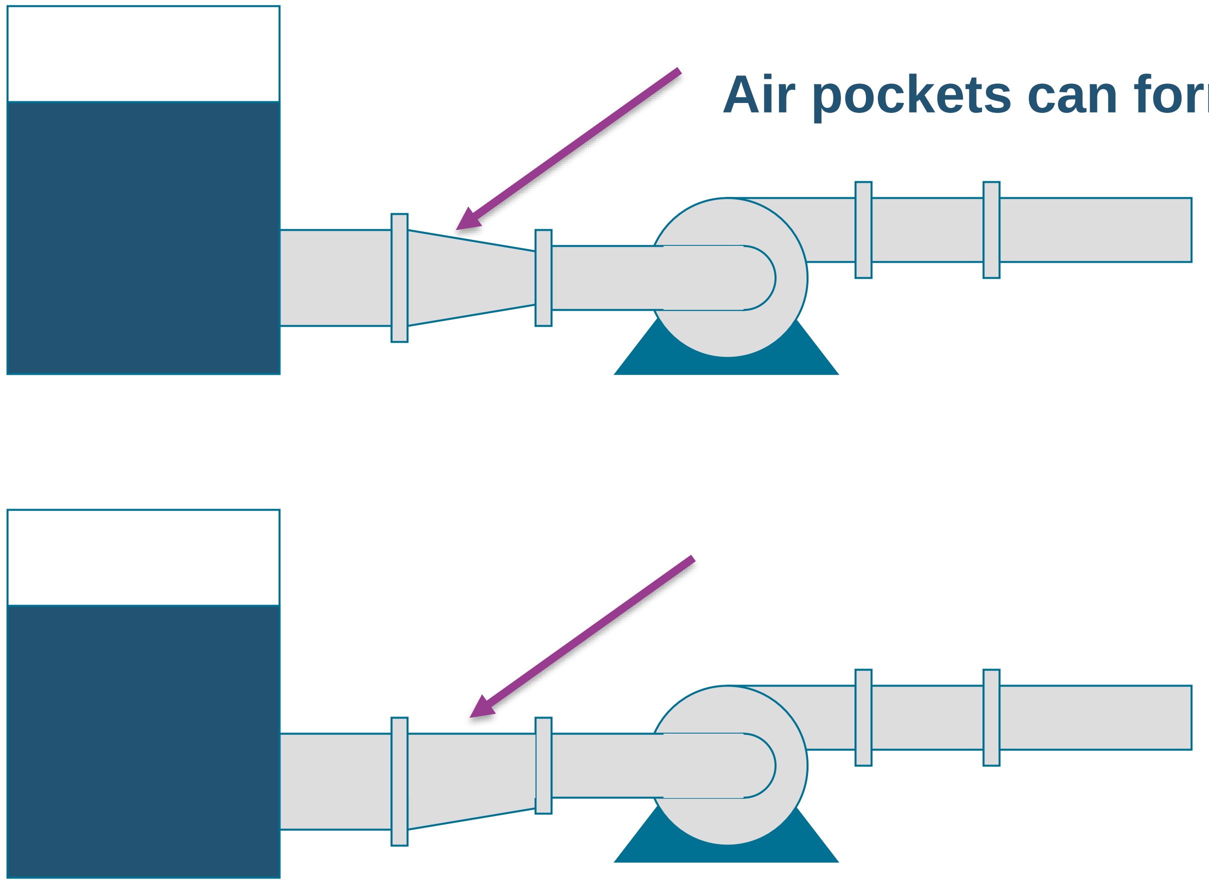
Result: Early pump failure

Solution: Increase the inlet pressure:

- Lower inlet height
- Reduce pump speed
- Cooler fluid
- Modify inlet piping



Typical Problems - Piping Configurations



Incorrect installation

Correct installation

Review & Discussion

06. Fans

Motor Applications

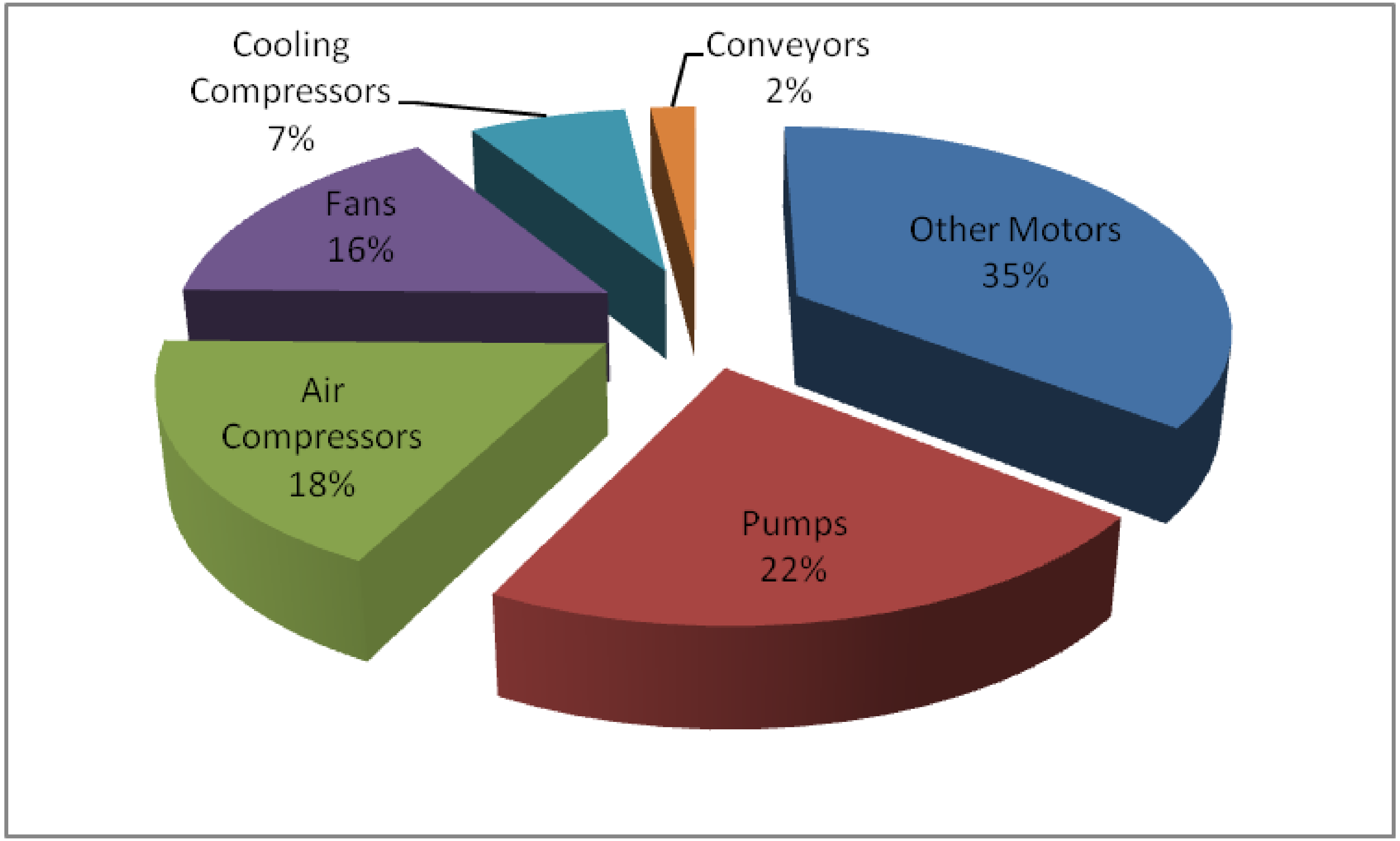
Motor Systems Optimisation (MSO) Expert Training (2020 Egypt Edition)

Samir Khafagui
Siraj Williams

Discussed Topics

- Fan Basics
- Fan Control
- Fan Optimisation
- Fan Starting
- Top Industrial Energy Saving Opportunities

Motor Systems Energy Use

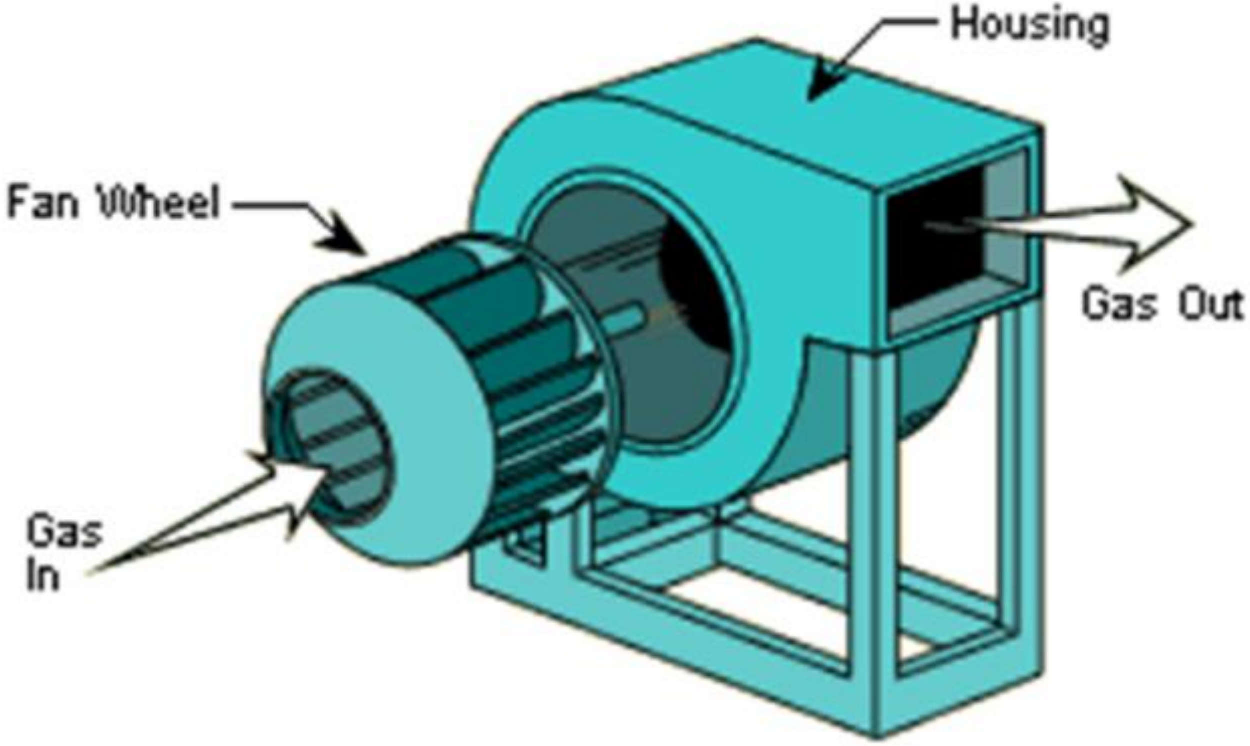


Disaggregation of motor electricity consumption by end-use, in the EU Industrial sector
Source: ISR – University of Coimbra (2012)

What affects fan energy performance?

Performance 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

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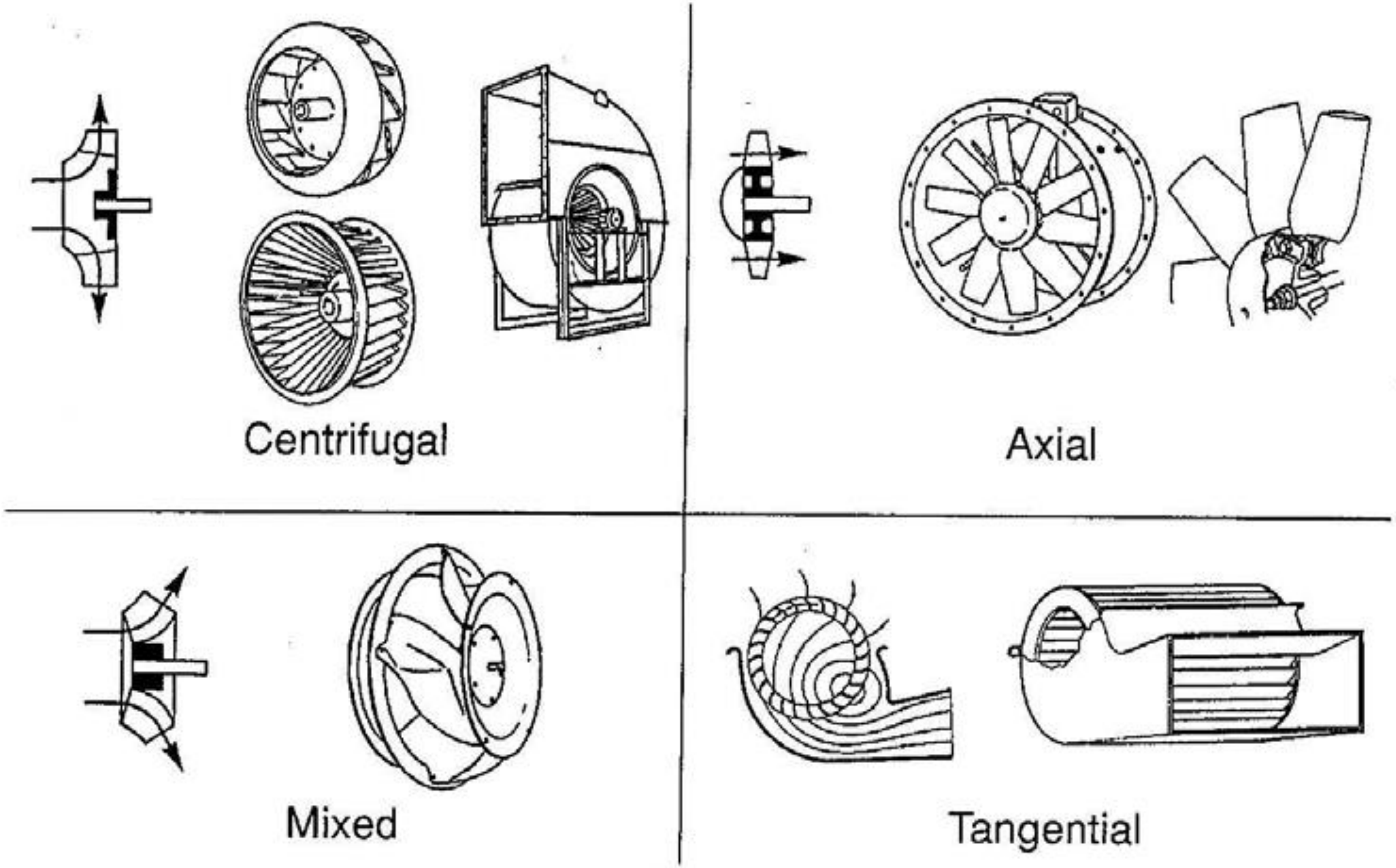

Typical Large Fan Efficiencies

Egyptian program for promoting Industrial Motor Efficiency
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Excludes housing

A guide only!

Fan type		Fan total efficiency % (peak)
Centrifugal	Aerofoil	88
	Backward-curved	84
	Backward-inclined	80
	Forward-inclined	70
Axial	Vane-axial	85
	Tube-axial	75
	Propeller	55
Mixed-flow		75
Tangential		25

Affinity Laws for Centrifugal Fans

Relation between fan Speed (N), Impeller Diameter (D), Flow (Q), Head (H) and Power (P)

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

For changes in speed (constant impeller)

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

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

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

For changes in impeller diameter (constant speed)

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

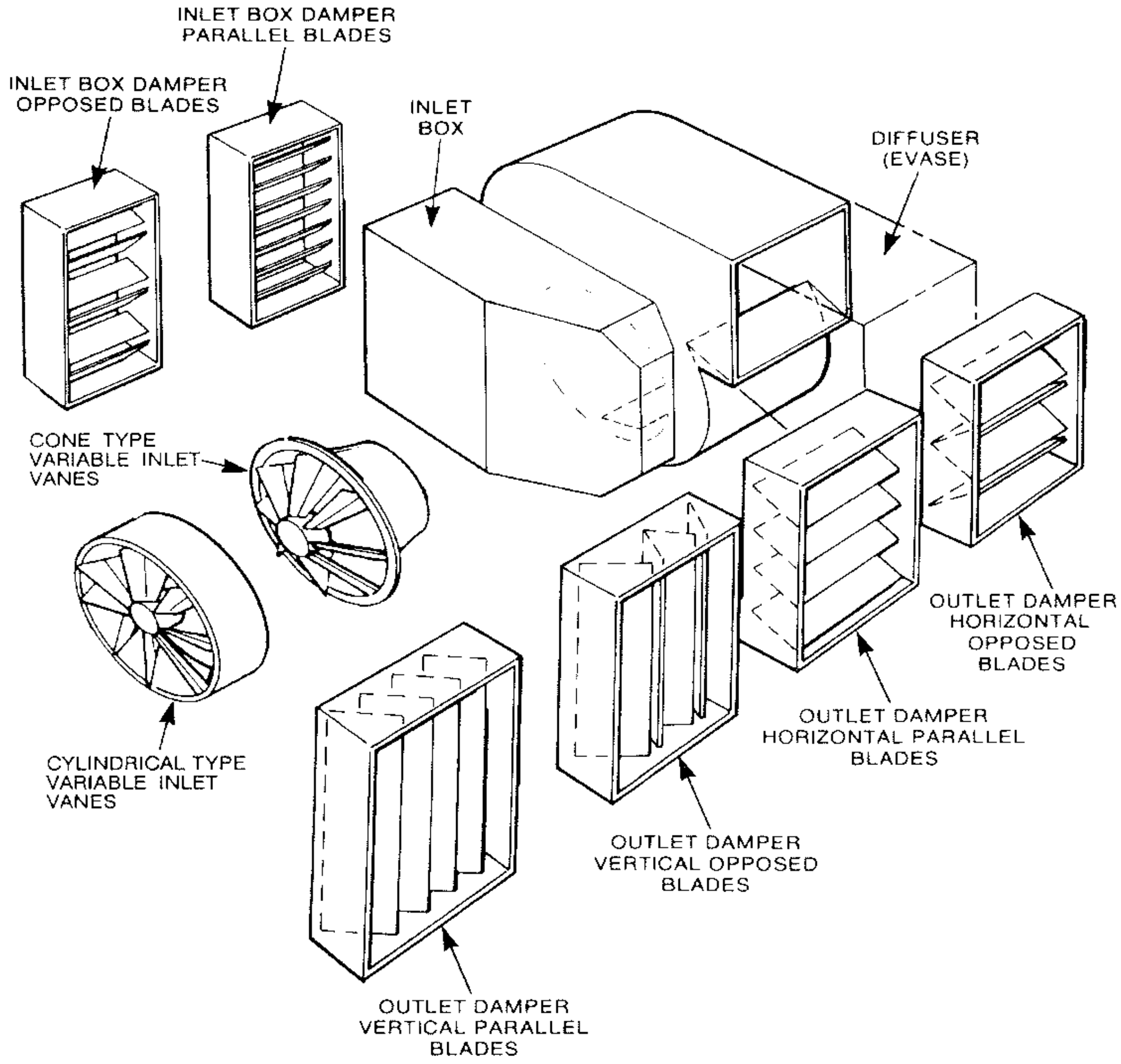
$$H_{new} = H_{old} * \left(\frac{D_{new}}{D_{old}}\right)^2$$

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

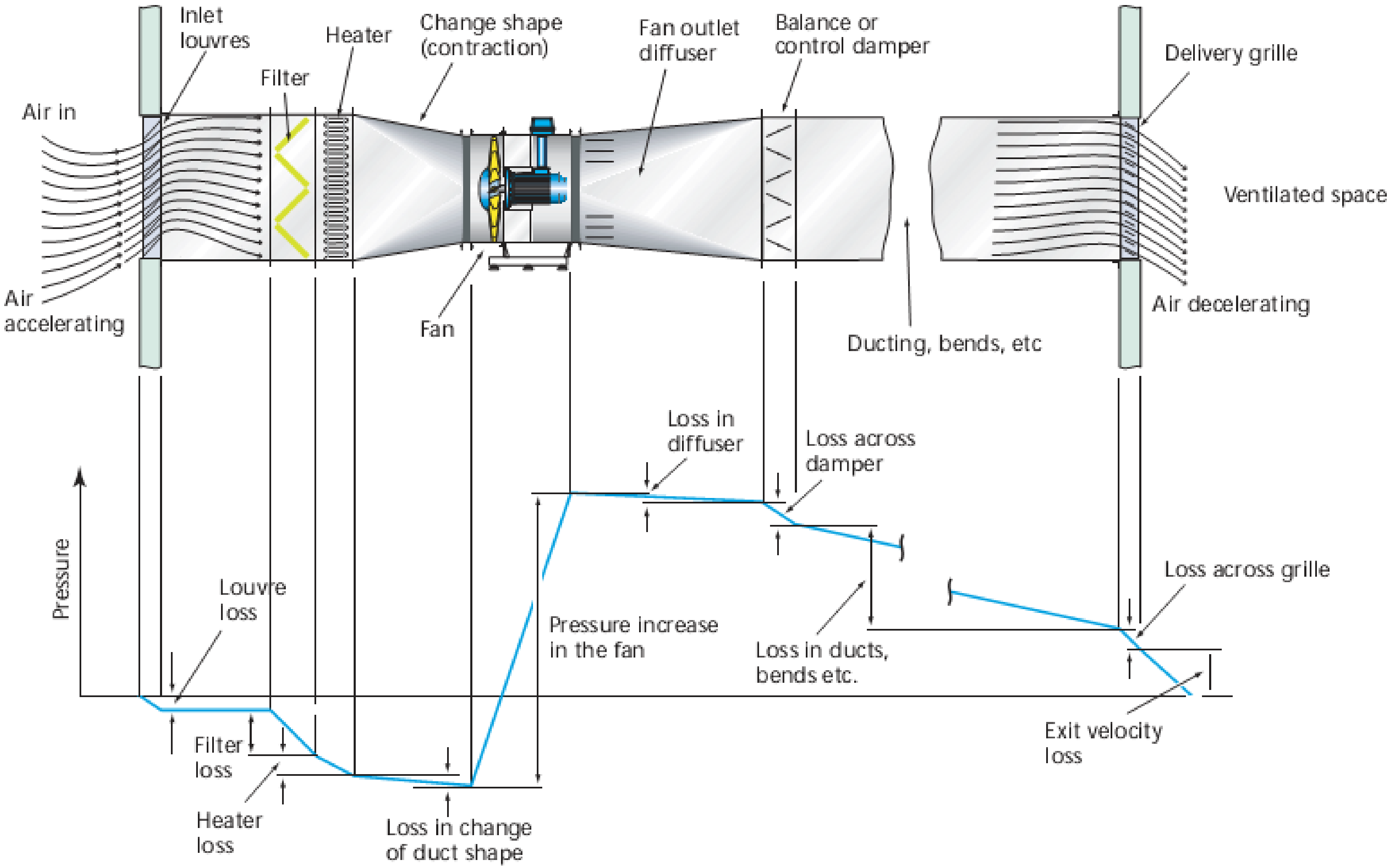
Mechanical Fan Flow Control

Change flow by restricting flow through the fan either at the inlet or the outlet

- Dampers (inlet and outlet)
- Inlet guide vanes



Losses Across a Typical Fan System



Source: CIBSE Fan Application Guide

Flow Control Methods for Fans

Egyptian program for promoting Industrial Motor Efficiency
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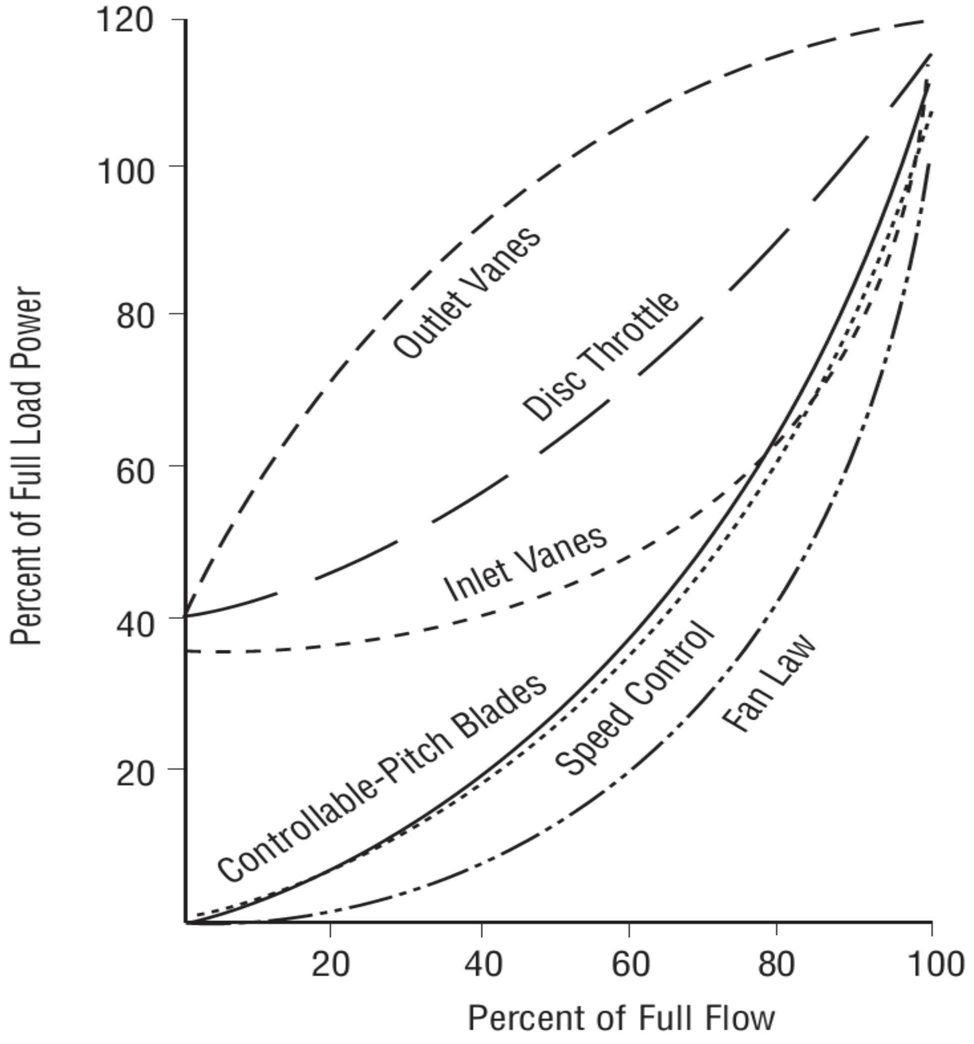
1. On Off Control
   - Fluid flow is controlled by switching fans on and off . This often requires a multi fan arrangement.
2. Inlet and Outlet Dampers
   - A valve positioned before or after the fan restricts the fluid flow so that less fluid flows through the fan, and also creating a pressure drop 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)

Other Speed Reduction Techniques

- Alter the pulley ratio
- Ensure multiple belt assemblies are matched

- Use a multiple speed or different speed motor

Relative Efficiency of Control Methods



Source: DOE Improving Fan Performance

Fan Systems – Energy Strategies

The most efficient flow of air into a fan is a non-restricted, uniform path

Elbows located directly on fan inlets increase losses and are to be avoided

Obstructions at fan inlets and outlets disrupt the flow, causing turbulence

Flex connections often cause poor transitions that disrupt flow

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)

Preventive Fan System Maintenance

Part	Preventive Maintenance
Air filter	Create a filter changing schedule based on recent life cycle cost analysis.
Bearing	Grease
Belt drive	Replace, then properly adjust tension and alignment.
Damper	a. Grease and adjust linkages b. Verify correct operation: make sure it opens and closes when it should.
Electric supply	Maintain specified balance, voltage and power factor.
Impeller	Clean and balance.
Inlet cone	Inspect for wear. Verify alignment and spacing between cone and impeller is within factory specs.

UNIDO Fan System Optimisation Checklist

Egyptian program for promoting Industrial Motor Efficiency
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Instructions: Use this checklist to qualitatively select the top fan optimization projects in your facility. Make a copy of this list for each of your major systems that operate 4,000 hours per year or more, then go through the list and add up the points for the conditions that apply. **If there are any control, production or maintenance indicators, then add points for size and run hours as follows:** *If the system operates more than 6000 hours add a point. **If the system is over 100 kW add a point per 100 kW (200 kW = 2 points, 300 kW = 3 pts, etc). Also add a point or points if production or maintenance problems are severe. Two or more points can indicate a good optimization opportunity. Four or more points probably indicate a very good opportunity. ***Note***: Fans with adjustable speed drives usually are not good candidates for optimization.

Fan System ____

Are there problems with the system?______________________________

Points** 1 ___ Motor _______ kW

Points* 1 ___ Operating hours _________

Tally the points __________

Control	Production	Maintenance
Points	Points	Points
2 ___ Spill or bypass	2 ___ Unstable or hard to control system	1 ___ System is excessively noisy
2 ___ Discharge damper	2 ___ Unreliable system breaks down regularly	1 ___ Buildup on fan blades
1 ___ Inlet damper	1 ___ Not enough flow or pressure for production	1 ___ Need to weld ductwork cracks regularly
1 ___ Variable inlet vane		1 ___ Radial fan handling clean air
1 ___ System damper		
1 ___ Damper is mostly closed		
1 ___ Fan operates when not needed		

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Top Industrial Fan Saving Opportunities

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- Fume extraction (metal)
- Dust extraction (textile, wood)
- Aeration blowers (process)
- Cooling towers (cooling water)
- Building ventilation
- Baghouse fan
- Boiler combustion





Review & Discussion

07. Compressed Air

Motor Applications

Motor Systems Optimisation (MSO) Expert Training (2020 Egypt Edition)

Samir Khafagui
Siraj Williams

Discussed Topics

- The cost of compressed air
- Typical compressors
- Compressed air system components
- Control of air compressors
- Factors affecting energy performance of compressed air systems
- How to assess energy performance

Why use compressed air in industry?

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Power

As an energy source to perform work

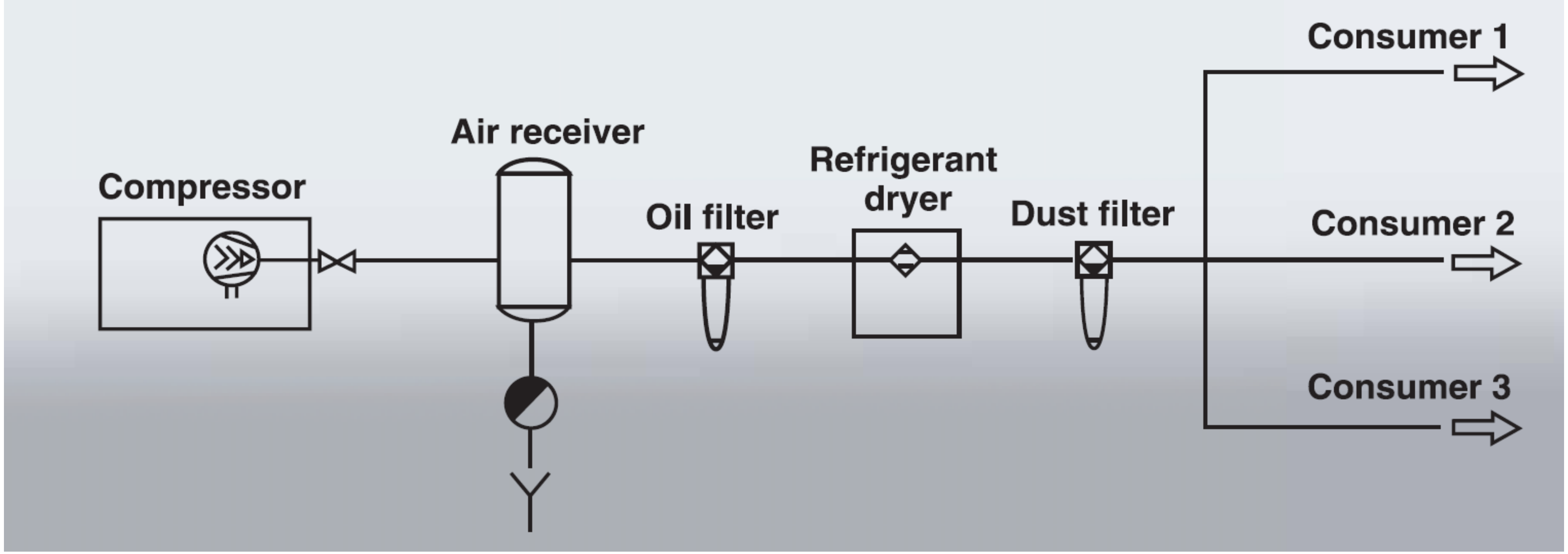
Process

Air becomes part of a process

Control

To stop, start or regulate the operation of a machine

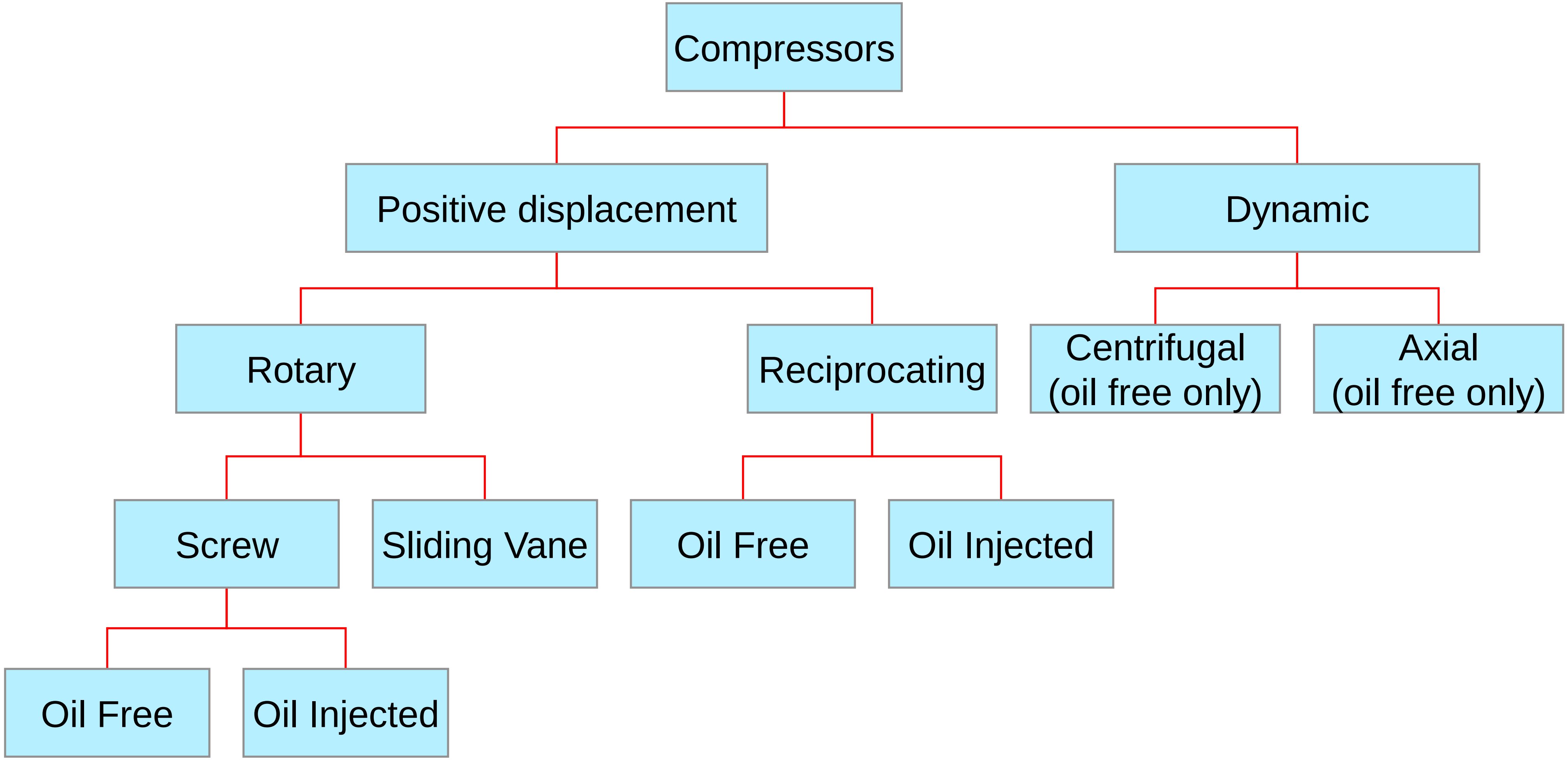
Typical Compressed Air System



Where does the energy come from?

What drives the compressor?

The Compressor Family



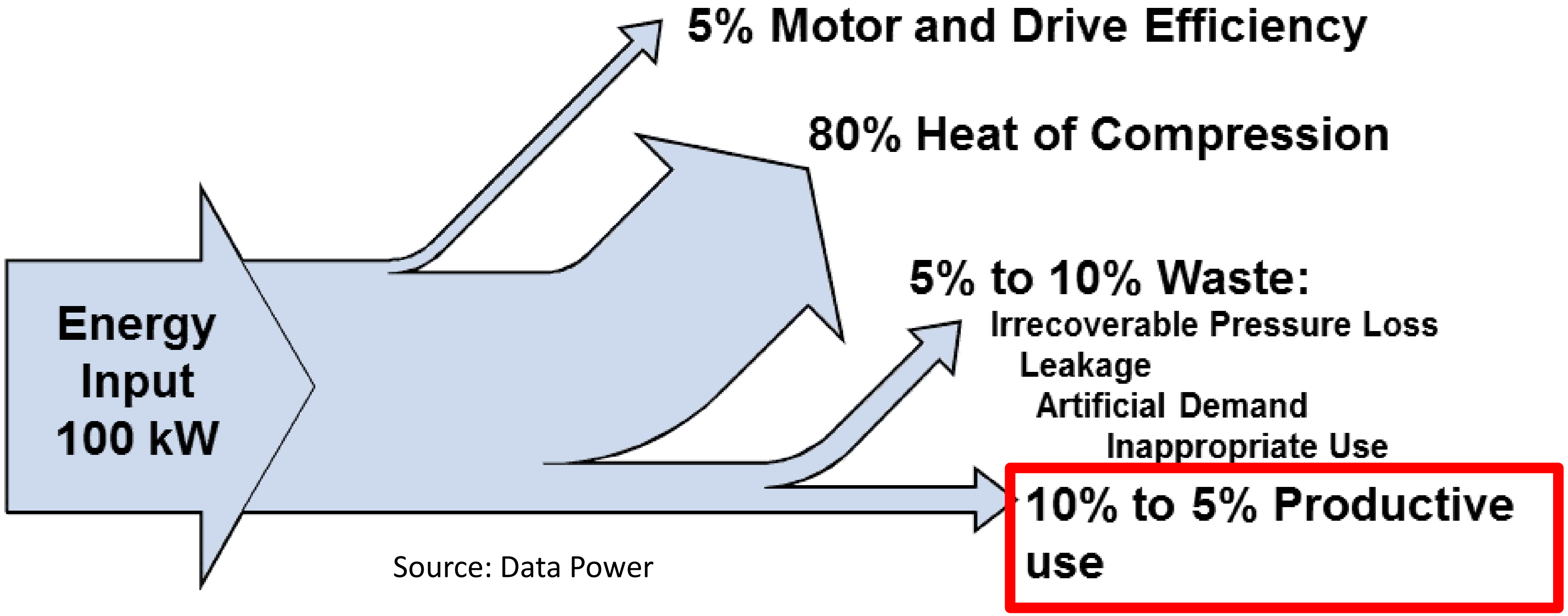
Why compressed air offers rich pickings?

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



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**!

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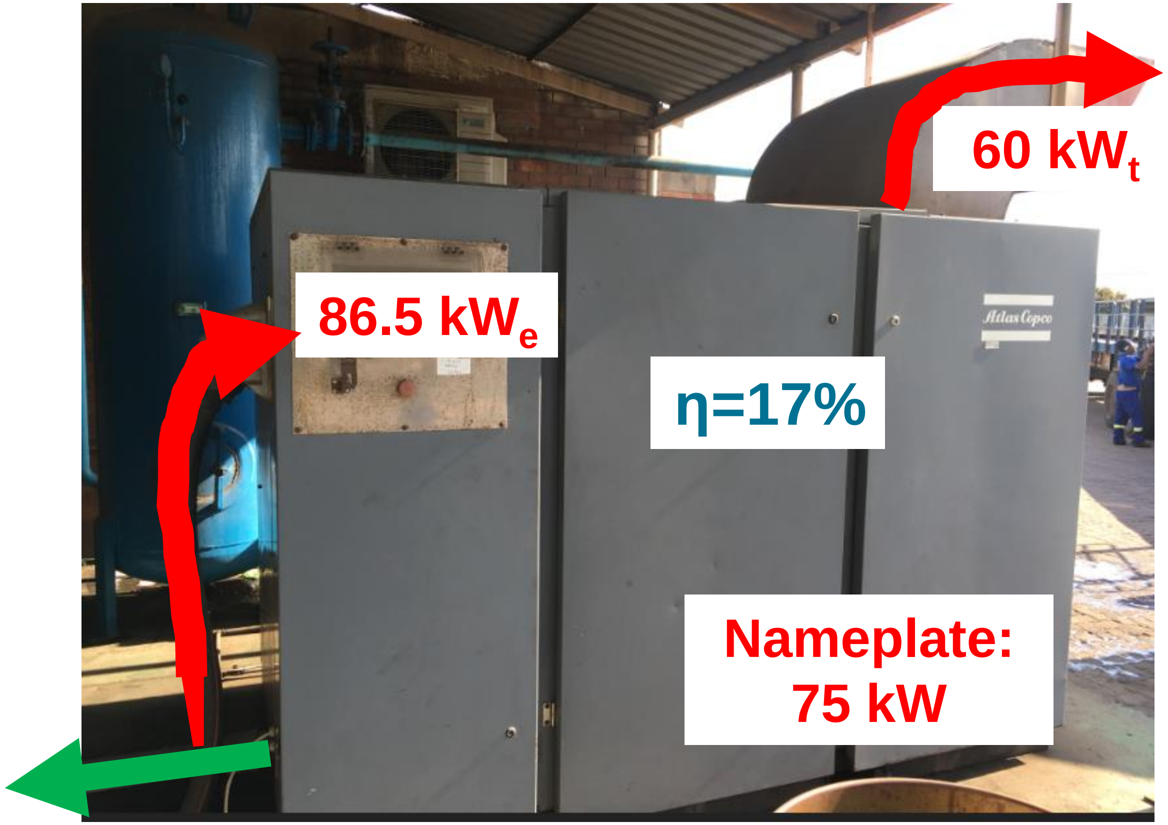
Compressed air is **THE** most expensive source of energy

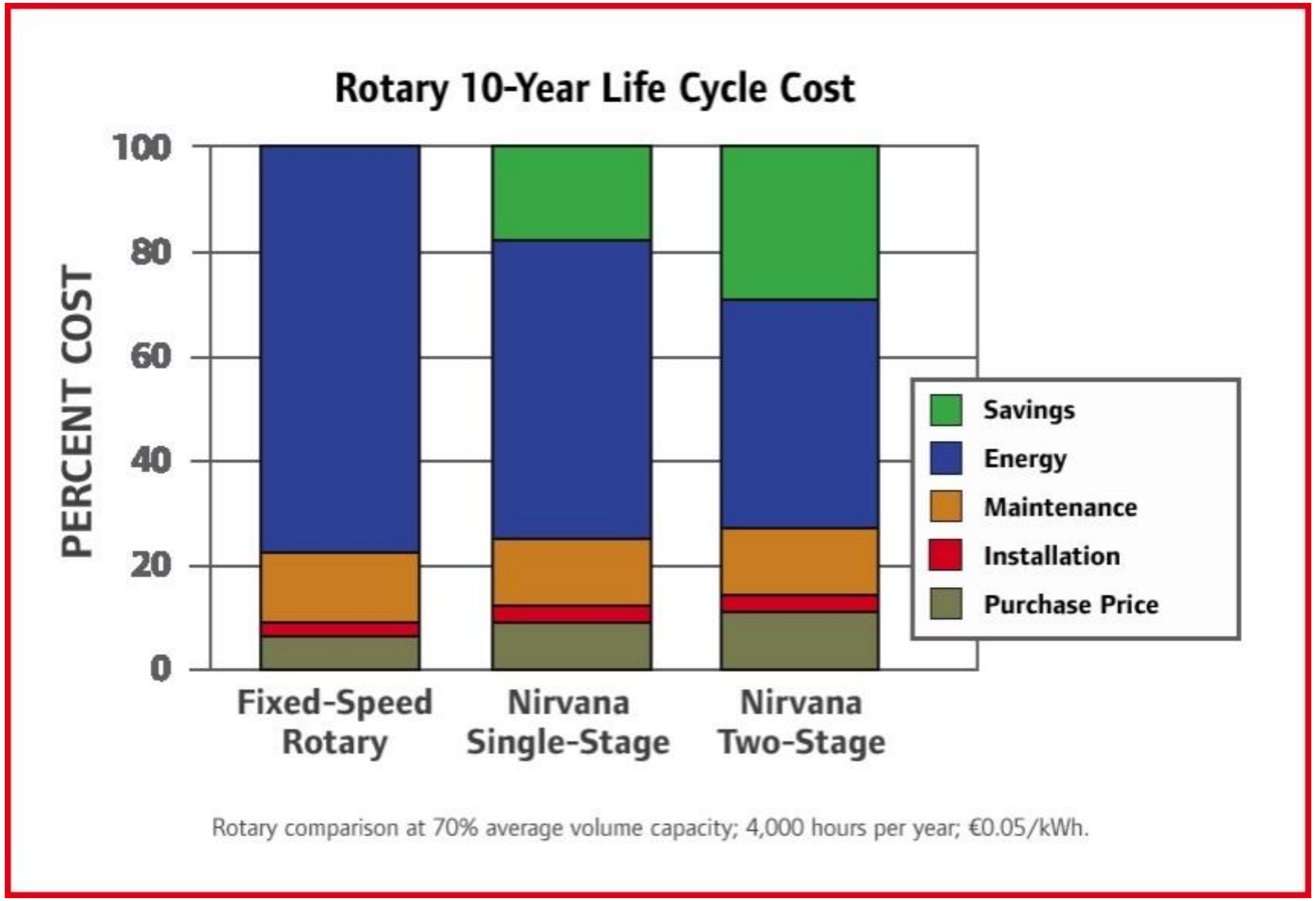
$$\eta = \frac{15\ kW\ out}{86.5\ kW\ in}$$

η = 17%



Source: Albert Williams

Life Cycle Cost Comparison



Ingersol Rand Nirvana Variable Speed Air Compressor

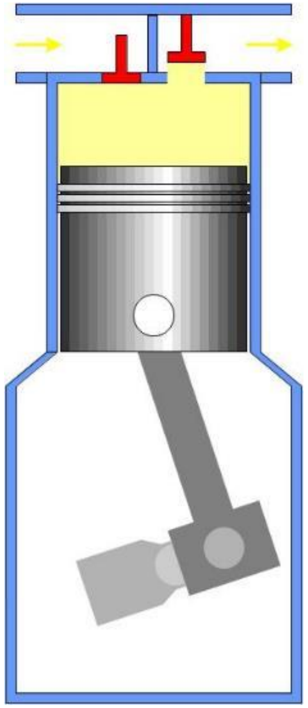
Typical Compressor Operating Cost

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

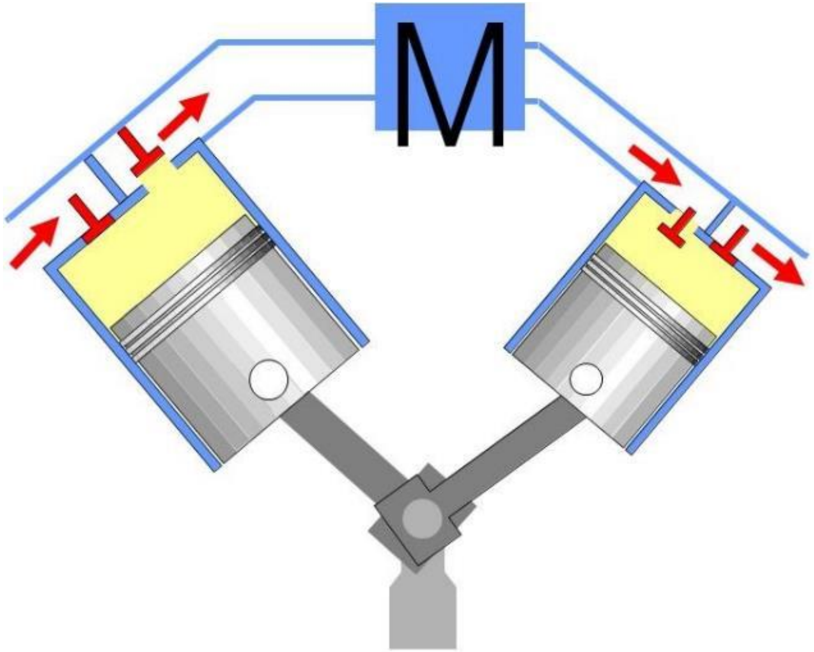
Compare with Purchase Price = $ 126,000

Reciprocating Compressors

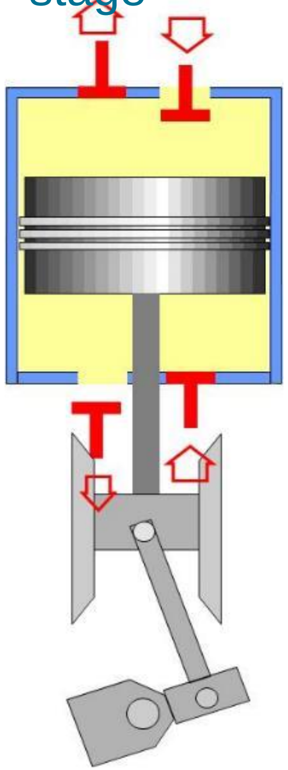
Single-acting, single-stage



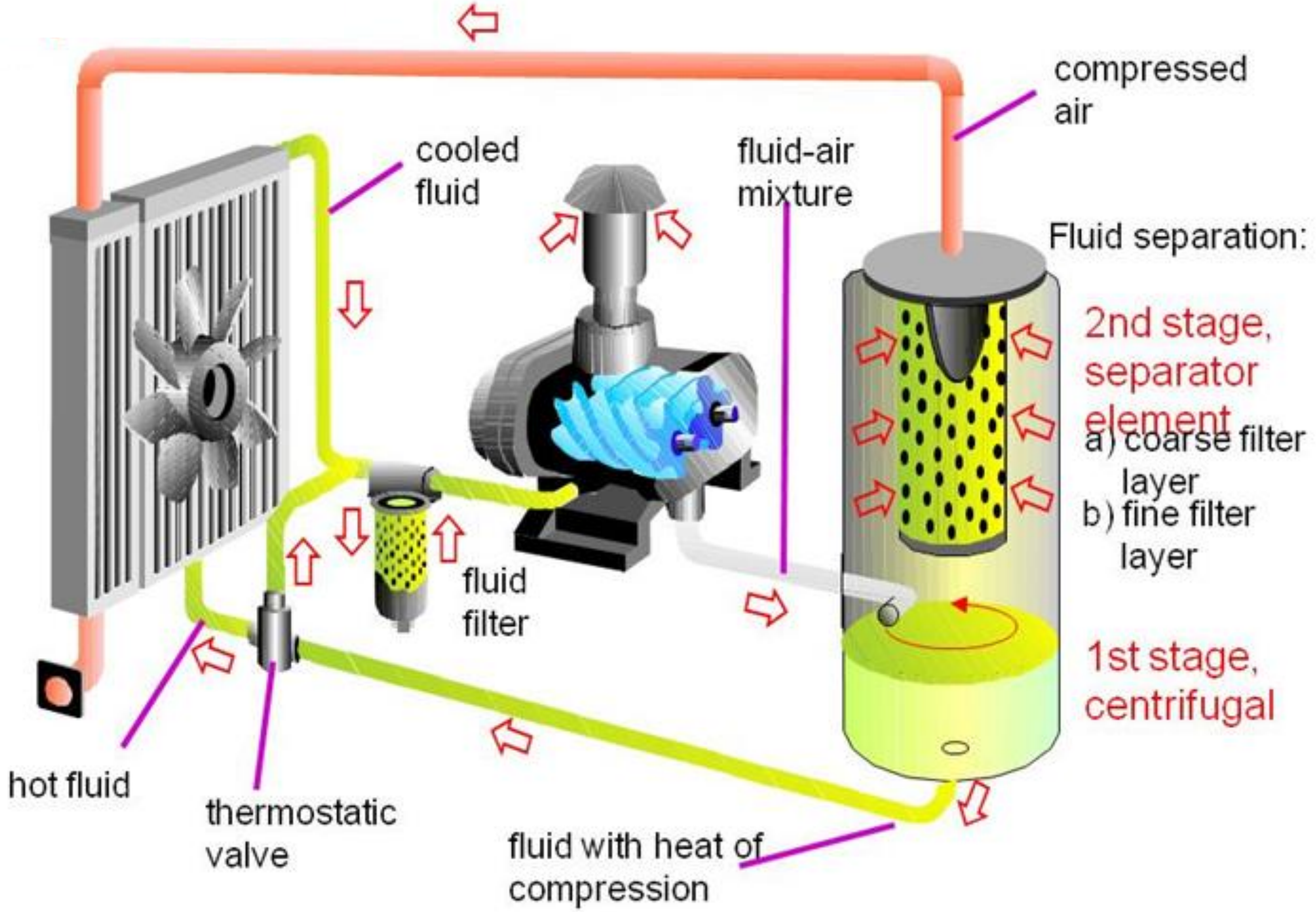
Single-acting, two-stage



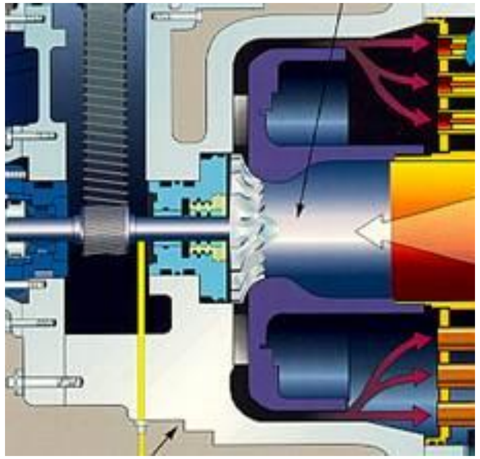
Double-acting, single-stage



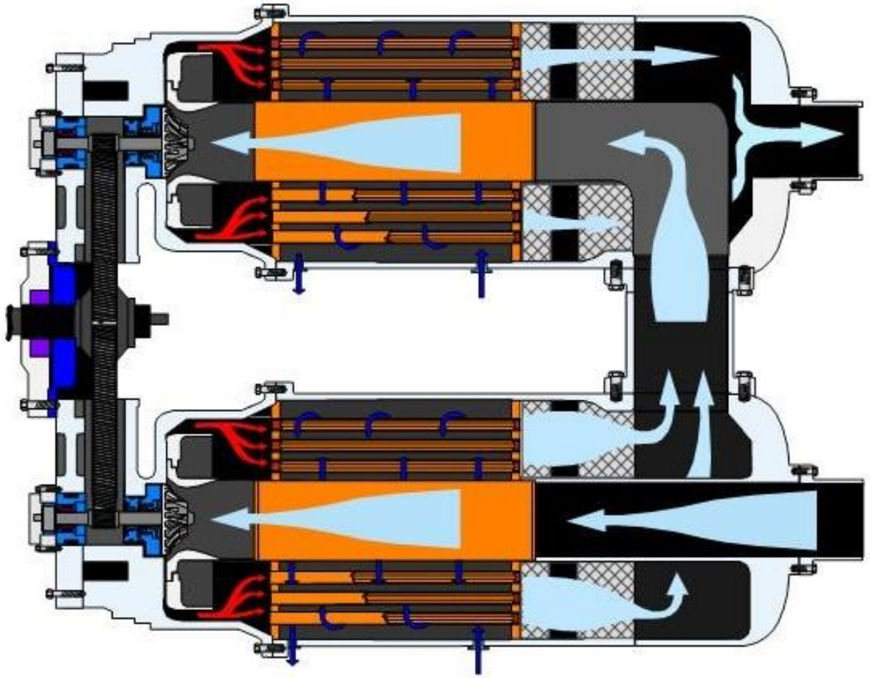
Oil Injected Screw Compressors



Centrifugal Turbo Compressor

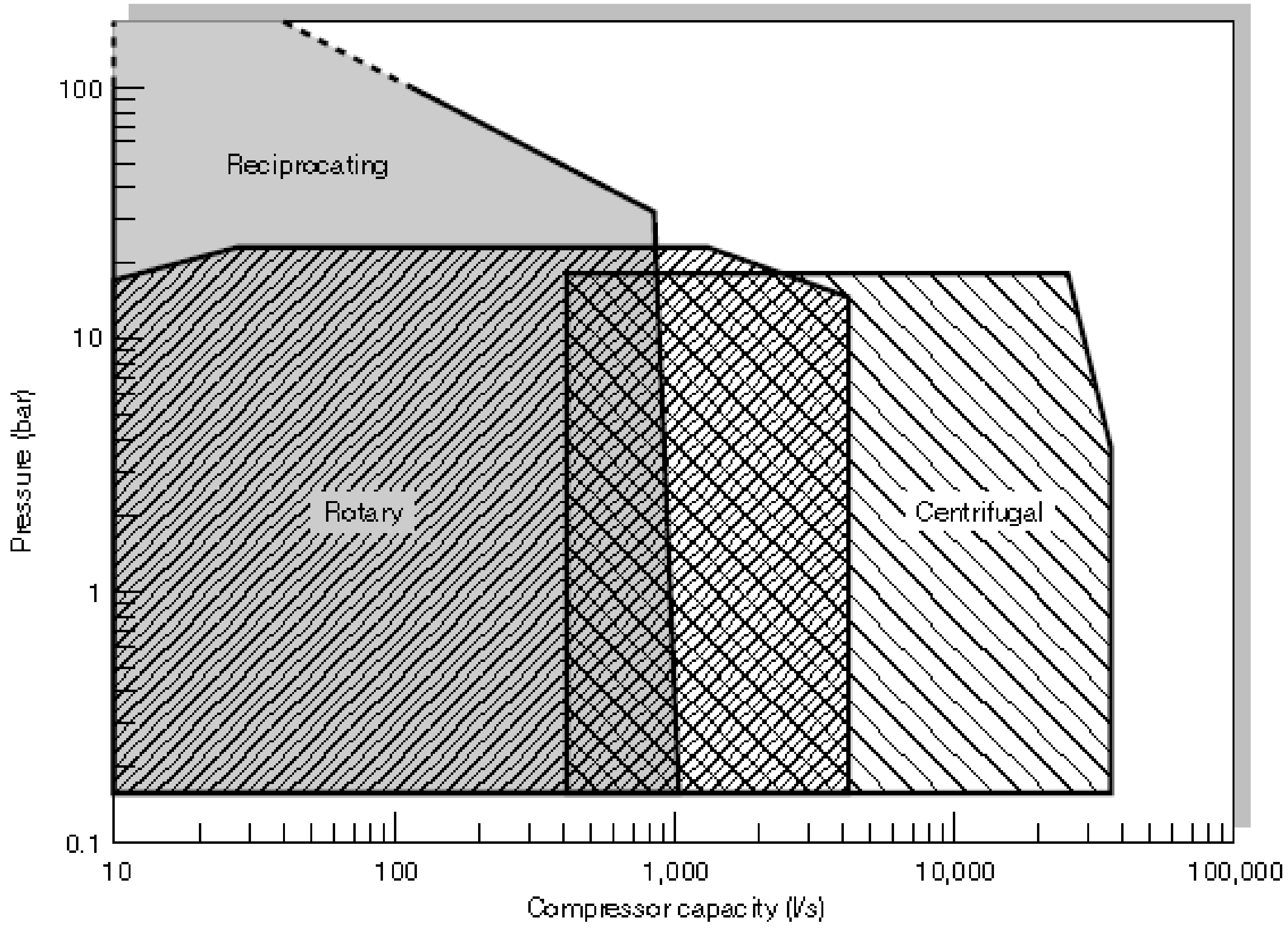


Characteristics:
Capacity: 35 - 1200 m^3/min
Stages: 1 - 6
Pressure range: 3 - 40 bar (g)
Speed range: 3000 - 80000 min^{-1}



2 stages

Compressor Range Chart



Range of Efficiencies

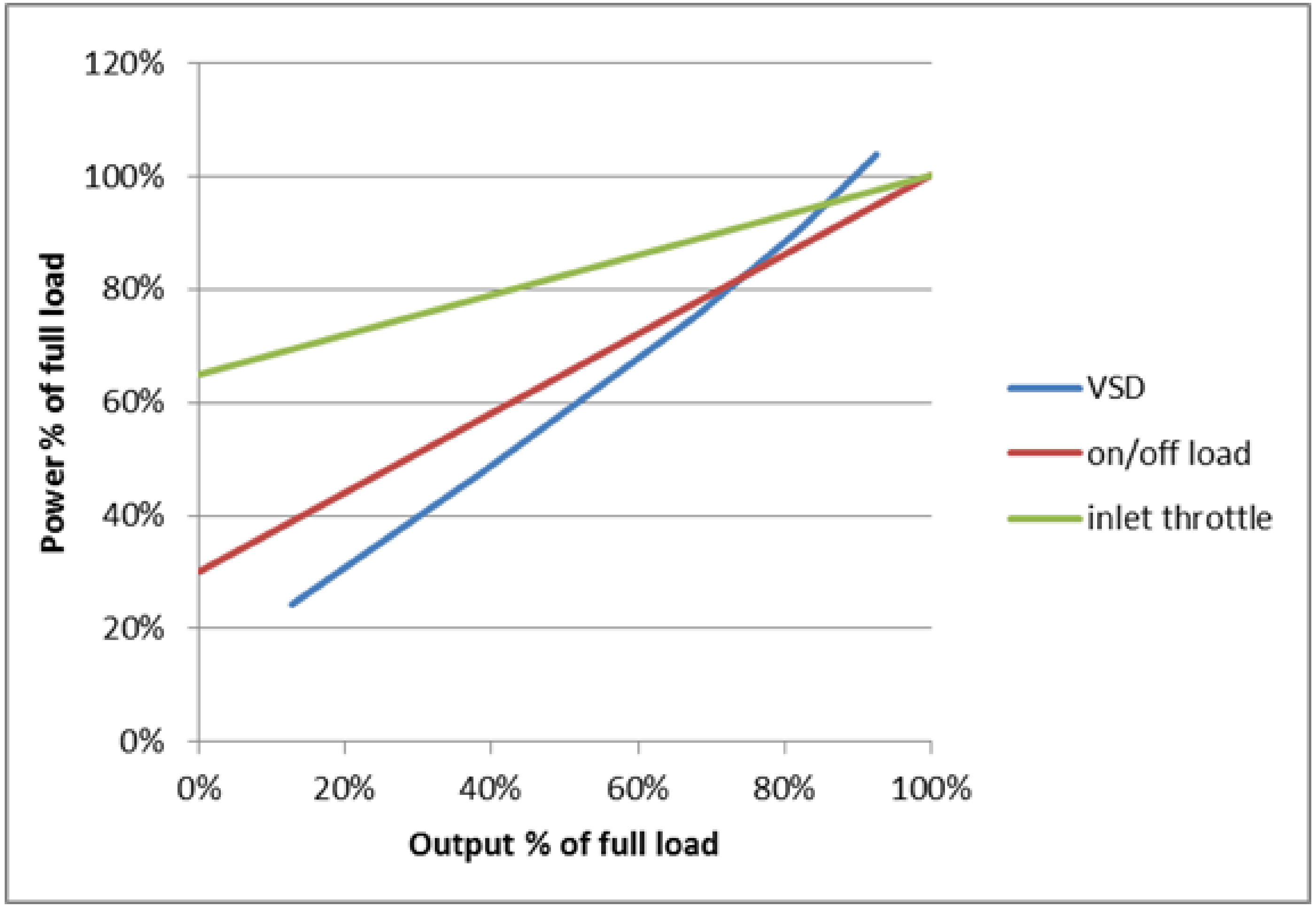
- Good rule of thumb when assessing if the compressor is appropriate for the size of the installation

Type	Range m3/h	SPC kW/100m^3/h	Part load efficiency
Lubricated piston	2-25	15-16	Good
	25-250	11-13.5	Good
	250-2500	10-11.5	Excellent
Oil injected screw	2-25	15-16	Poor
	25-250	11-13.5	Fair
	250-2500	10-11.5	Fair*
Oil free screw	25-250	12-15.3	Good
	250-2500	10-12.2	Good
Centrifugal	500-2500	11-13.5	Excellent**
	>2500	9.7-11	Excellent**

Variable Speed Control

- Better part load performance
- More accurate pressure tracking
- No gearbox
- BUT higher full load energy consumption
- NOT suitable for base load supply

Control of Positive Displacement Air Compressors



Typical Compressed Air System

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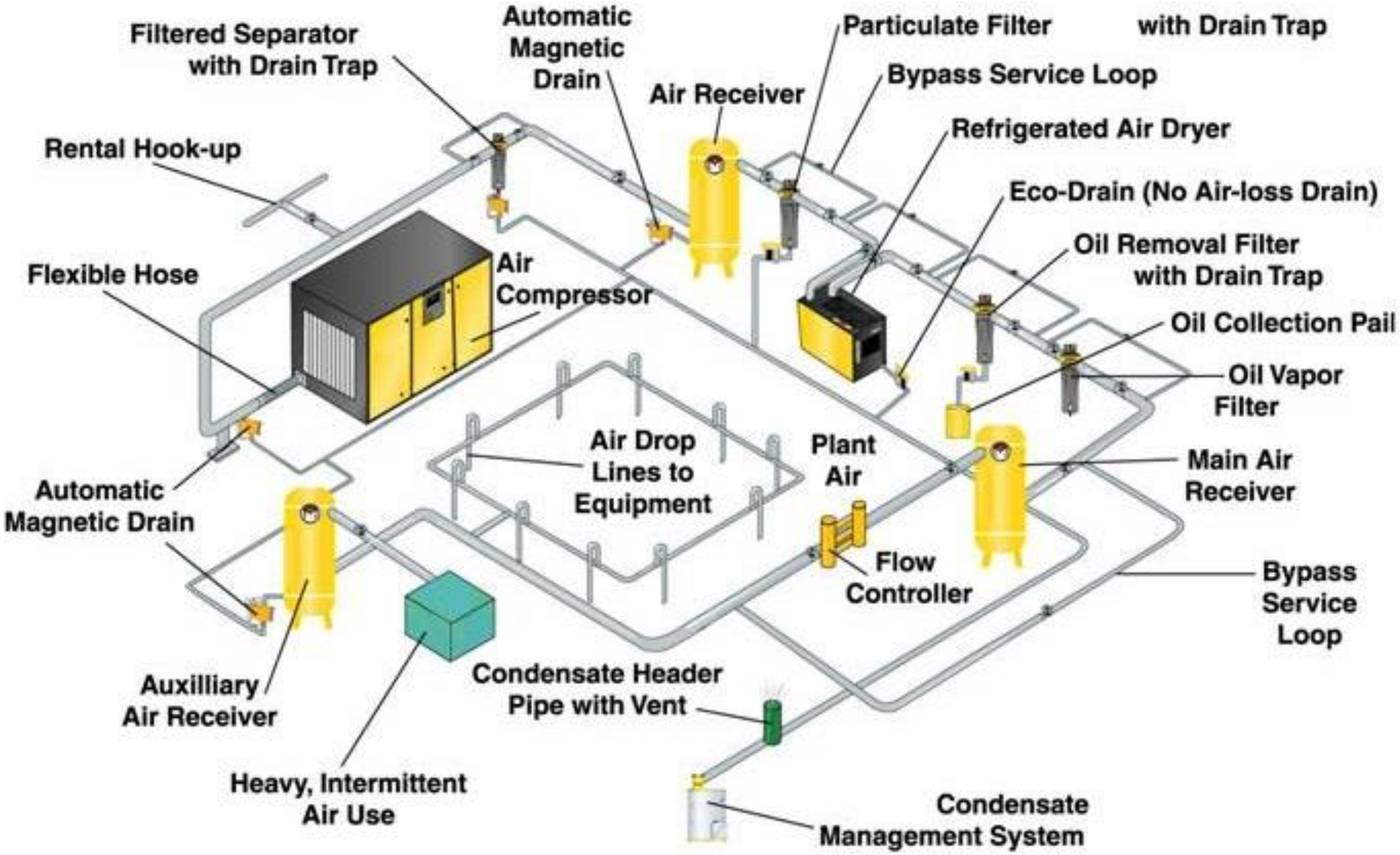
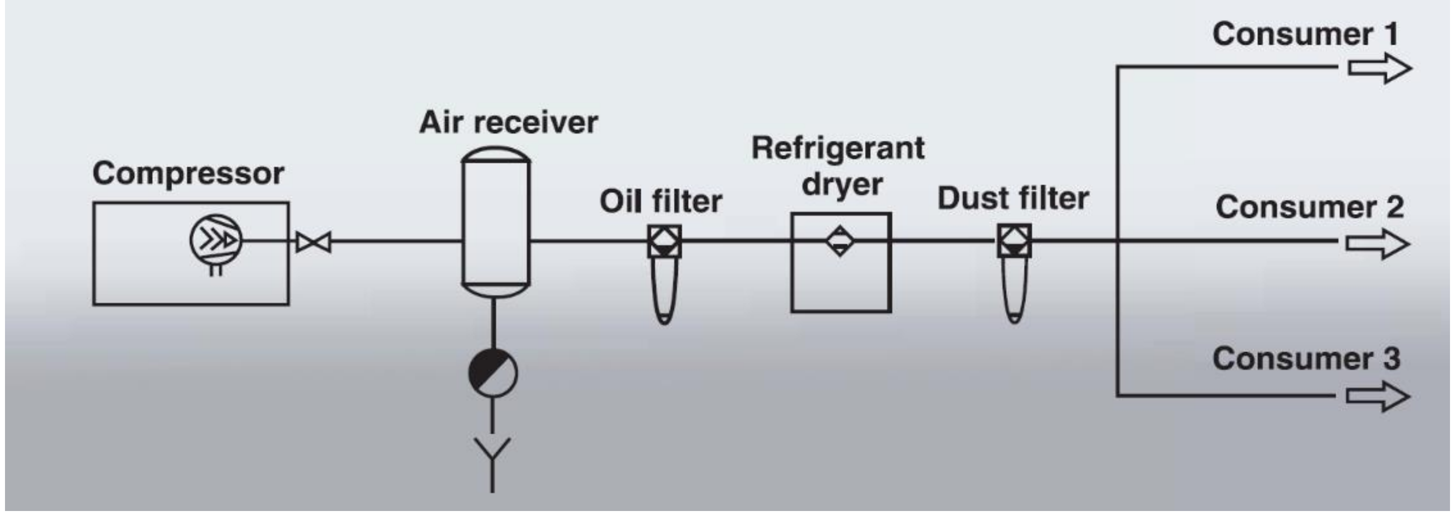


Assessment of Compressed Air Systems

- Understand the motor implications of compressed air systems.
- Understand how to optimally select and control air compressors to meet actual requirements.
- Understand how system problems will have a huge impact on motor running hours.

Learn to ask pertinent questions about compressed air systems as you walk around on a motor audit – you will never be lost for words and you will learn more about how the plant works!

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

Use Less Air

1. Eliminate leaks
2. Isolate equipment when not used
3. Eliminate inappropriate uses
4. Reduce artificial demand




Leakage Losses

Hole Diameter	Air Consumption at 6 bar (g) (m3/min) sharp orifice 0.61 coefficient	Air Consumption at 6 bar (g) (m3/min) rounded orifice 0.97 coefficient	Power Loss (kW) Shaft Power 6.2 kW / m^3/min.	Power Loss (kW) 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!

Common Sources of Air Leaks

- Filter, Regulator, Lubricator
- Manual Drain Valves
- Quick Disconnect (QD) fittings
- Hose clamps
- Push-on Hose fittings
- Cut or Punctured Hose
- Pipe fittings
- Pipe Unions
- Flange Gaskets
- Old Rusted Piping
- Pneumatic Cylinder Rod Packing
- Pneumatic Cylinder Body
- Directional Control Valves
- Valve Pilot Lines and Ports
- Valve Stems and Packing

Estimating Amount of Leakage

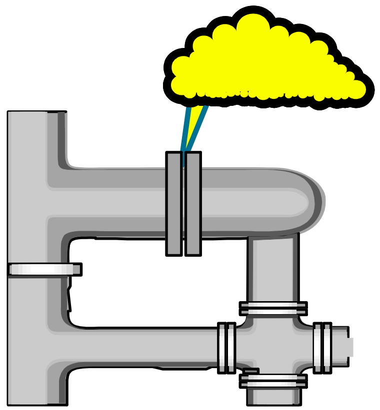
- Start the compressor when there are no demands on the system (when all the compressor operated end-use equipment is turned off).

$$\text{Leakage (\%)} = [(T \times 100)/(T+t)]$$

T – On Time
t – Off Time

Managing Air Leaks

- Not practical to eliminate ALL air leaks
- Should not be more than 10% of the mean production demand in a normal factory
- Typical industrial installations will have between 15% and 50% leakage rates (over 80% measured on one occasion)
- Conduct leakage rate test no load running decay time or data logging
- Leaks come back but seldom in the same place
- Regular on-going leakage campaigns must be conducted



Isolate Equipment When Not in Use

Isolate air using production machinery when not being used

Use local solenoid valves operated by:

- No product flow sensing
- Isolation switches
- No operator (burglar alarm mats)
- Turning off the air with the lights when everyone goes home

Use similar methods for unused zones / sections

Inappropriate Use of Compressed Air

- Cleaning
- Component ejection
- Ventilation - cooling of people & products
- Agitation of paint or cleaning baths
- Moving product around bends or on conveyors
- Keeping product in line
- Using air at higher pressures than necessary
- Vacuum generation on large scale

NB – Offer an alternative

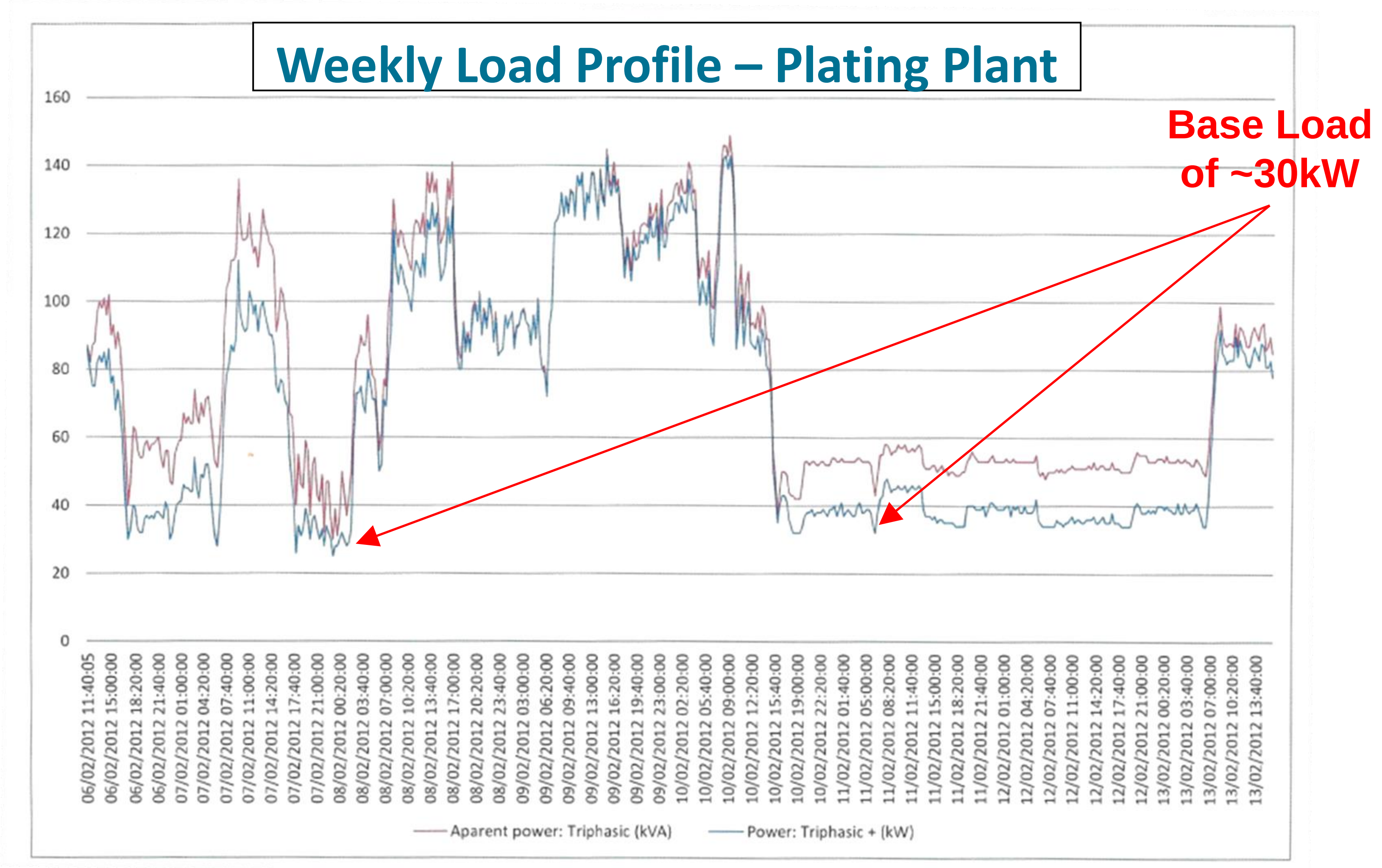
Blowing

- Use intensifying nozzles (can save 40%)
  - For product ejection
  - For cooling
- Quieter can overcome area noise issues
- Use air knives at reduced pressure
- Use fans
- Use low pressure blow guns that are safer and quieter

Optimise Compressor Control

- Demand (flow) profile
- Pressure profile
- Select optimal control methodology

Demand Profile



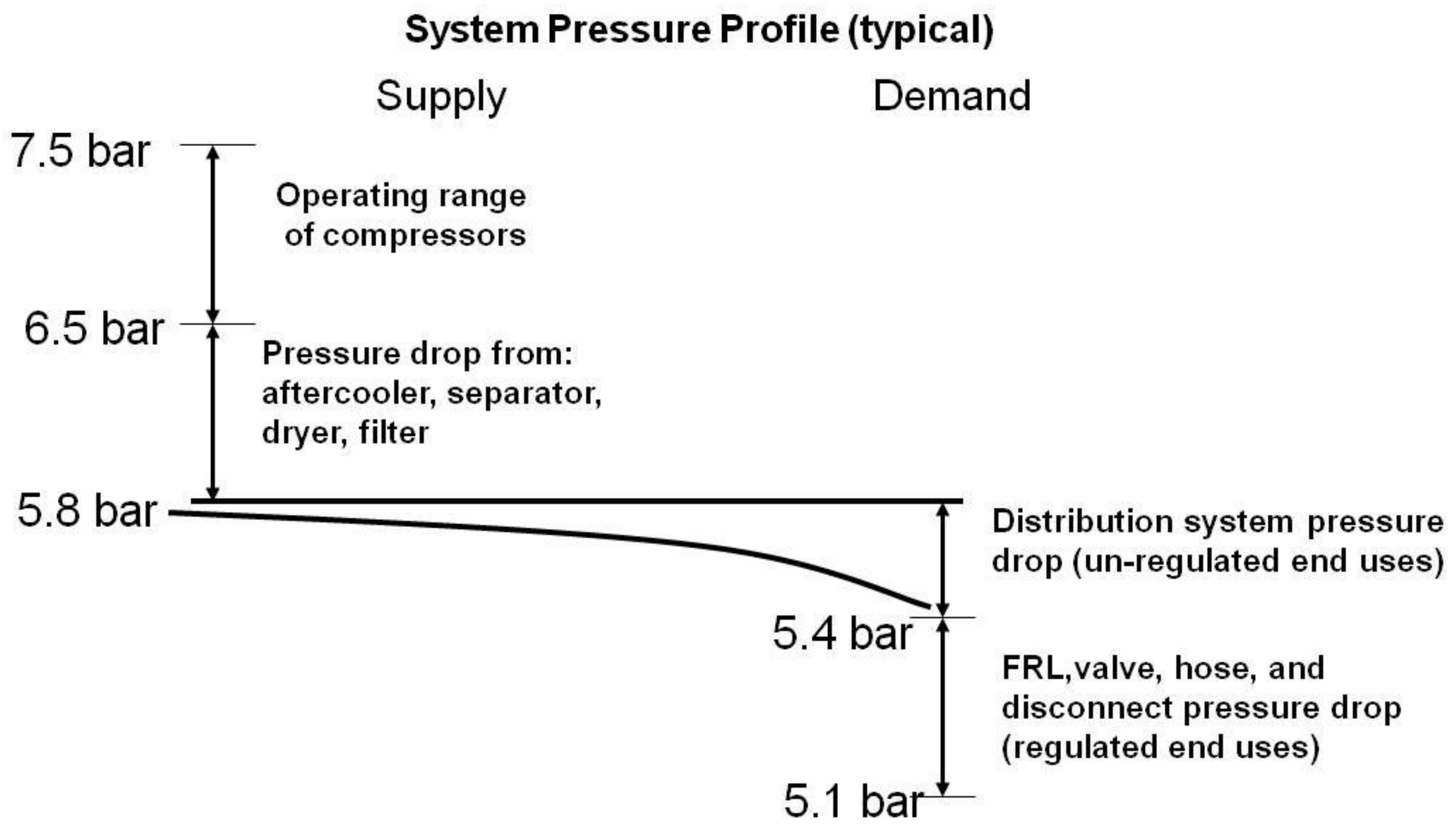
Can be used to:

- Identify opportunities for improvement
- Identify losses
- Determine compressor sizing requirements

Pressure Profile

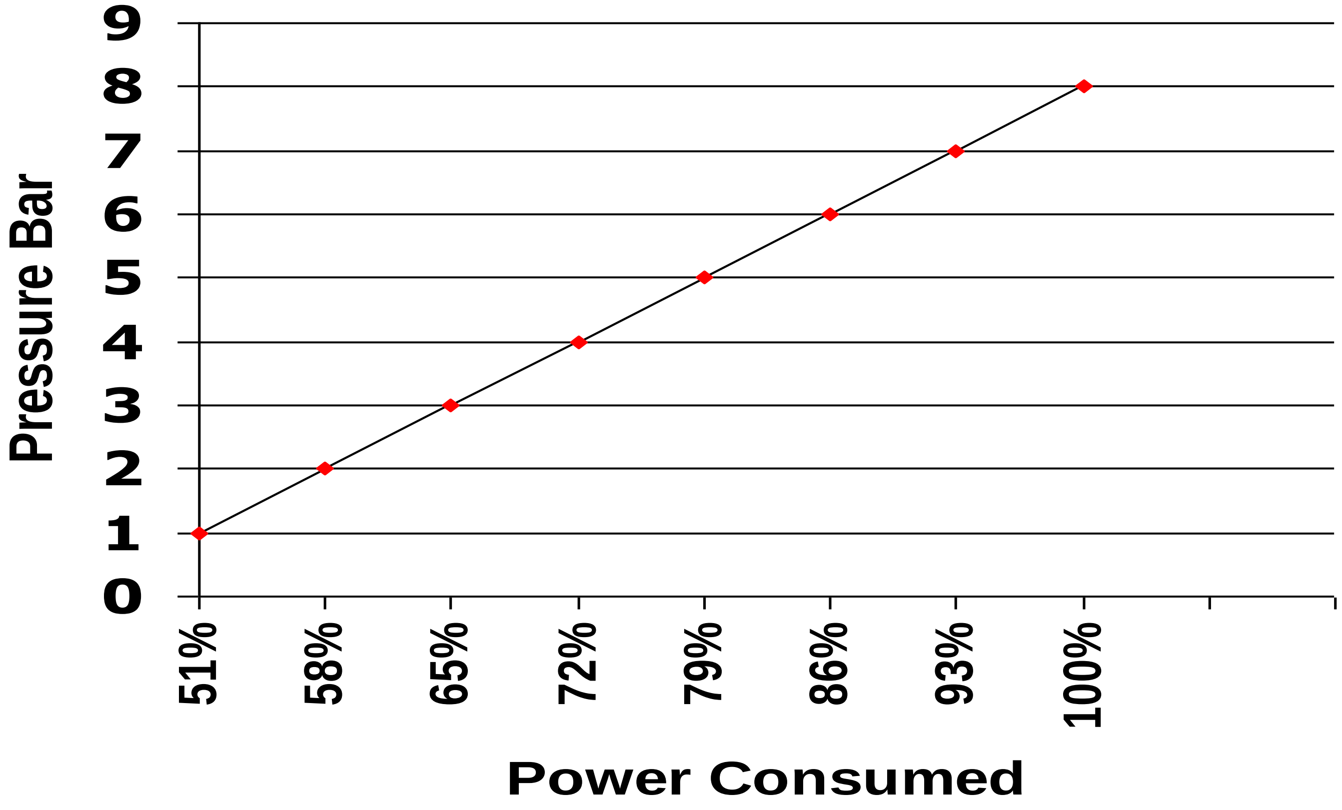
Pressure loss due to:

- Excessive filtration
- Small bore tubing or kinks
- Small fittings causing local restrictions



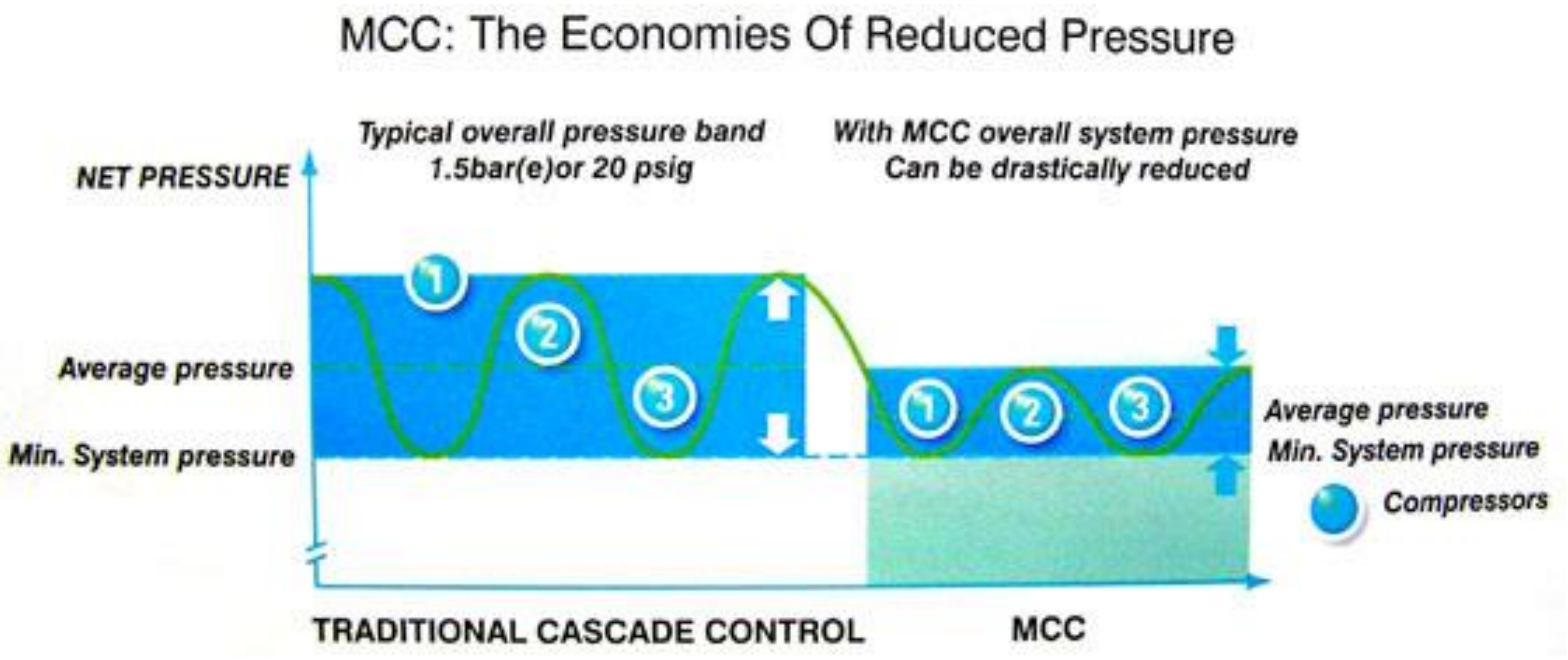
Optimise System Pressure

- Reduce system pressure = Reduced energy cost



"A reduction of 1 bar saves 6-7% in energy"

Multiple Compressor Controllers



Atlas Copco Electronikon Multiple Compressor Controller

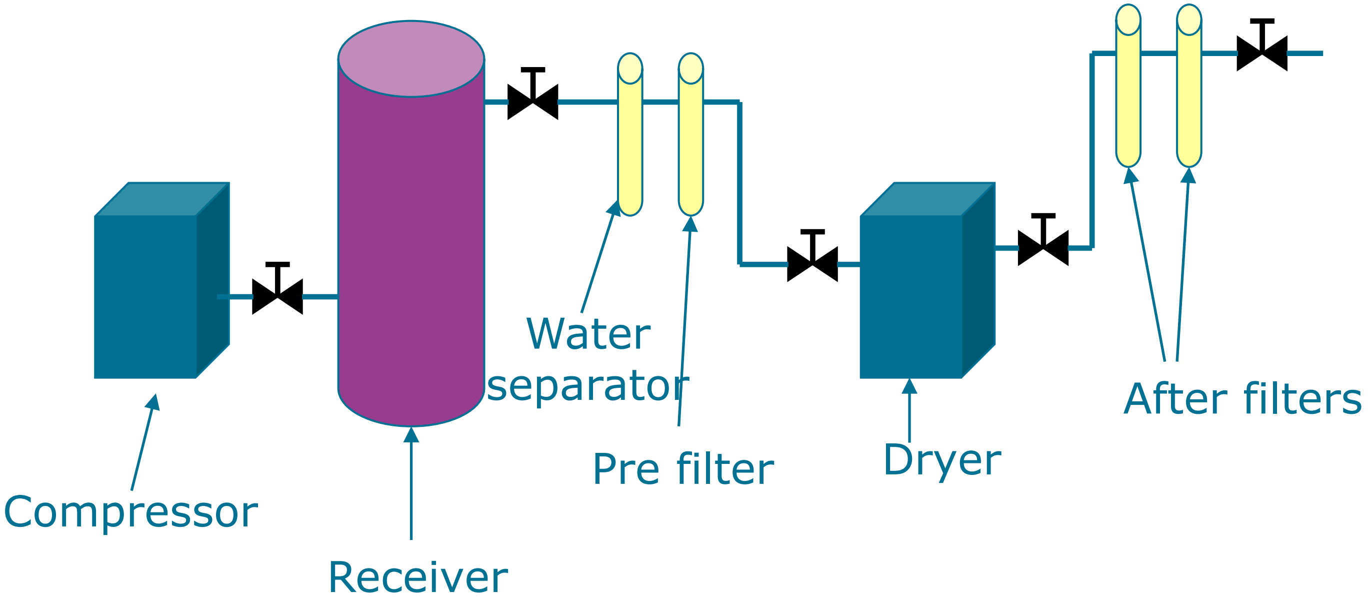
Improve Quality of Air to Process

- Improve air treatment
- Use air receivers correctly
- Improve piping and distribution

Air Treatment Systems

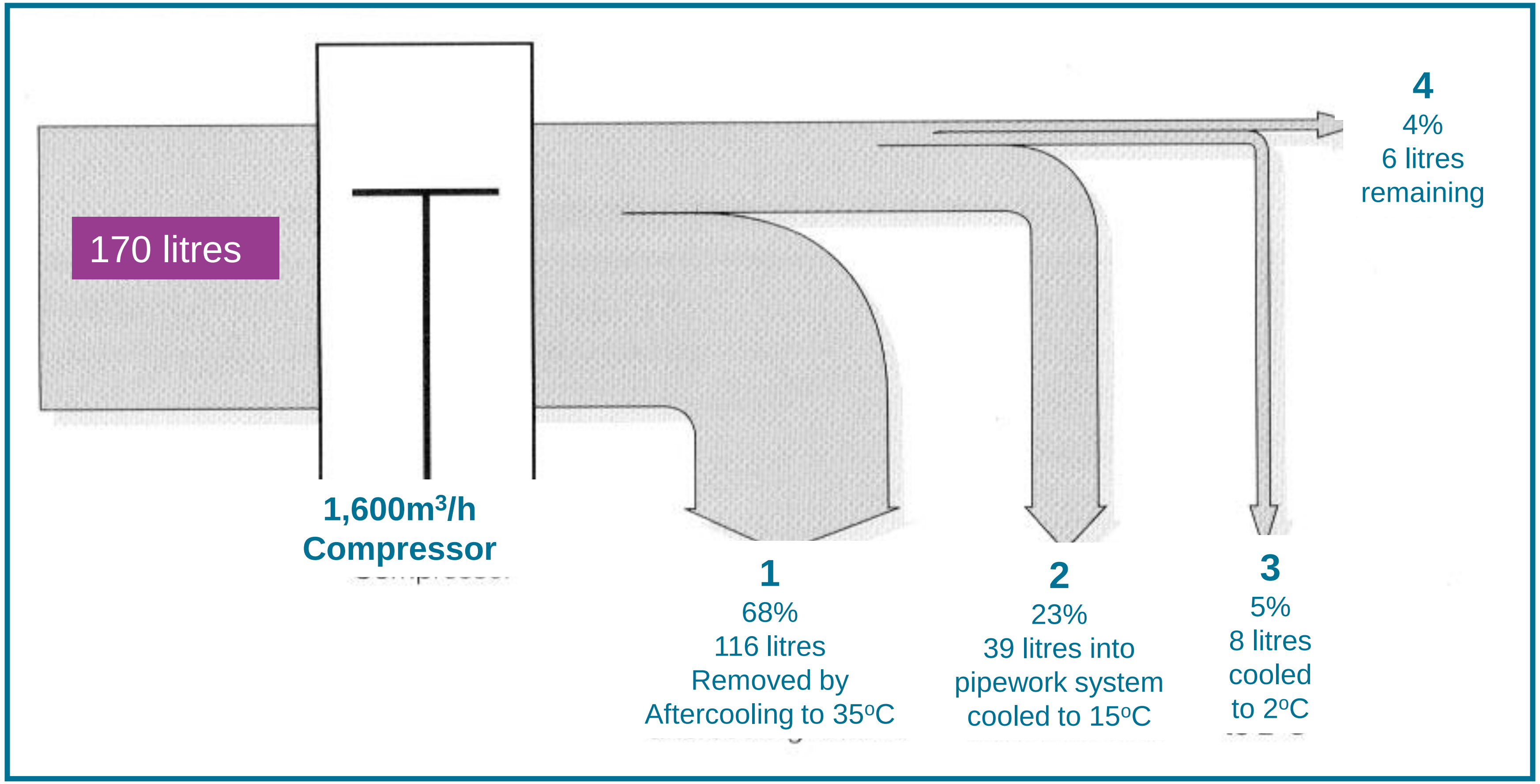
Reduces water, dust and oil in the delivered air

Treat the main supply of air to minimum quality then upgrade at point of use where required



In atmospheric air there are around 150 million dust particles/m^3
At 7 barg there are 1.2 billion dust particles/m^3

Condensate Removal



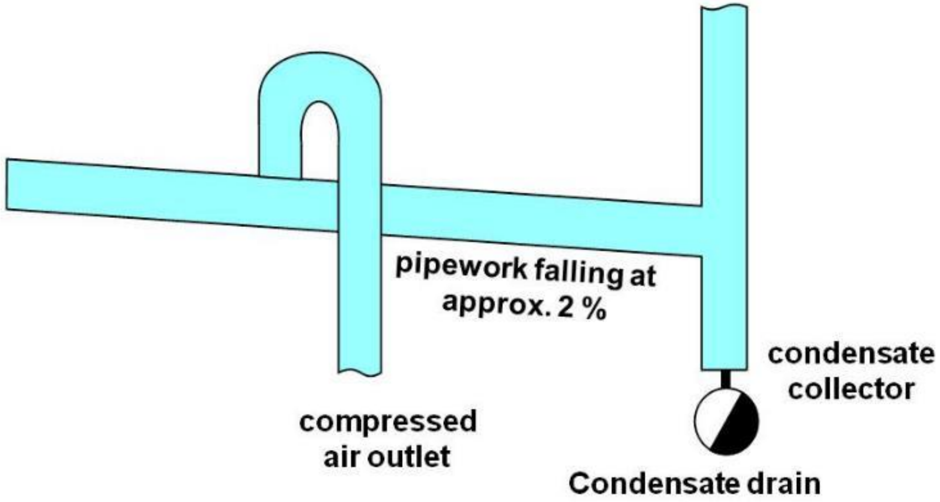
All amounts are based on a single 8 hour shift

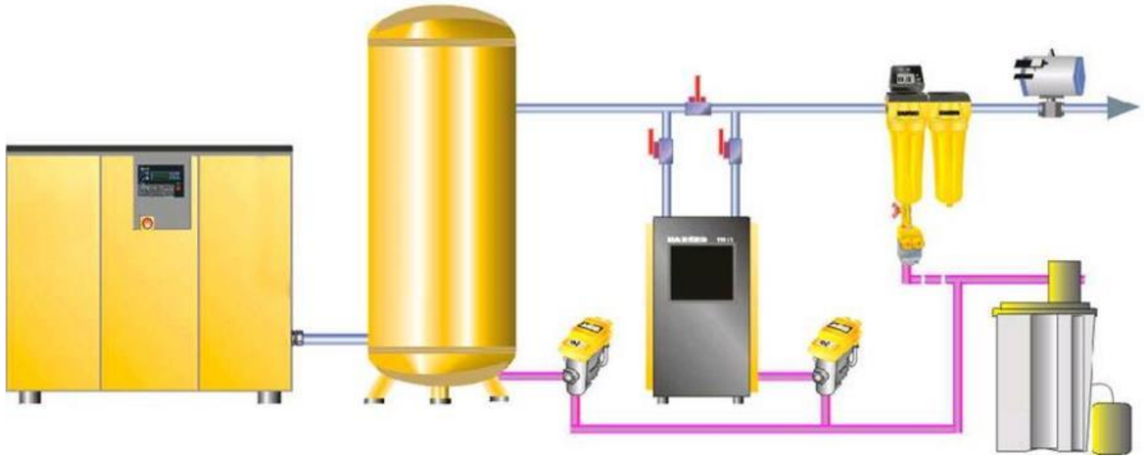
Condensate Separation and Drainage

The compressed air discharged from the aftercooler of a compressor is normally 100% saturated with water vapor.

If the temperature of the compressed air falls, the water vapor condenses.

A coarse separation of the condensate can be achieved if the pipework and the compressed air outlets are installed as shown in the illustration.

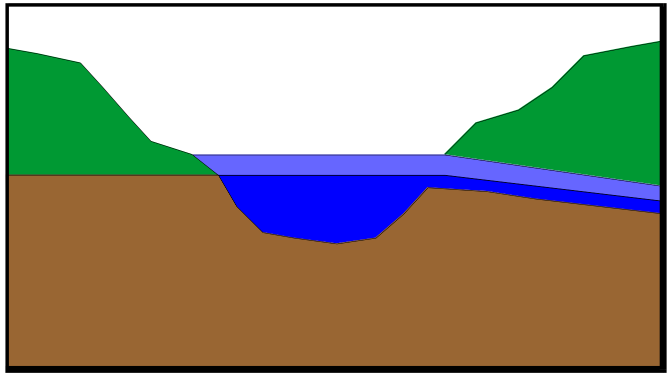




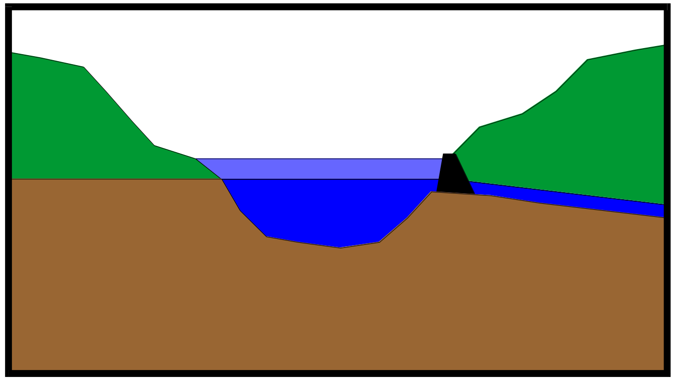
Air Receivers

- Size to prevent compressor cycling too quickly
- Typical size in litres is 6-10 times compressor output in litres/second
- Ensure receivers are well drained, 50% full of water = 50% less air storage capacity
- Receivers can only absorb short duration peak flows

Storage: Lake – vs – Reservoir

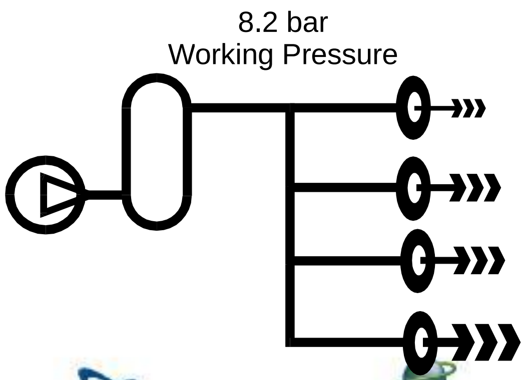


LAKE

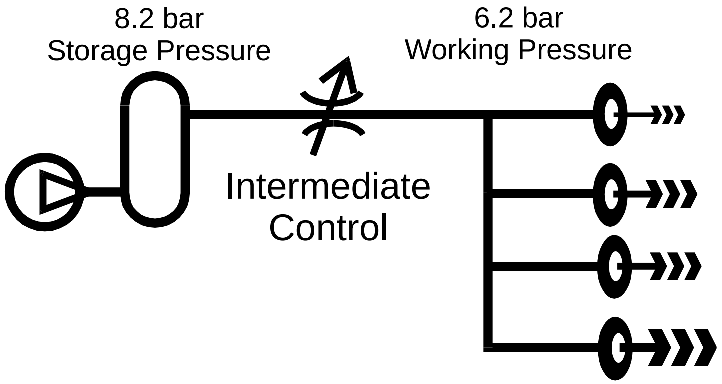


RESERVOIR

AIR RECEIVER



AIR STORAGE



Watch out for open drain valves!

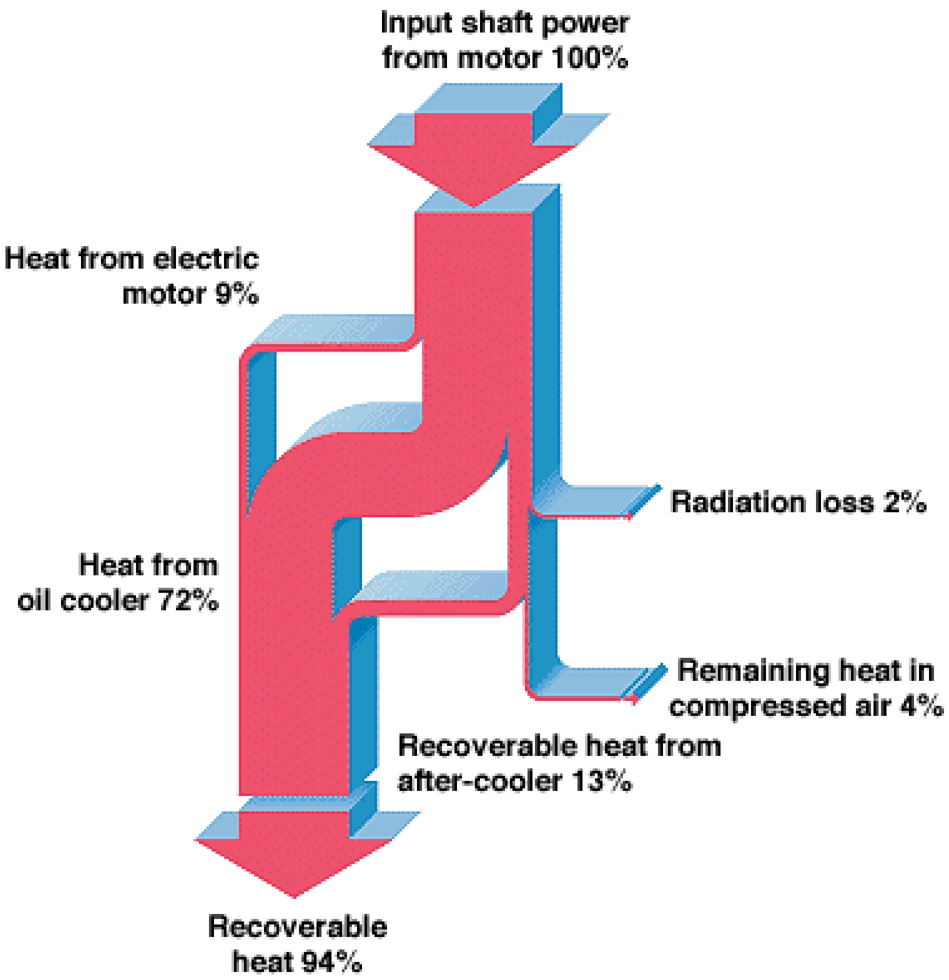
- An open valve to drain water can cost more each month than the cost of an automatic drain

Heat Recovery

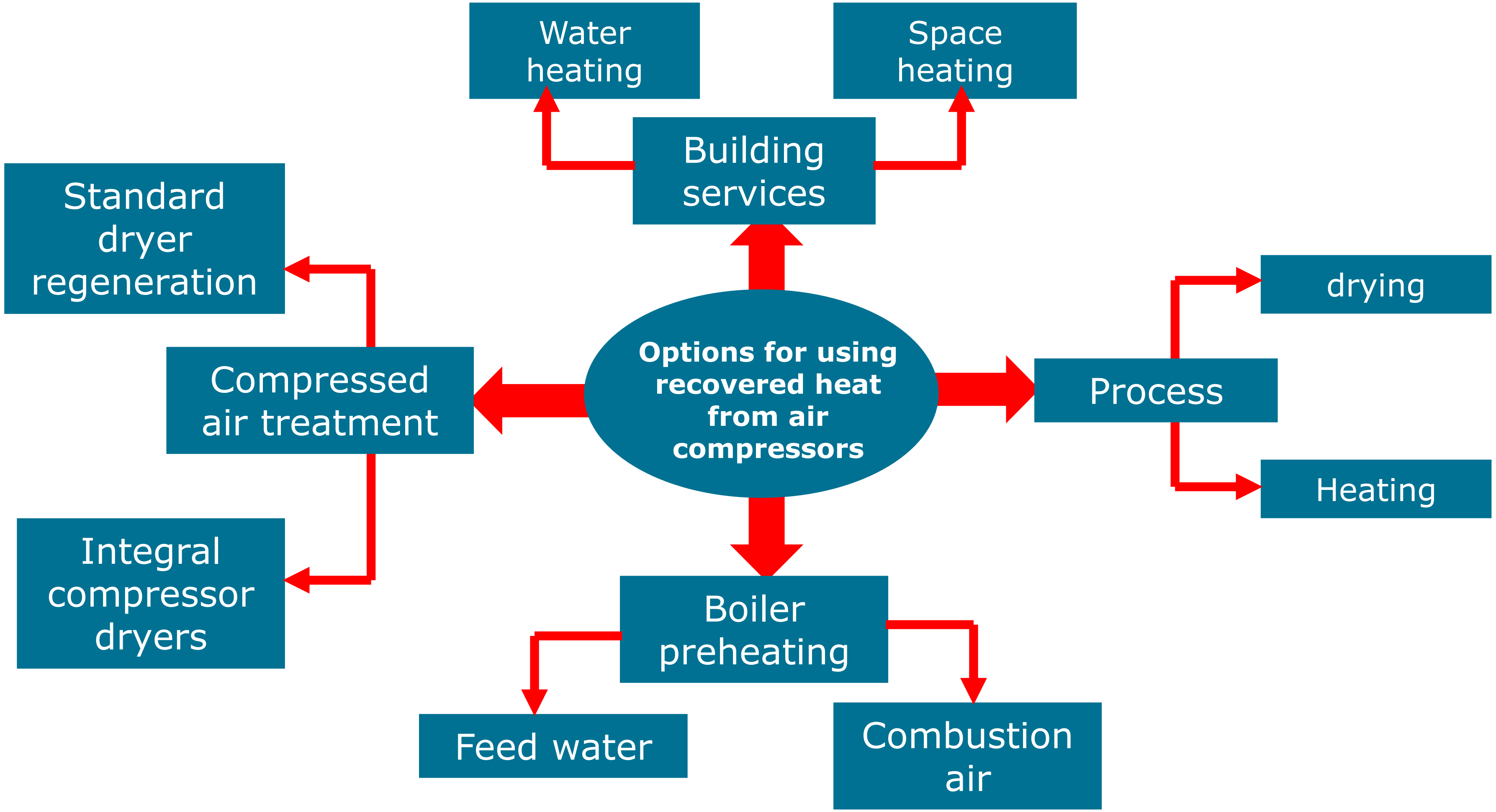
Approximatey 85% of input energy can be recovered for heating applications.

The possibility for heat recovery depends on:

- Heating demand of the factory
- Matching of compressor operation and heat demand
- Proximity of compressor station to heating distribution lines/consumers
- Temperatures



Options for Heat Recovery



Review & Discussion

Egyptian program for promoting Industrial Motor Efficiency

SAVE TODAY ... POWER TOMORROW

Motor Systems Optimisation Expert Training - Day 2

(2020 Egypt Edition)

Presented by:

Samir Khafagui & Siraj Williams

UNIDO

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08. Measurements

Motor Assessment

Motor Systems Optimisation (MSO) Expert Training (2020 Egypt Edition)

Samir Khafagui
Siraj Williams

Discussed Topics

- Data collection
- Instruments
- Software available
- Manufacturer support

Condition Monitoring

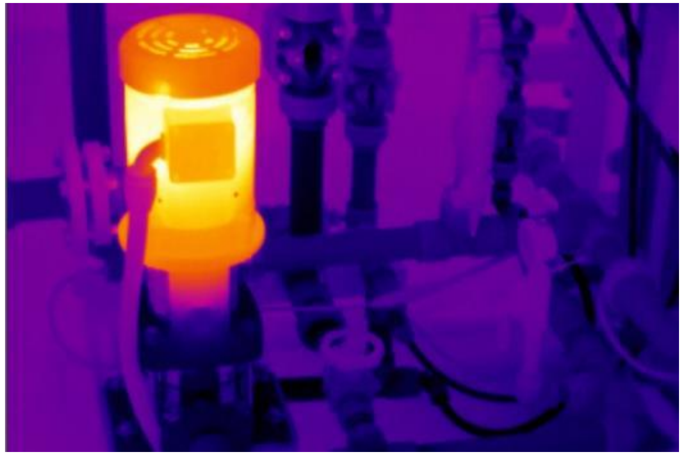
- Real time monitoring
- Early detection of potential failures
- Trending and performance tracking
- Requires upfront capital, but reduces total cost of ownership by:
  - Decrease maintenance costs
  - Increase equipment availability
  - Save costs on prematurely changed equipment

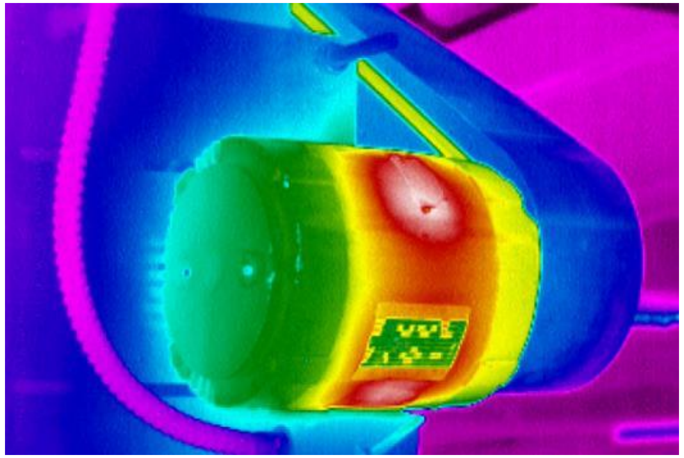
Power Quality and Energy Loggers

Power data logger with basic quality of supply analysis

Measure the load current at point of usage

Thermal Imaging





Vibration monitoring

US Dept of Energy Support Software

Egyptian program for promoting Industrial Motor Efficiency
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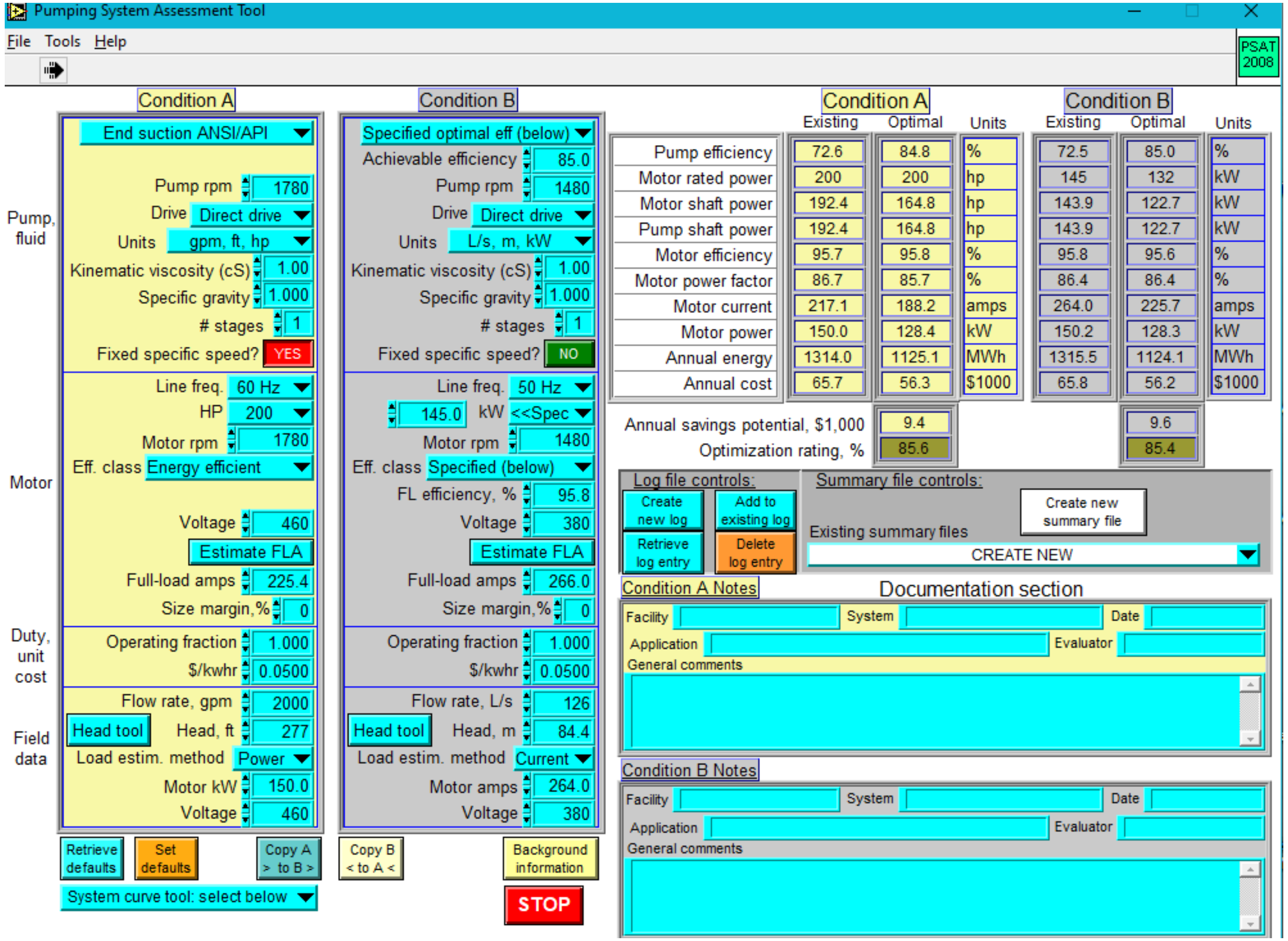
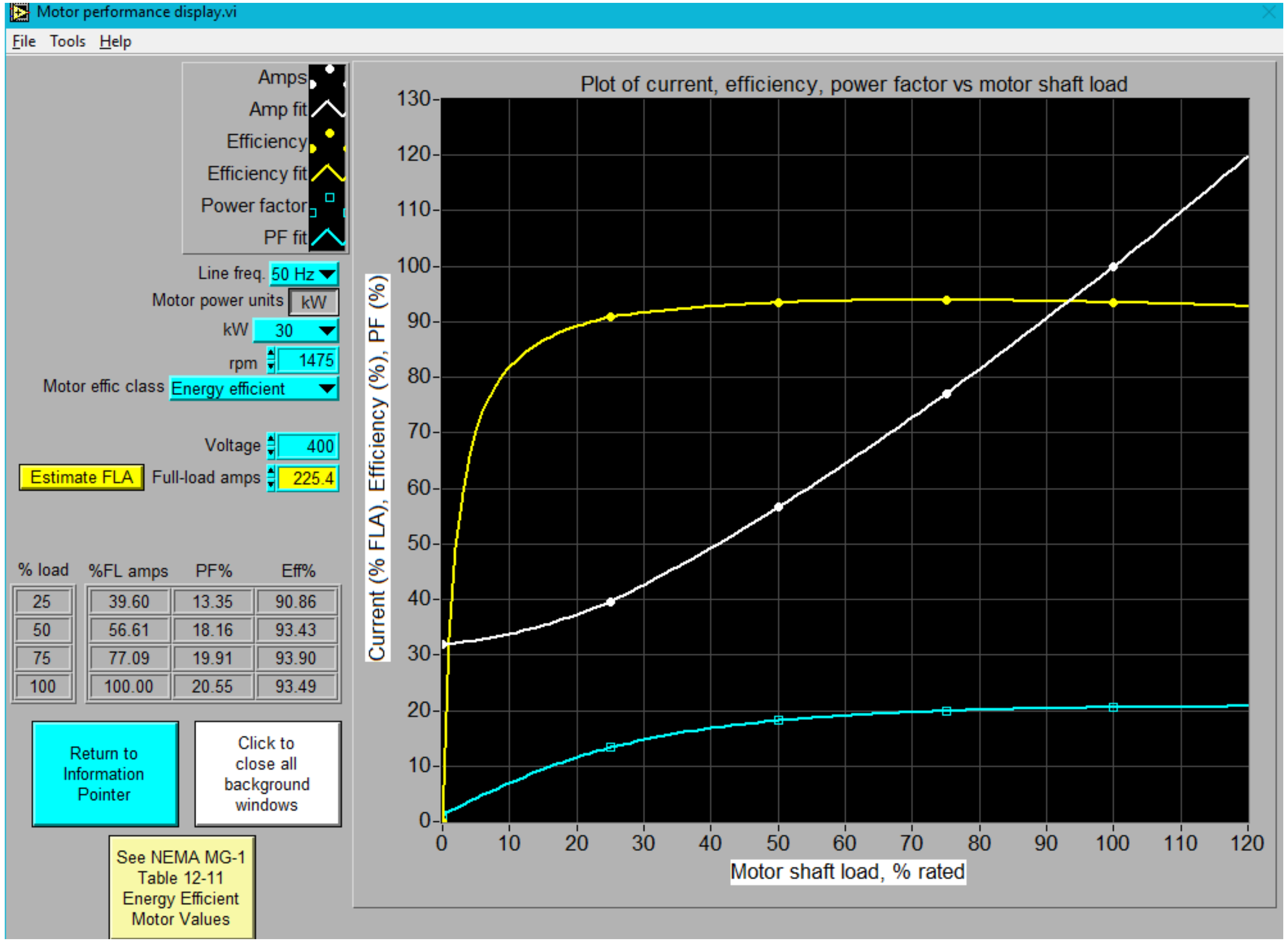
- Free of charge
- PSAT (Pumps)
- FSAT (Fans)
- Currently being replaced by online tools with improved functionality

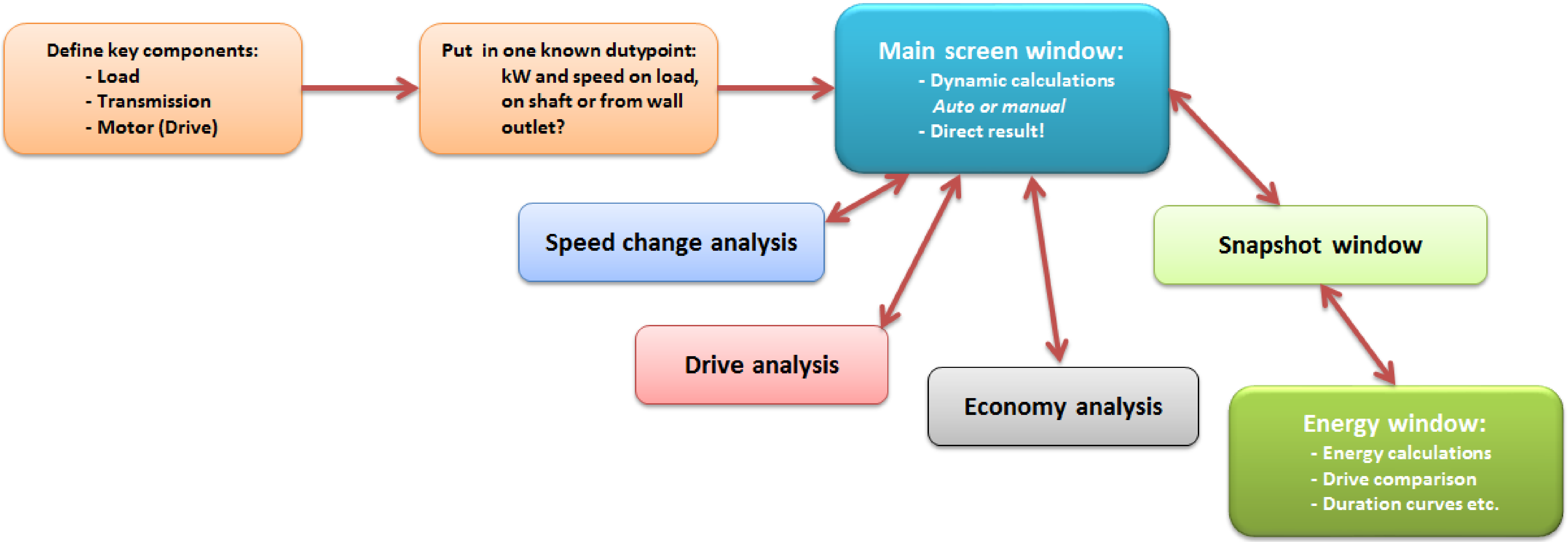


UNIDO Support Software

- Motor load estimation tool in PSAT
- Good approximation of power and power factor at part load operation

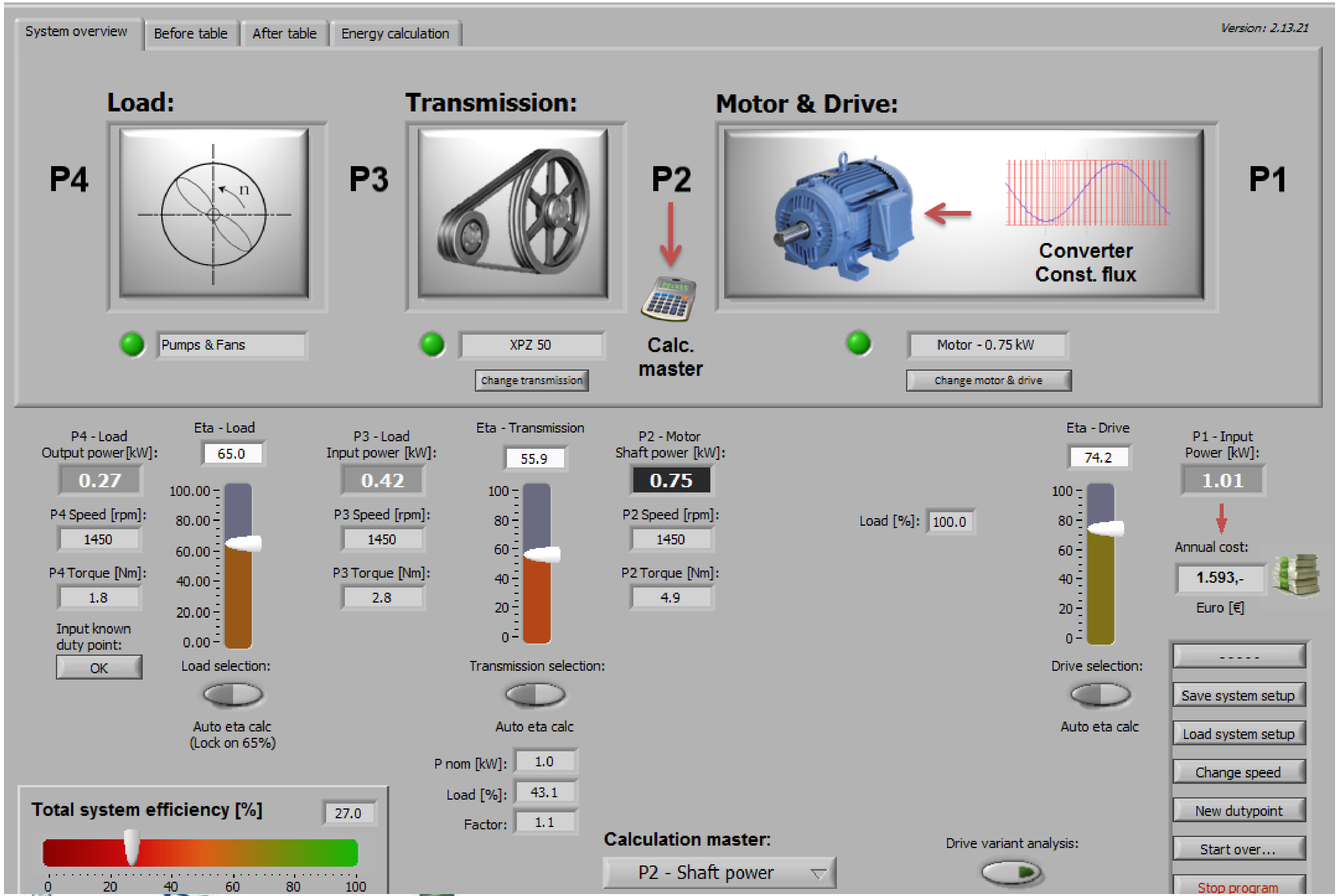


EMSA - Motor Systems Tool



https://www.motorsystems.org/motor-systems-tool

EMSA – Motor Systems Tool



Industry Support

Almost all major suppliers of electric motors now offer:

- Support for the use of adjustable frequency drives with their motors, using industry guidelines based on IEC 60034-31 for the selection and application of energy-efficient motor systems.
- Power Drive System (PDS), where the motor and drive is supplied as a single combined package, driven by the latest standards (IEC 61800-9 series).
- Online software to model the use of drives and calculate potential energy savings for the most common mechanical applications (pumps, fans and compressors).

Industry Support Software

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- https://www.sinasave.siemens.com/en/home
- https://energysave.abb-drives.com/
- http://ecatalog.weg.net/tec_cat/retornoinvestautomation.asp?cd_mercado=000U
- https://www.toshiba.com/tic/motors-drives/low-voltage-adjustable-speed-drives

Siemens - Sinawave

Egyptian program for promoting Industrial Motor Efficiency
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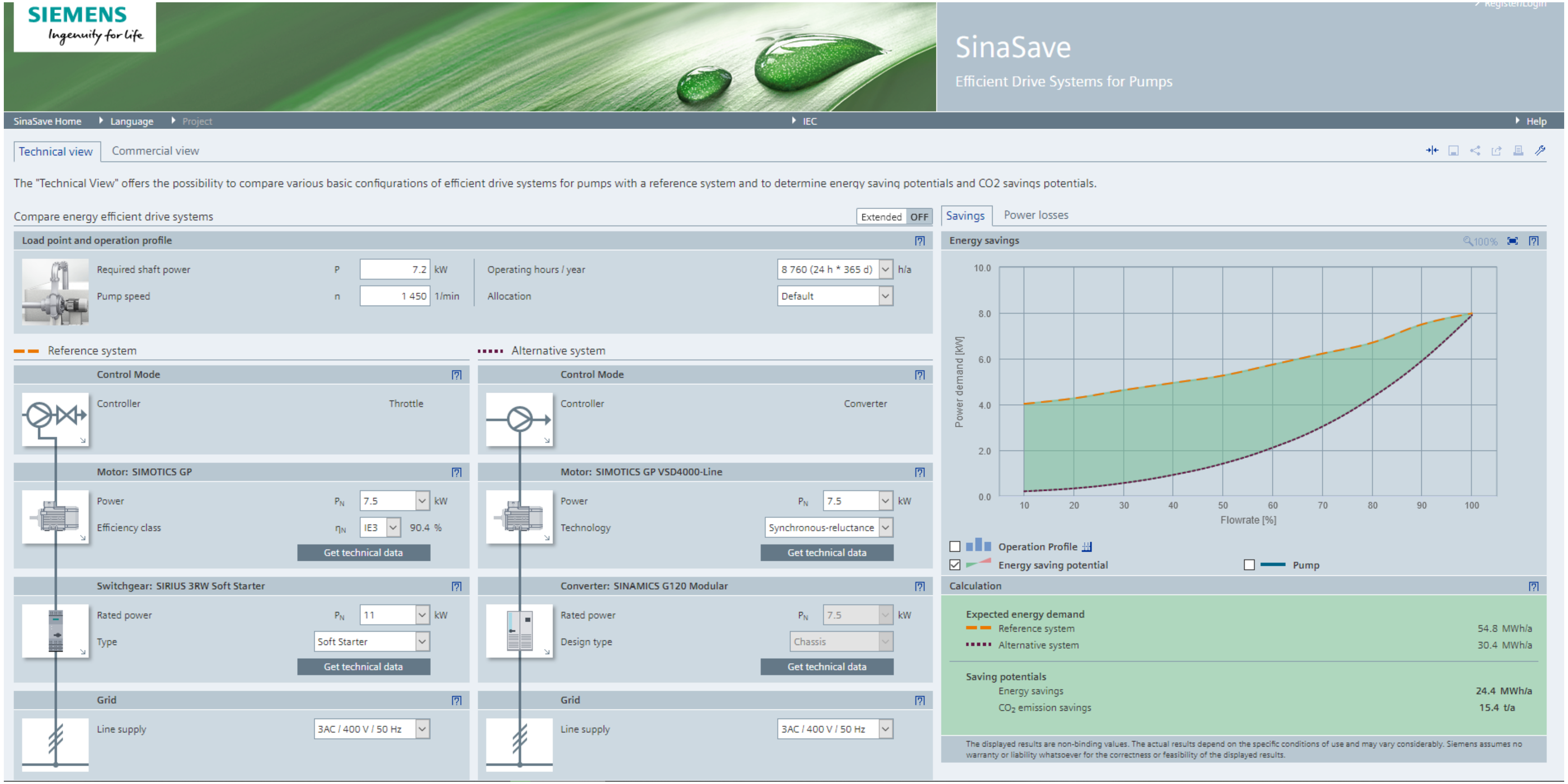


09. Motor Controls

Motor Operation

Motor Systems Optimisation (MSO) Expert Training
(2020 Egypt Edition)

Samir Khafagui
Siraj Williams

Discussed Topics

- Motor Starting
- Variable Speed Drives
- Types
- Advantages and disadvantages
- Mitigation of effects caused by VSDs

Why is motor starting important?

Motor starting impacts three main elements: the rest of the plant, the driven load, and the motor itself.

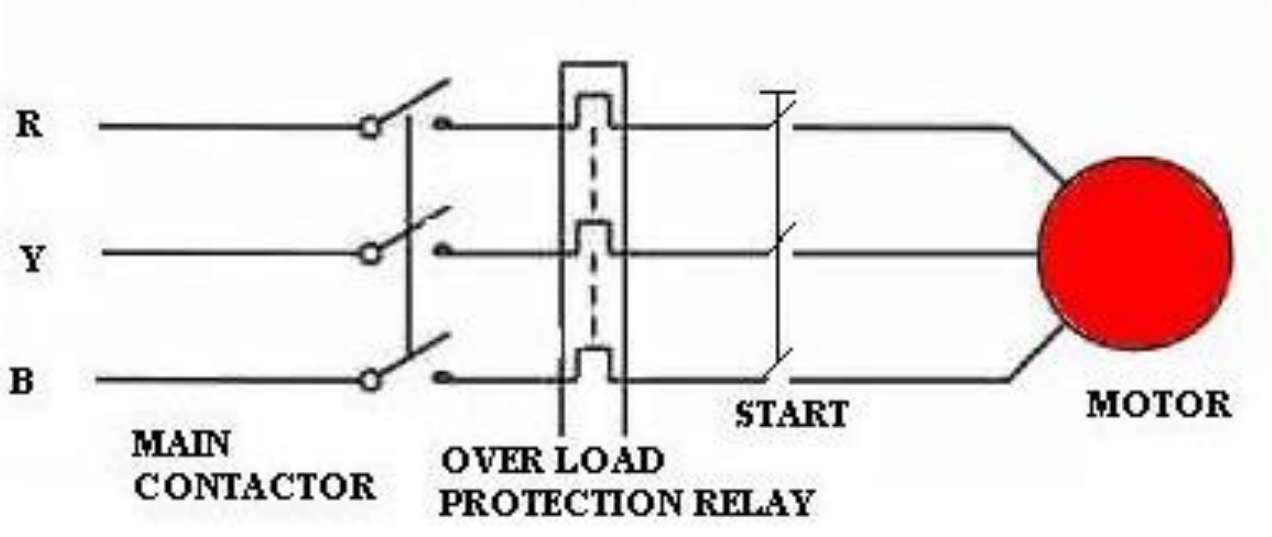
- Voltage drop during starting is the main impact on the palnt. It is produced by the large current drawn by the motor direct on-line starting and is relative to the short-circuit impedance of the system.
- The driven load is mainly impacted by the intensity of the start or the applied torque. Some high inertia loads like fans, or specific applications like water pumps, will suffer a sudden application of high torque, which may result in a high torsional effect or water hammer. In such cases, progressive starting is recommended.
- The motor is impacted through mechanical stress, starting duration, and heating. It is recommended that thermal stress is limited to 80-90% of the motor thermal capacity to avoid premature aging.

Starting Methods

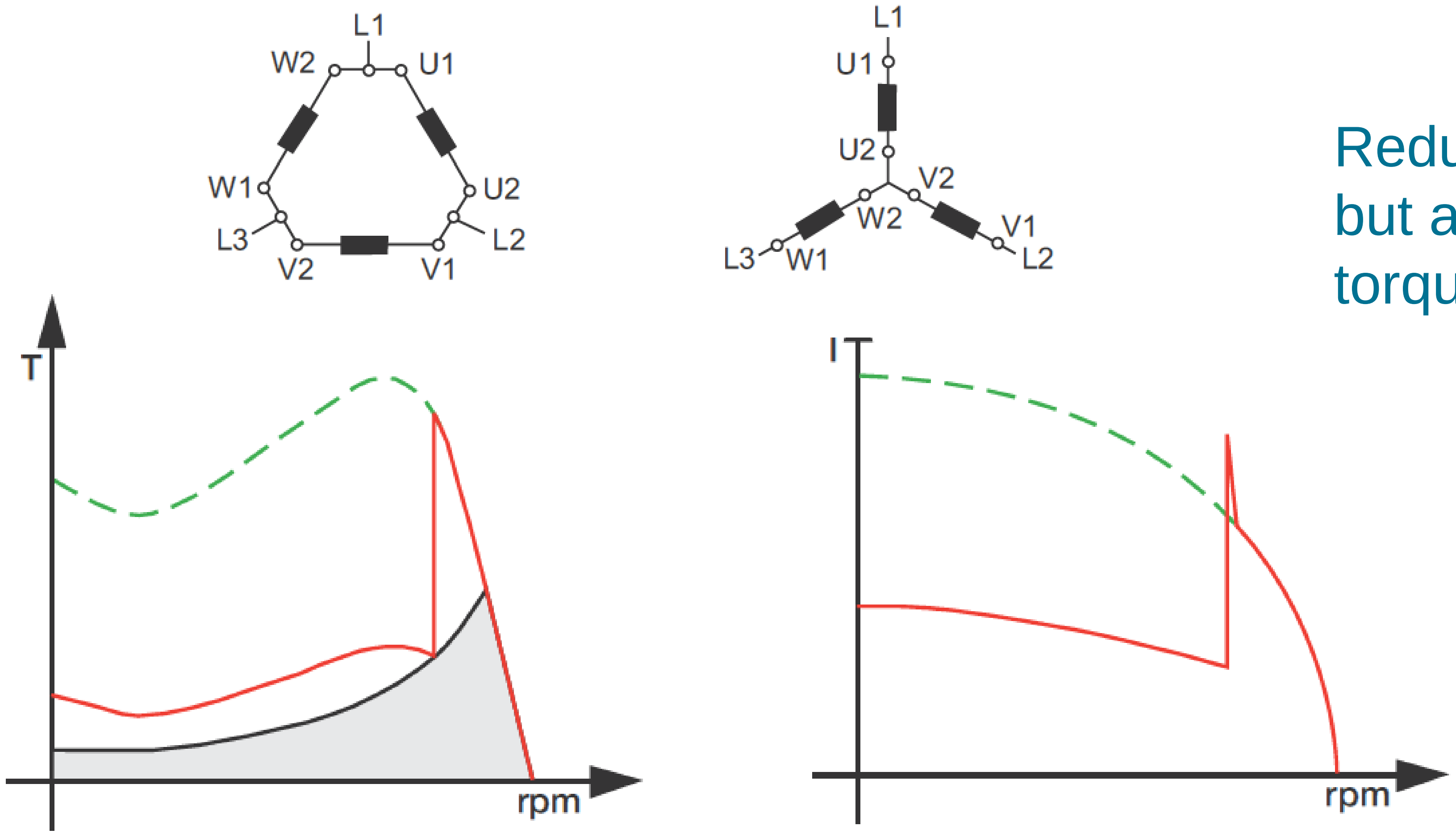
- Direct On-Line
- Star / Delta
- Auto-Transformer
- Soft Starter
- Variable Speed Drive

Direct On line (DOL)

Direct on line (DOL) starting is the simplest and most economical way to start an induction motor, but it causes a considerable starting current, typically 5 to 7 times the rated current.



Star / Delta Start



Torque/speed curve at Star-Delta start

Current curve at Star-Delta start

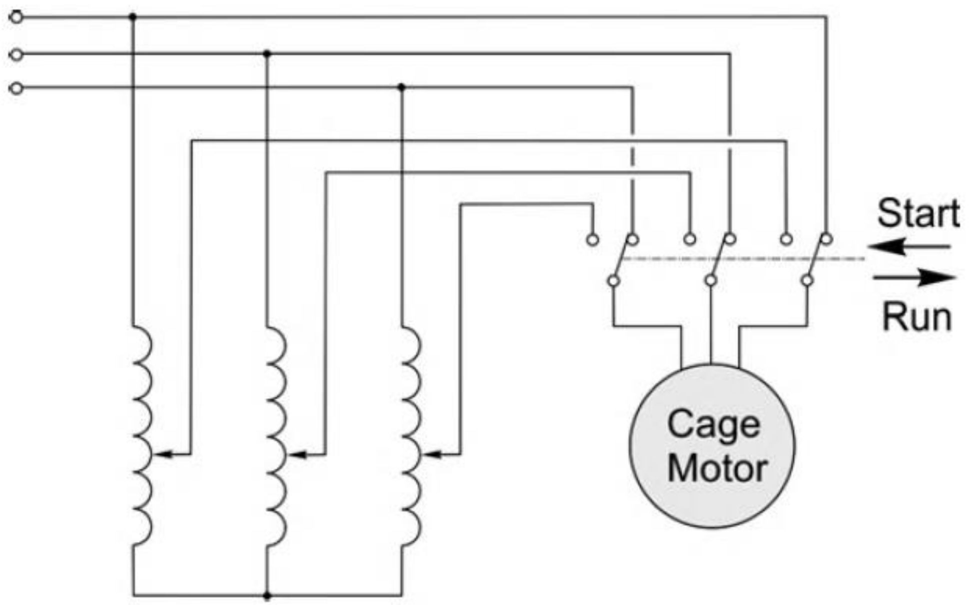
Reduces starting current, but also reduces starting torque

Autotransformer Starting

An autotransformer start, also called RVAT (Reduced Voltage Autotransformer), is another starting method that reduces the starting current, as the voltage across the motor is reduced during starting. The torque is reduced as the square of the applied voltage.

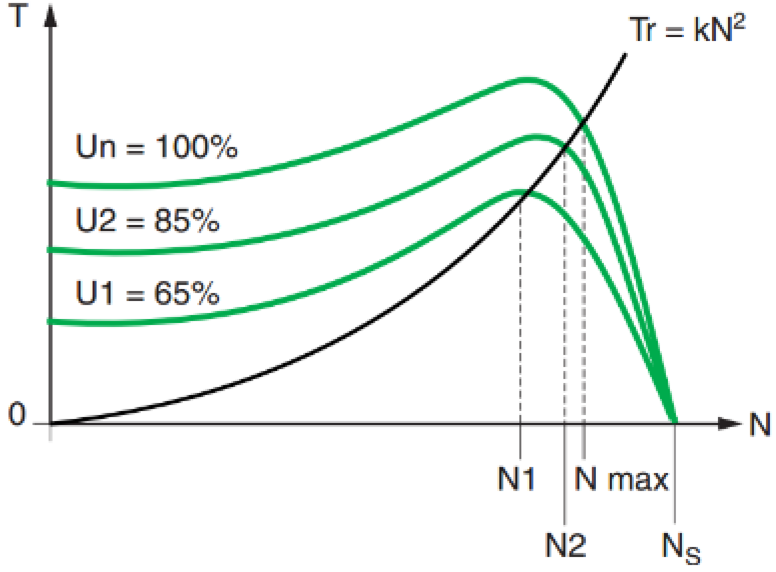
Three main steps:

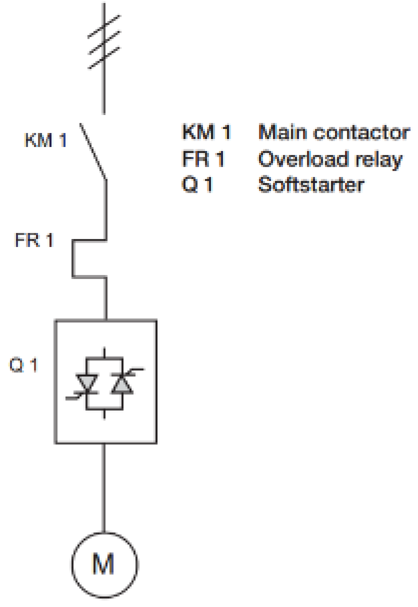
- In the first step, the motor is connected to the starting voltage with autotransformer.
- The autotransformer neutral is then opened and the motor is connected to the network through the autotransformer impedance.
- In the last step, the motor is connected in direct on line



Soft Starter

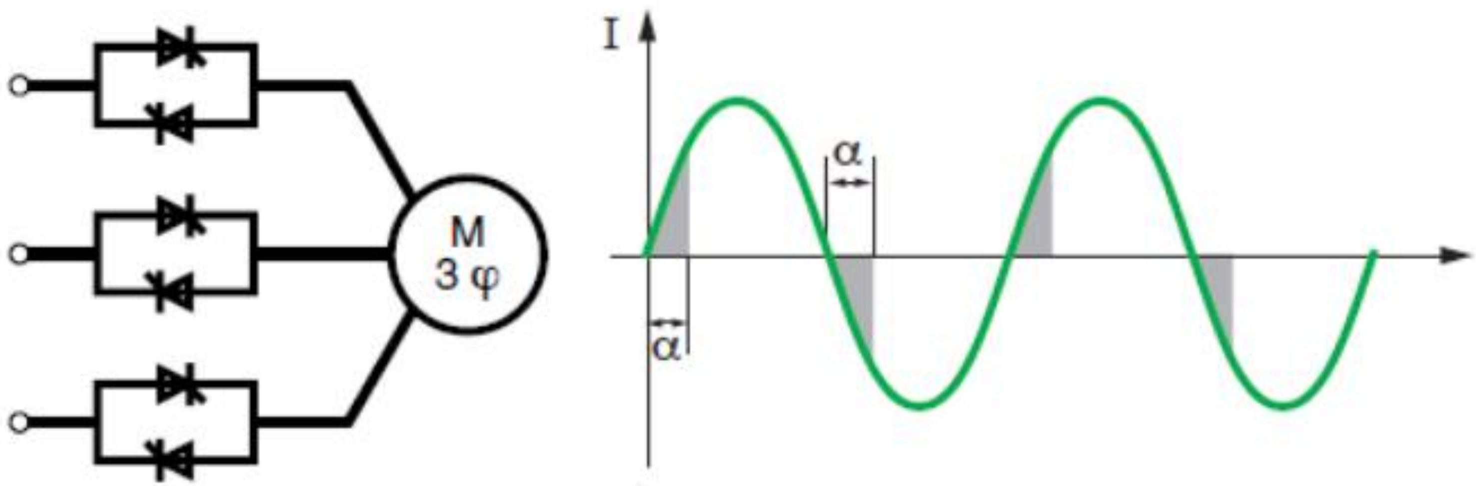
- Voltage control device that applies a much lower than normal voltage to the motor to limit the starting current.
- As the motor starts moving slowly, the voltage is increased in steps until the motor has reached its operating speed
- Also has the ability to soft stop which is especially useful for conveyors and certain pumps

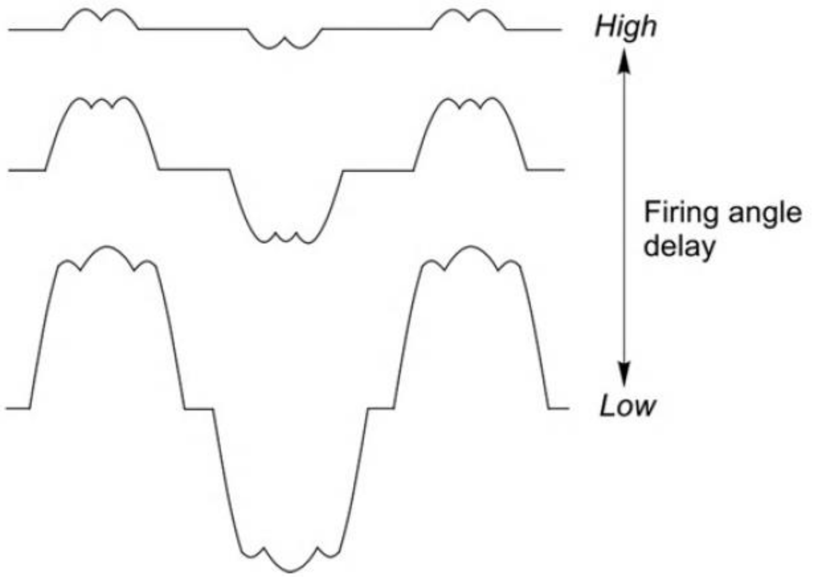




Single line diagram for a softstarter

Soft-Starter Motor Current





Each thyristor is fired once per half-cycle, the firing being synchronized with the utility supply and the firing angle being variable so that each pair conducts for a varying proportion of a cycle.

typical motor current waveforms

Soft -Starter – Starting Current Requirements

-A lower starting voltage decreases the starting current, but the starting torque is much reduced since the motor torque is given by:

$$T_{motor} = k_1 U^2$$

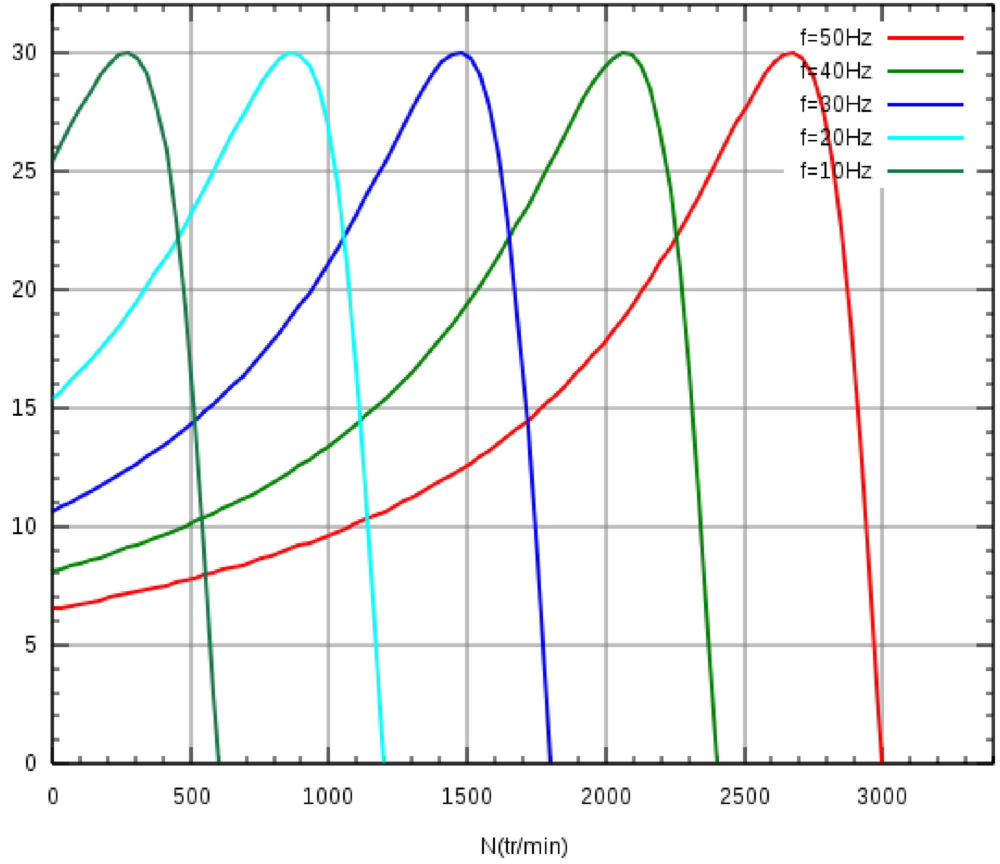
-The motor must provide a torque able to drive the load and a torque to accelerate it in an acceptable time (function of the load+motor inertia). Therefore minimumum starting torque is given by:

$$T_{Load\ starting\ torque} + T_{acceleration}$$

-The minimumum starting torque is used to define the starting current

Variable Speed Drive (VSD)

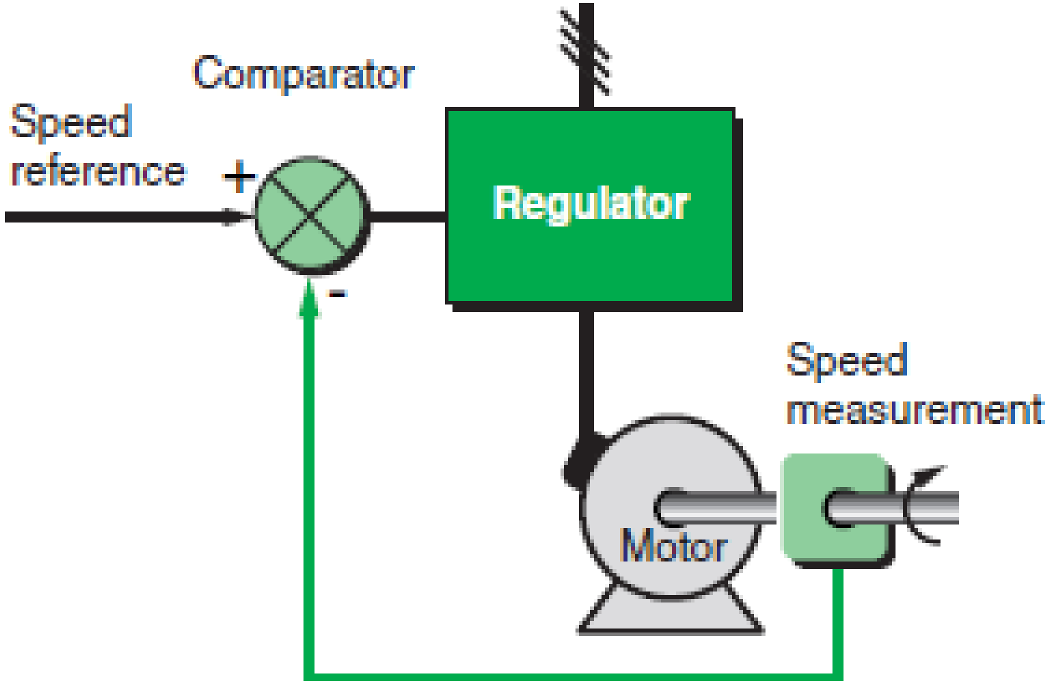
- Control device that applies a change in frequency to control the speed
- During start up it operates similar to a soft starter by limiting the voltage during start up
- Also called variable frequency drives (VFD) and adjustable speed drives (ASD)



Comparing Motor Starting Methods

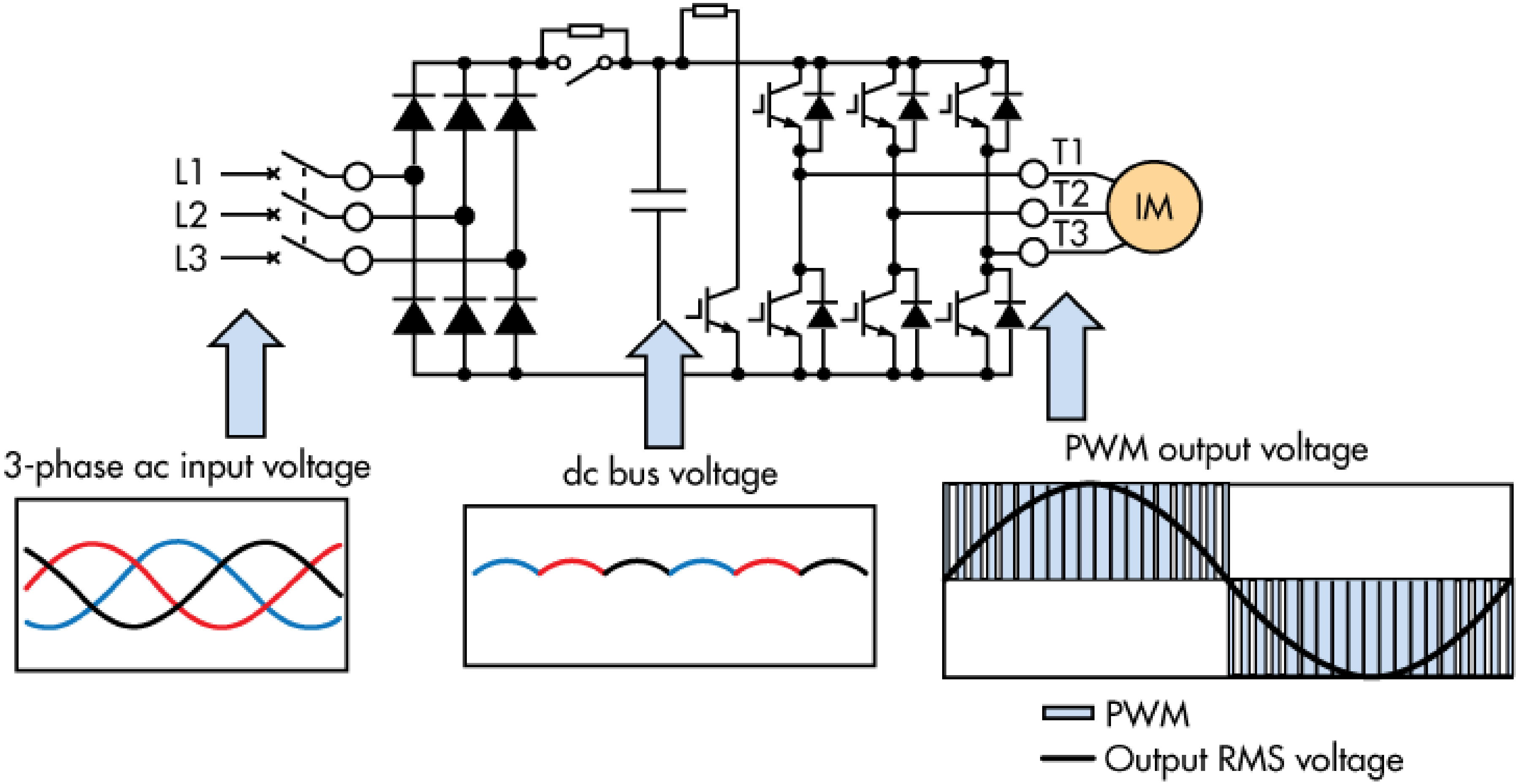
	Direct On Line	Star Delta	Autotransformer	Soft Starter	Variable Speed Drive
Network impact	High voltage drop High reactive power demand High starting current	Reduced voltage drop Reduced reactive power demand starting current at 1/3 of DOL	Reduced voltage drop Reduced starting current from network Higher starting current to motor	Reduced voltage drop Reduced and controlled current from network Smooth increase in current and reactive power demand	No impact to network Low starting current Very low reactive power demand
Mechanical impact	High starting torque High stress Coast stop Rapid starting	Reduced initial stress High stress at transition from star Coast stop Prolongated start	Higher torque for lower starting current from network Reduced mechanical stress Coast stop Prolongated start	Smooth application of torque to load Soft-stop possible Prolongated and repetitive start independente of voltage drop	Smooth acceleration No mechanical stress Soft-stop possible Controlled starting time
Thermal impact	Slighly increased heating	Slighly increased heating	Higher heating	Higher heating	Very low heating
Main Applications	All constant speed applications	Pumps, compressors	Pumps, compressors	Pumps, fans, compressors	All applications requiring speed / torque control
Not recommended	weak supply (voltage dip) For frequently started motors it	High inertia loads like fans For high starting torque applications	High inertia loads like fans For constant torque applications	For constant torque applications	For constant speed applications

Principle of Speed Regulation

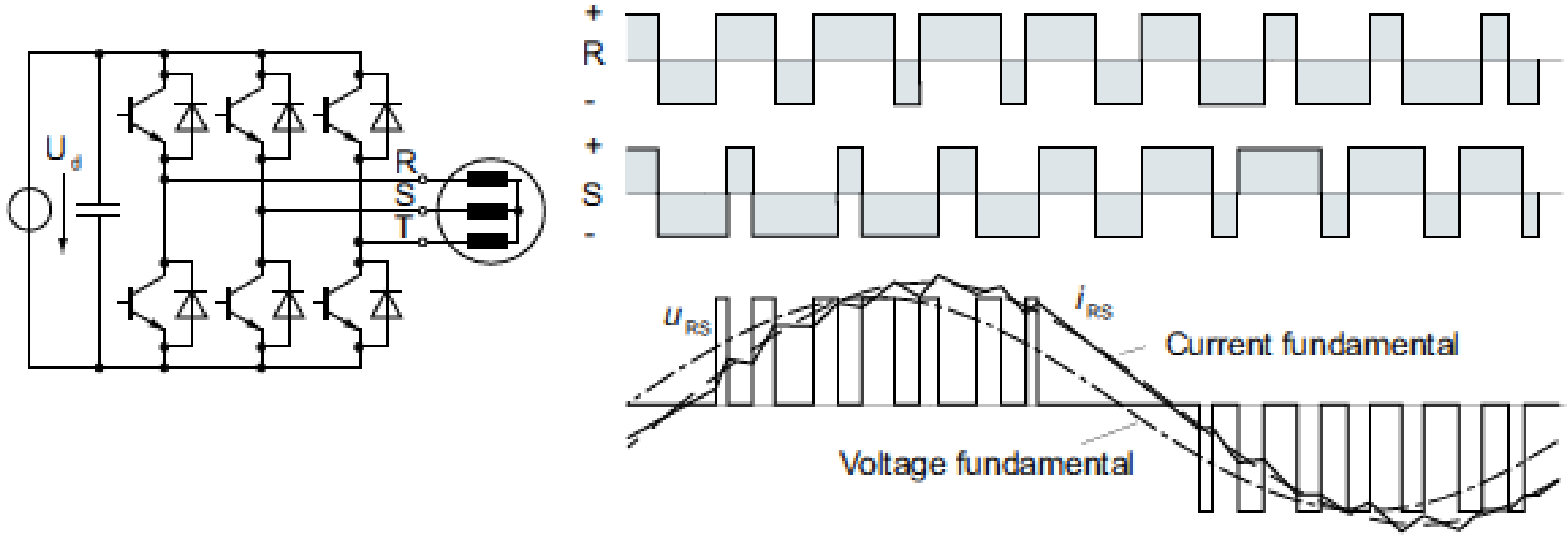


- VSD enable closed loop feedback control where speed can be controlled more precisely.
- In many cases this improves production quality and sometimes even production volume

Variable Speed Drives – VSDs



PWM inverter

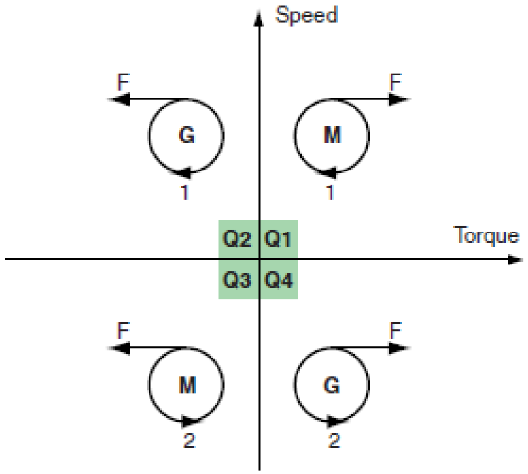


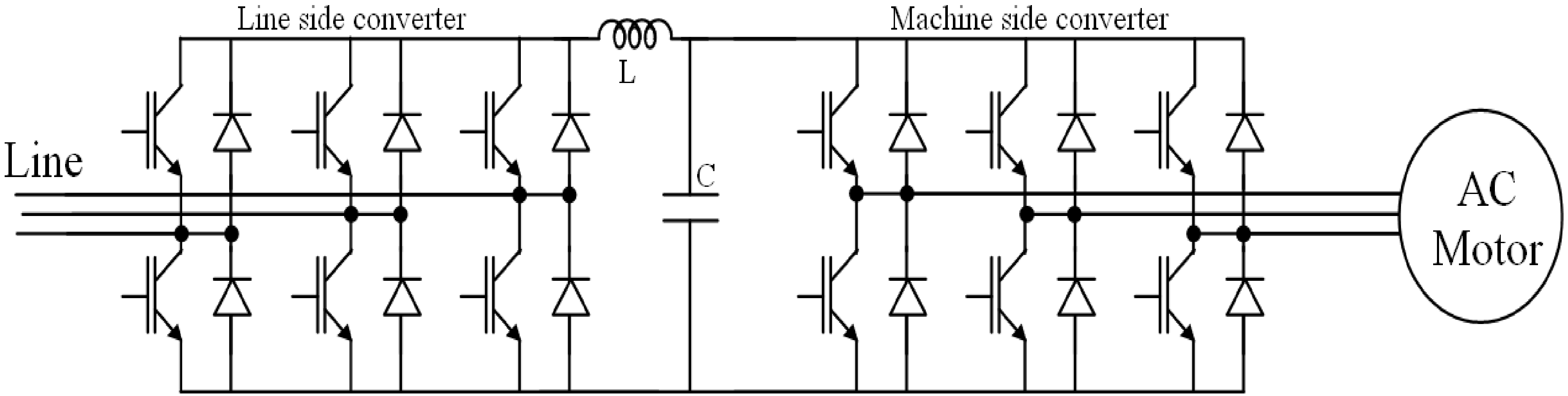
Circuit diagram and control principle of a PWM inverter

PWM – Pulse Width Modulation

Bidirectional VSD

- Four Quadrant Control Capacity
  Regeneration Capacity
  Bidirectional Power Flow





Types of VSDs – Pros and Cons

VSD Type	Advantages	Disadvantages
Pulse-Width Modulation (PWM)	Good power factor throughout speed range. Low distortion of motor current. Wide speed range (100:1). Multi motor capability.	No regeneration capability. Limited to VSDs bellow 1000 kW *. Slightly (about 1%) less efficient than VSI or CSI
Six-step Voltage-Source Inverter (VSI)	Good efficiency. Simple circuit configuration. Wide speed range (10-200%). Multi-motor capability.	Poor power factor at low speeds (unless a rectifier/chopper AC/DC converter is used). No regeneration capability. Operation below 10% of rated speed can produce cogging.
Force Commutated Current-Source Inverter (CSI)	Simple and robust circuit design. Regenerative capability. Built-in short circuit protection. Wide speed range (10-150%).	Bulky. Poor power factor at low speed/load. Possible cogging below 10% of rated speed.

Types of VSDs – Pros and Cons

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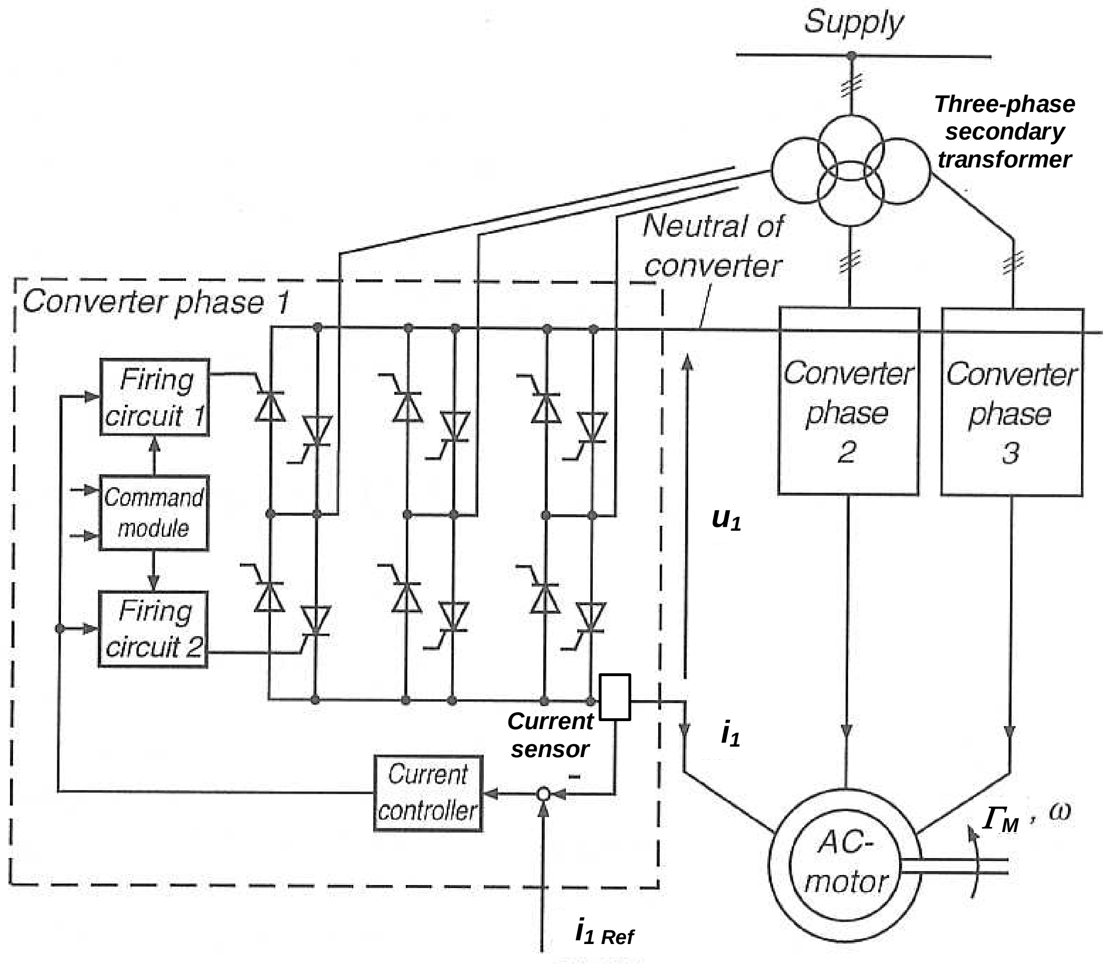
VSD Type	Advantages	Disadvantages
Load-Commutated Inverter (LCI)	Simple and inexpensive circuit design. Regeneration capability. Built-in short-circuit protection.	Poor power factor at low speed. Can only be used with synchronous motors.
Static Kramer Drive	VSD power is less than motor power. Can be retrofitted to wound rotor induction motor (W.R.I.M.) with external resistor.	Can only be used with W.R.I.M. Poor power factor at low speeds. Subsynchronous speed (50-100%)only.
Static Scherbius Drive	VSD power is less than motor power. Wider speed range (70-130%). Can be retrofitted to W.R.I.M. with external resistor if overspeed is possible.	More complex and costly than Kramer drive. Can only be used with W.R.I.M.
Cyclo-Converters	Can operate down to zero speed. High torque capability with field-oriented control. Can be used with induction and synchronous motors.	Cannot be used above 33% of input frequency. Complex circuit design. Poor power factor at low speed.

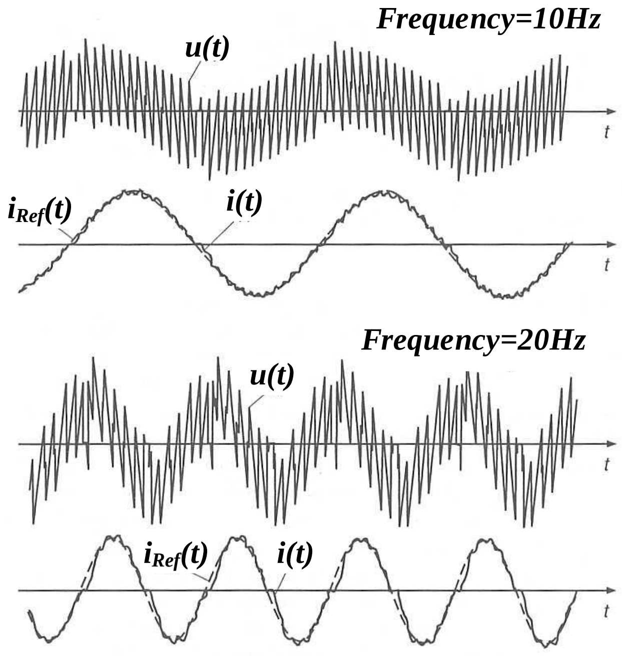
Common Types of VSD and Applications

Controlling the	Three-phase AC drive	Application
Stator voltage	Three-phase AC power controller with squirrel-cage induction motor	Drive for pumps, fans, up to 6 kW - in special cases up to 50 kW
Stator frequency, stator voltage	Current-source DC link converter with synchronous motor (converter motor)	Drive for processing machines, pumps, blowers, up to 60 MW
	Voltage-source DC link converter with synchronous motor or squirrel-cage induction motor	Drive for textile machines, roller tables, machine tools, up to 20 MW
	Cycloconverter with synchronous motor or squirrel-cage induction motor	Drives with very low speeds, e.g. rock crushers, up to 15 MW
Stator frequency, stator current	DC link converter with squirrel-cage induction motor	Drive for fans, centrifuges, mixers/agitators, up to 1800 kVA

Cycloconverters



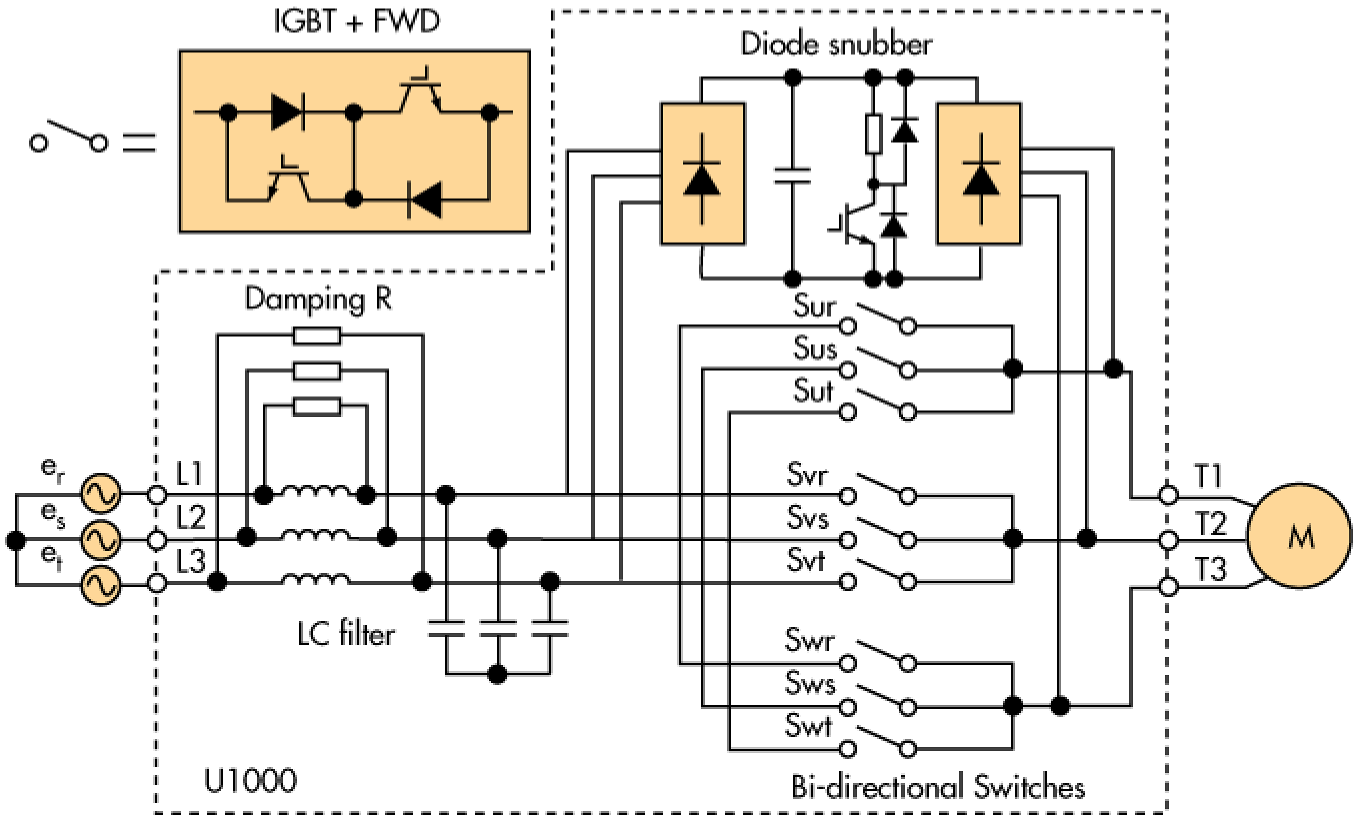
Special type VSD Direct AC-AC Conversion (>1MW, Low Speed (0-15 Hz), High Power)



Matrix Converters

A matrix drives employs a system of nine bi-directional switches arranged in a matrix to convert a three-phase AC input voltage directly into a three-phase AC output voltage.

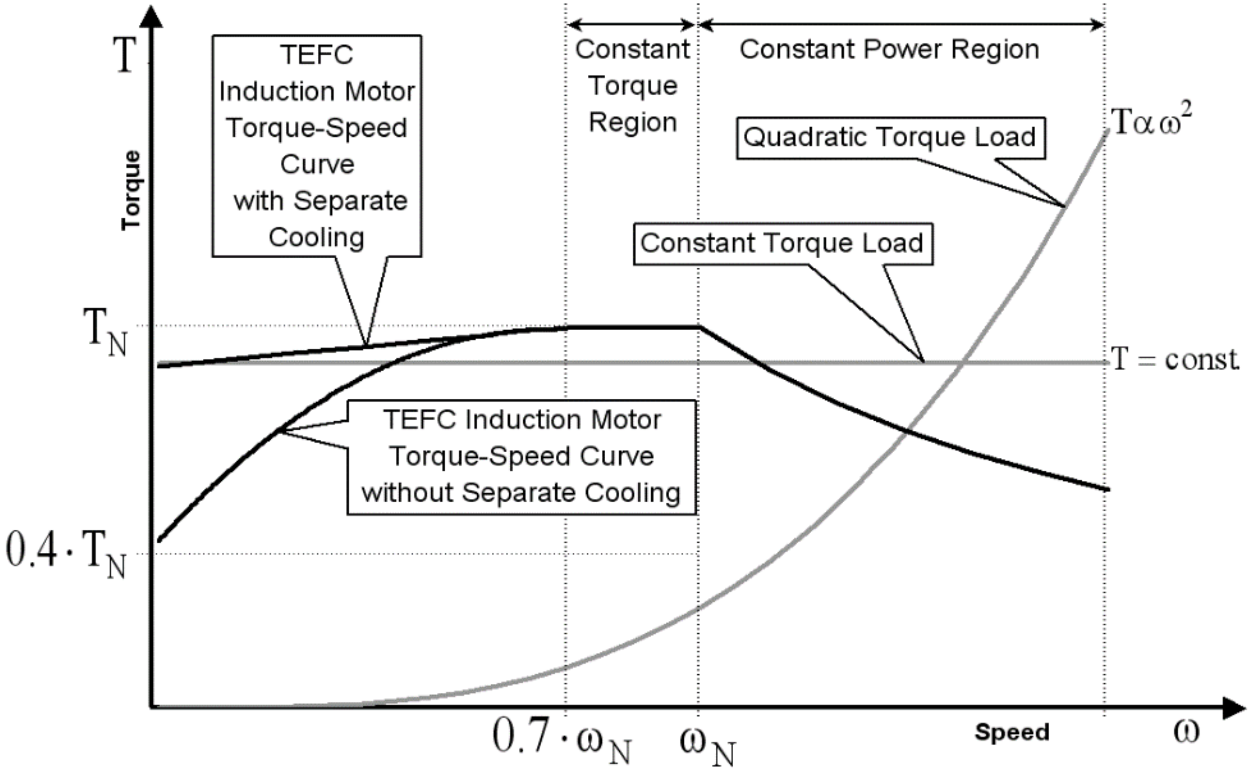
The matrix drive eliminates the need for a rectifying circuit and DC smoothing circuit found in conventional AC drive inverters.



VSDs-Variable Speed Drives – Operating Areas

Motor torque and power limitations in totally-enclosed fan-cooled induction motors fed by a PWM VSD, assuming motor constant nominal operation temperature (switching frequency > 5 kHz, field weakening point at nominal frequency).

Torque-speed curves for different types of loads.



PWM – Pulse Width-Modulation
VSD – Variable Speed Drive

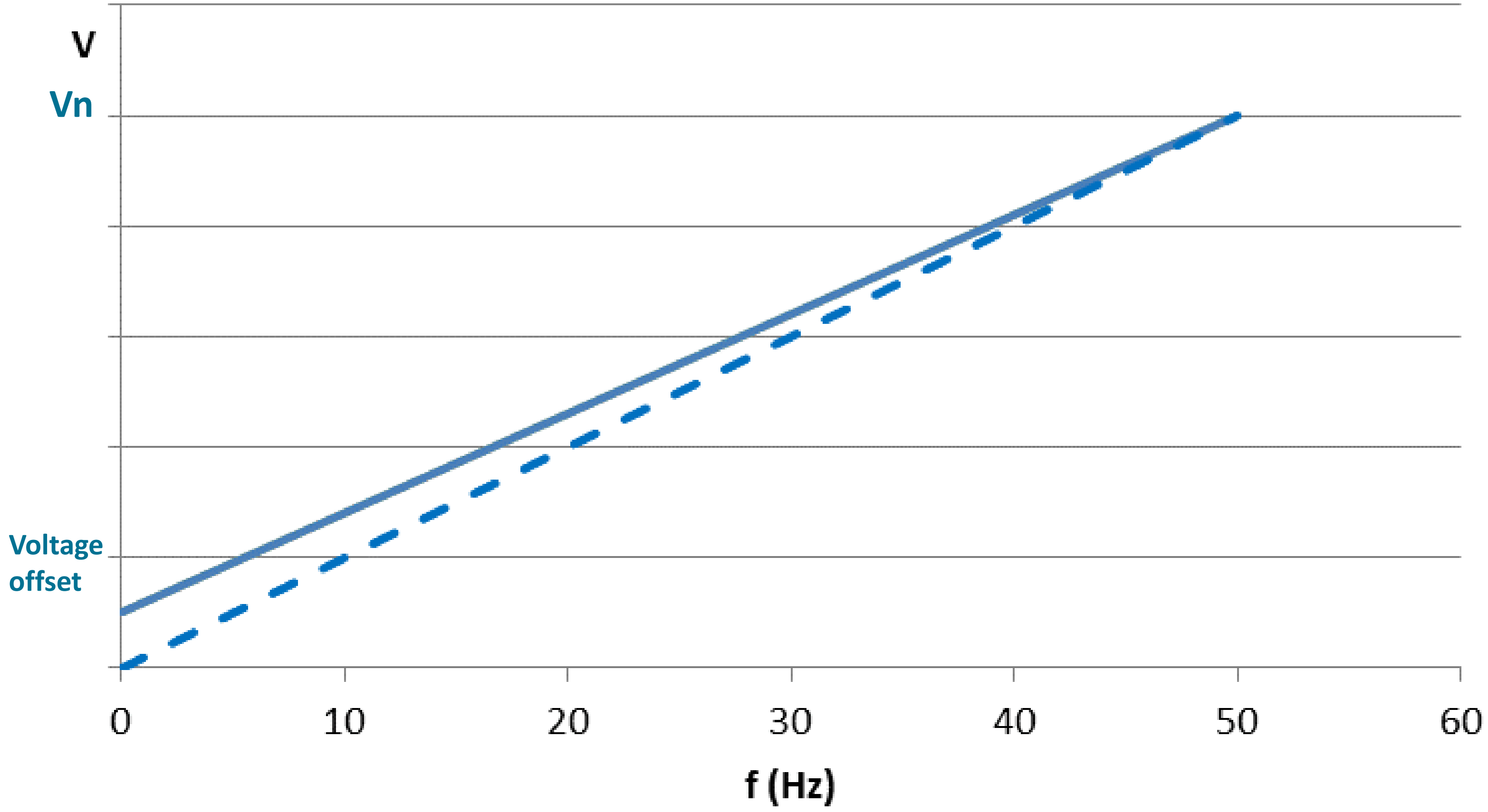
Open Loop Systems (Manual Control)

- In an open loop control system the controlling parameters are fixed or set by an operator and the system finds its own equilibrium state, depending on the load characteristics.
- Simple for process requirements that are very stable and static.
- Where process requirements vary, operation might not achieve optimal efficiency.

V/f (Voltage / Frequency) Control

- The voltage amplitude is specified as a function of the actual motor frequency, and the desired torque.
- In most VSDs the V/f characteristic can be adjusted. The most usual characteristic types are those with a constant torque or a square-law characteristic for pumps and fans.

Voltage Variation with Frequency



V/f Control Characteristics

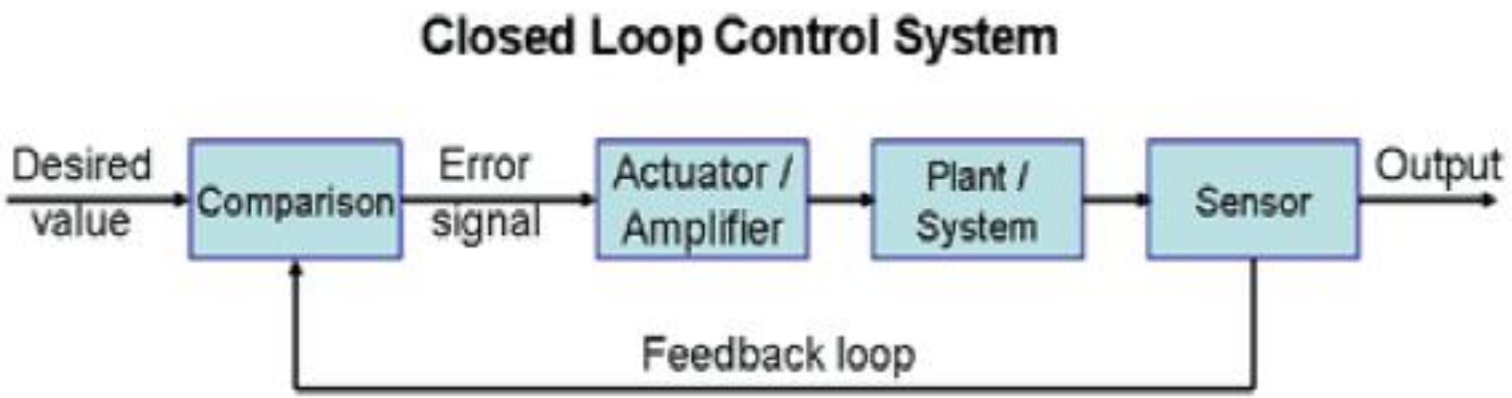
The following measures improve the properties of V/f control:

- Slip compensation maintains the speed constant during load changes using a load current-dependent frequency boost. The slip compensation becomes effective from approx. 10 % of the rated motor speed. This therefore allows a speed holding accuracy to be achieved.
- FCC control (Flux Current Control, extended I*R compensation) also improves the speed holding accuracy during load changes. FCC adapts the voltage - and therefore the rotor flux - to the load.
- The voltage increase at low frequencies ("boost") optimizes the starting behavior.
- The current limiting control is used as stall protection.

Closed Loop Control Systems

(Automatic Control)

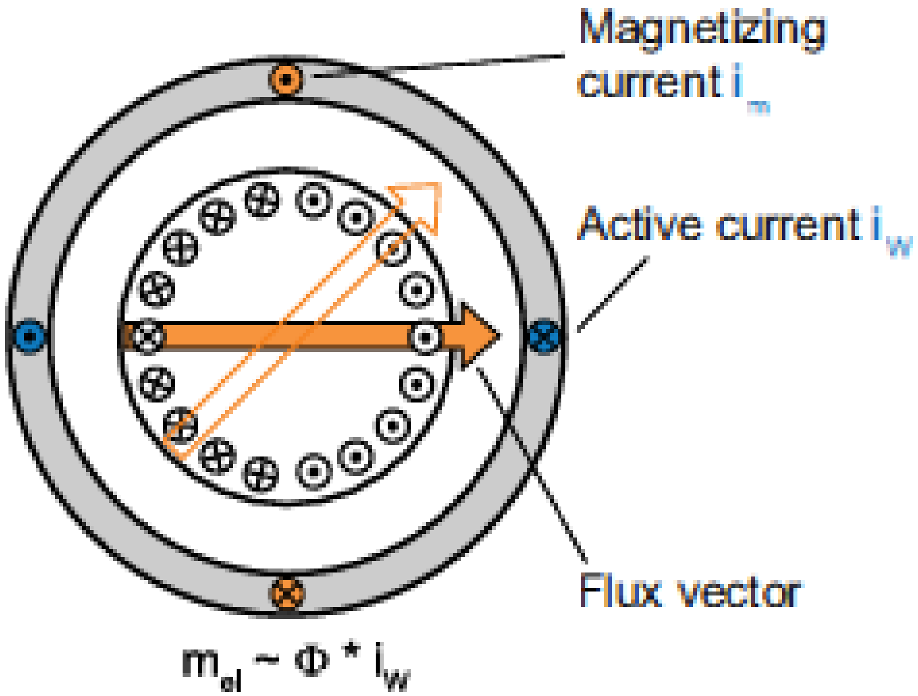
- Also called feedback control systems, or negative feedback systems, they allow the user to set a desired operating state as a target or reference and the control system will automatically move the system to the desired operating point and maintain it at that point thereafter.



Vector Controlor or Field Oriented Control (FOC)

Vector control (Also called Field-oriented control - FOC) is a control technique for polyphase motors (induction and synchronous motors), which allows a three-phase motor to be operated with the same high dynamic performance as a DC motor.

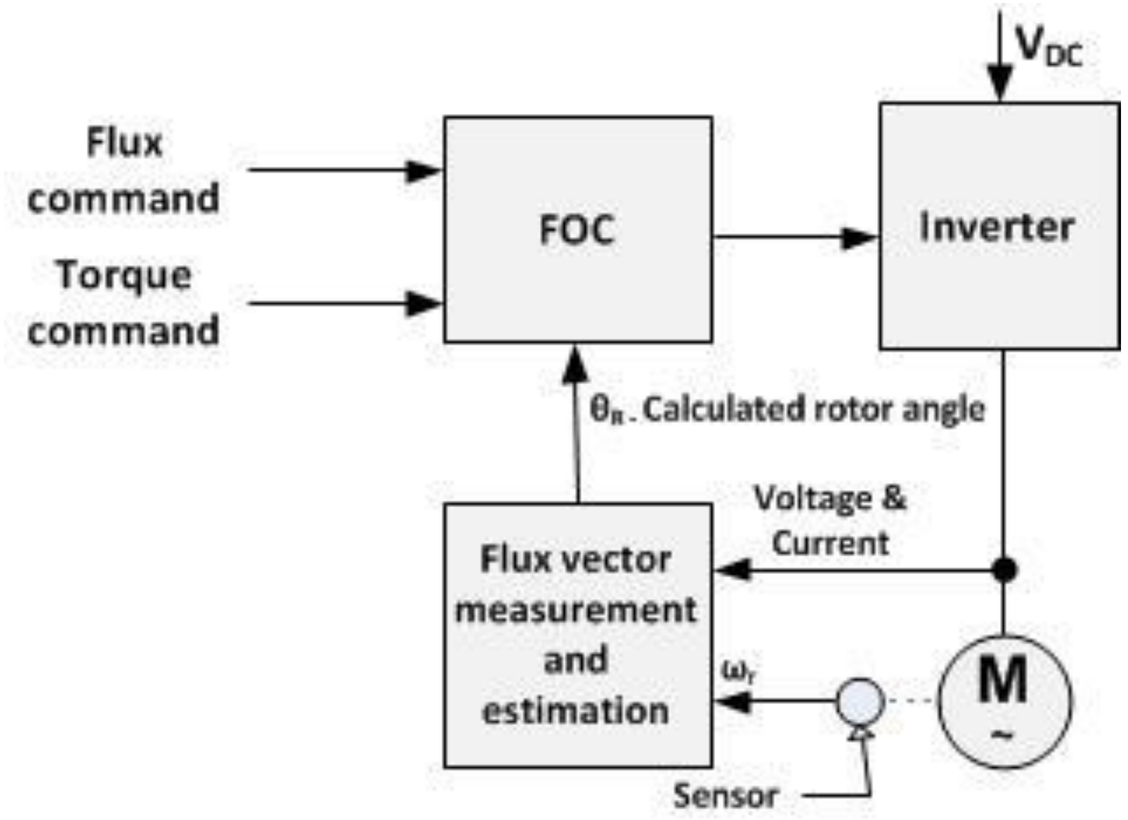
The behaviour of a DC motor is emulated in an induction motor by orienting the stator current with respect to the rotor flux so as to attain independently controlled magnetic flux and torque.



Vector Control

- The reference system of the machine equations is not orientated to the stationary stator, but to a rotating magnetic field.
- The field appears to be stationary in this rotating reference system. The voltages - and especially the currents - in the motor can now be referred to this system
- The current in the motor is split up into a field-generating component (magnetizing current i_d, in the direction of the field) and a torque generating component (active current i_q, perpendicular to the field [quadrature axis]); both of these can be controlled independently of one another.
- Using matrix calculations, the quantities between the rotating ***d-q*** axis reference frame are transformed in the stationary $\boldsymbol{i_1}$, $\boldsymbol{i_2}$, $\boldsymbol{i_3}$ reference frame, and vice-versa.

Vector Control



- Knowing the alignment of the magnetic field in the motor is a precondition for field-orientated control. This is determined from measured data (currents, voltages, speed or position of the rotor derived from a sensor) in a motor model or flux model.

- So-called sensorless closed-loop controls, do not require a position and speed encoder, also calculate these quantities through sophisticated control algorithms.

Advantages of the VSDs

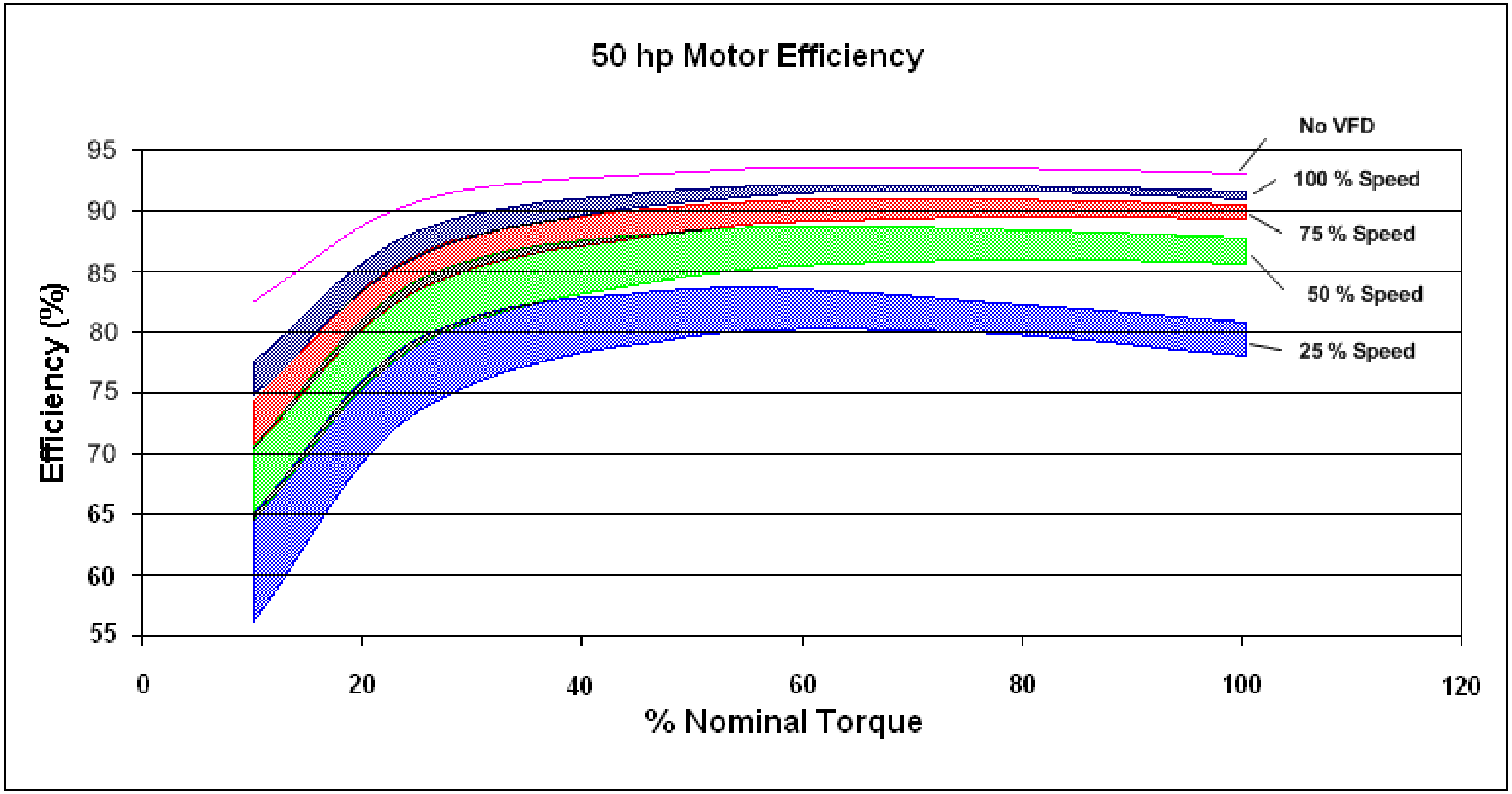
- Energy savings associated to the speed control;
- Improvement of the dynamic performance of induction motors;
- High efficiency of the VSDs (96-98%) and high reliability;
- High power factor (if active front end is used);
- Small size and location flexibility;
- Soft starting and stopping;
- Regenerative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

Motor Efficiency Reduction of VSD Fed Induction Motor

Operation of AC machines on a non-sinusoidal supply inevitably results in **additional losses** in the machine. These losses fall into three main categories.

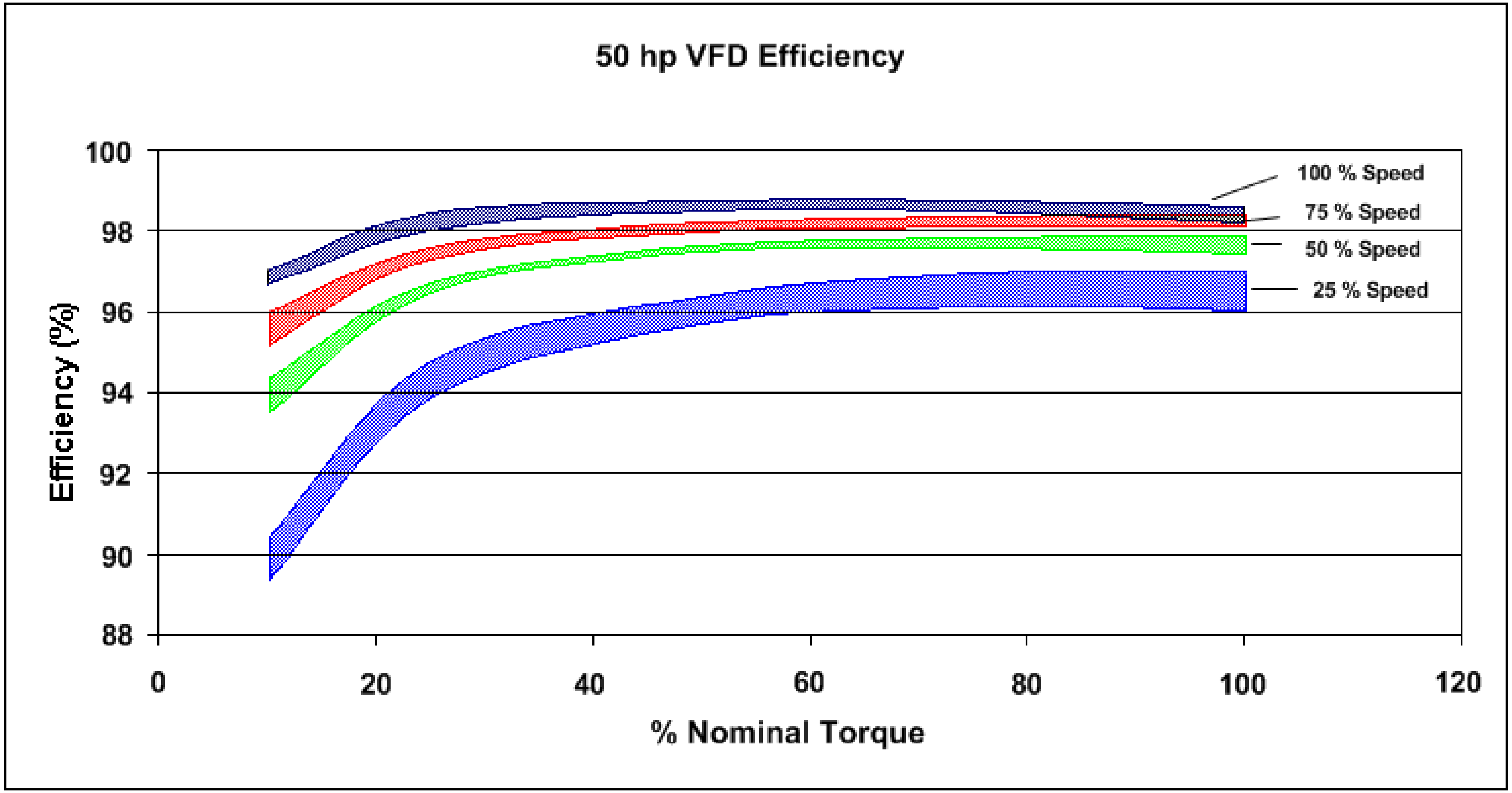
- **Stator copper loss**. This is proportional to the square of the RMS current. Additional losses due to skin effect must also be considered.
- **Rotor copper loss.** The rotor resistance is different for each harmonic current present in the rotor. This is due to the skin effect and is particularly pronounced in deep bar rotors. Because the rotor resistance is a function of frequency, the rotor copper loss must be calculated independently for each harmonic. Although these additional losses used to be significant in the early days of PWM inverters, in modern drives with switching frequencies above 3 kHz the additional losses are minimal.
- **Iron loss.** This is increased by the harmonic components in the supply voltage.

Example - 37 kW (50hp) Motor Efficiency



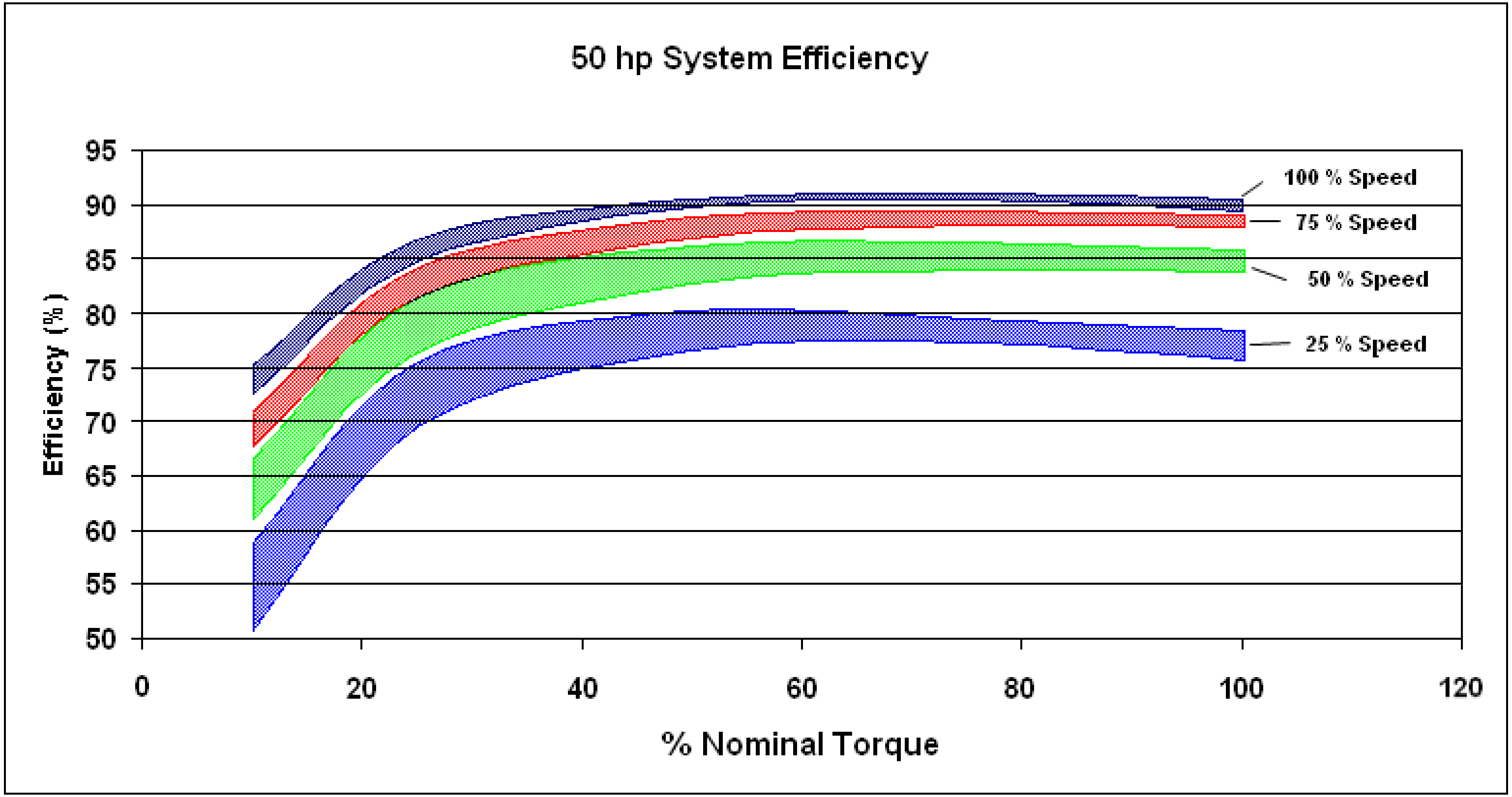
Source: LTE Canada 2009

Example – 37 kW (50 HP) VSD Efficiency



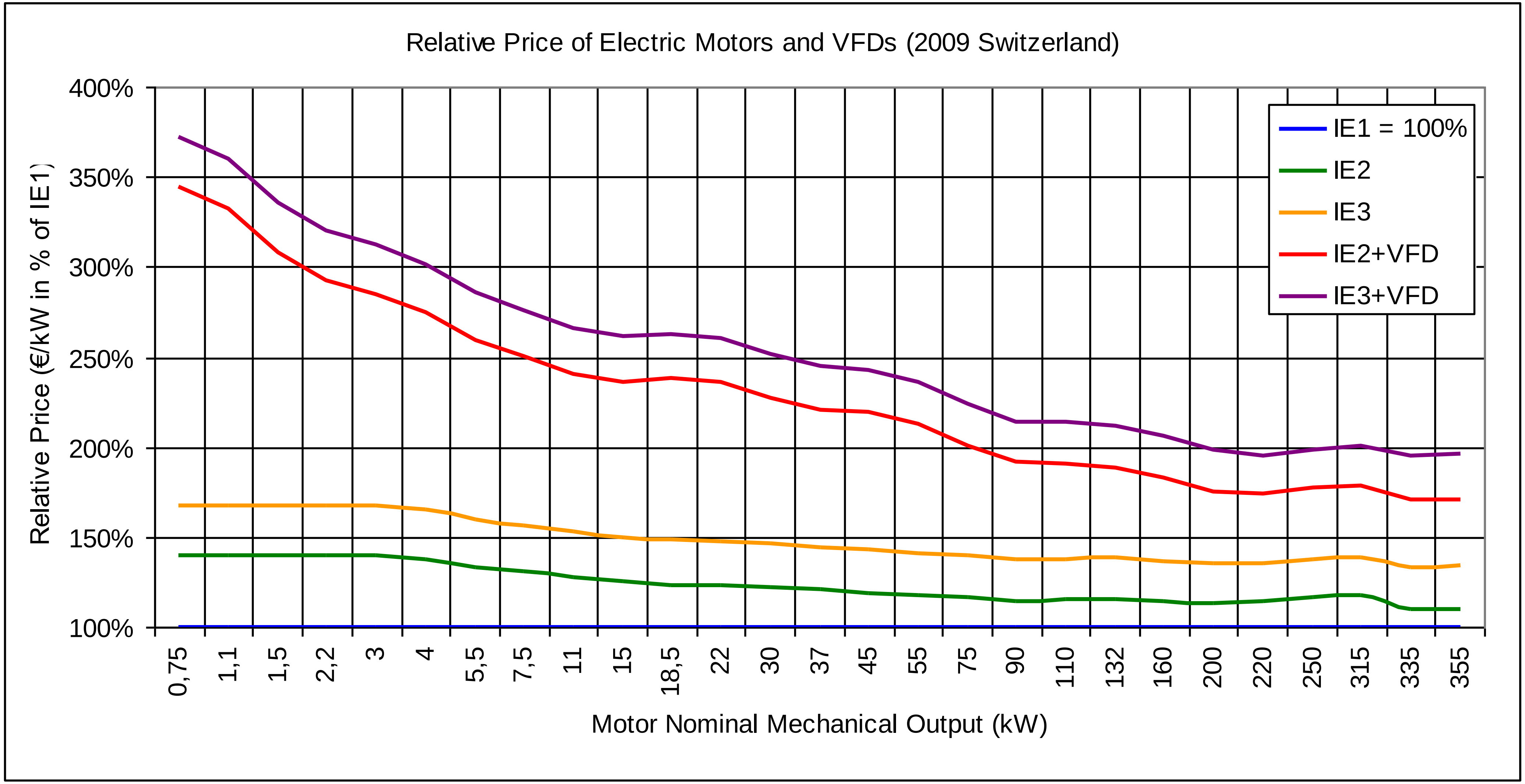
Source: LTE Canada 2009

37 kW (50 Hp) Motor + VSD Efficiency



Source: LTE Canada 2009

Historical Prices of Motor and VSDs

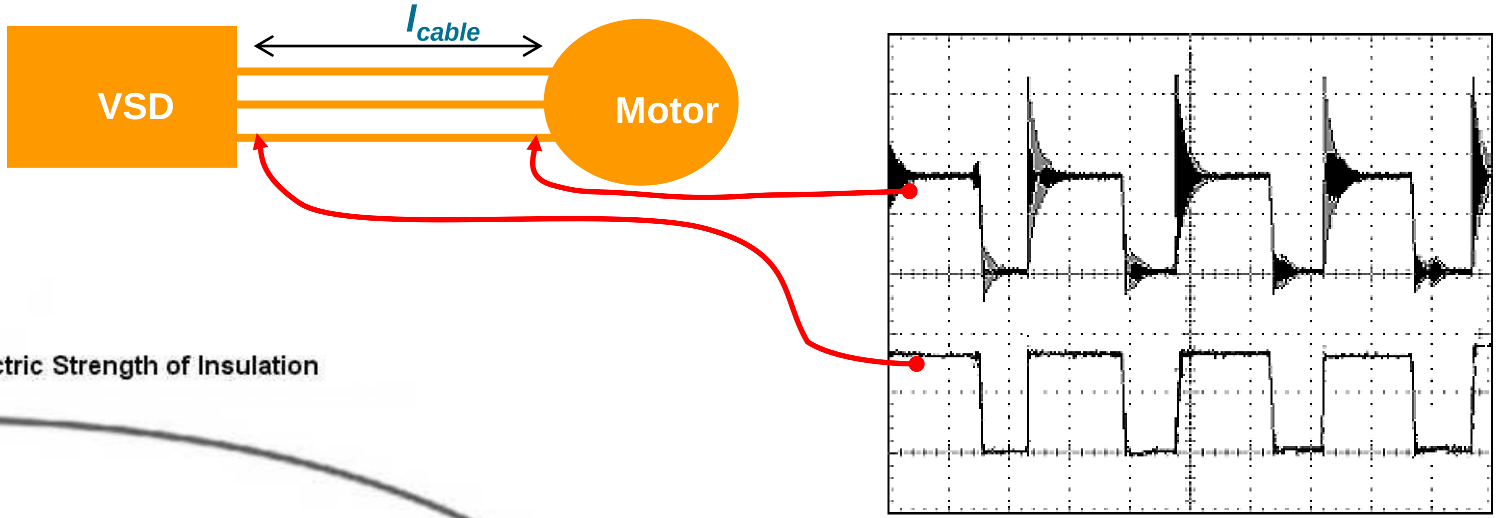


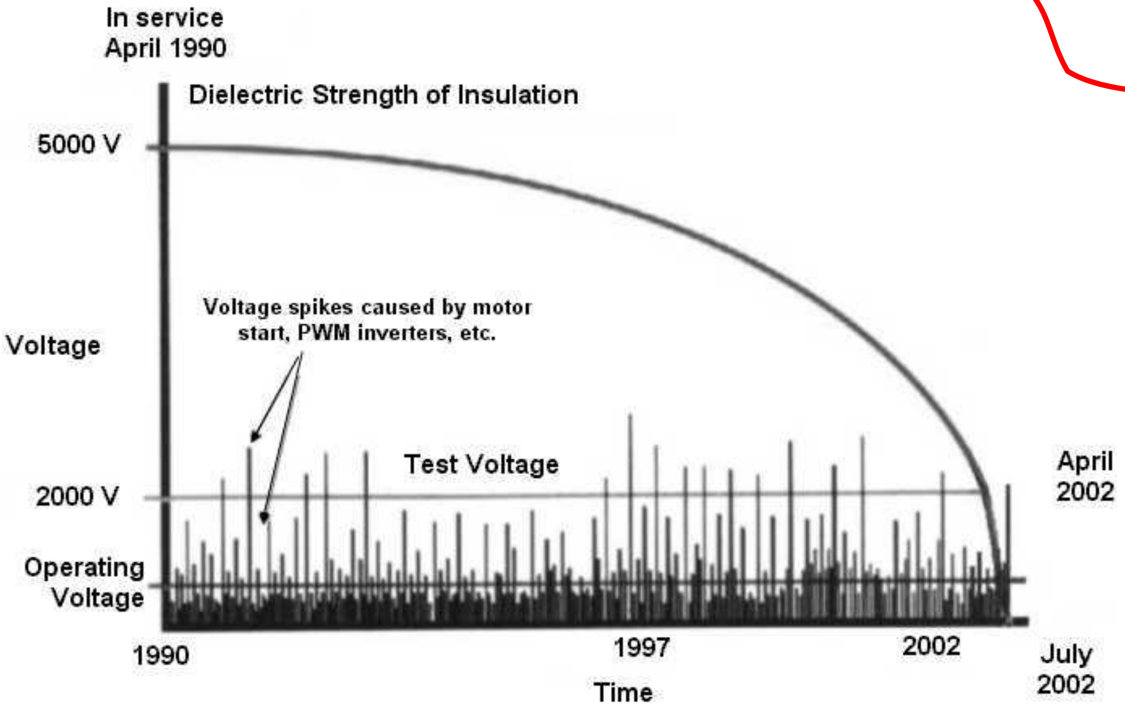
Source: A+B International

Disadvantages of VSDs

- Inject harmonic distortion in the network, which may lead to higher losses and premature failures of equipment in the installation.
- Voltage spikes leading to failure of insulation in windings of old motors
- Bearing current leading to premature failure

Voltage Transients at the Inverter Fed Motor Terminals





(!) PARTIAL DISCHARGE

↓ LIFETIME

GOOD SOLUTION!

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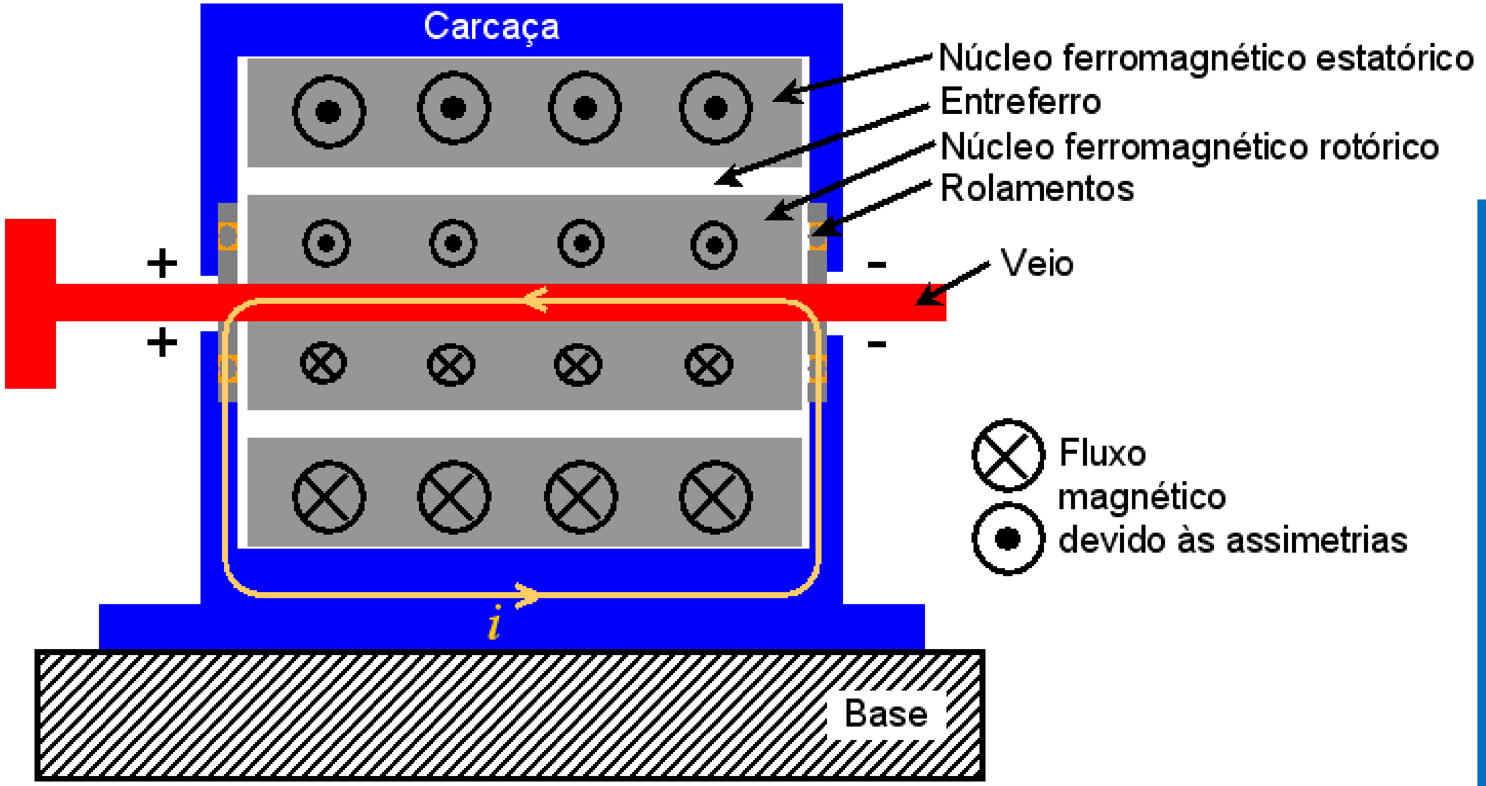
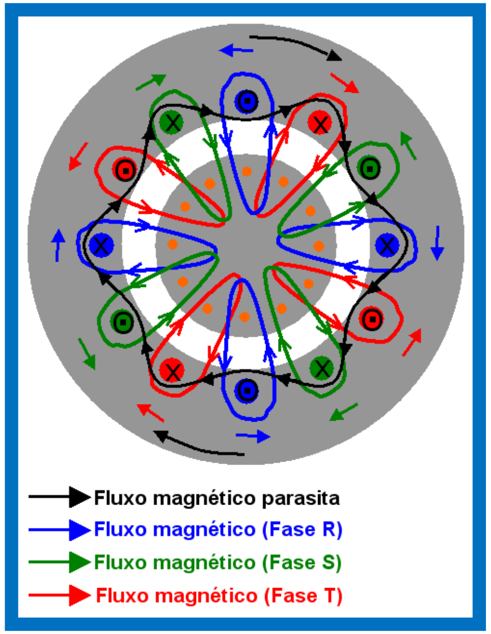
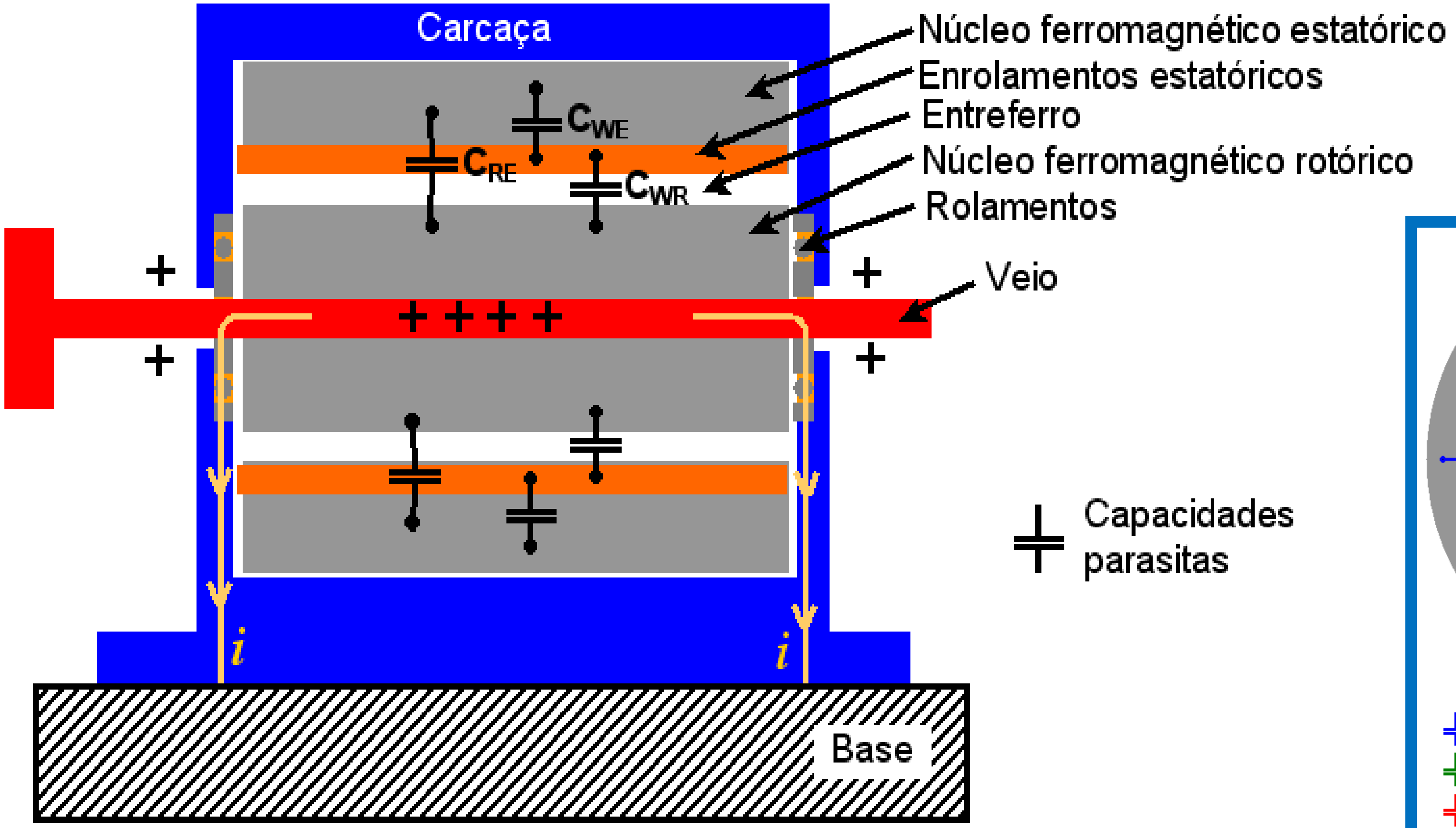
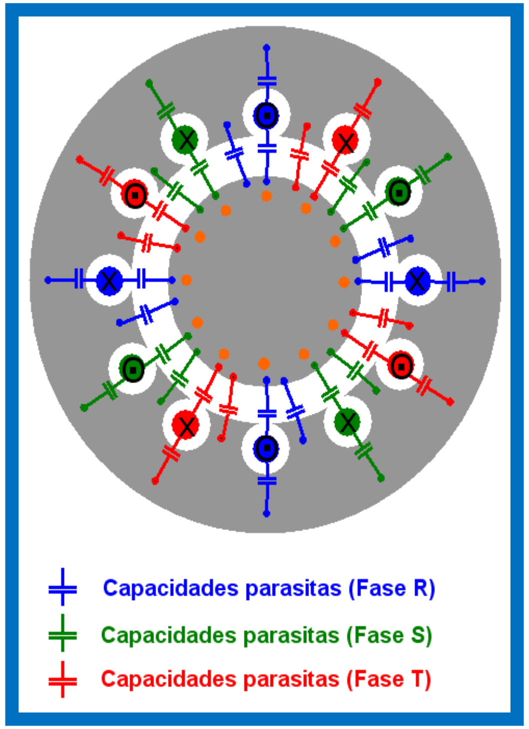




Circulating Currents

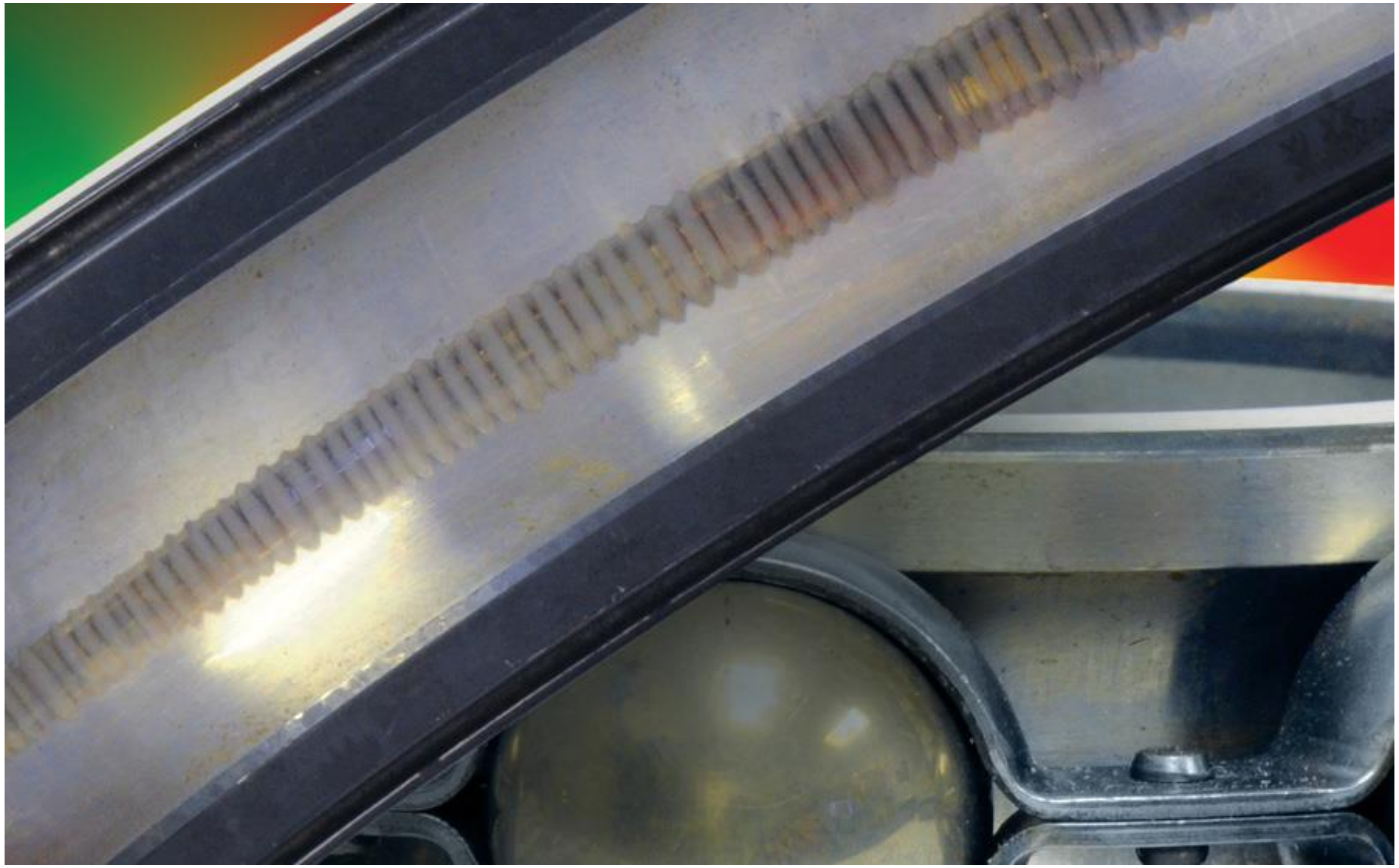
Bearing Current in Inverter-Fed Motor





Common Mode Currents

Bearing Race Pitting



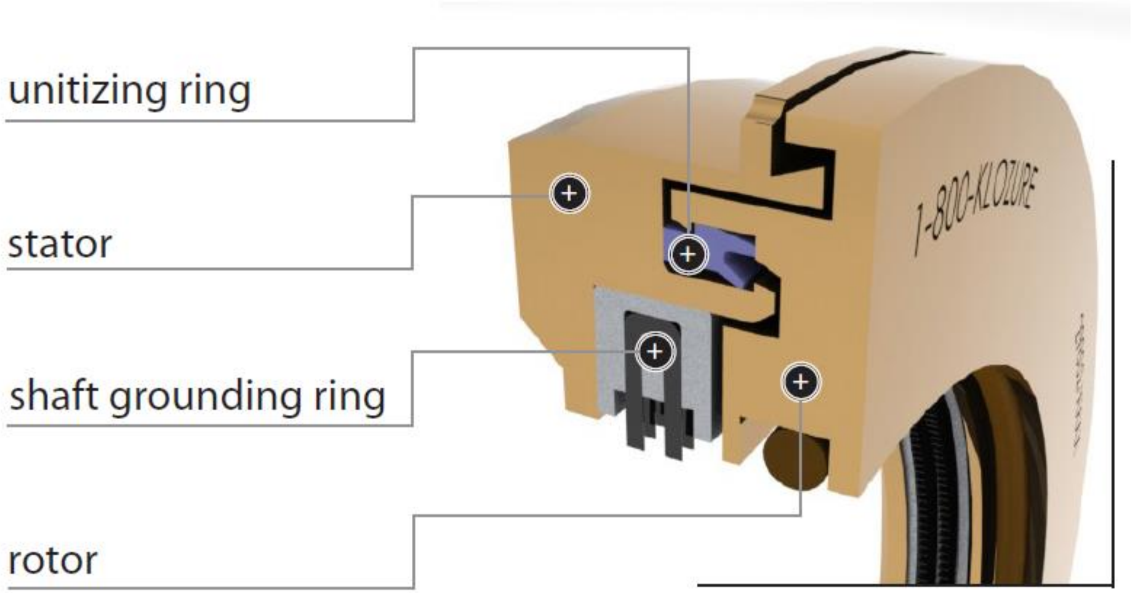
Bearing Current in Inverter Fed Motor

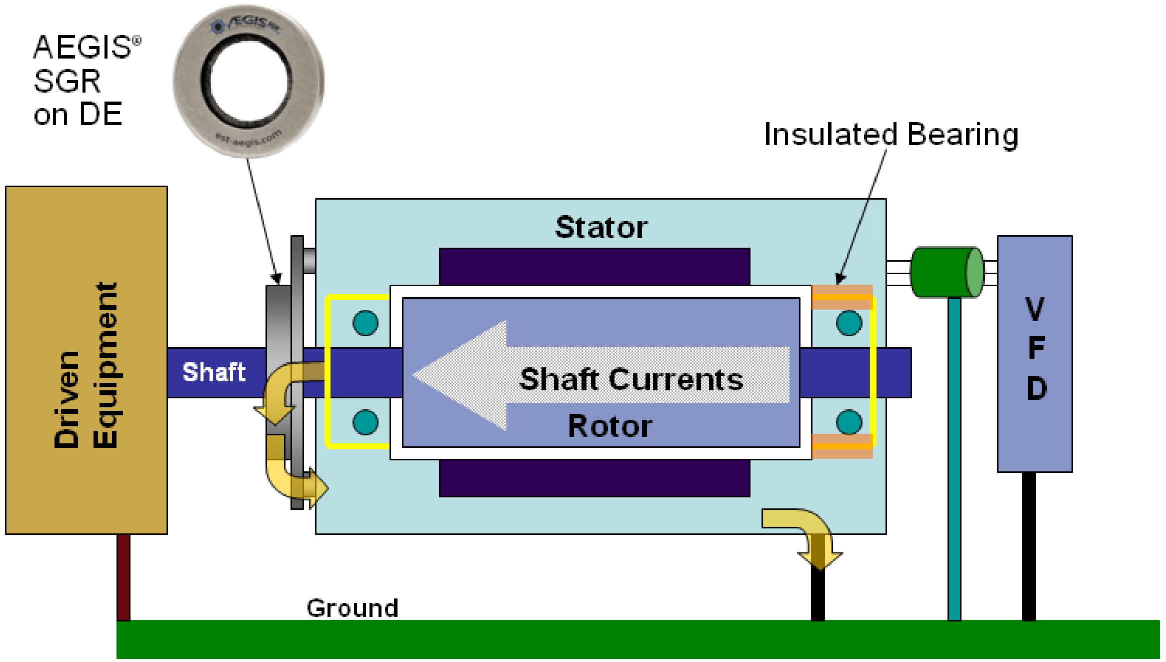
To mitigate the bearing currents in inverter-fed motors several techniques can be adopted:

- proper switching frequency selection;
- cables with of proper type and size (e.g. shielded);
- well designed ground system;
- filters between the motor and inverter;
- insulated bearings;
- shaft-ground connection (e.g. using a contact brush);
- etc.

the users should ask manufacturers about these issues.

Shaft Grounding Rings





Aluminum Oxide Insulated Bearings

-Designed to prevent electric current from passing through the bearing

-Have the external surfaces of either **their inner** or outer **ring** coated with an **insulating aluminium oxide layer,** by applying a sophisticated plasma-spray process for an outstanding quality finish

-High electrical resistance
The aluminium oxide coating provides a minimum electrical resistance of 200 MΩ and can withstand voltages up to 3 000 V DC.

•

Ceramic Ball Bearings

Steel rings precision matched with silicon nitride (ceramic) balls

- Prevent electrical arcing
- Lower maintenance costs
- Increase service life
- Extend grease life
- Reduce wear from vibration
- Lower operating temperatures
- Reduce wear from contamination
- Suitable for high temperature and corrosive environments

Review & Discussion

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10. Power Quality

Motor Assessment

Motor Systems Optimisation (MSO) Expert Training (2020 Egypt Edition)

Samir Khafagui
Siraj Williams

Discussed Topics

- Electromagnetic compatibility
- Voltage effects and mitigation techniques
- Energy storage solutions (ride through)
- Harmonics and mitigation techniques

Definition of Power Quality

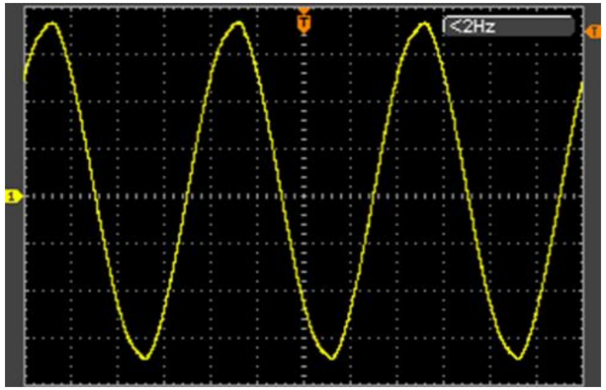
From a **quality perspective**:

- may be defined as the measurement, analysis, and improvement of the bus voltage to maintain a sinusoidal waveform at rated voltage and frequency[1]

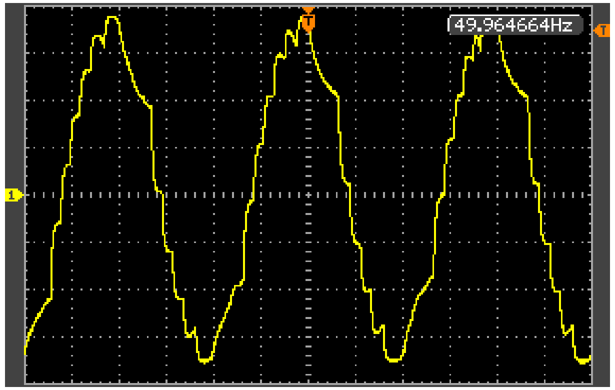
When viewed from a **compatibility perspective**:

- the ability of an equipment or system to function satisfactorily in its electromagnetic (EM) environment (immunity) without introducing intolerable electromagnetic disturbances to anything in that environment (emission)[2]

At generator

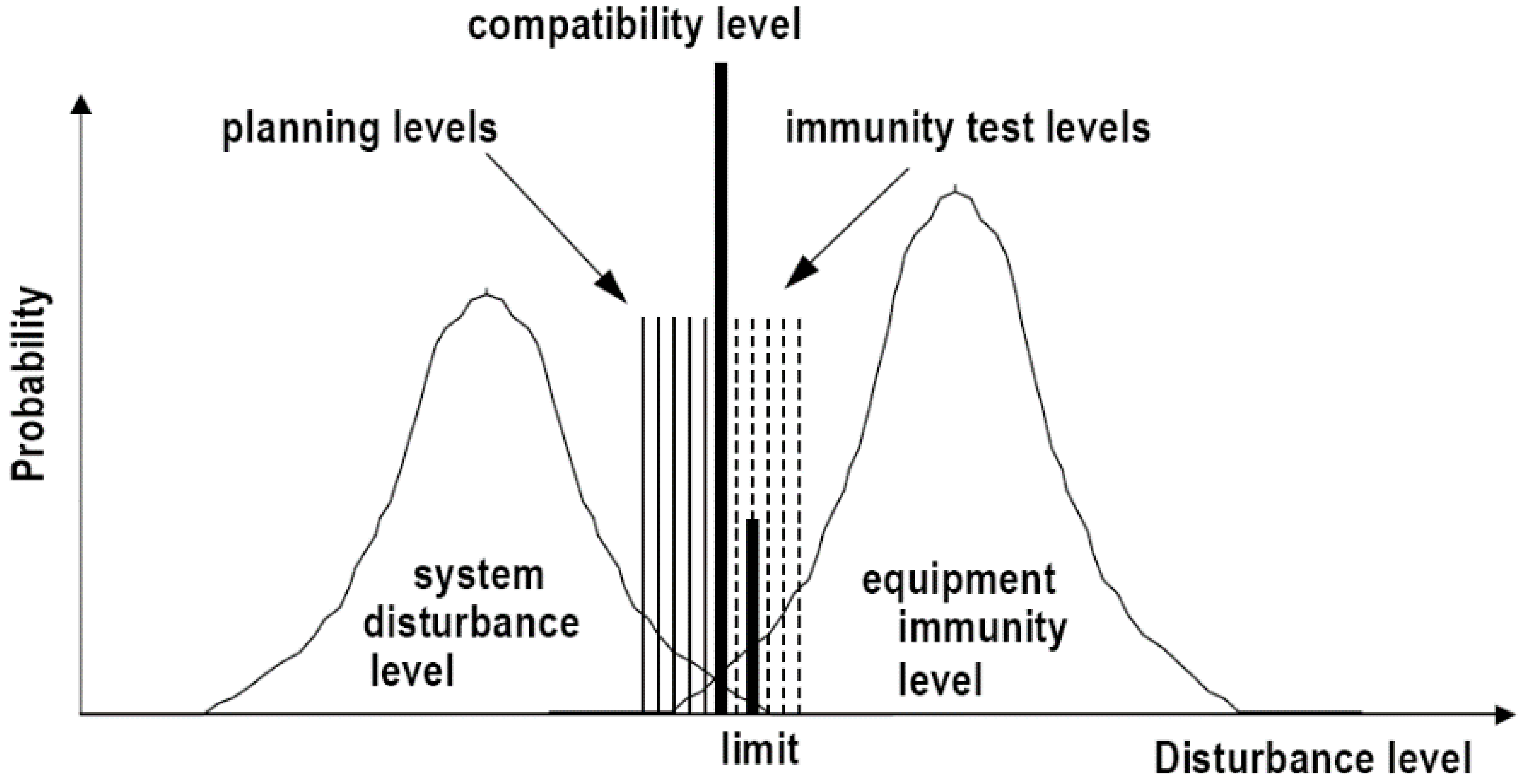


At point of use



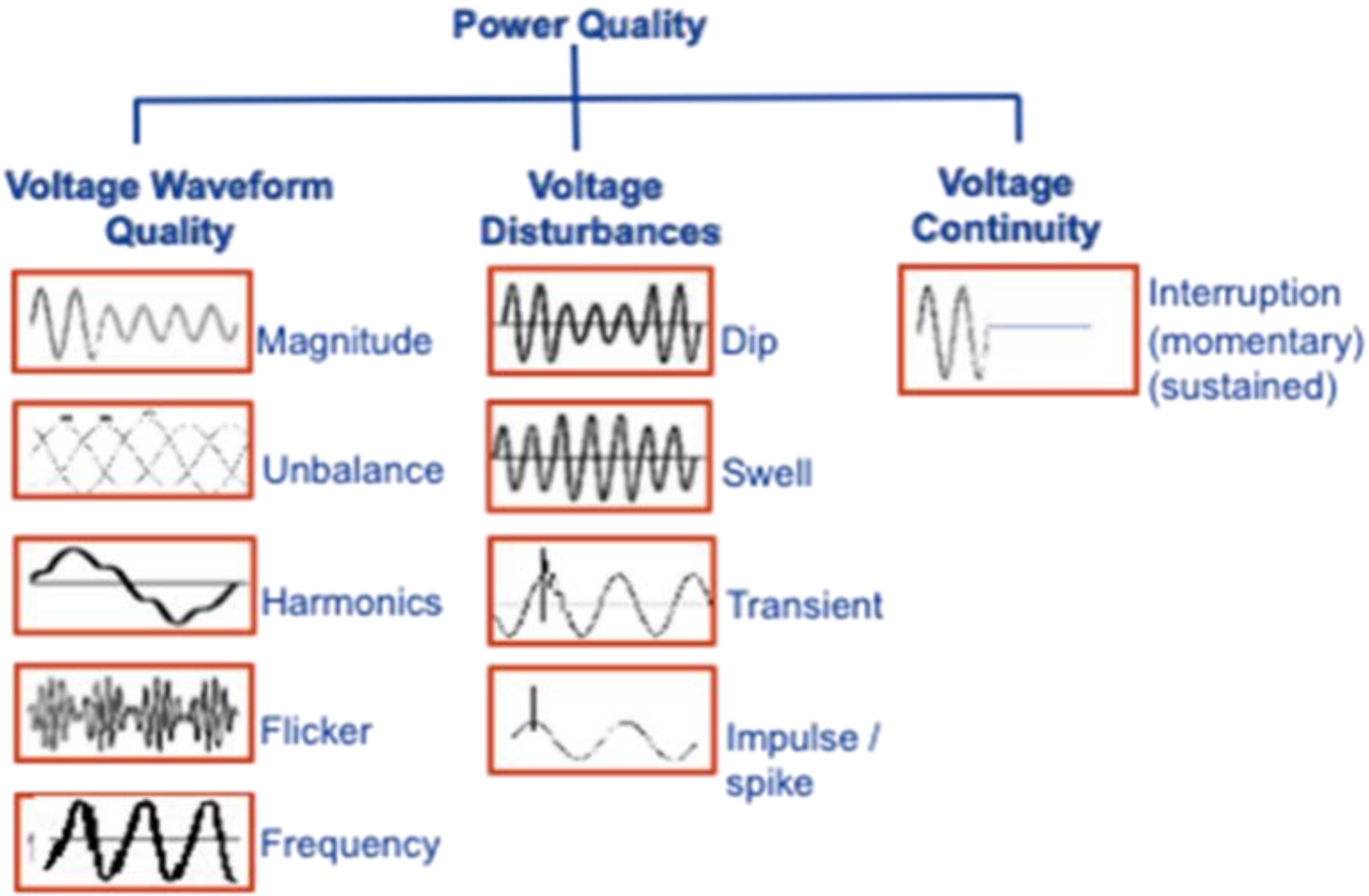
1. Masoum et al. Power quality in Power systems and electrical machines
2. International Electroctechnical Commission (IEC)

Electromagnetic compatibility



Source: UNIDO Power Quality Course: South Africa 2020

Types of Power Quality Occurrences



Source: Eskom Power Quality Course Notes

Voltage Magnitude

Steady state voltage not close to nominal voltage

- System voltage regulation

Short reduction in voltage magnitude (dip)

- Momentary short circuits – birds, lightning, other causes
- Start up of very large motors
- Operation of large intermittent loads (eg arc furnaces)
- Energisation of power transformers

Short increase in voltage magnitude (swell)

- Sudden loss of large load
- Sudden increase in generation

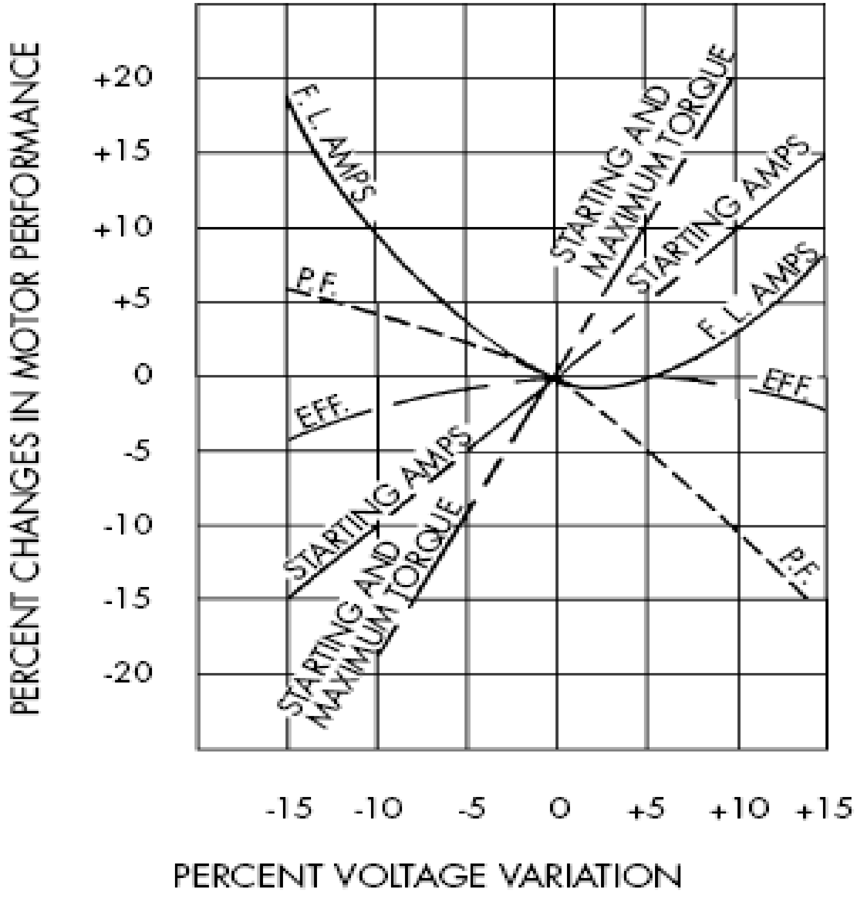
Effect on motor systems

- Change in torque speed characteristic
- May cause extra heating reducing life span
- Reduction in motor efficiency

Voltage Magnitude – User Mitigation

MAINTAIN VOLTAGE LEVELS

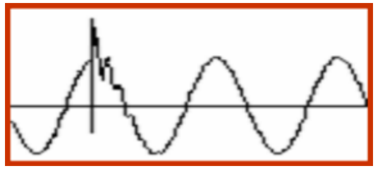
- When operating at less than 95% of design voltage, motors ty efficiency.
- Running a motor above its design voltage also reduces power



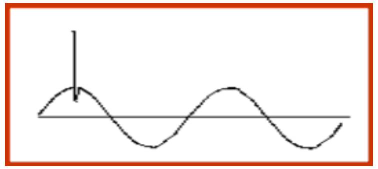
Voltage Variation Effect on Motor Performance

Transients and Impulses

- Transients
  - Switching of load circuits
  - Capacitor switching



- Impulses
  - Very large spike in voltage <50us - lightning



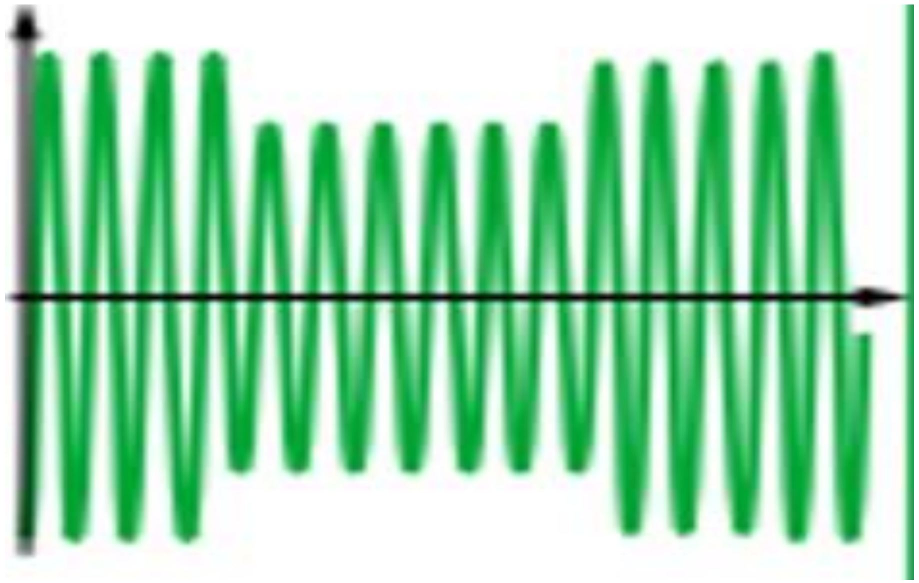
- Effect on motor systems
  - Insulation breakdown, premature failure
  - Failure of motor drives
  - Unwanted tripping of loads

Transients and Impulses – User Mitigation

- Appropriate electrical network design
- Ensure electrical protection systems operating as designed
- Install surge protection
- Specify equipment that can withstand the effects of lightning if situated in a high lightning area

Voltage Sags / Dips

Voltage sags or dips of 10-30% below nominal for 3 to 30 cycle durations account for the majority of power system disturbances, and are thus the major cause of industry process disruptions.



Sag Mitigation

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Increased concerns due to the susceptibility of VSDs to power disturbances, and the costly results of process disruptions require ride-through capabilities in VSDs, using several options:

- Additional Capacitors
- Use of Load Inertia
- Operate VSDs at Reduced Speed/Load
- Boost Converter Ride-Through
- Active Rectifier VSD Front End
- Energy Storage

Additional Capacitors

- By adding capacitors to the DC-bus, additional energy needed for full power ride-through during a voltage sag can be provided to the motor.

Advantages:

- Simple and rugged approach, can provide limited ride-through for small disturbances.

Disadvantages:

- Cost is high.
- Large cabinet space, additional pre-charge circuits and safety considerations.

Use of Load Inertia

- The inverter control software can be modified such that when a power disturbance causes the dc-bus voltage to fall below a specified value the inverter will adjust to operate at a frequency slightly below the motor frequency, causing the motor to act like a generator.

- It is best used in high inertia loads that can slow down during a momentary power disturbance. This approach can provide ride-through at reduced power (speed and torque) for up to 2 seconds for loads of 5kW-1MW.

Use of Load Inertia

Advantages:

- No additional hardware is required, only a software modification in the inverter.
- Commercial drives are available on the market with this feature with 2 seconds of ride-through for sags to 80% nominal voltage.
- Since the drive and motor have been actively transferring energy during the power disturbance, no loss of phasing has occurred between the drive and the motor and the motor's magnetic field has not de-energized. Thus, there are no delays to start accelerating the motor as soon as the ac power line returns to normal, assuming the load can handle it.

Disadvantages:

- The motor speed and torque will be reduced which may not be acceptable.
- The sustainable ride-through duration will be dependent on the load inertia.

Operate VSD at Reduced Speed / Load

- Since the DC-bus current varies with the frequency of the drive for variable torque loads, such as fans and pumps, a reduction in the motor speed will result in a reduction in the dc-bus current. Hence, a fan and pump system running at 40Hz will draw less current than a system running at 50Hz and will therefore be able to operate for a longer period during a voltage sag situation.

- Suitable Applications - Small drives, 5-10kW, with variable torque (fans and pumps), high inertia and low friction loads. Can provide ride-through at reduced power for up to 0.01 seconds.

Operate VSD at Reduced Speed / Load

Advantages:

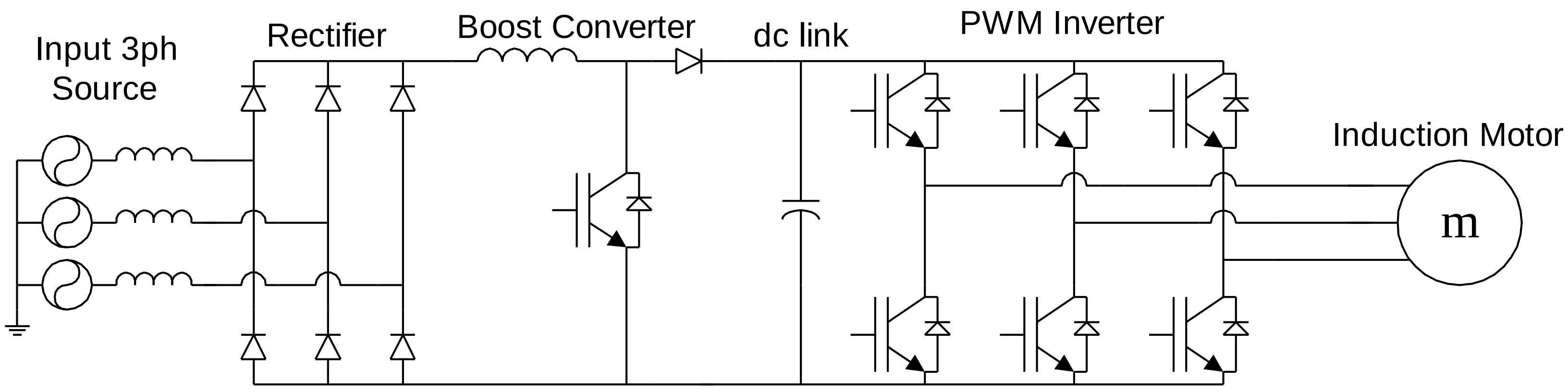
- No additional hardware is required.
- At 50% speed and load, would provide four times the ride-through of a normal drive system.

Disadvantages:

- Application may not tolerate reduced speed/load operation.
- Only useful for variable torque (fans and pumps) loads.

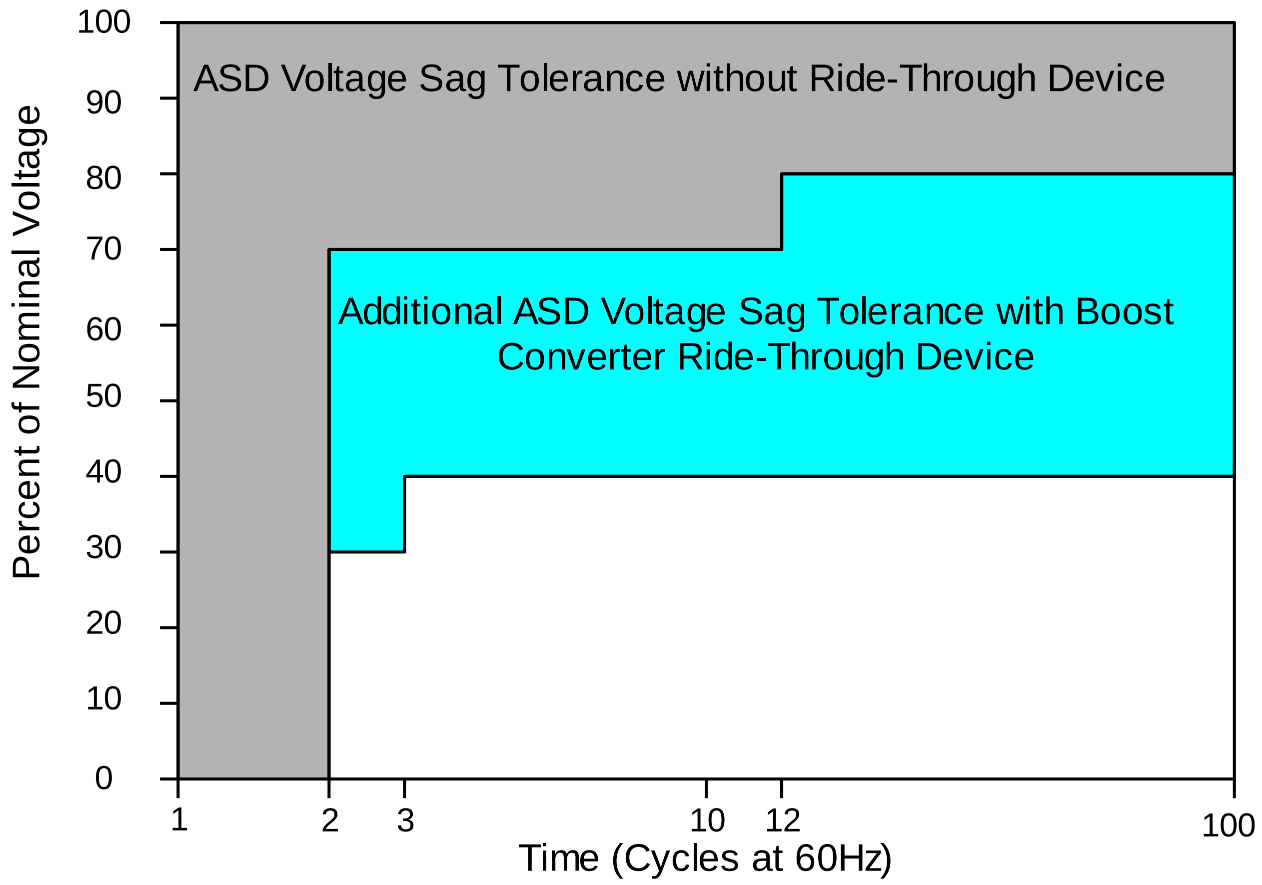
Boost Converter Ride-through

- During a voltage sag, the boost converter will sense a drop in the dc-bus voltage and begin to regulate the DC-bus to the minimum voltage required by the inverter.
- Suitable applications - New or retrofit applications, and where drives are connected to a common DC-bus. For 10 - 200 kW loads, can provide ride-through for 5 seconds at reduced power.



Boost Converter Ride-through

Boost converter ride-through providing additional capacity to a standard VSD with ride-through capability



Boost Converter Ride-through

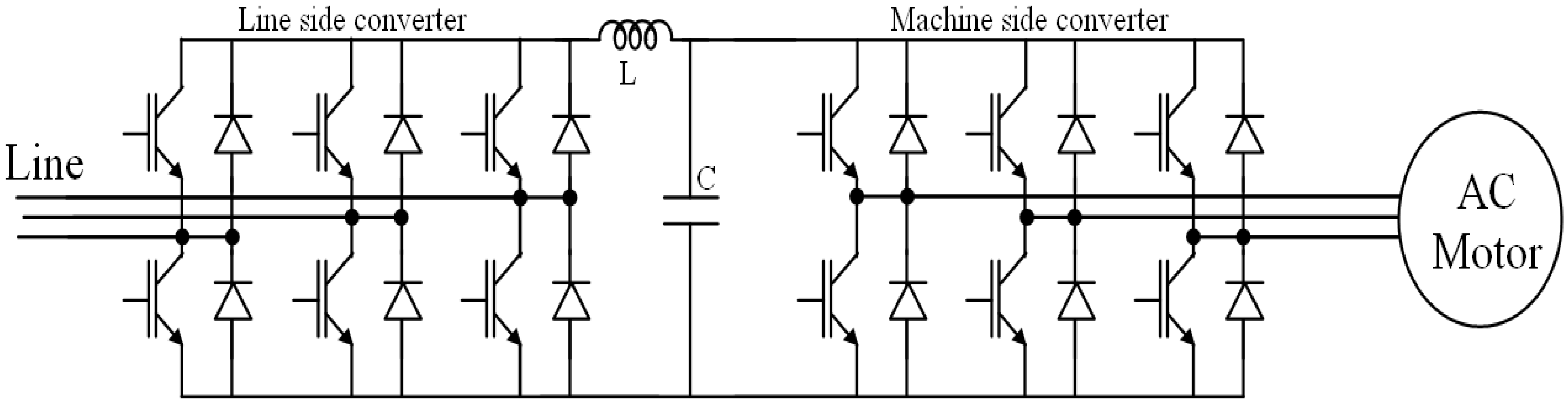
Advantages:

- Can provide ride-through for sags up to 50%.
- The dc-bus voltage can be regulated as required by the inverter, and is user adjustable.

Disadvantages:

- The dc-link inductor and the additional diode are in the series path of the power flow.
- Additional hardware required, which will have to be suitably rated due to the additional current drawn during a voltage sag.
- In the case of an outage, the boost converter will not be able to provide ride-through, and the drive will trip.

Active Rectifier VSD Front End



- Also called a bi-directional drive or regenerative drive
- Suitable applications - New VSD applications where regenerative braking is considered to improve overall efficiency. VSDs with active rectifiers are available from most drive manufactures up to 500kW, however at twice the cost of a standard diode rectifier option.

Active Rectifier VSD Front End

Advantages:

- Clean input power at unity power factor
- Active rectifier provides a regulated dc bus voltage, hence is self correcting under voltage sags. Suitable rectifier derating is necessary to provide a full power ride-through under a sag.
- Power flow in both directions enables regenerative braking. This feature could add to improved efficiency is some applications.

Disadvantages:

- An VSD with an active PWM rectifier is nearly equivalent to two diode rectifier VSDs. This approach comes with additional cost.
- The VSD package is larger in size since in addition to the active rectifier hardware, three input filter inductors become necessary.
- Active PWM rectifier operates the VSD with higher dc-link voltage, this results is higher differential mode dv/dt at the motor terminals. Also due to two PWM IGBT inverter stages the common mode dv/dt and EMI is higher.

Energy Storage - Batteries

- Battery back up systems operate similarly to adding capacitive energy storage.
- Electrochemical batteries prevail due to their low price and mature technology.

- Suitable applications - New or retrofit applications, and where drives are connected to a common dc-bus.
- For 5kW-10MW loads and can provide full power ride-through for up to 1 hour.

Energy Storage - Batteries

Advantages:

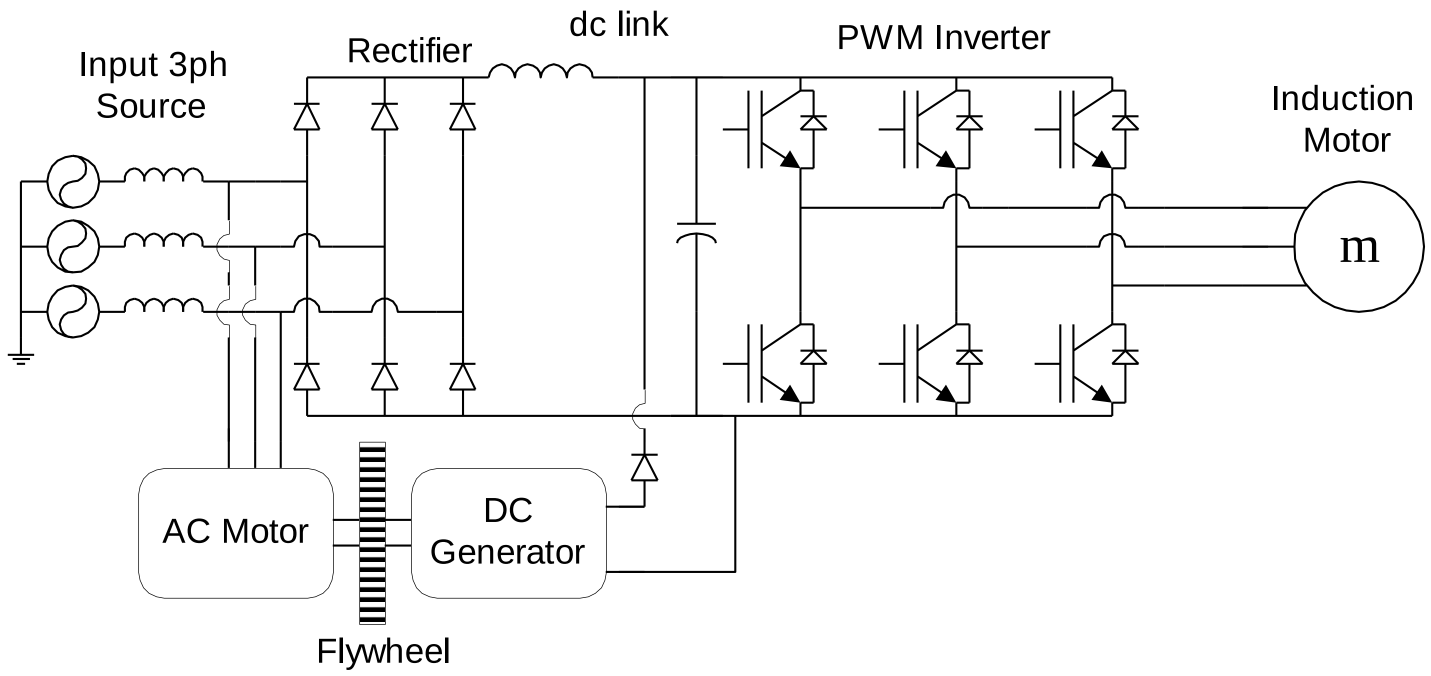
- Can provide ride-through for deep sags and full outages.
- Batteries are easily obtained.
- Transfer time is almost instantaneous.

Disadvantages:

- Additional hardware and space required, though not as much as with standard capacitors.
- Relatively low cycle life
- More maintenance required to ensure peak performance.
- The electrolyte is corrosive and may be hazardous to the application, and will need to be properly disposed of when depleted.

Energy Storage - Flywheel

A flywheel is an electromechanical device that couples a rotating electric machine (motor/generator) with a rotating mass to store energy for short durations. The motor / generator draws power provided by the grid to keep the rotor of the flywheel spinning.



During a power disturbance, the kinetic energy stored in the rotor is transformed to DC electric energy by the generator, providing power directly to the dc-bus of the ac drive.

Energy Storage - Flywheel

Advantages:

- Can provide ride-through for deep sags and full outages.

Disadvantages:

- Additional hardware and space required.
- Maintenance is required for the rotating compone

Energy Storage - Super Capacitors

- Super capacitors offer substantial increases in energy density over conventional capacitors due to the choice and preparation of the electrode materials and increases in the effective capacitive plate surface area.

- A VSD can be designed with integrated super capacitors, or as an add-on module. The add-on bank of super capacitors would be about the size of the drive itself.

Energy Storage - Super Capacitors

Advantages:

- Can provide ride-through for deep sags and full outages.
- Long cycle life and fast recharge rates.
- Easily monitored state of charge.
- Minimal maintenance needs.

Disadvantages:

- Additional hardware and space required, though not as much as with standard capacitors.

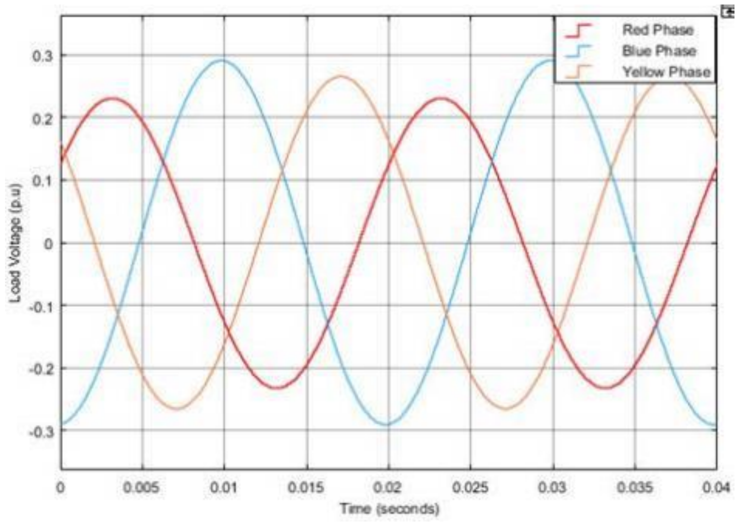
Sag Ride Through Options

ASD Ride- Through Alternatives	Cost Rs/KW	Ride-Through Duration Limit	Power Range	Efficiency	Cycle Life	Charging Time
Additional Capacitors*	30000	0.1sec.	100kw	95%	10000	Seconds
Load Inertia	≈0	2.0 sec.	1kw-1mw	---	---	Continues
Reduced Speed/Load	≈0	0.01 sec.	5-10kw	---	---	---
Lower Voltage Motors*	≈0	0.01 sec.	5-10kw	---	---	---
Boost Converter**	5000-10000	5.0 sec.	5-200kw	90%	---	---
Active Rectifier**	5000-10000	5.0 sec.	5-200kw	---	---	---
Battery Backup*	5000-10000	5.0 sec.,1hr.	5kw-1MW	70-90%	2000	Hours
Ultra Capacitors*	15000-20000	5.0 sec.	5-100kw	90%	10000	Seconds
Motor-Generator Sets*	10000-15000	15.0 sec.	100kw	70%	---	---
FlyWheels*	10000-15000	15.0 sec.,1hr.	1kw-10MW	90%	10000	Minutes
SMES*	30000-40000	10.0 sec.	300-1000KW	95%	10000	Minutes-hours
Fuel Cells*	75000	1 hr.	10kw-2MW	40-50%	continues	continues

* provides Full-power ride-through
** provide full-power ride-through for single-phase sags<50%

Voltage Unbalance

- Caused by
  - Unbalanced 3 phase loads
  - Unequal transformer tap changer settings
  - Large single phase loads
  - Open delta connected transformers and loads
  - Unequal impedance in transmission and distribution conductors
  - Interwinding short in one phase of a motor winding



- Effect on motor systems
  - Overheating of motor, reducing lifespan
  - Loss of motor performance
  - Reduction in efficiency

Calculation of Voltage Unbalance

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True voltage unbalance factor (requires Fortescue Transform):

$$\% \, VUF = \frac{Negative\ sequence\ voltage\ component}{Positive\ sequence\ voltage\ component} \times 100$$

Voltage Unbalance 1 (very good approximation using line voltages):

$$\% \, UB = \sqrt{\frac{1 - \sqrt{3 - 6\beta}}{1 + \sqrt{3 - 6\beta}}} * 100, \qquad \text{where } \beta = \frac{V_{ab}^4 + V_{bc}^4 + V_{ca}^4}{\left(V_{ab}^2 + V_{bc}^2 + V_{ca}^2\right)^2}$$

NRS 048-2:2015 (South Africa)

Voltage Unbalance 2 (good approximation for values below 10%)

$$\% \, LVUR = \frac{\max voltage\ deveiation\ from\ the\ average\ line\ voltage}{average\ line\ voltage} \times 100$$

ANSI/NEMA Standard MG1-1993 (USA)

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Voltage Unbalance Limits - Egypt

- Based on Section 5 of the Egyptian Electric Power Transmission Code, at transmission level, all Distributors must ensure that the voltage unbalance does not exceed 2%

- From a motor perspective, NEMA recommends that unbalance at the motor terminals should not exceed 1%. Unbalanced voltage at motor terminals can cause phase current unbalance of 6 to 10 times the voltage unbalance.

Effects of Unbalance on Motor Systems

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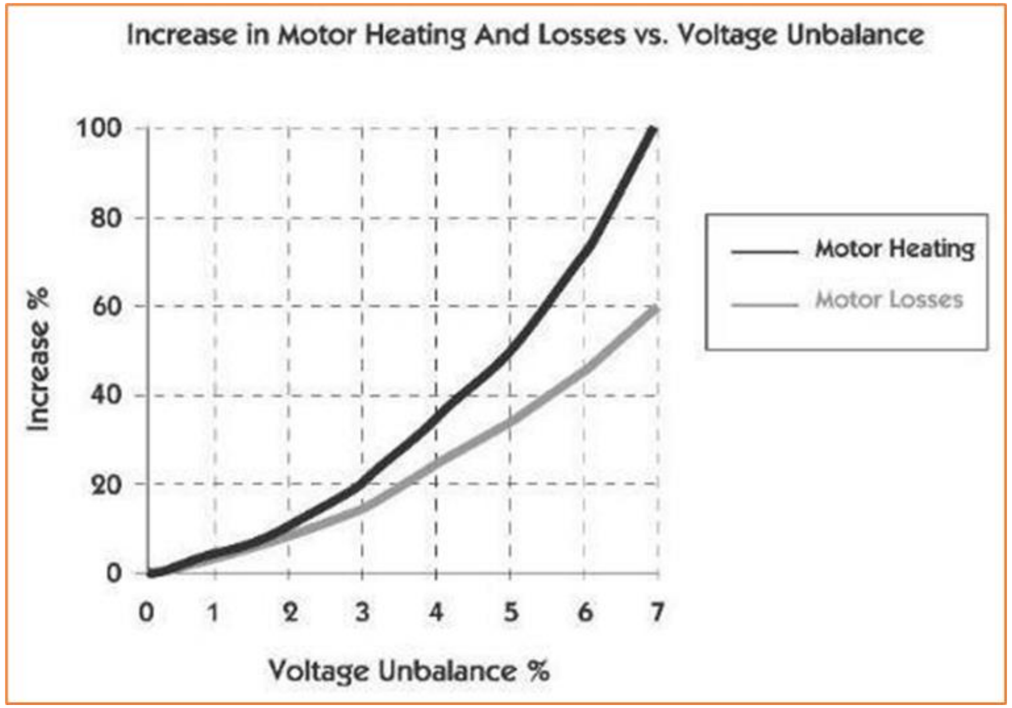
CORRECT UNBALANCE AS MUCH AS PRACTICAL

- An unbalanced system causes extra heating in the motor windings
- Motor has to be derated to reduce the probability of premature failure
- Effect of unbalanced voltage on winding temperature:

Temp Rise = 2 x (unbalance %)^2



Source: www.pumpsandsystems.com

Exercise – Motor Unbalance

- Assume a 100 kW motor operated at 75 % load, 8000 hours per year at a 2.5% voltage unbalance
- Using the data in the table below, calculate the savings if the unbalance was corrected to an unbalance value of 1%.

Motor Efficiency* Under Conditions of Voltage Unbalance

Motor Load % of Full	Motor Efficiency, % Voltage Unbalance		
	Nominal	1%	2.5%
100	94.4	94.4	93.0
75	95.2	95.1	93.9
50	96.1	95.5	94.1

Exercise - Solution

Energy used before = 100 x 0.75 x 8000 x (1/0.939)
= 638 978 kWh /year

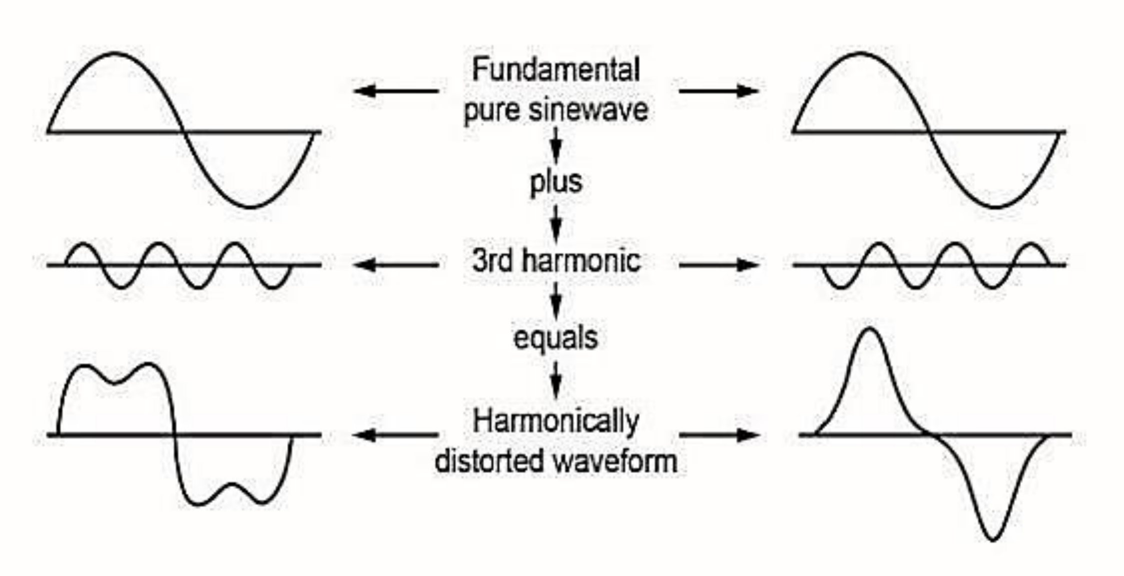
Energy used after = 100 x 0.75 x 8000 x (1/0.951)
= 630 914 kWh /year

Savings= Energy used before – energy used after
= 638 978 – 630 252
= 8 063 kWh /year

But what about all the other motors connected to the same network?

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 (3rd harmonic)

What causes harmonics?

- Harmonics and harmonic distortion are caused by the presence of non-linear loads

Sources of non-linear loads

- Welding machines, arc furnaces, induction furnaces
- Power electronics like variable speed drives (VSD), soft starters, power inverters, other electronics like PLCs, computers, servers, fax machines
- Control gear from lighting (fluorescent lamps, HID lamps), appliances like refrigerators, microwaves, television screens

Non Linear Loads

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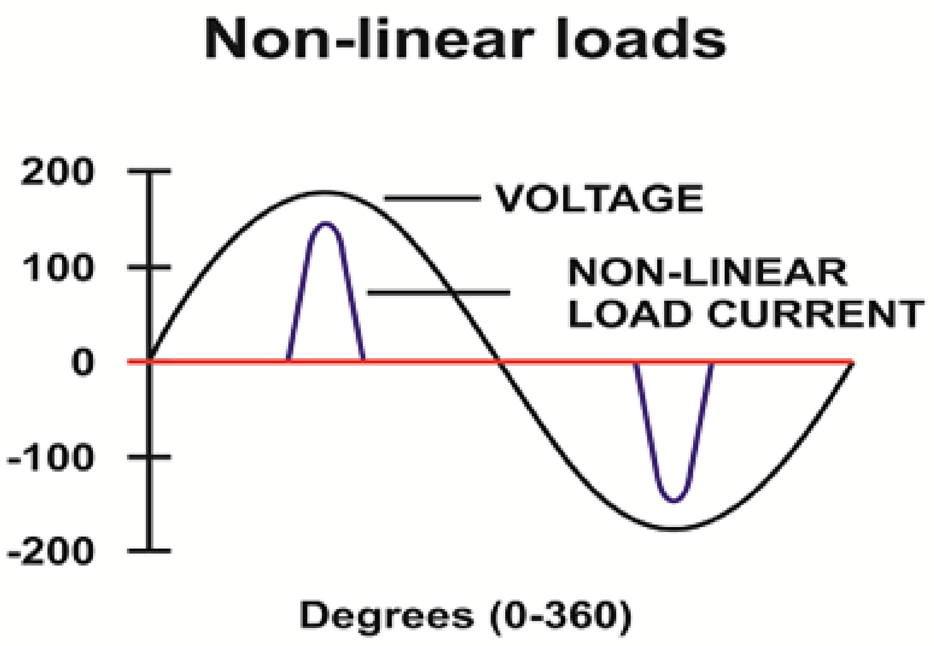
- Loads that do not exhibit a constant impedance during the sinusoidal cycle
- The voltage is not proportional to the current

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



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

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.

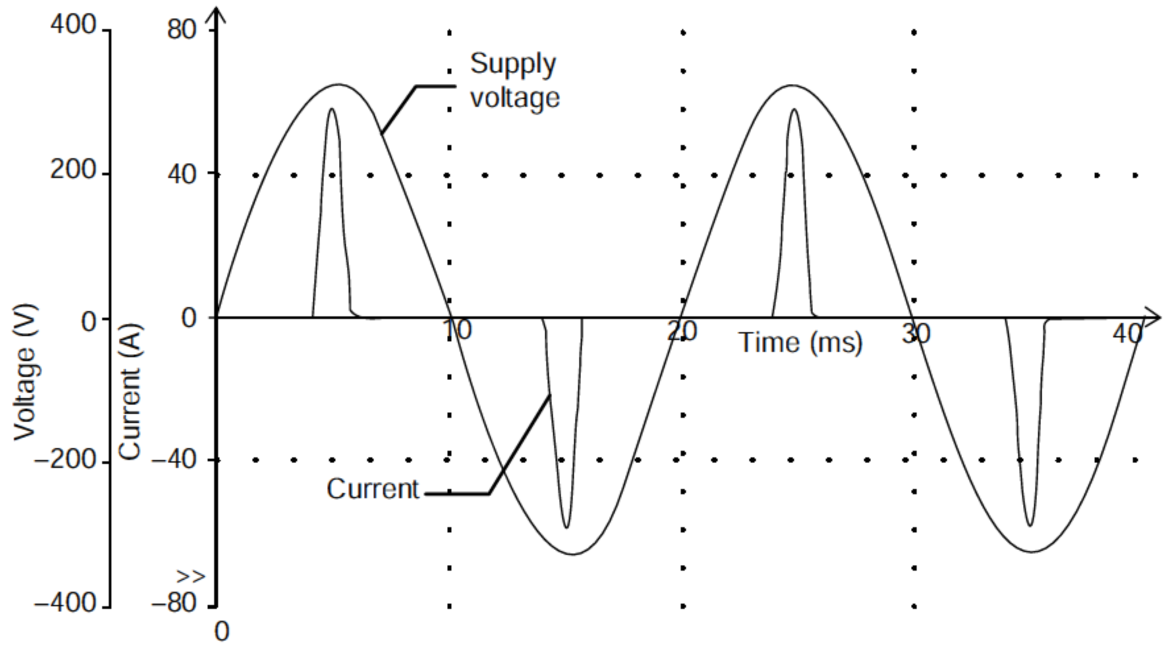
Excessive heating of transformers and associated equipment, and damage to power factor correction capacitors..

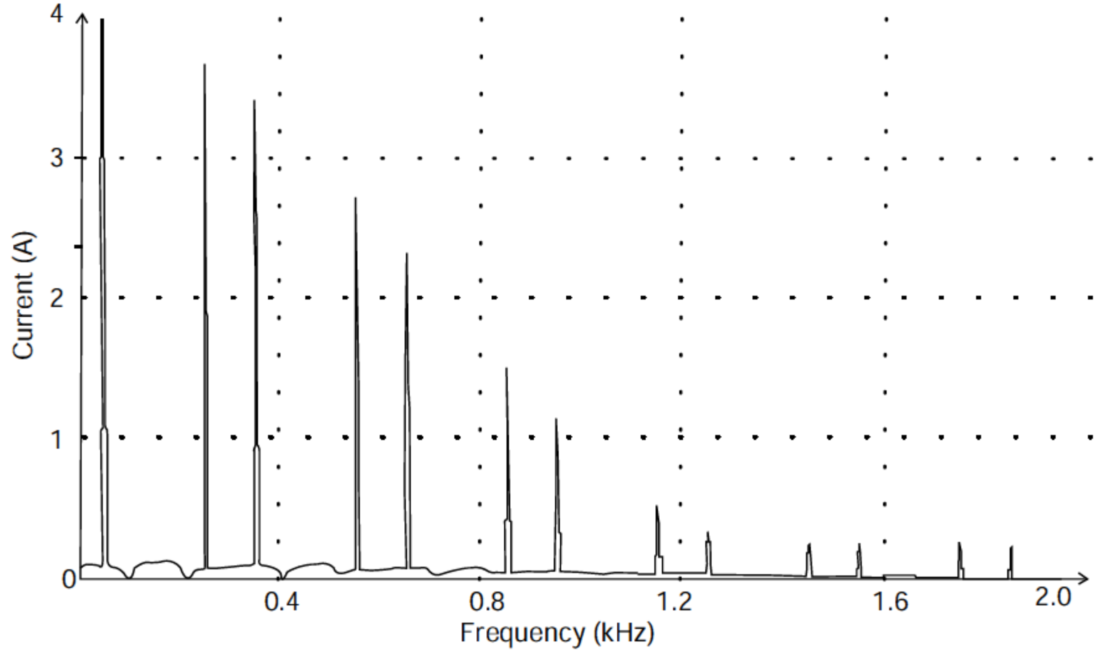
How Harmonics Affect Motor Systems

Generation of system harmonics caused by invert fed motors

- 5th, 11th, 17th.
  - Called negative sequence harmonics
  - Cause a torque in the opposite direction to normal motor rotation resulting in a reduction in motor performance
- 7th, 13th, 19th..
  - Called positive sequence harmonics
  - Cause a pulsing torque out of sequence with normal motor rotation increasing heating and losses
- 3rd, 9th, 15th ...
  - Called zero sequence (triplen) harmonics
  - In unbalanced systems will cause currents to flow in the neutral conducor of earthed systems causing dstortion of the voltage magnitudes of the phases

Harmonic Generation within VSDs





Typical input current waveform for a 1.5 kW three-phase drive and corresponding harmonic spectrum (only 1 phase shown)

Effect of Harmonics on Motor Systems

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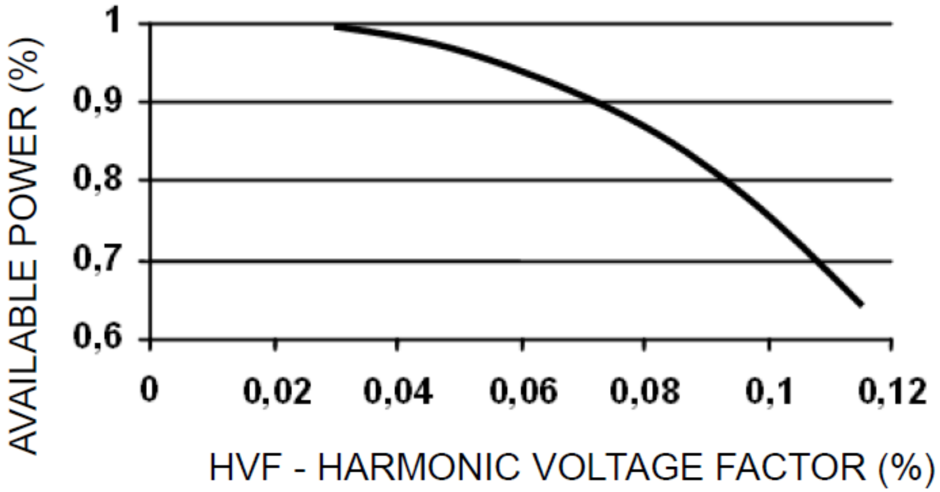
- Change in torque speed characteristic
  - May cause extra heating reducing life span
    - Reduction in motor efficiency

Harmonic Voltage Factor (HVF):

- Derating a motor to mitigate extra heating caused by harmonics



$$HVF = \sqrt{\sum_{n=5}^{n=\infty} \frac{(V_n)^2}{n}}$$

Harmonics - Remedial Actions

- Remove unnecessary non-linear loads
- Change point of connection of identified electrical equipment
- Where possible, use 3ph drives instead of 1ph drives
- Install additional inductance
- Change the size of DC smoothing capacitor
- Use harmonic filters
- Use a drive with an active input converter
- Use 12 pulse drives

Harmonics - Remedial Actions

Connect the equipment to a point with a high fault level (low impedance)

- When planning a new installation, there is often a choice of connection point. The harmonic voltage caused by a given harmonic current is proportional to the system source impedance (inversely proportional to fault level). For example, distorting loads can be connected to main busbars rather than downstream of long cables shared with other equipment.

Use three-phase drives where possible

- Harmonic current for a three-phase drive of given power rating is about 30 per cent of that for a single-phase drive, and there is no neutral current. If the existing harmonics are primarily caused by single-phase loads, the dominant 5th and 7th harmonics are also reduced by three-phase drives.

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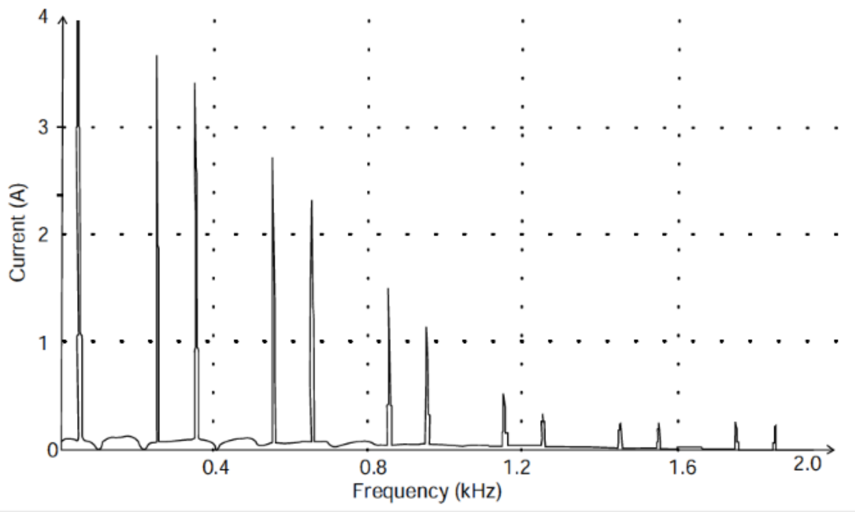
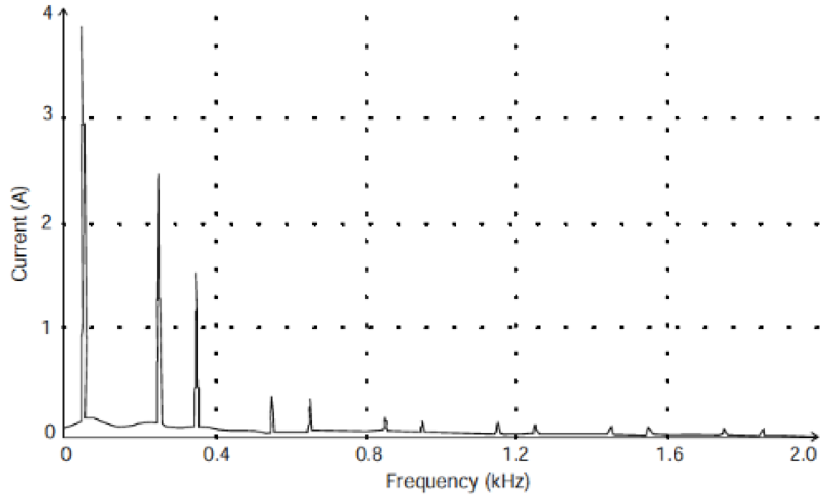
Install additional inductance

- Series inductance at the drive input gives a useful reduction in harmonic current. The benefit is greatest for small drives where there is no DC inductance internally, but useful reductions can also be obtained with large drives.





Harmonic spectrum for 1.5kW 3ph drive WITH and WITHOUT a 2% input inductor.

Harmonics - Remedial Actions

Use a lower value of D.C. smoothing capacitance

- For a three-phase rectifier, the capacitance value can be much reduced provided that the inverter is adapted to compensate for the resulting voltage ripple. The input current waveform is then improved and tends towards the 'ideal' case with a large D.C. inductance, where the current is approximately constant during the 120° conduction period.

Use a harmonic filter

- Harmonic filters are built using an array of capacitors, inductors, and resistors that deflect harmonic currents to the ground. Each harmonic filter could contain many such elements, each of which is used to deflect harmonics of a specific frequency.

Harmonics - Remedial Action

Use a drive with an active input converter

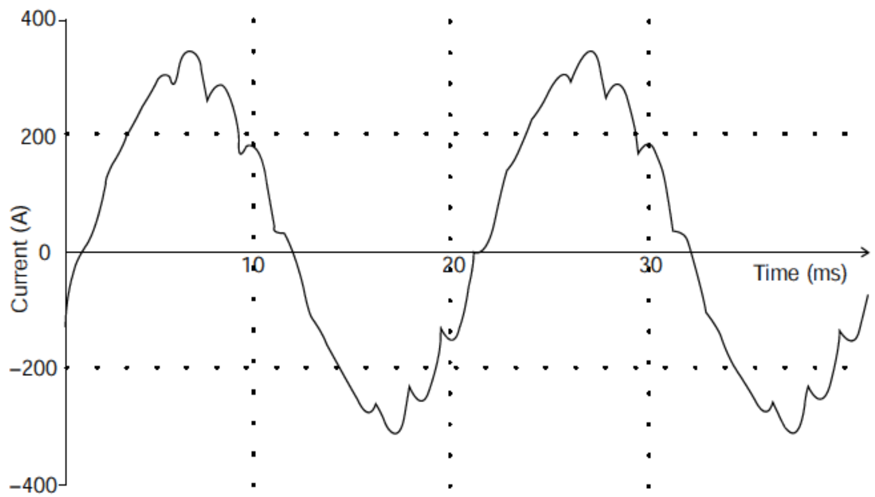
- An active input converter using PWM generates negligible harmonic current, as well as permitting the return of power from the load to the supply.

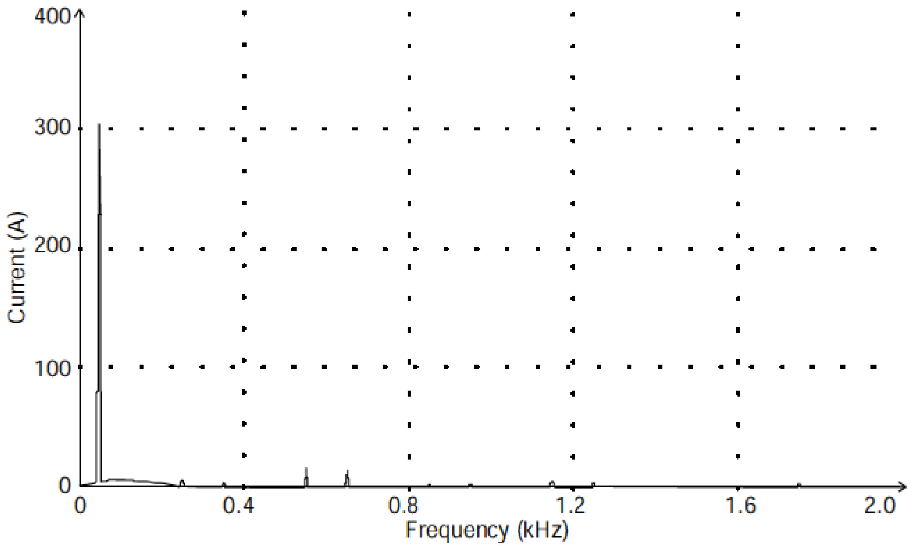
Use a higher pulse number (12 pulse or higher)

- Standard three-phase drives rated up to about 200 kW use six-pulse rectifiers. 12-pulse rectifier eliminates the crucial 5th and 7th harmonics (except for a small residue caused by imperfect balance of the rectifier groups). Higher pulse numbers are possible if necessary, the lowest harmonic for a pulse number p being (p–1).

Harmonics - Remedial Actions

Use a higher pulse number (12 pulse or higher) drive





Input current waveform for 150 kW drive with 12-pulse rectifier and corresponding harmonic spectrum

Typical Harmonic Currents

Harmonic current levels for standard AC drive arrangements

	Harmonic current as percentage of fundamental					
	I_3	I_5	I_7	I_{11}	I_{13}	I_{THD}
Single-phase, no inductance	97	91	83	62	51	206
Single-phase, 2% inductance	90	72	50	13	6	130
Three-phase, no inductance	0[a]	49.6	28.2	6.6	6.0	58
Three-phase, 3% inductance	0[a]	35.0	12.2	7.4	3.9	38
12-pulse	0[a]	1.8	0.6	4.5	3.1	5.8
Active input converter	0[a]	1.4	0.3	0.5	0.2	3.3

[a]For a balanced supply.

Other User Mitigation

Select Efficient Transformers

Install efficient and properly sized step-down transformers. Older, under loaded, or overloaded transformers are often inefficient.

Identify and Eliminate Distribution System Losses

Regularly check for bad connections, poor earthing, and shorts to ground. Such problems are common sources of energy losses, hazardous, and reduce system reliability.

Minimize Distribution System Resistance

Power cables that supply motors running near full load for many hours should be properly sized in new construction or during rewiring. This practice minimizes line losses and voltage drops.

Harmonics in Future

Harmonics will only increase in industry as more companies use sophisticated electronics to control the production machinery.

The development of a suitable harmonic strategic plan could be result in significant future savings and reduction in loss of production.

Cost of Power Quality

Direct costs

- Damage to the production equipment, cost of repair / replacement
- Loss of production and raw material, revenue loss
- Salary and other administrative costs during non-productive period
- Restarting costs
- Some utility tariffs will include a penalty for excessive reactive power (kVAr). Reactive power is unusable power that increases power demand and its costs

Indirect costs

- Inability to accomplish deadlines
- Loss of future orders

Costs of Power Quality

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	Minimum	Maximum
Industrial		
Automobile manufacturing	5	7,5
Rubber and plastics	3	4,5
Textile	2	4
Paper	1,5	2,5
Printing (newspapers)	1	2
Petrochemical	3	5
Metal fabrication	2	4
Glass	4	6
Mining	2	4
Food processing	3	5
Pharmaceutical	5	50
Electronics	8	12
Semiconductor manufacturing	20	60
Services		
Communication, information processing	2	3
Hospitals, banks, civil services	0,5	1
Restaurants, bars, hotels	0,1	0,5
Commercial shops	1	10

Cost of

momentary interruption

of

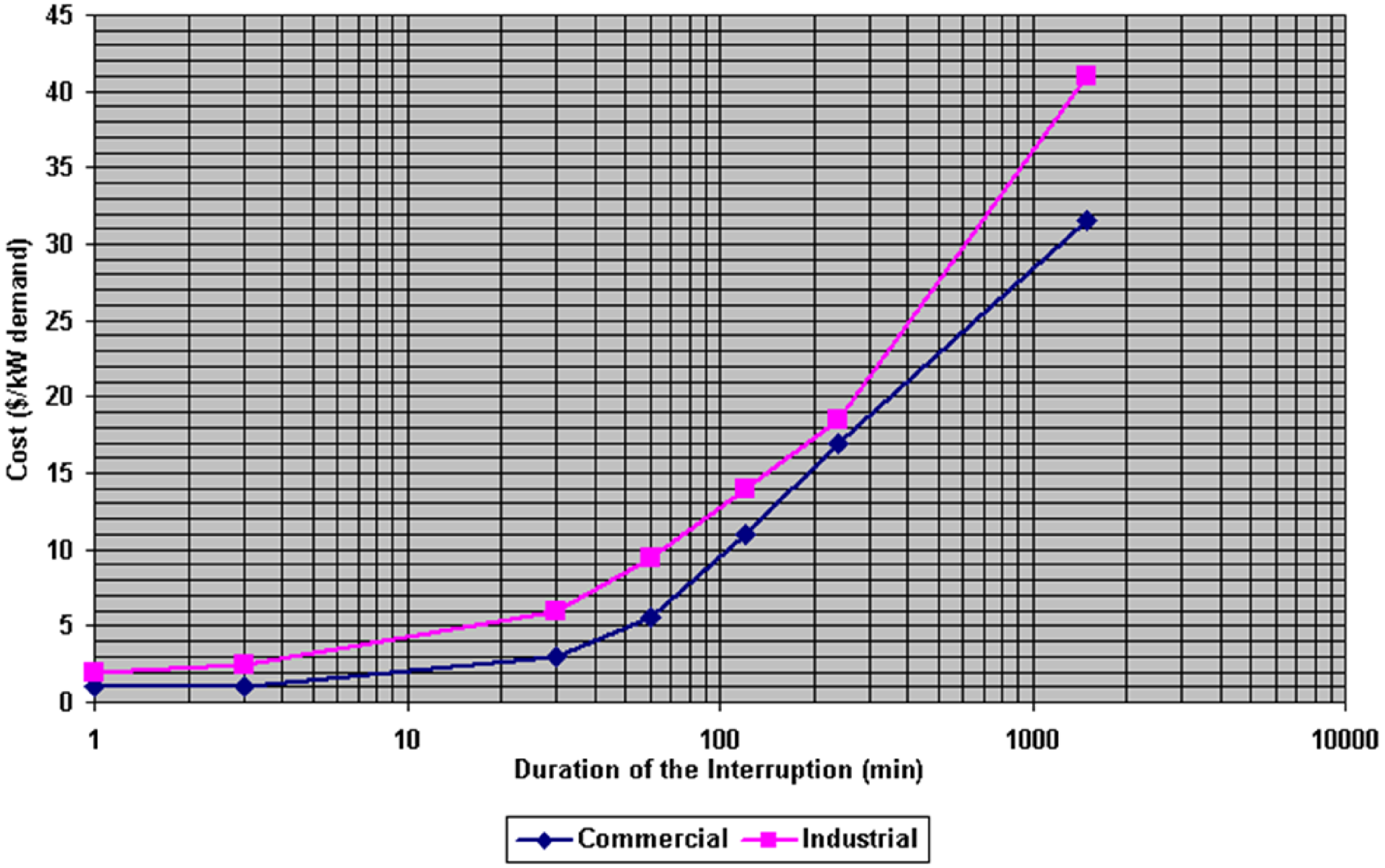
1 minute duration

in $/kW demand

Source: Electrotek Concepts

Cost of Power Quality

Costs of an event rises exponentially as duration increases



Review & Discussion

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11. Power Factor

Motor Assessment

Motor Systems Optimisation (MSO) Expert Training (2020 Egypt Edition)

Samir Khafagui
Siraj Williams

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Discussed Topics

- What is power factor?
- What equipment affects power factor?
- Affect of power factor on motors
- Power factor in Egypt

Power Factor

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From an energy efficiency perspective:

Power Factor *(pf)*

is a ratio that indicates how much of the power supplied or generated can be used to perform useful work in a specific electrical system.

Variation of *pf*

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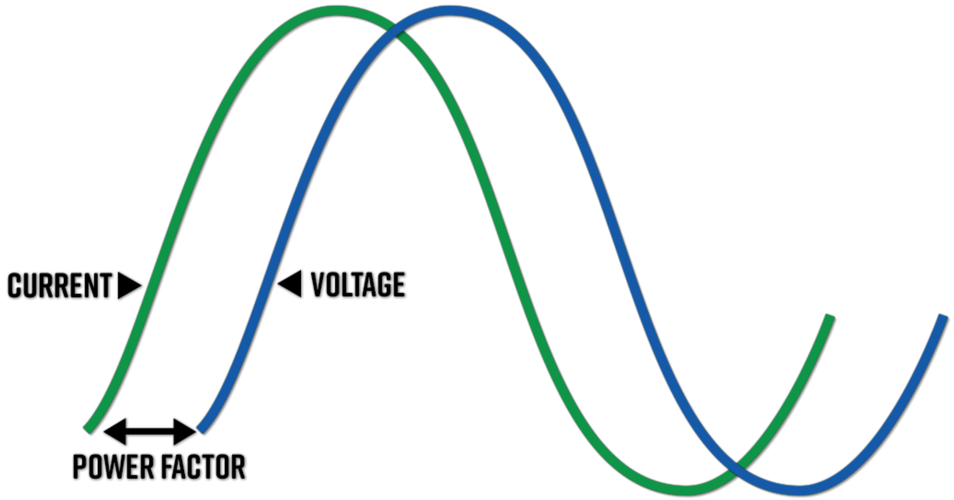


Wave 1 = Voltage (V)

Wave 2 = Current (I)

θ = angle between V and I

Power (kW) = (Voltage) x (Current) x (Phase angle between them)
= V x I x Cosθ

As the angle between the 2 waveforms increases, the available useful power (kW) decreases

Equipment Affecting ***pf***

Component type	PF Effect	Wave forms	Examples
Resistive	Unity	The current and voltage waves will be exactly in phase	• Heater elements
Inductive	Lagging	The current wave will "lag" behind the voltage wave	• Induction motors • Induction and arc furnaces • Welding machines • Inductors and chokes • Transformers at low or no load • Old electromagnetic ballasts in lighting systems
Capacitive	Leading	The current wave will "lead" the voltage wave	• Capacitors • Over excited synchronous machines

Why improve power factor?

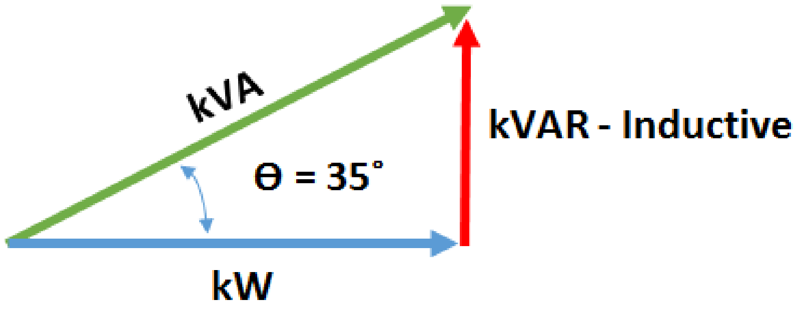
Improving a poor or low power factor:

- Can reduce the peak maximum demand and consequently, the overall cost of electrical supply
- Could reduce the probability of paying a penalty for a poor overall power factor
- Could increase the system capacity
- Could reduce the system losses
- Could improve the overall voltage level
- Could result in longer life cycle for motors by running cooler and more efficiently

Improving the Power Factor

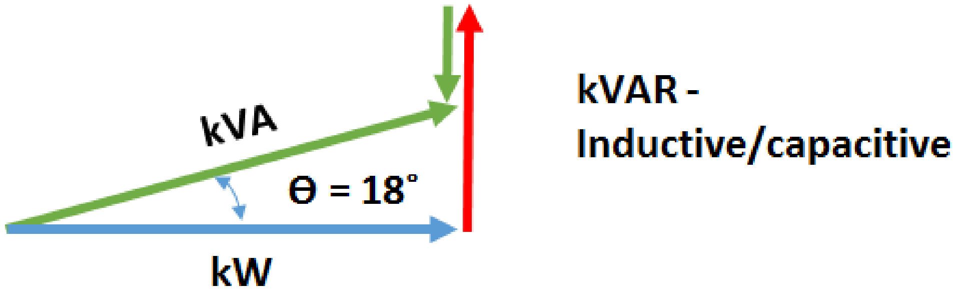
- Most reactive components are **inductive**.
- Improve the power factor by **adding capacitance to the system**.
- This reduces the phase angle.

Low power factor



pf = cos(35˚) = 0.82

Add capacitive loads



pf = cos(18˚) = 0.95

Partial Load *pf* of Induction Motors

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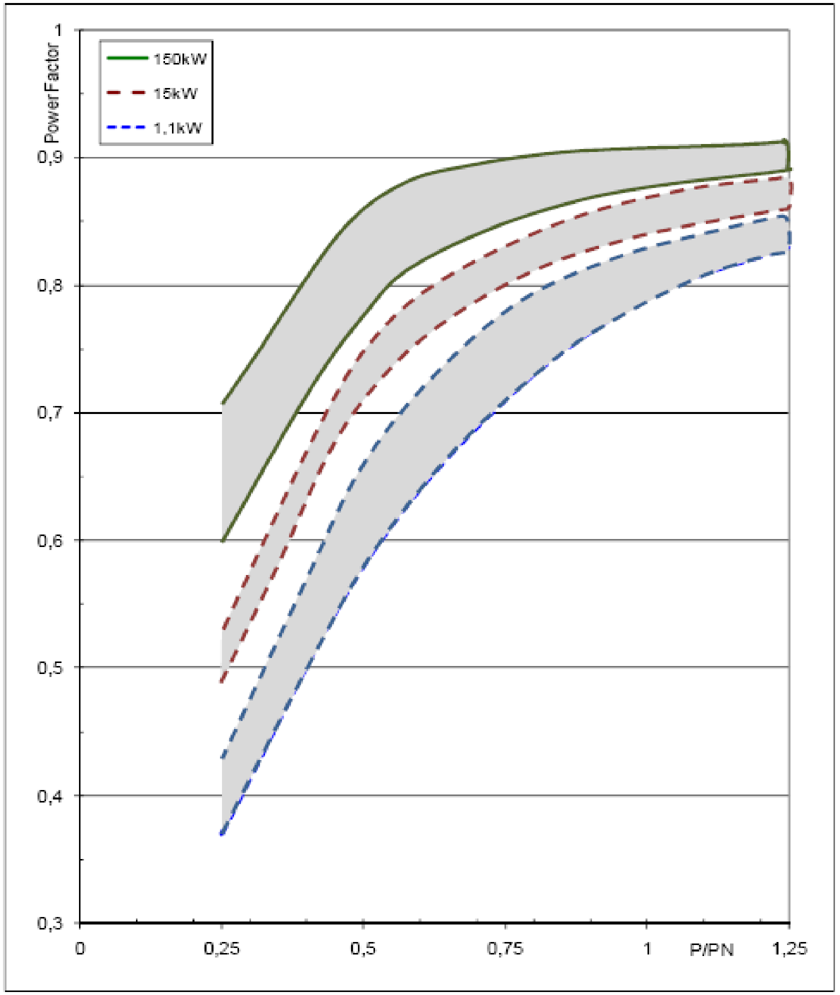
- Workhorse of industry
- 70% of all industrial electrical loads are motors
- 90% of all electrical motors in industry are induction motors
- Poor part load power factor
- Most motors in industry operate at part load

Motor Load Variation	
Motor Load	**Typical pf**
0%	17%
25%	55%
50%	73%
75%	80%
Full Load	84%
125%	86%

Oversized Motors and Power Factor

Maintain High Power Factor:

- Low power factor reduces the efficiency of the electrical distribution system both within and outside of your facility.
- Low power factor results when induction motors are operated at less than full load.



Typical Power Factor vs Motor Load

Source: IEC 60034-31

Harmonics and *pf*

- With linear loads the power factor is only related to the **50Hz** sinusoidal wave
- With non-linear loads the waveforms of the harmonics also need to be included, as each will have its own power factor
- The new **total power factor** will be a summation of the fundamental **+** the power factors of the harmonics
- The **50Hz** power factor is called the **displacement power factor**
- The power factor adjustments due to the harmonic wave distortion is called **distortion power factor**
- For non-linear loads the total power factor is **less** than the displacement power factor

Power Factor Limits for Egypt

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- At consumer level power factor limits are determined by the relevant local distribution supply authority
- Financial incentives are usually provided to consumers to maintain a high power factor
- At transmission level:

Power Factor Limits - Transmission		
Supply Voltage kV	**Permissible Range of Aggregate Power Factor at Point of Connection**	**Factor (F)***
500/400	0.98 lagging to unity	0.2031
220	0.96 lagging to unity	0.2917
132	0.95 lagging to unity	0.3287
66kV and below	0.90 lagging to unity	0.4843

* F = tan $(\cos^{-1}(pf))$

The Aggregate Power Factor (APF) at a Connection Point is given by:

- APF = Sum P/ [$\{(\text{Sum P})^2 + (\text{Sum Q})^2\}^{0.5}$]

where:

- Sum P is the coincident total summated Active Energy at the Connection Point for 15minutes; and
- Sum Q is the coincident total summated Reactive Energy at the Aggregate Connection Point for the same 15 minutes during which the active energy is measured.

Source: Egyptian Electric Power Transmission Grid Code

Worked Example – Power Factor Correction

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Consider the following motor:

- Operates 24 hours a day, 5 days a week, 50 weeks per year
- At a power factor of cosϕ = 0.81
- Motor electrical input power was measured at 200kW
- Electricity costs are EGP 0.66/kWh and EGP198/kVA

- What would the demand cost savings be if the power factor were corrected to cosϕ = 0.94? (Demand = Apparent Power)

Worked Example - Solution

Before:

$$S = \frac{P_{actual}}{\cos\varphi} = \frac{200}{0.81} = 246.9\ \text{kVA}$$

$$Demand\ Cost = S * \frac{Cost}{kVA} * 12\ (months) = 246.9 * 198 * 12 = \boldsymbol{EGP\ 586,667\ pa}$$

$$Energy\ Cost = P * \frac{Cost}{kWh} * hours = 200 * 0.66 * (24 * 5 * 50) = EGP\ 792{,}000\ pa$$

After:

$$S = \frac{P_{actual}}{\cos\varphi} = \frac{200}{0.94} = 212.7\ \text{kVA}$$

$$Demand\ Cost = S * \frac{Cost}{kVA} * 12\ (months) = 212.7 * 198 * 12 = \boldsymbol{EGP\ 505,532\ pa}$$

$$Energy\ Cost = P * \frac{Cost}{kWh} * hours = 200 * 0.66 * (24 * 5 * 50) = EGP\ 792{,}000\ pa$$

Review & Discussion

- Any questions?

12. Egyptian Case Studies

Motor Assessment

Motor Systems Optimisation (MSO) Expert Training
(2020 Egypt Edition)

Samir Khafagui
Siraj Williams

Most Common Applications

- Pumps and cooling tower fans for water utility
- Fume extraction fans at steel plants
- Air cooler fans at petrochemical plants
- Compressed air optimisation

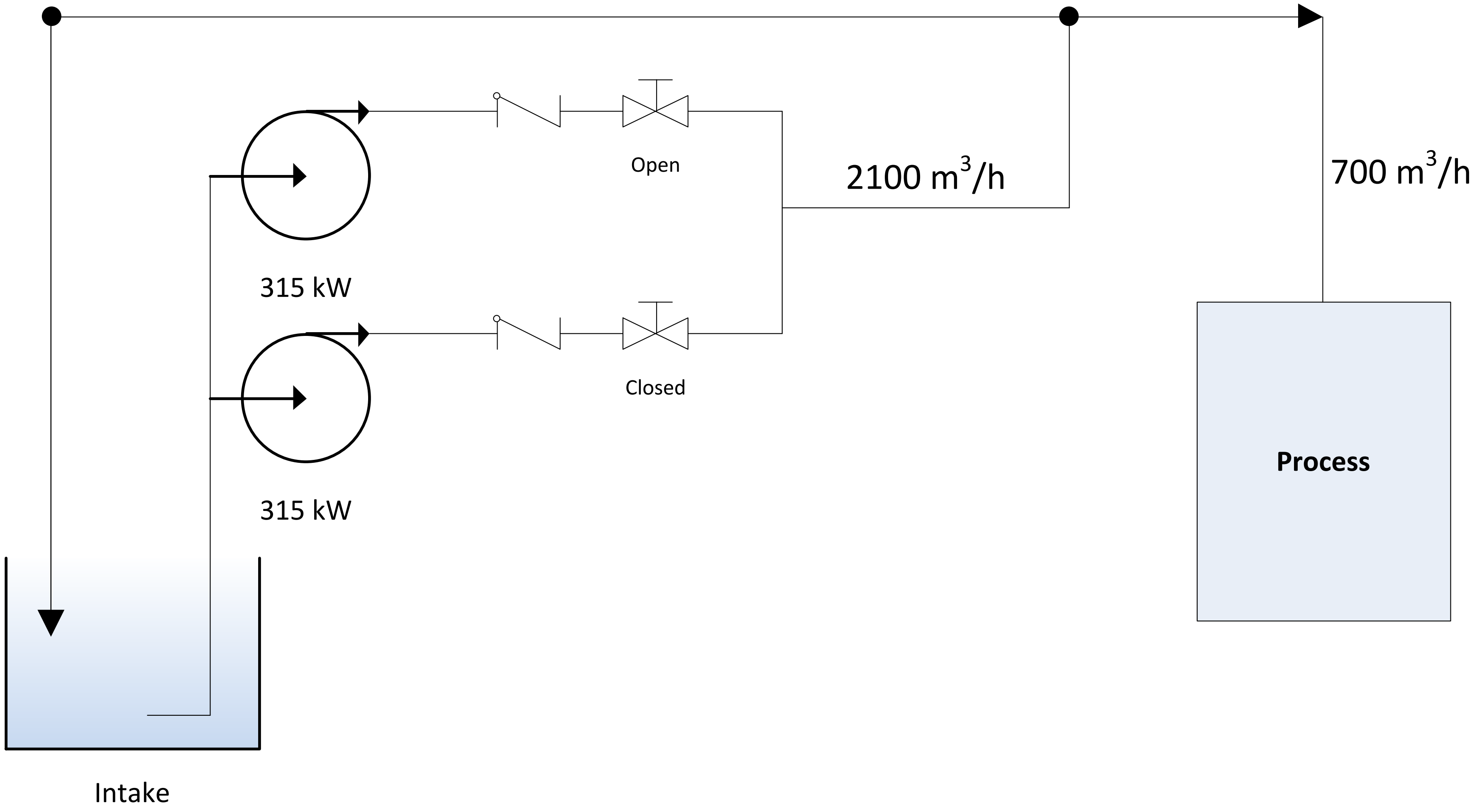
Case 1: Pump System at Petrochemical Plant

- A company draws cooling water from a nearby canal.
- It is pumped using one of two 315kW motors. (One motor standby) and delivers a steady flow of 2100m^3/h.

- The Energy Team has asked you to optimise the pump system. What opportunities can you identify?

Findings

- The process only requires 700m^3/h on average
- Peak flow of 1000 m^3/h was recorded during extreme weather
- Excess water is pumped back to the intake sump via a bypass line
- Motors are direct on line start
- Pumps are alternated on a regular basis


Open
2100 m3/h
700 m3/h
315 kW
Closed
315 kW
Process
Intake

Case 2: Air Cooler Fan at a Petrochemical Plant

- A petrochemical plant operates an air cooling system for gasoil units.
- Each unit has a main fan and a back-up fan. The main fan operates continuously, while the back-up fan is only used when extra cooling is required.
- The back-up fan is kept operational even when not needed to ensure a very fast response to changes in cooling medium temperature.
- The cooling power of the back-up fan is currently controlled using a variable pitch blade (adjustable in steps of 25% from 0 to 100%).

- What opportunities exist for motor system optimisation?

Possible MSO Opportunities

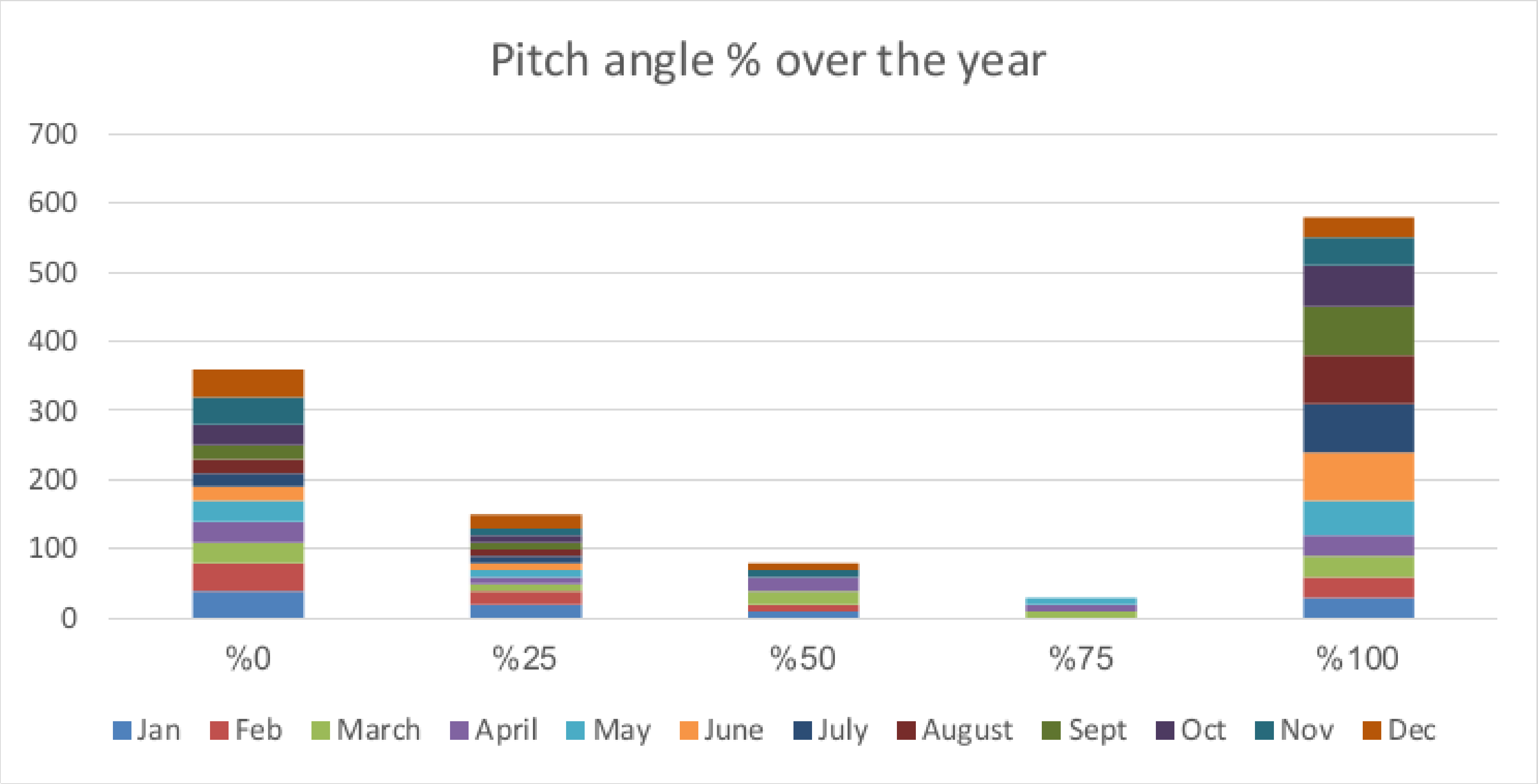
For the Motor System:

- Switch off back-up fan when not needed
- Increase capacity of main fan so that it can operate under all conditions:
  - New larger fan
  - Increase impeller size
  - Use VSD to increase speed of main fan
- Install VSD for back-up fan
- Install VSD for main and back-up fan

Findings

- Fan rated at 37 kW.
- Cooling medium is very sensitive to temperature fluctuation.
- Main fan operates full power all the time.
- Back–up fan not needed for approximately 37% of the time on average per year.
- Cost to maintain pitch control blades on back-up fan approximately EGP 50,000 per year.

Analysis



Pitch angle % over the year
700
600
500
400
300
200
100
0
%0
%25
%50
%75
%100
Jan
Feb
March
April
May
June
July
August
Sept
Oct
Nov
Dec

Outcome

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System	Saving Opportunity	Annual Energy Savings [kWh p.a.]	Financial Savings [EGP p.a.]	Investment [EGP]	Payback [years]
Air Cooler Fans in Gasoil Units	Controlling back-up fan using VSD	82,300	63,300	40,000	0.6
	Shutting off the fan when not needed	50,000	38,000	0	0

- Total energy savings of 132,000kWh per year per fan.
- Total cost saving of EGP100,000 per year at an initial cost of EGP40,000 per fan.
- Savings include a reduction in fan maintenance costs and downtime.
- Savings can be extended to other air cooler fan systems

Lessons Learned

- Understanding load requirements and load profile is important in determining the most suitable option.
- Energy efficiency interventions can sometimes include enhancement and improvements of maintenance activities.
- Applying MSO can be a good starting point to provide impetus for companies to implement an energy management system (EnMS).

Case 3: Sucker Rod Pumps at a Petrochemical Plant

- A petrochemical plant operates hundreds of sucker rod pumps at various oil fields in Egypt. One of these fields have over 250 pumps ranging between 10 and 55 kW.
- The energy systems expert for the company has investigated the optimisation of two of these pumps. Any savings achieved could be easily extended to the 250 pumps in this one field alone.

- What opportunities exist for MSO?

Sucker Rod (Donkey) Pump

Possible MSO Opportunities

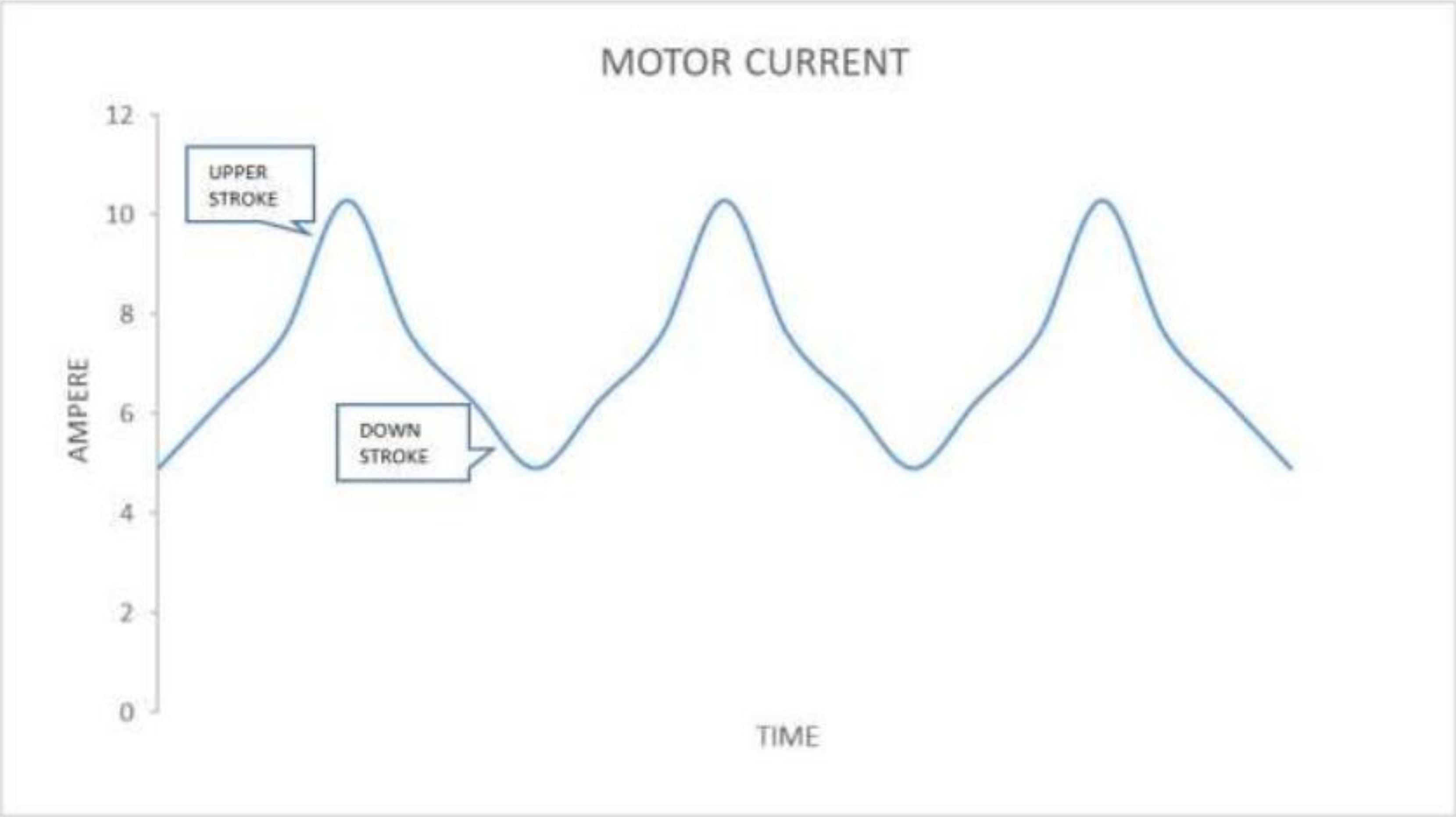
For the Motor System:

- Replace existing motor with correctly sized one from workshop
- Install new correctly sized motor
- Change transmission ratios
- Install VSD with different motor options (existing, IE3, smaller IE3)
- Regenerate VSD with different motor options

Findings

- Of 238 pumping units inspected at the oil field:
  - 102 motors are oversized
  - 45 motors are undersized
  - 92 pumps required counterbalance
- Voltage drops were excessive (up to 12.5%) in some cases

Analysis


MOTOR CURRENT
12
10
8
6
4
2
0
AMPERE
UPPER STROKE
DOWN STROKE
TIME

Outcome

Egyptian program for promoting Industrial Motor Efficiency
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System	Saving Opportunity	Annual Energy Savings [kWh p.a.]	Financial Savings [EGP p.a.]	Investment [EGP]	Payback [years]
Sucker rod pumping unit driven by a 15 kW motor	1. Increase Mechanical Transmission Efficiency	3,768	9,759	5,000	0.5
	2. Using new Smaller Motor (10 kW) from existing stock	18,144	46,994	0	0
	3. Using VSD and change pulley size	48,259	202,078	115,000	0.6
Sucker rod pumping unit driven by a 37 kW motor	1. Increase Mechanical Transmission Efficiency	10,409	26,960	5,000	0.25
	2. Using new Smaller Motor (15 kW) from existing stock	92,613	239,867	0	0
	3. Using new Smaller IE3 Motors (15 kW)	100,800	261,000	88,000	0.4

Lessons Learned

- In some cases energy efficiency initiatives may result in productivity improvements.
- Visual inspection can sometimes highlight issues that may affect the choice of the solution.
- Development and maintenance of a comprehensive motor database can enhance the implementation of motor efficiency solutions for multiple or parallel motor systems.

Case 4: Sea Water Pumps at a Petrochemical Plant

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- Cooling water is supplied to a petrochemical plant via a sea water pumping station.
- The pumping station consists of 6 x 6.6kV vertical pumps ranging from 825 to 925kW, consuming approximately 13% of total plant energy consumption.
- Under normal conditions 2 pumps are operational, with pumps being rotated on a regular basis.
- The energy team have chosen this system as it is a lower risk for production but consumes a large quantity of energy.

- What opportunities exist for MSO?

Possible MSO Opportunities

For the Motor System:

- Operate most efficient pumps
- Improve pump efficiency
- Install VSDs
- Upgrade motors to more efficient ones

Findings

- Pumps providing more than actual flow required.
- All discharge valves are throttled to approx. 60% open.
- Discharge header very well designed, but leaks detected in discharge piping network.
- Pumps were installed in 1963, 1982 and 2009, with different efficiencies.
- Power factor correction installed in 2017, improving from 0.7 to 0.98.

Analysis

Item	*Actual water consumption m^3/hr*	*Observations*
CDU- 1	*500*	*Using Portable F.M.*
CDU-2	*570*	*Design*
VDU	*385*	*Estimated 60% Design*
1/2 MILLION	*245*	*Using Portable F.M.*
TOTAL Distillation units	***1700***	
Reformer complex	***1200***	*Flow Indicator(note 2)*
Coker complex	***2800***	*Estimated 70% Design*
Total	***5700***	

Actual cooling requirements were determined.

This allowed the energy team to adjust the sea water pump output to match the requirements.

Outcome

System	Saving Opportunity	Annual Energy Savings [kWh p.a.]	Financial Savings [EGP p.a.]	Investment [EGP]	Payback [years]
Sea Water Pumps	1. Discharge Valves Opening Adjustment	750,000	530,000	0	0
	2. Run only one Pump during Units Outages	2,730,000	1,900,000	0	0
	3. Using New Efficient Smaller Pumps	1,480,000	1,000,000	8,000,000	8
	4. Replacing Manual Valves by Motorized	518,000	366,000	3,000,000	9

- Opportunity 1 and 2 implemented at no cost.
- Total cost saving of EGP2,430,000 (equivalent to 3,480,000 kWh) per year.
- Opportunities 3 and 4 will be considered when replacing the 2 old pumps (from 1963).

Lessons Learned

- Measurement and understanding of load requirements are essential to the successful outcome of an optimisation project.

- The MSO methodology can provide good support to deploy a culture of improvement, especially in old companies with high resistance to change.

Case 5: Cooling Water Pumps at Chemical Plant

- A chemical plant operates a pumping system that supplies cooling water to various sections of the plant.
- The system consists of 4 x 37kW pumps, operated with manual valve flow controls.
- The system consumes approximately 7% of the total plant energy consumption.

Findings

- 2 x pumps are operational with the other 2 on standby under normal load conditions.
- PT100 (temperature sensors) installed to monitor the actual water temperature.
- Water temp (ΔT) and power consumption were monitored
- Total power consumption was 45kW and ΔT 5-8°C

MSO Opportunities

- Replace motor and pump with smaller units
- Install VSD to control pumps instead of throttle valve
- Re-arrange piping system to reduce losses

Outcome

- 2 x VSD installed to control the 2 pumps in operation, with throttle valves fully open.
- Motor speed adjusted until ΔT maintained at 5-8°C. Speed reduced to 50% of original speed.
- Power consumption reduced to 9kW.
- Payback < 4 months

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13. Control Applications

Motor Assessment

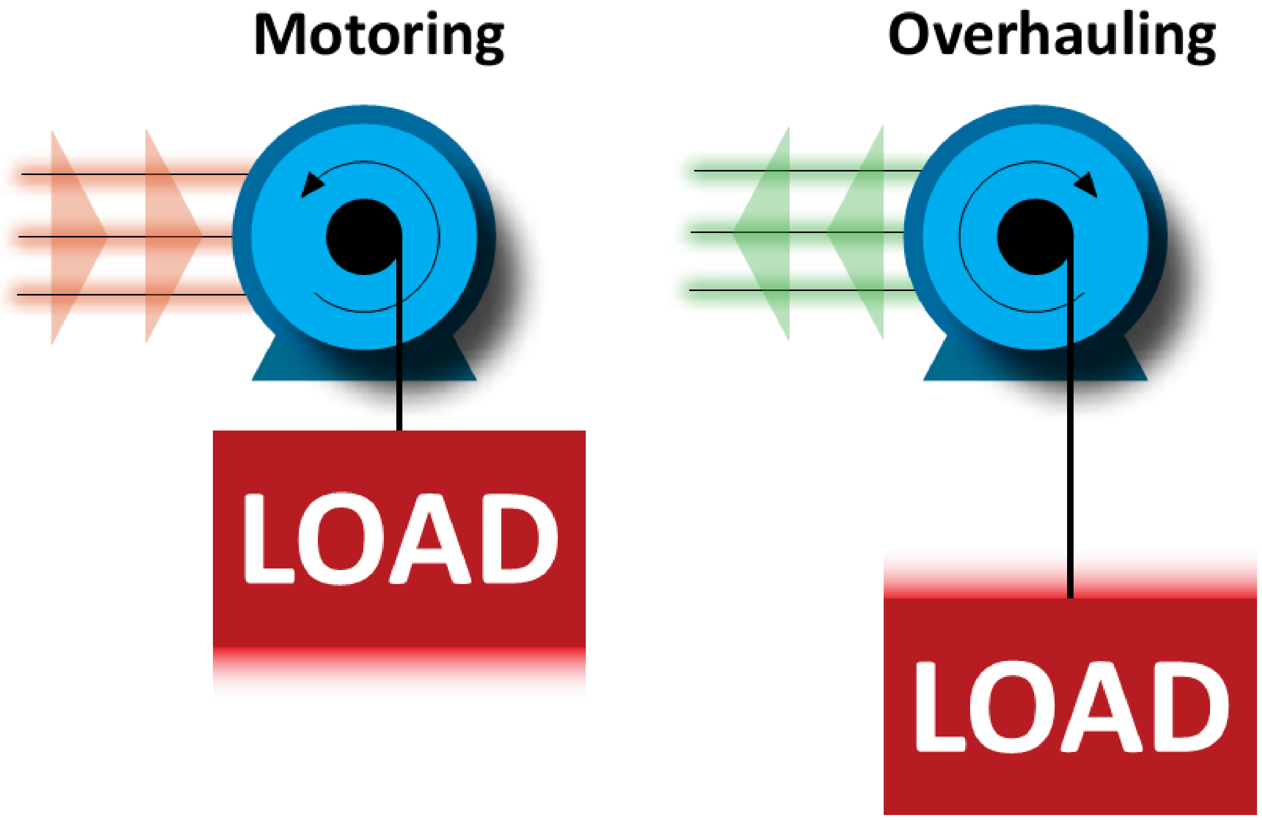
Motor Systems Optimisation (MSO) Expert Training
(2020 Egypt Edition)

Samir Khafagui
Siraj Williams

Discussed Topics

- Concept of overhauling and regeneration
- Common configurations
- Worked example of picking crane
- Class exercise

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**.

Source: www.bonitron.com

Overhauling – Energy Dissipation

- When the load drives the motor, there is a danger of the motor experiencing an overvoltage
- A braking device is applied to prevent the overvoltage:
  - Mechanical brake – mechanical friction device
  - Dynamic brake – electric circuit that allows the energy to be dissipated through a resistor bank

Overhauling Opportunities

Raising and Lowering: Here a load is raised, and then lowered. Power is required to raise against gravity, and braking is required when lowering. Typical examples would be hoist operations in a vertical direction. The recoverable energy is almost equal to the energy used for raising).

Periodic Deceleration: Here a load is stopped very quickly and the inertia of the mechanical load tries to keep the motor turning. Typical examples would be crane operations in a horizontal direction. (The load inertia, duration of the stop and the number of stops will determine the amount of energy that can be recovered).

Overhauling Opportunities (2)

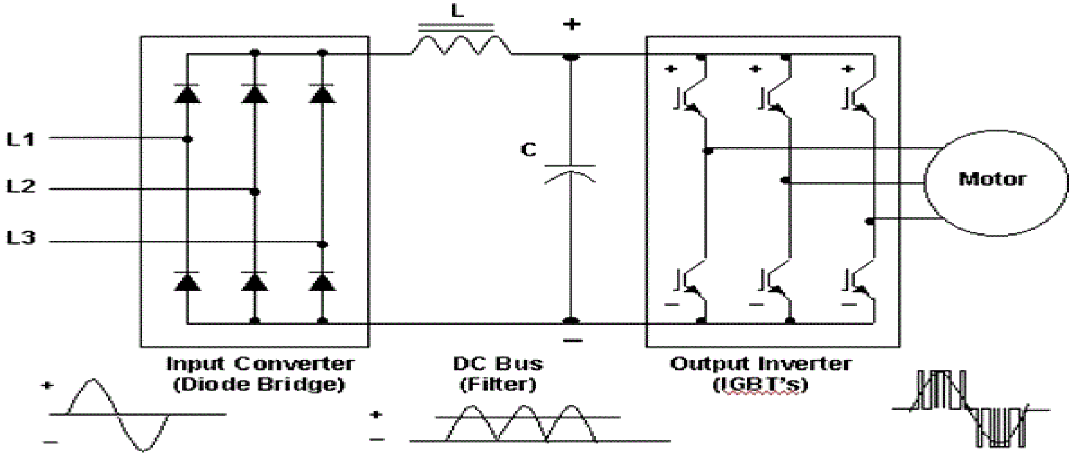
Continuous Deceleration: Here a load is continuously trying to accelerate the motor, usually because of gravity. A typical example would be a decline conveyor, where the motor is used as a brake to control the speed of the belt. (The heat dissipated by the brake could be recovered).

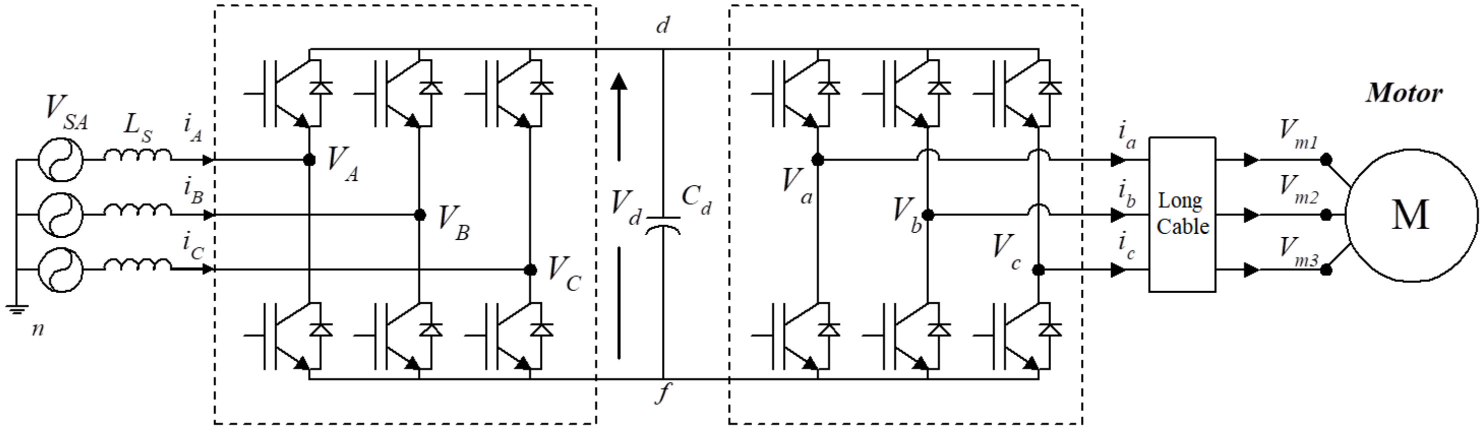
Holding Tension: Here two machines are usually used to hold some material at a set tension. Both machines will be running forward, but their torques will be opposite, one driving forward, the other holding in reverse, thereby creating the required tension on the material. A typical example would be a metal strip in a steel strip mill.

Energy Recovery from Overhauling

- With new drive technology this energy can now be recovered.
- Requires a bi-directional drive (also called active front end)
- The higher initial drive cost may be offset by the energy savings
- Typical savings for systems with high vertical operations (raising and lowering) are above 20%

Standard vs Regenerative VSD





Using a Common DC Bus

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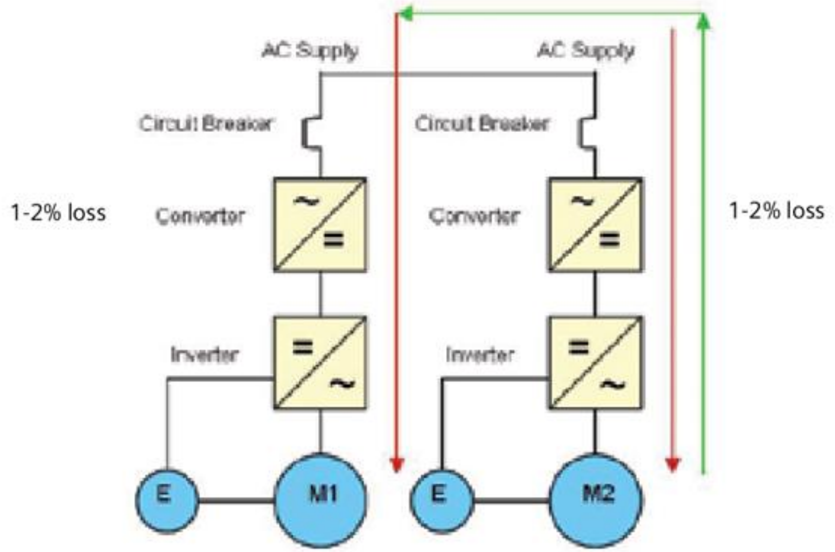
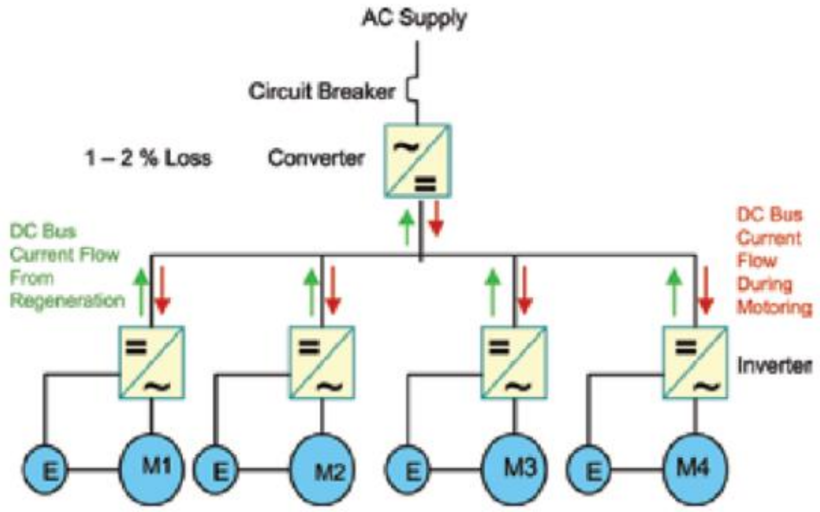
Separate Supply



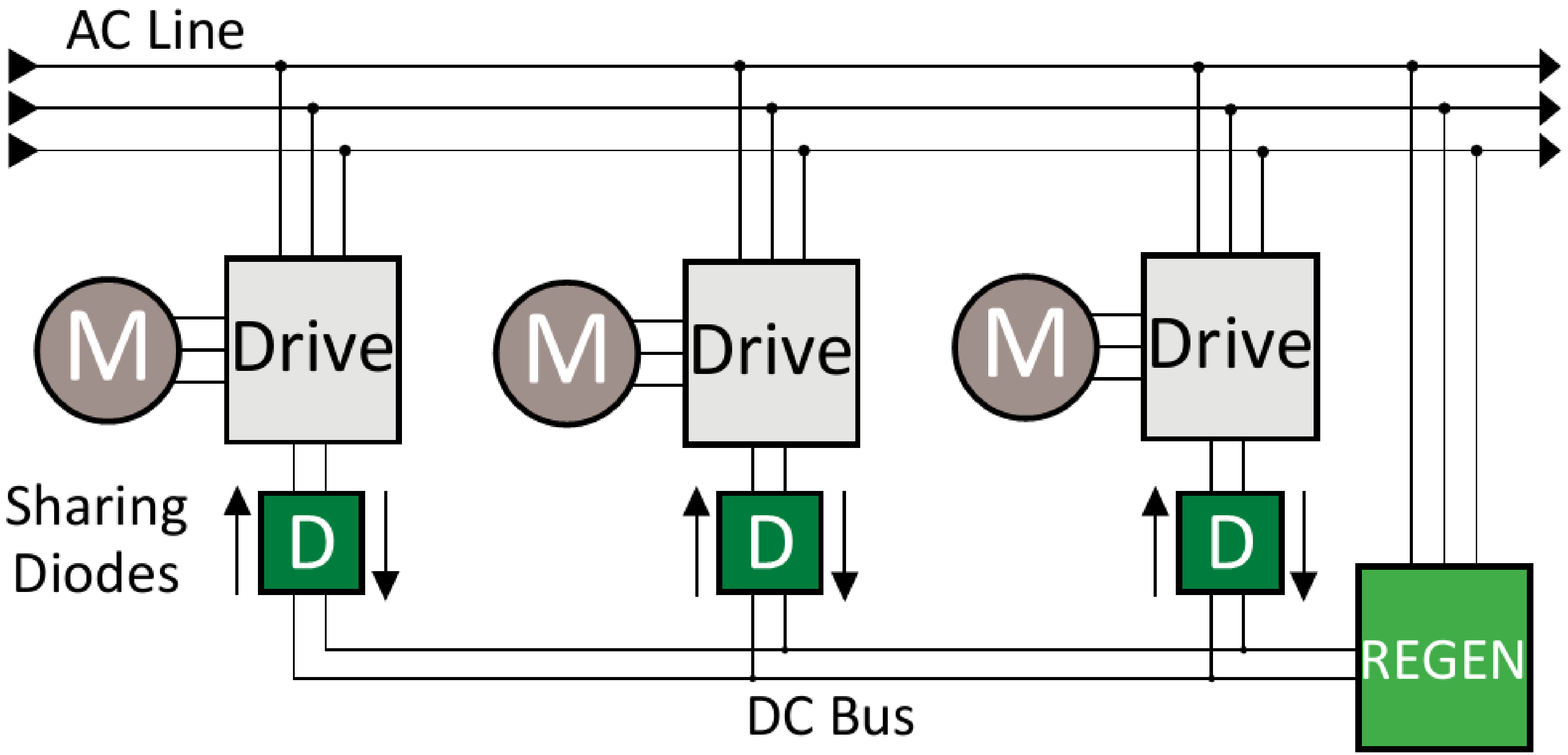
Common DC Bus



Legend: Red – motoring; Green – regeneration

Where motor loads are used in parallel, the use of a common DC bus can also improve the overall efficiency

Regeneration on a Common DC Bus



Source: www.bonitron.com

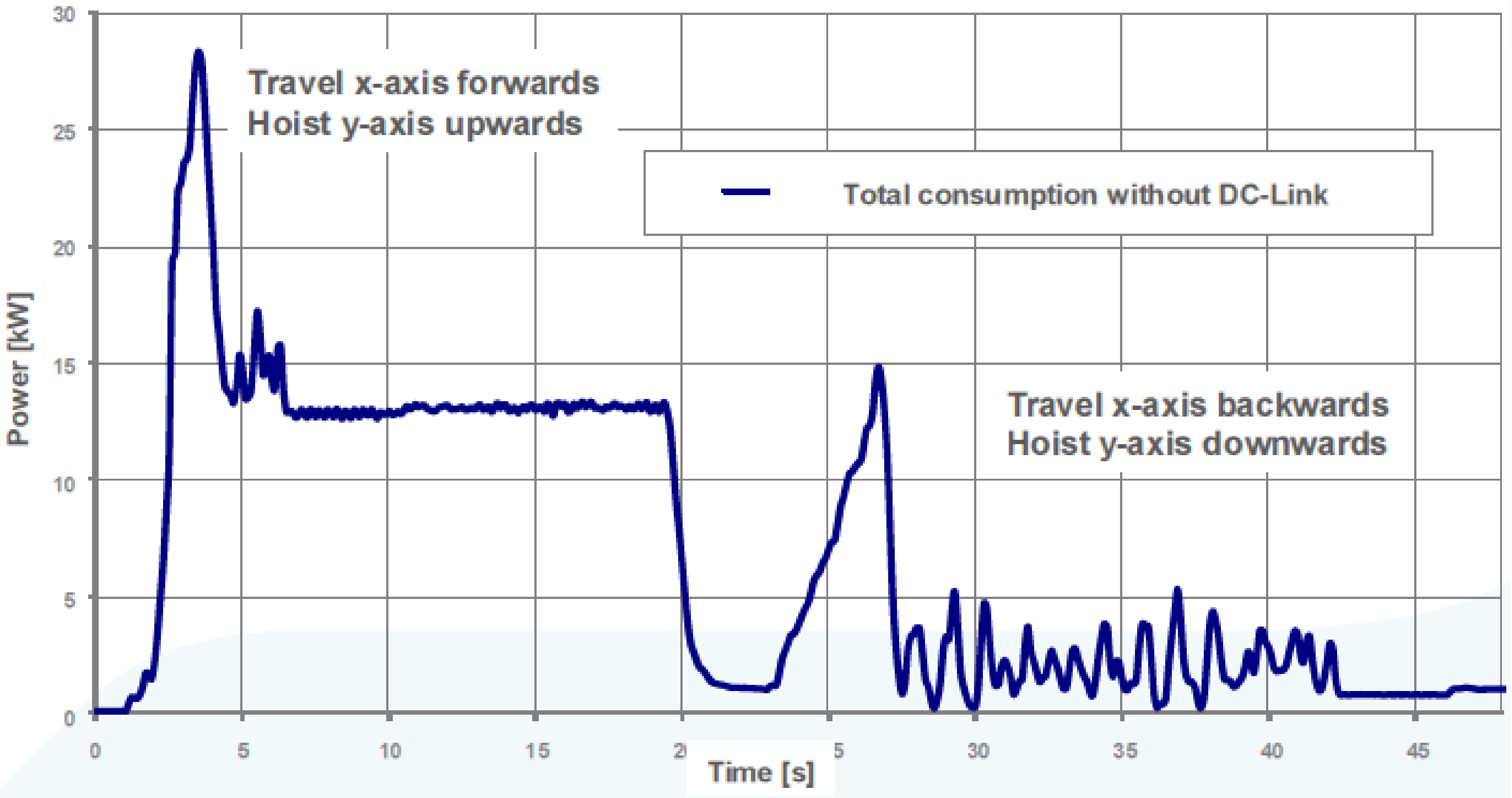
Latest Trends in Material Handling

- Installing VSDs to new conveyor systems, often without the need for a transmission
- Intelligent electronic controls where high torque is required at start-up
- Regenerative drives using new generation high efficiency electronically commutated motors for all lifting operations (elevators and cranes)

Regeneration Using a Picking Crane

- With conventional control, kinetic or potential energy is dissipated via a braking resistor
- With the intelligent control of the travel and hoist drives, kinetic or potential energy is used directly in the second axis. By using a common DC link even further energy savings can be achieved.
- Installing VSDs with regenerative capabilities can save up to **40%** of the energy consumption.

Picking Crane – Power Consumption



With Common DC Bus

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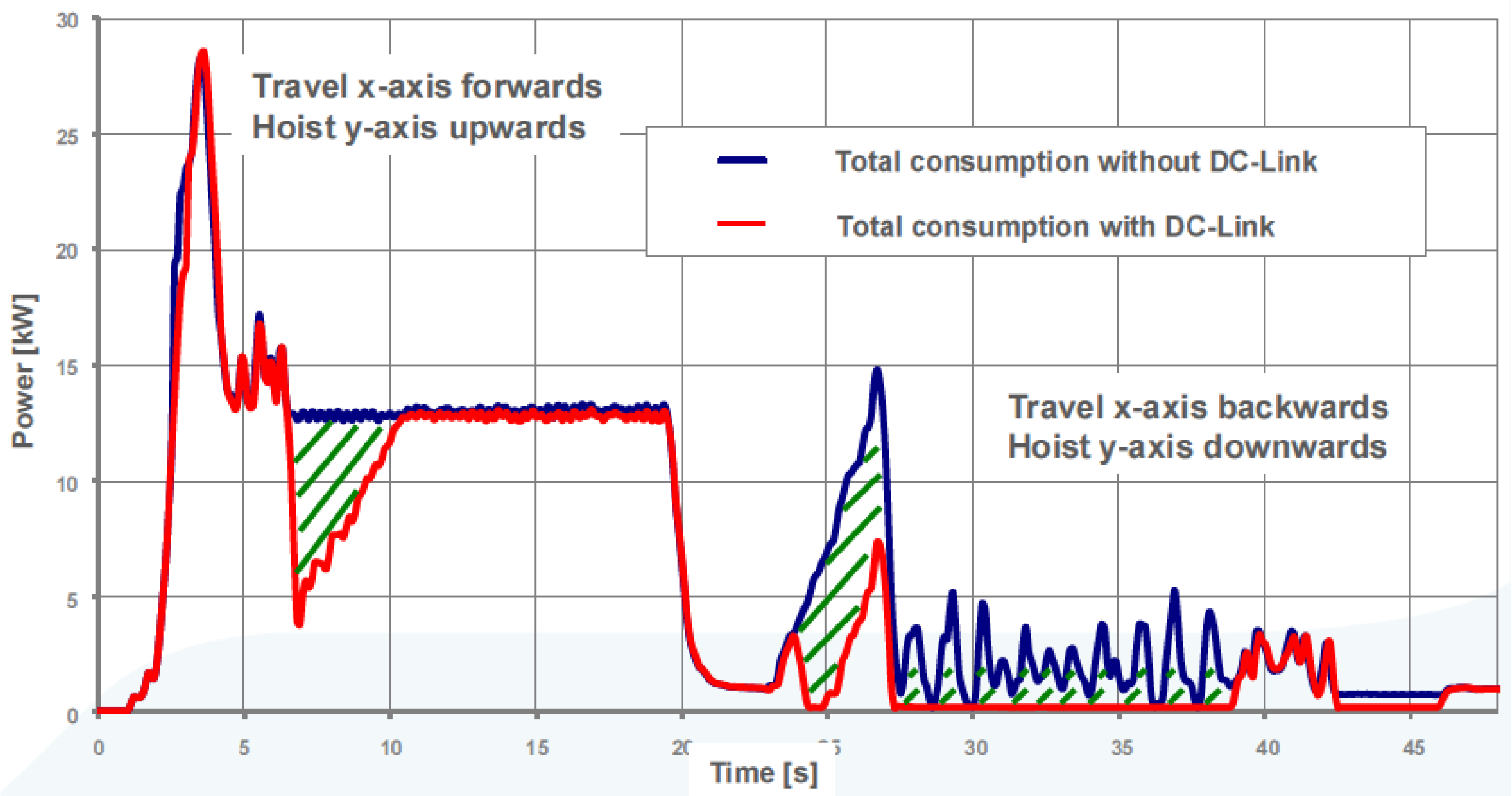

The total energy consumption falls dramatically by as much as **25%** with maximum unit power and optimum utilization of the unit dynamics

Recycled Energy from Traveller (X-axis)

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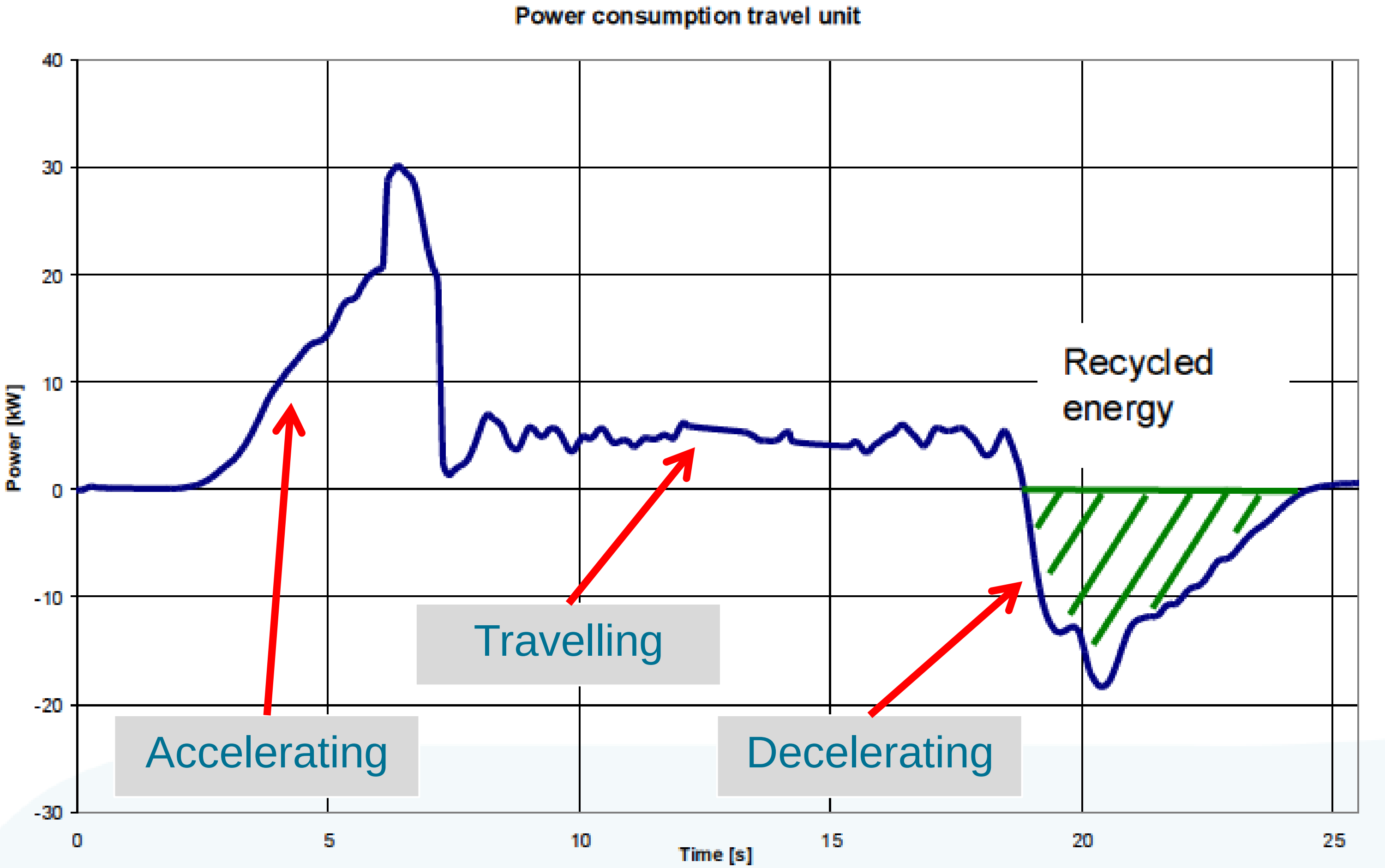
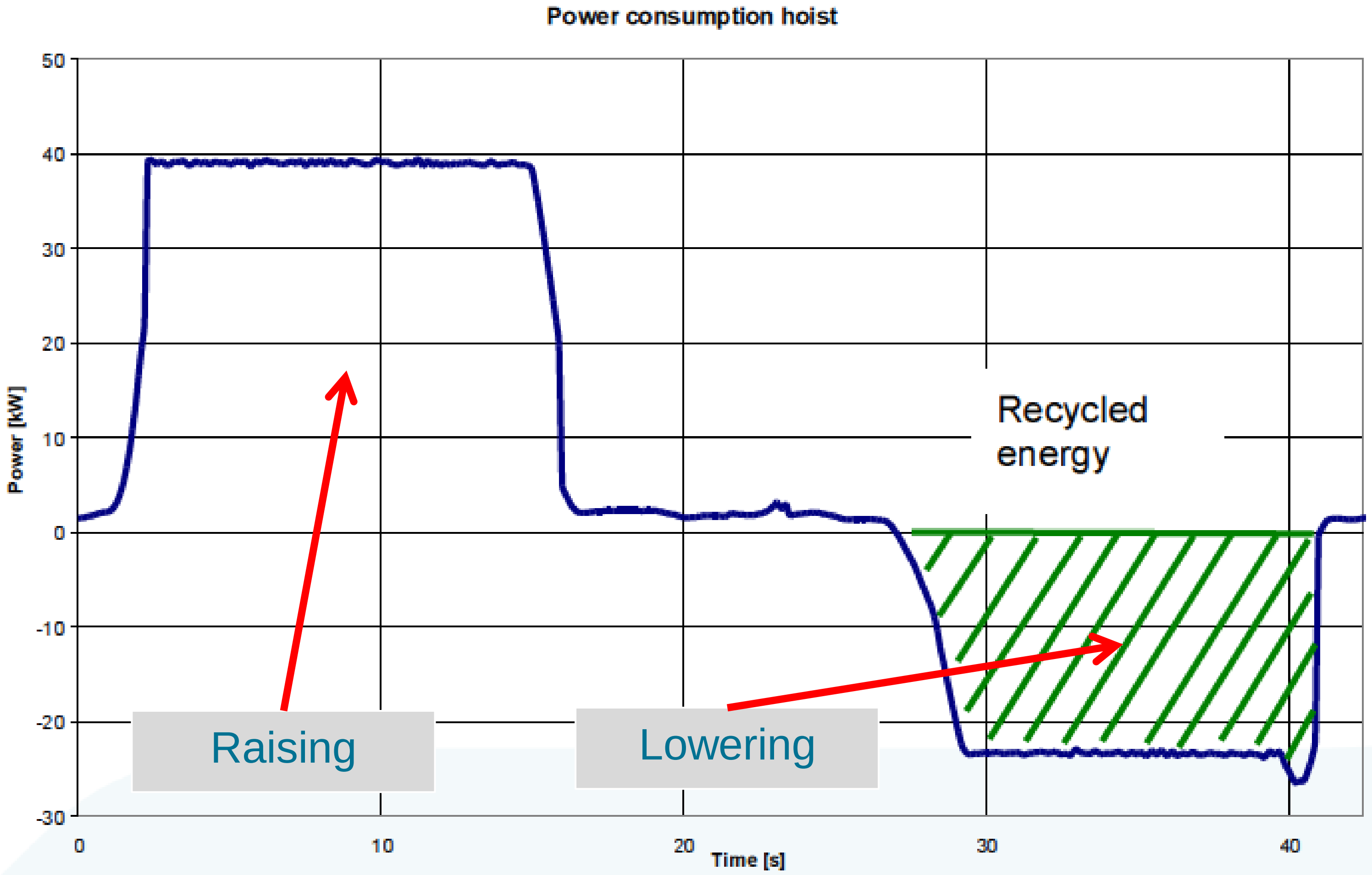


Recycled Energy from Hoist (Y-axis)



Overhead Gantry Crane at Steel Plant

What are the opportunities for possible regeneration through overhauling during the following phases:

- Raising
- Lowering
- Traversing

Class Exercise

The Planning Department are considering refurbishment of the Melt Shop. You are asked to determine if it is feasible to upgrade the existing gantry crane to include regeneration.

1. Develop a ***Measurement Plan*** for determining the existing energy consumption, and then show how to calculate the potential savings for a new system using a regenerative drive to utilise the braking energy.
2. What other factors would you consider in the development of the business case?

Review & Discussion

- Any questions?

13. Maintenance and Repair

Motor Systems Optimisation (MSO) Expert Training (2020 Egypt Edition)

Samir Khafagui
Siraj Williams

Discussed Topics

- Review of key concepts:
  - Common failures
  - Prevention of failures
  - Energy saving motor maintenance
  - Choosing a repair facility
- Motor Policy
- Condition monitoring techniques

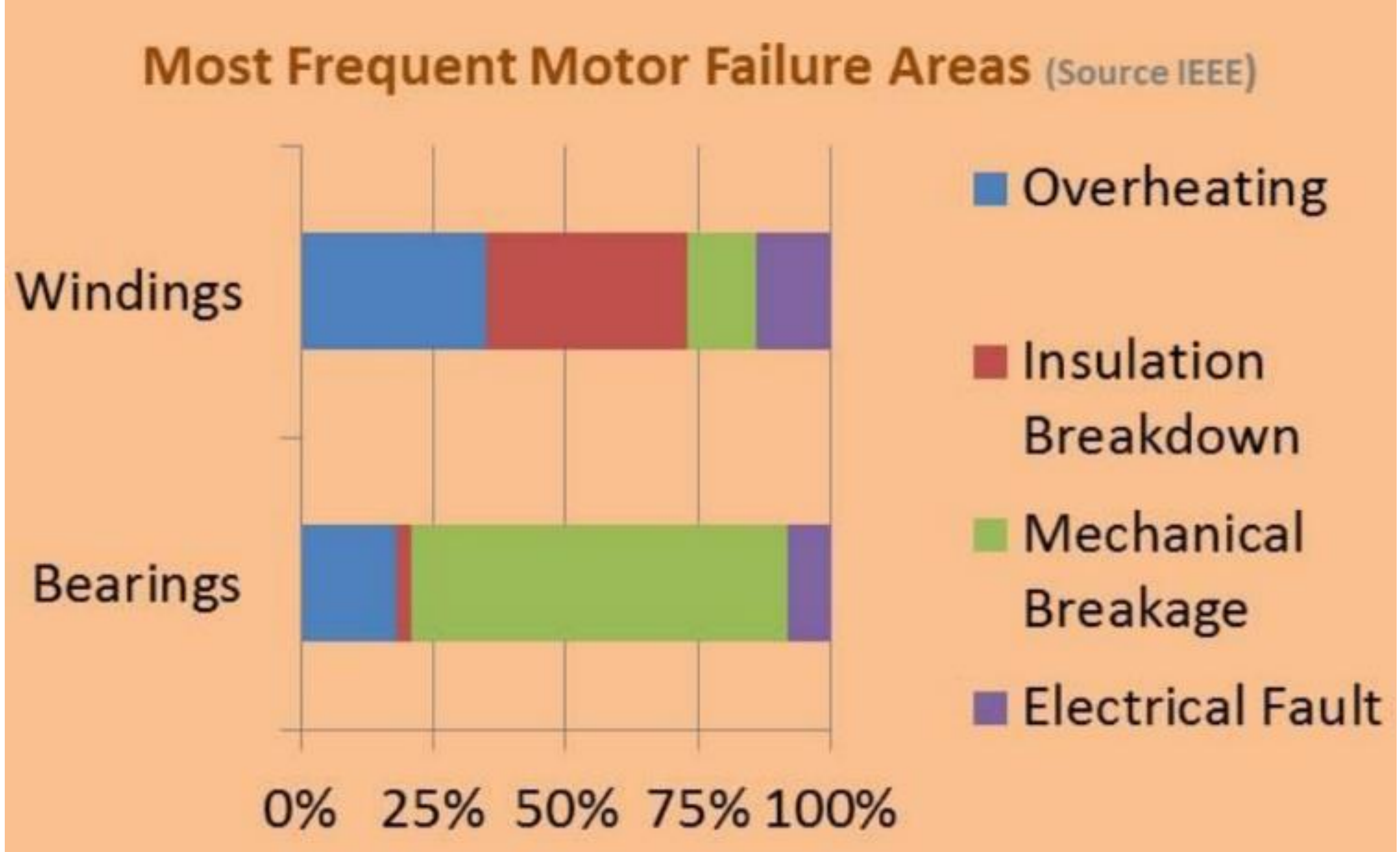
Why motors fail?

Problems arising from:

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

Common Motor Failure Modes

Failure Cause	%
Bearings	51
Windings	16
External	16
Other	17



Source: IEEE

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

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

Where Better Maintenance Saves Energy

Shaft alignment	Lubrication	Dirt removal
Ventilation	Voltage balance	Harmonic filtering

Why have a maintenance policy?

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Motor Management

- Improved maintenance techniques
- Defining acceptable limits for operation
- Prioritizes maintenance of motors

Repair or replace?

- Decision tree to facilitate choice
- Standardisation of spares
- Facilitates external contract for repair

Procurement

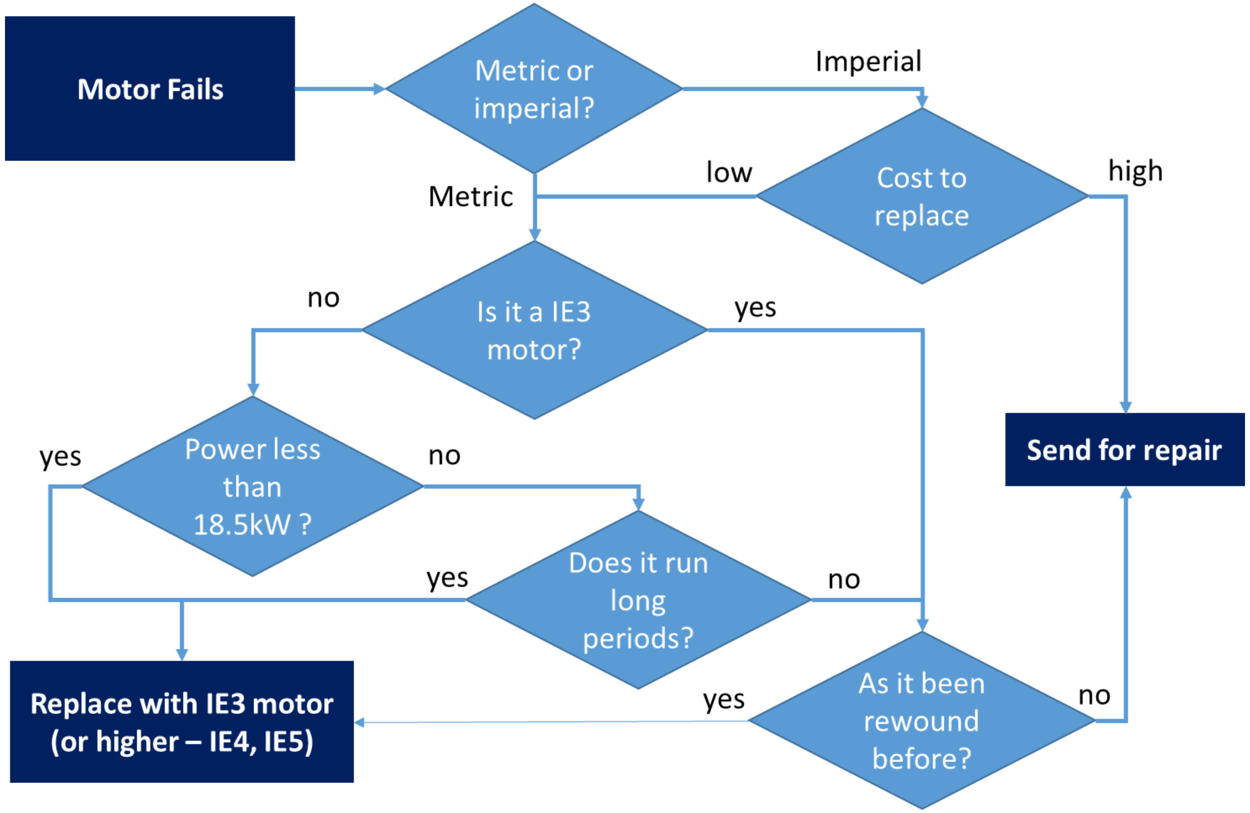
- Management endorsed
- Life cycle cost (LCC) or Total cost of ownership (TCO)
- No need to motivate for high efficiency motors

Example of a Repair/Replace decision chart

This involves several key questions relating to what happens when a motor fails:

- Efficiency
- Size
- Running hours
- Past rewind history
- Metric / Imperial
- Other costs to change

Note that bearing replacement does not figure in this.



Source: ABB Motors – others produce similar diagrams

Condition Monitoring Techniques

- Thermal Imaging
- Vibration analysis
- Shock Pulse Analysis

How?

- Define acceptable limits for operation
- Include a maintenance plan to manage
- Record a history and trend over time

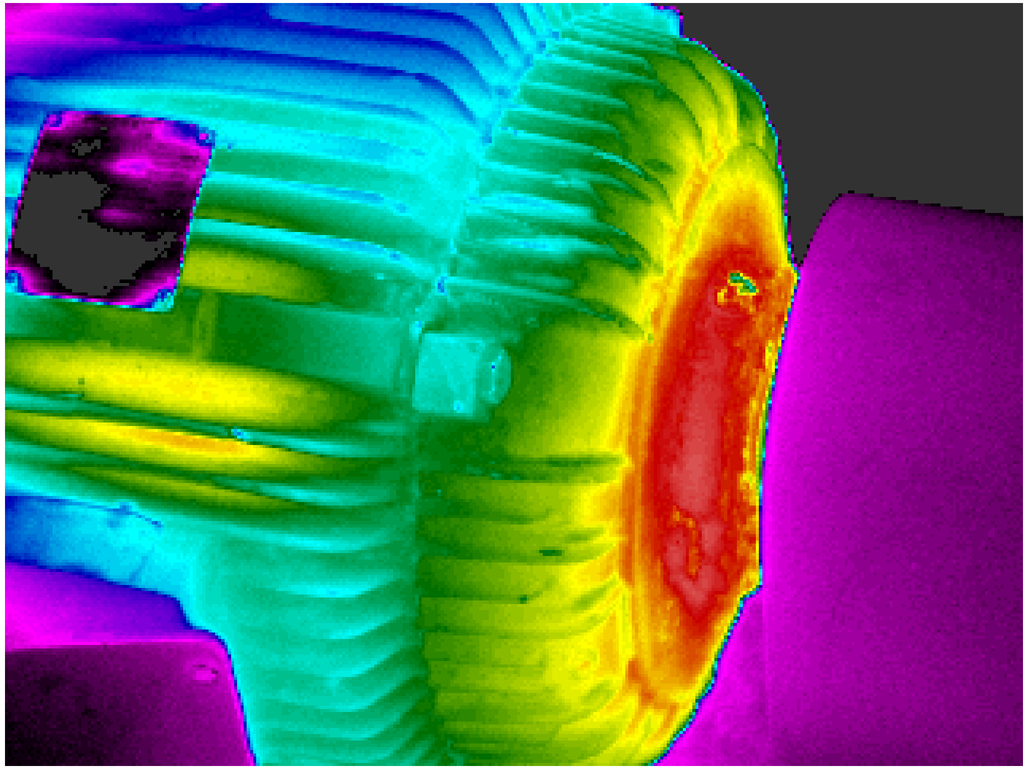
Thermal Imaging

Look for:

- Hot spots in windings
- Over-heated bearings
- Over-heated terminal connections

Note:

- Understand thermography to interpret results
- Regular surveys (in house or external)
- Trending equipment over time



Island Thermal Imaging

Vibration Analysis

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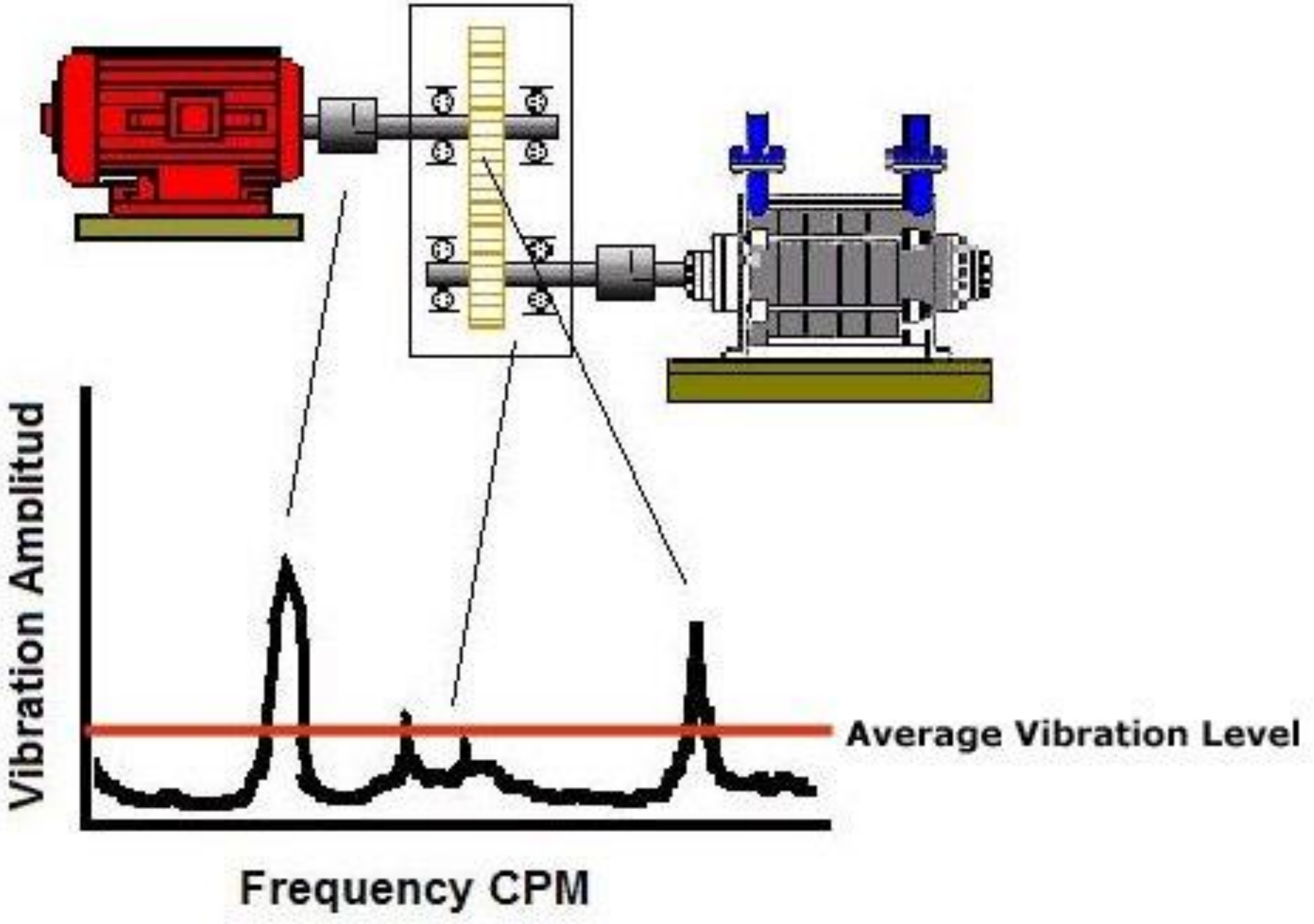
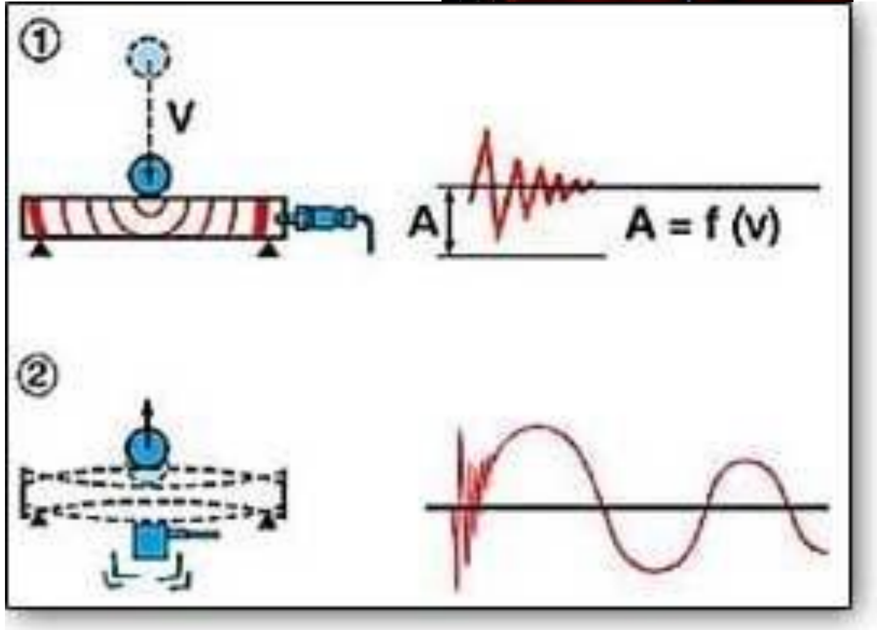
- Improvement on listening
- Identify different components by their frequency
- Best to trend over time
- For SMEs, call in outside help



Shock Pulse Vibration

- Ideal for condition monitoring of bearings
- Can measure **lubrication** (regular or "carpet" level) and
- **Damage** (peak values) – like hitting a pothole.
- Rpm should be entered in order to adjust for speed.
- Budget $3-5kUS. Its best for looking at changes over time.
- Can be done in house.

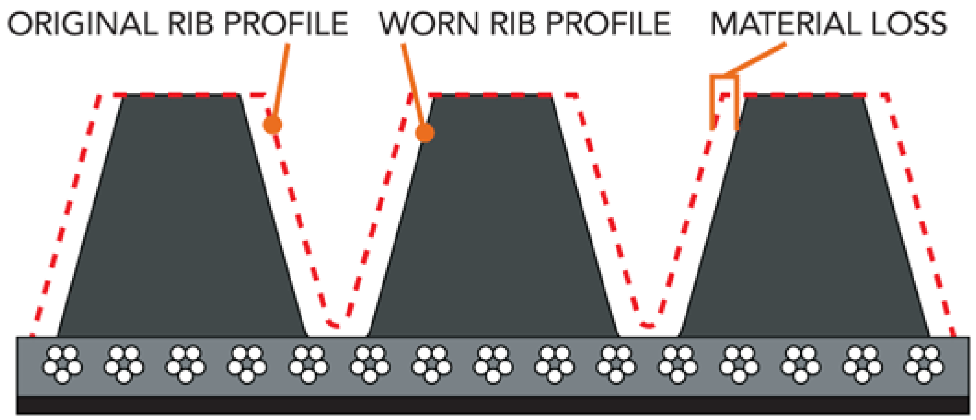


Transmission Belts

Check for drive belt wear, and replace pulleys if needed.

Check for belt tension use tension meter and belt wear using simple profile gauges.

Improvements in transmission belts can sometimes be equivalent to replacing a motor with a higher efficiency equivalent.



Enlarged Rib Cross-section

Review & Discussion

- Any questions?

14. Development of MSO Business Case

Motor Systems Optimisation (MSO) Expert Training (2020 Egypt Edition)

Samir Khafagui
Siraj Williams

Discussed Topics

1. Business case report

2. Financial evaluation of MSO cases
    1. Basic types of evaluation
    2. Time value of money
    3. NPV and LCC

Business Case Reports

Key elements of a business case report:

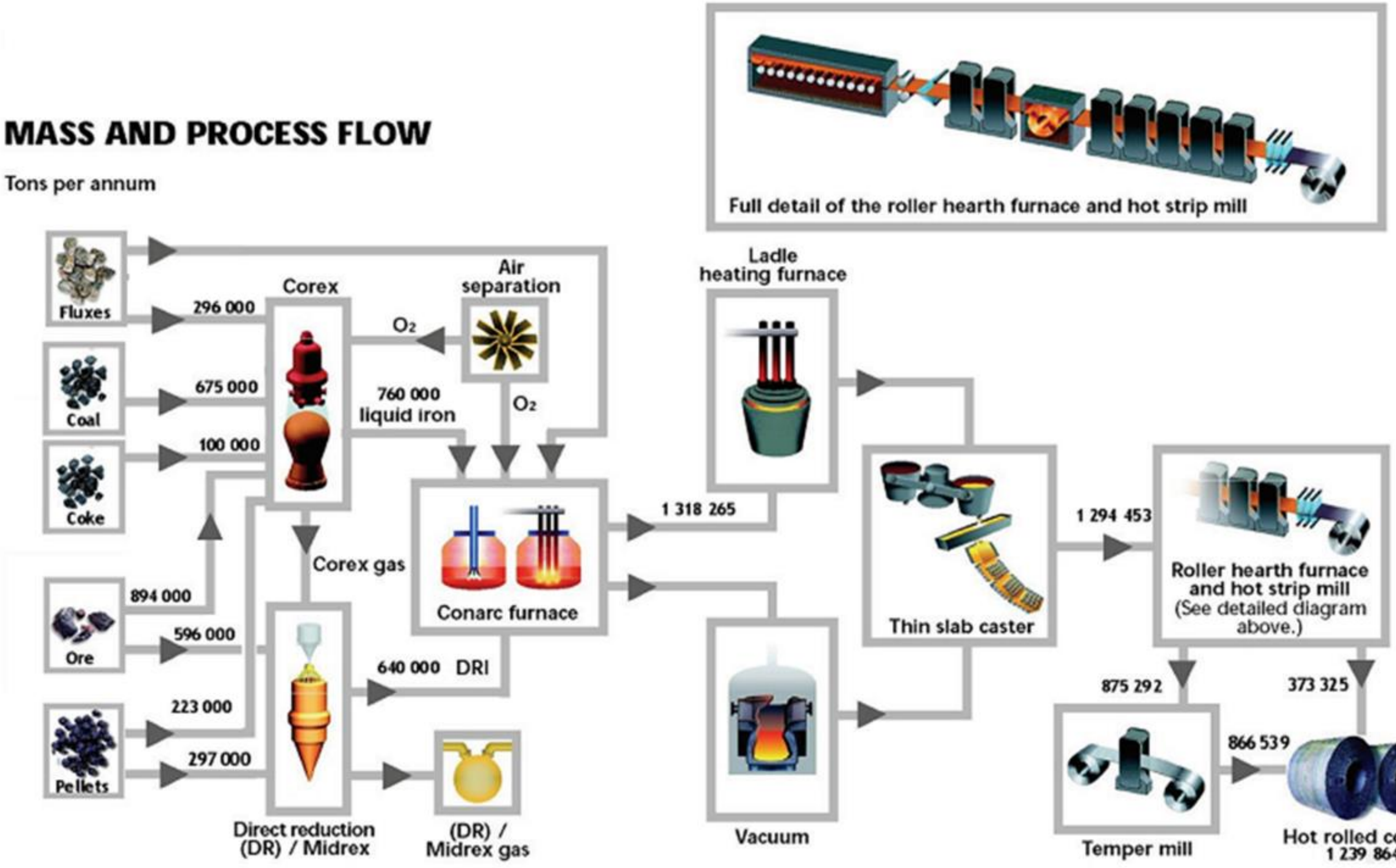
- Executive summary
- Objectives of study
- Plant process overview
- Plant electricity network and costs
- Motor system selection
- Measurements and findings
- Analysis of motor system results
- Energy saving opportunities
- Opportunities summary
- Recommendations

Objective of study

- Important to state what the purpose of the study is (feasibility, business case, process or equipment audit)
- Methodology of assessment (why, who, what, where, when, how)
- Expected outcomes

Plant Process Overview

- Overview of plant production
- Simple bock diagram
- Key parameters for energy
- Pie chart or bar chart of SEUs if available

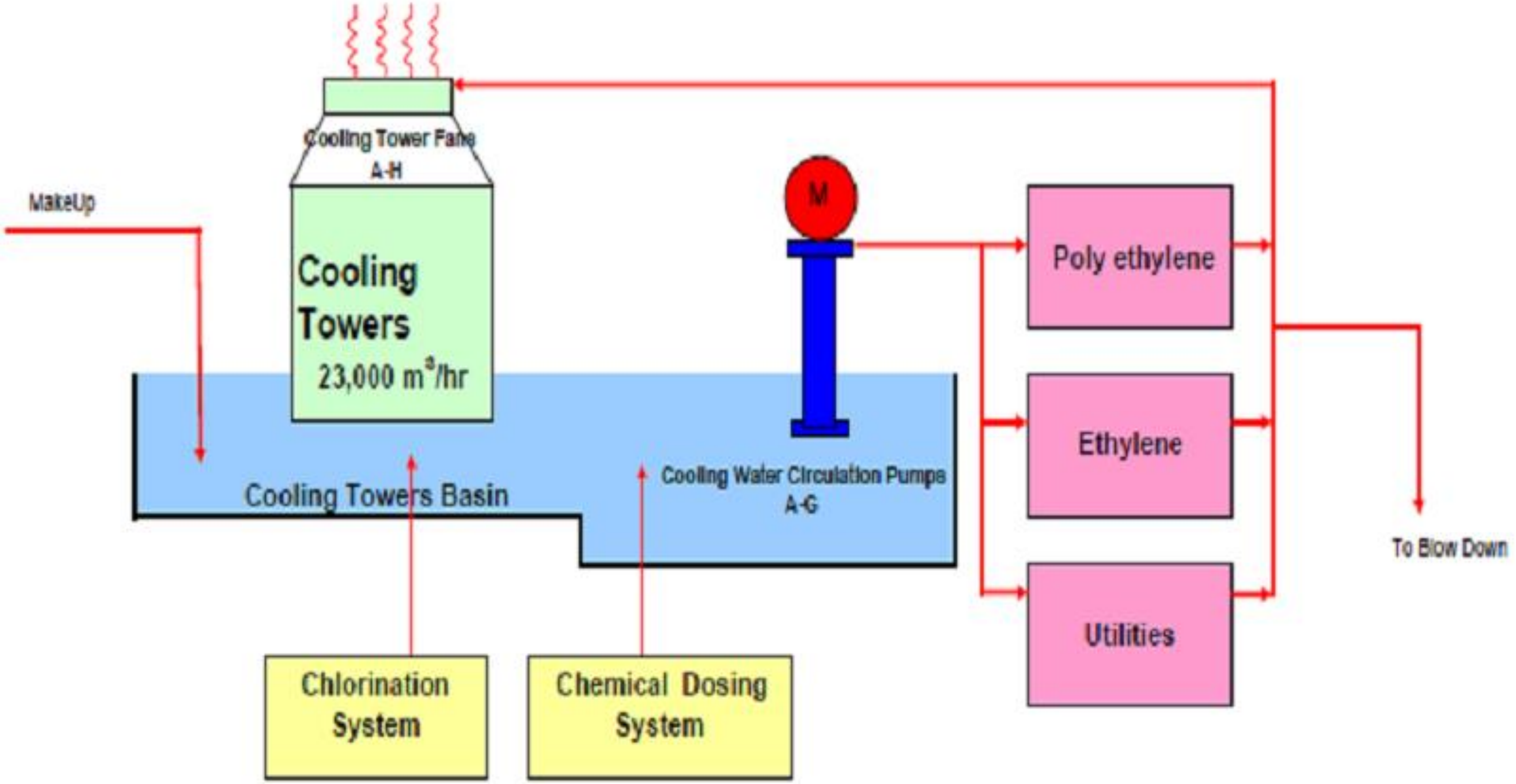


SOURCE: www.arcelormittalsa.com

Motor System Overview

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

- Simple bock diagram of motor system being assessed
- Operating parameters for production
- Pie chart or bar chart of SEUs if available



SOURCE: SIDPEC

Plant Electrical Network and Costs

- Overall plant energy consumption
- Major energy drivers if available
- Simplified single line layout
- Highlight the motor system to be assessed

Motor System Selection

- An explanation of how the motor system was chosen and why
- Usually with a list of the major motors at the plant

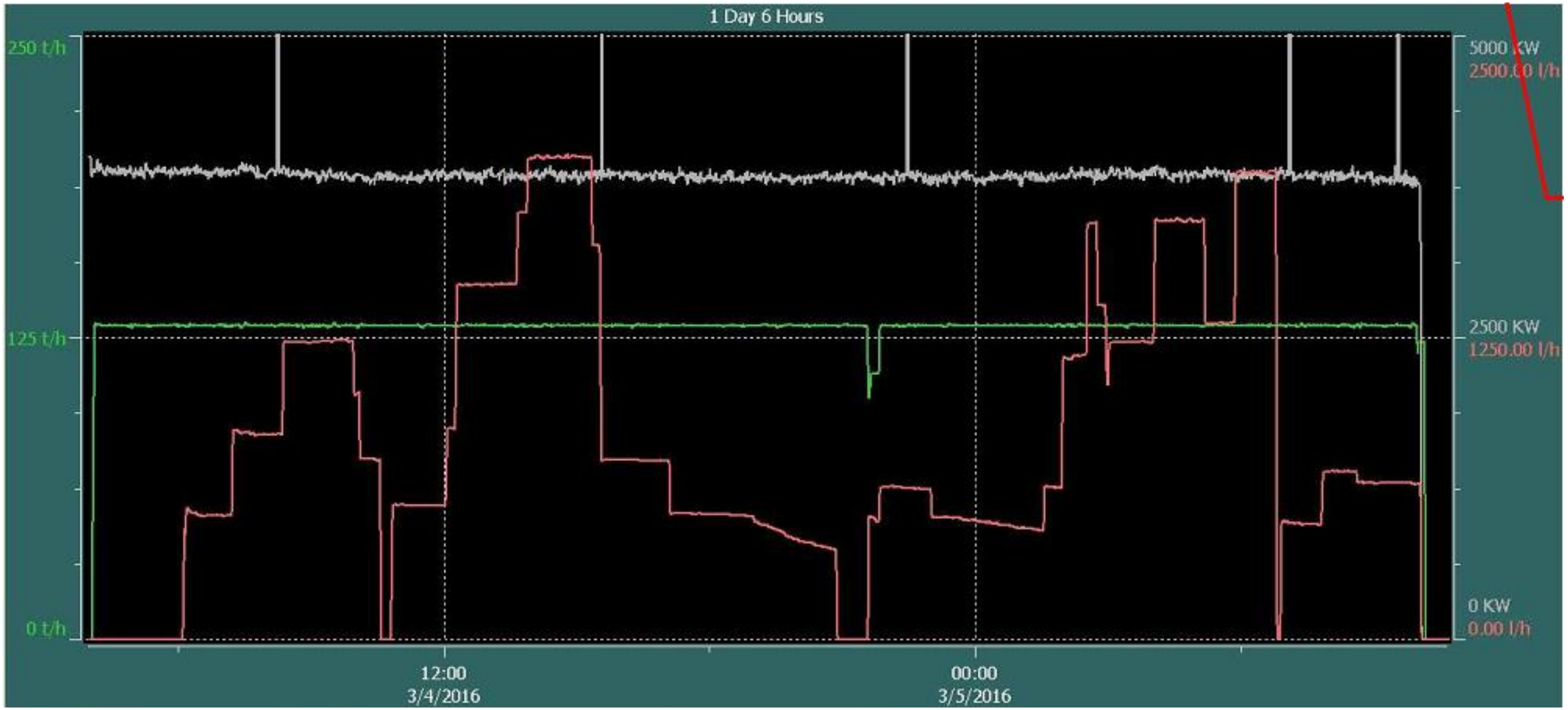
Major Motor List

	Plant System	Motor Application	No of Motors	Rated Power	total
1	Refrigiration A300	OLD Comp. NH3	5	300	**1500**
2	Refrigiration A300	NEW Comp. NH3	4	330	**1320**
3	Refrigiration B08	Comp. NH3	3	400	**1200**
4	air compressors	air comp motor	4	135	**540**
5	air compressors	air comp motor	2	250	**500**
6	Refrigiration A300	5 ºC pump	4	75	**300**
7	air dryer	Compr. Air dryer	3	90	**270**
8	Amenity Chillerno.1	Chiller Comp no. 2	2	104	**208**
9	B08 colling tunnel 1	Cooling cell from 1 to 12	12	17	**204**
10	B08 colling tunnel 2	Cooling cell from 1 to 12	12	17	**204**
11	process(UHT3.4.5)	UHT3.4.5	1	200	**200**
12	Amenity Chillerno.1	Chiller Comp no. 1	2	90	**180**
13	process(UHT3.4.5)	UHT3.4.5	1	160	**160**
14	process	MP1	1	132	**132**
15	Amenity Chillerno.1	Chiller Comp no. 3	2	63	**126**
16	Refrigiration A300	OLD Evap. Cond fan	4	30	**120**
17	Refrigiration B08	MPG Secondary Pumps	3	37	**111**
18	process(UHT3.4.5)	UHT3.4.5	6	18.5	**111**
19	process(UHT2)	UHT2	1	110	**110**
20	process(UHT3.4.5)	UHT3.4.5	1	110	**110**
21	process	CIP 4	7	15	**105**
22	air dryer	Compr. Air dryer	1	104	**104**

Measurements and Findings

- Measurement of existing energy parameters
- Operating conditions of load and process
- Set points and specifications of load and process

Process Load Profile

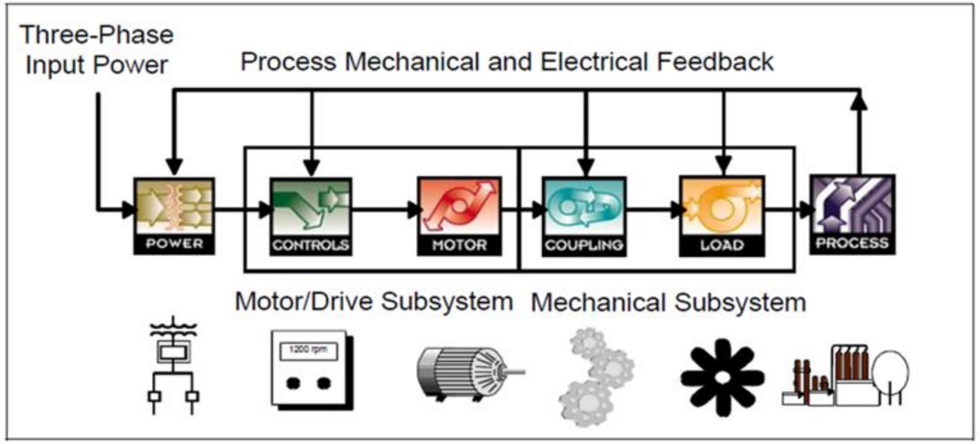


Provide a suitable explanation of the load profile.

Analysis

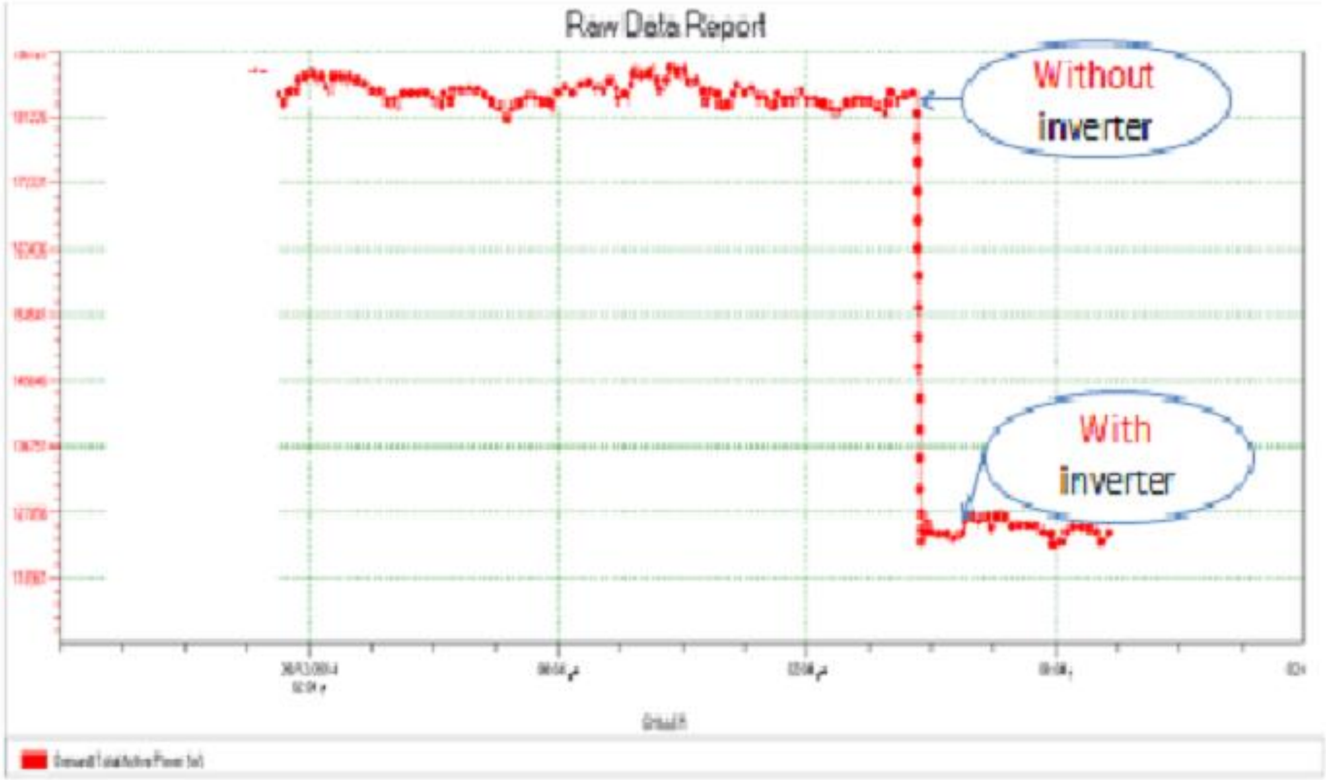
- Must include baseline (initial energy consumption) calculation
- Must include an analysis of all elements of the motor system
- Include any assumptions (eg. costs, operating parameters) that were used to calculate energy consumption.

Analysis of the Motor System



All elements of the system should be investigated and analysed.

Analysis of the Motor System



Good example of graphic to show savings results

Energy Savings Opportunities

- After analysis and identification of opportunities
- Quantify each opportunity (energy savings)
- Rank the opportunities using a risk matrix relevant to your organisation
- Summary table or diagram to highlight key numbers and options

Risk Matrix for Opportunities

- An example of a simple risk matrix for opportunities. The actual energy and cost savings could be included in the matrix.
- The risk column may be expanded to include for example, production risk, financial risk, overall business risk.

Sr.	Proposal Description	Implementation Cost	Implementation Time	Payback Time	Risk
1	Medium voltage drives	Very high	Very high	Medium	No Risk
2	Enhanced Soft starter	high	Very high	Medium	Low
3	Switching ON/OFF	No Cost	Immediately	Immediately	Very High
4	Optimizing the operation control	No Cost	Immediately	Immediately	No Risk

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

Good Opportunities Summary

Egyptian program for promoting Industrial Motor Efficiency
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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**

Recommendations

- From the list of opportunities, recommend which ones will be implemented and in which order.
- If opportunities will not be implemented or will be delayed, explain why.

Financial Evaluation of MSO Projects

- Basic types of evaluation
- Time value of money
- NPV and LCC

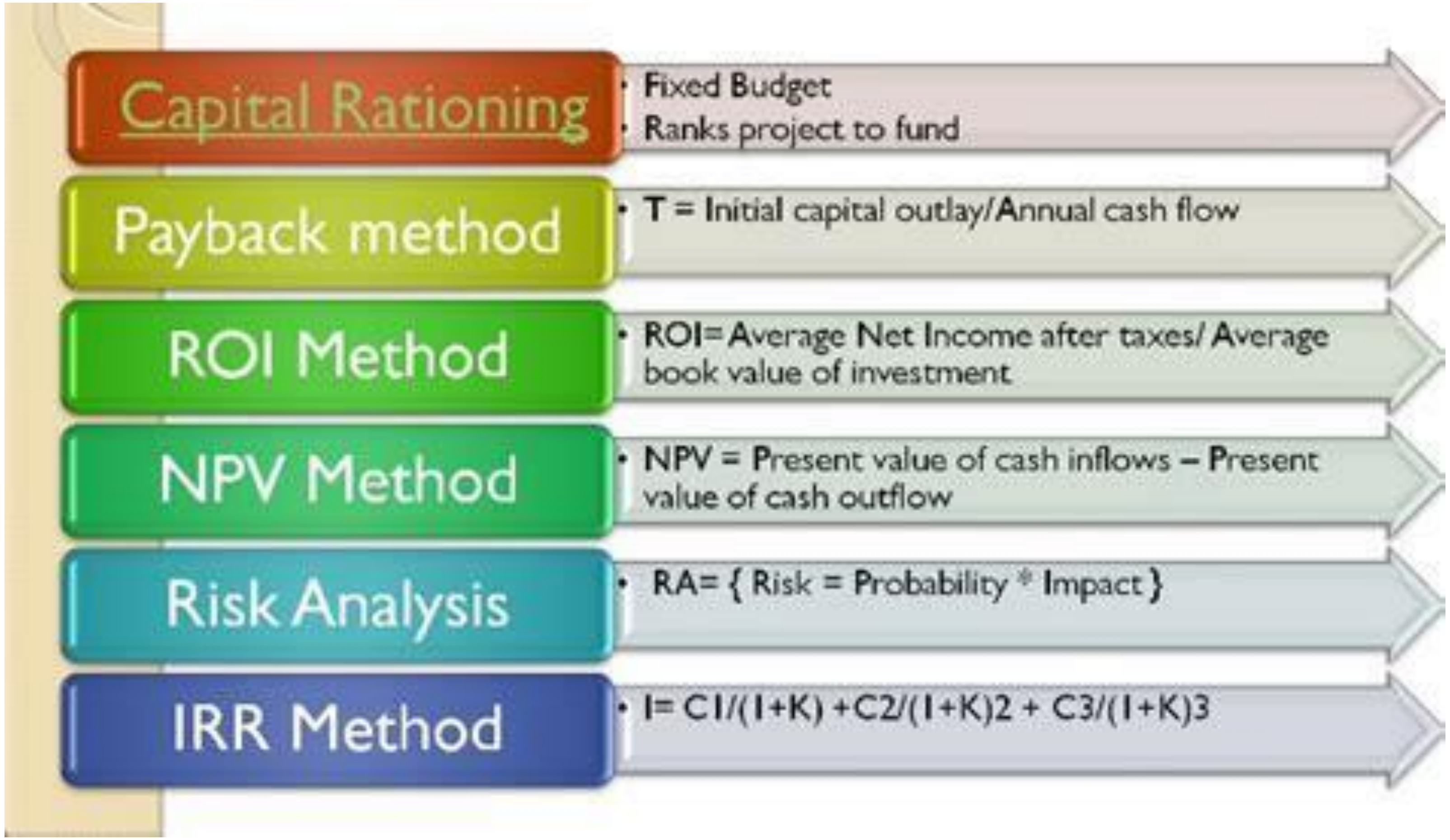
What is financial appraisal?

- All organisations need to control spending
  - Current spending (expenses)
  - Capital spending (investment)

- Need to make choices of where to spend
  - Spend; Yes or No?
  - Choose between options for investment in savings project
  - Choose between options using life cycle cost (LCC)

- Need tools to help with these choices

Common Methods of Appraisal



Source: www.slideshare.net

Some Financial Choices

- Two motors are the same
  - One costs EGP300 000 and the other EGP250 000
  - Which one should you buy?

- Two motors are not the same
  - One costs EGP300 000 and the other EGP250 000
  - Which one should you buy?

- I will give you EGP100 now or EGP200 in 12 months time?

- Two compressors:
  - One costs EGP50,000 to buy and EGP100,000 p.a. to operate
  - The other EGP60,000 to buy and EGP90,000 p.a. to operate
  - Which is best?

Simple Payback (SPB)

- SPB = Initial Cost / Annual Savings
- Usually organisations have a limit e.g. only opportunities with a payback of less than 2 years will be considered
- Called “simple” because it does not take into consideration the effects of inflation, taxes and the cost of capital

Simple Payback (SPB)

Egyptian program for promoting Industrial Motor Efficiency
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Advantages

- Simple and quick
- Good starting point to rank projects
- Useful as a quick estimate
- Can be used for low cost opportunities

Disadvantages

- Too simple for large or critical projects that require a detailed analysis
- Does not account for inflation, discount rates
- Does not account for life cycle costs

Time Value of Money

- Very important concept !!

- If I offer you the choice of EGP5,000 now or EGP800 p.a. for 10 years which would you choose?
  - Option 1: You spend both forms of payment upon receipt
  - Option 2: You invest both forms of payment at 11% interest pa and 22% inflation

Inflation and Interest

- Due to inflation, money is worth less in future than it is now.
- Assuming 22% inflation, then EGP100 now is worth EGP78 in one year's time.
- Investing money in a bank, the nominal value of the money grows at the interest rate.
- Assuming an interest rate of 11%, EGP100 will be EGP111 at the end of the year.
- But due to inflation that EGP111 will only have the buying power of EGP86.50

Discount rate (or hurdle rate)

Need to know discount rate

- This is the return the organisation will decide to invest at
- Sometimes increased for more risky projects
- Related to the cost the organisation incurs in raising the capital
- Weighted average cost of capital (WACC) (debt and equity)
- Usually your accountant will know the discount rate
- Assuming the money is available

Net Present Value (NPV)

- Present Value (PV) or present worth (PW)
  - The value now of a future amount of money
  - EGP100 in 1 year at 22% inflation has a present value of EGP78

- NPV is the value now of a future stream of cash flows
  - Negative cash flows are outgoing
  - Positive cash flows are incoming
  - In energy terms, we invest in a project now to make a saving in energy in future
  - We may include maintenance and repair costs
  - We may have a scrap / salvage value at the end

Net Present Value (NPV)

$$PV = \frac{FV}{(1+i)^n}$$

- Where
- *PV is the present value of all incoming cash flows*
- *FV is the sum of all cash flows*
- *i* is the discount rate
- *n* is the number of periods

$$NPV = PV - INV$$

- INV is the initial investment
- NPV is the net present value
- If NPV > 0 then it is profitable
- It is viable if:
  - If you have the money
  - It is the best NPV available
  - It is practical and will not affect production

Worked Example

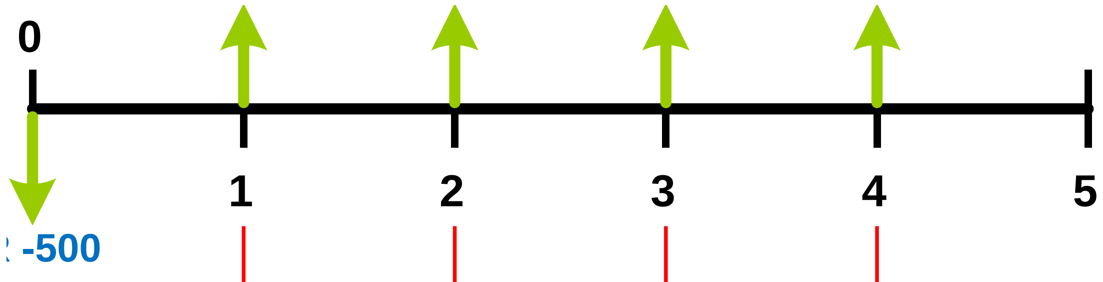
EGP1000 investment and EGP200 savings for 4 years at a 22% discount rate. Savings increase at 12% p.a.

$200 * (1.12)^1 = \text{EGP } 224$

$200 * (1.12)^2 = \text{EGP } 251$

$200 * (1.12)^3 = \text{EGP } 281$

$200 * (1.12)^4 = \text{EGP } 315$



$$\frac{-500}{(1.22)^0} = \text{EGP } -500$$

$$\frac{224.00}{(1.22)^1} = \text{EGP } 184$$

$$\frac{251}{(1.22)^2} = \text{EGP } 169$$

$$\frac{281}{(1.22)^3} = \text{EGP } 155$$

$$\frac{315}{(1.22)^4} = \text{EGP } 142$$

NPV = EGP 150

YES!

Positive cash flow (incoming e.g. savings)
Negative cash flow (outgoing e.g. investments)

Internal Rate of Return (IRR)

- Very similar to NPV
- Doesn't use discount rate, but calculates a rate of return (IRR) based on the projected cash flows
- The IRR is then compared with the discount rate (or the company hurdle rate, or with the IRR of other projects)
- If IRR = discount rate, then NPV = 0
- If IRR > discount rate, then NPV > 0

IRR = indicator of the efficiency of yield (%)
NPV = indicator of the magnitude of investment return (EGP)

NPV and IRR Calculation – UNIDO Tool

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Financial Benefits of an investment				
Year 0	- 500		Discount Rate	22%
Year 1	224		Savings Inflation	12%
Year 2	251			
Year 3	281			
Year 4	315			
Year 5				
Year 6				
Year 7				
Year 8				
Year 9			**NPV**	**R 148.96**
Year 10			**IRR**	**36%**

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.

Life Cycle Cost (LCC)

- Example
  - Buy a fixed speed pump for EGP 5,000 and annual running costs of EGP7,000

OR

  - Buy a variable speed pump for EGP 10,000 and annual running costs of EGP 3,000

Life Cycle Cost (LCC) – UNIDO Tool

Life Cycle Costing (LCC)				
	Option 1	Option 2		
Cost	-5,000	-10,000	Interest/Discount	22%
Year 1	-7,000	-3,000	Savings Inflation	12%
Year 2	-7,840	-3,360		
Year 3	-8,781	-3,763		
Year 4	-9,834	-4,215		
Year 5	-11,015	-4,721		
Year 6	-12,336	-5,287		
Year 7	-13,817	-5,921		
Year 8	-15,475	-6,632		
Year 9	-17,332	-7,428		
Year 10	-19,412	-8,319		
LCC	**LE 45,237**	**LE 27,244**		

Review & Discussion

- Any questions?

15. eMobility

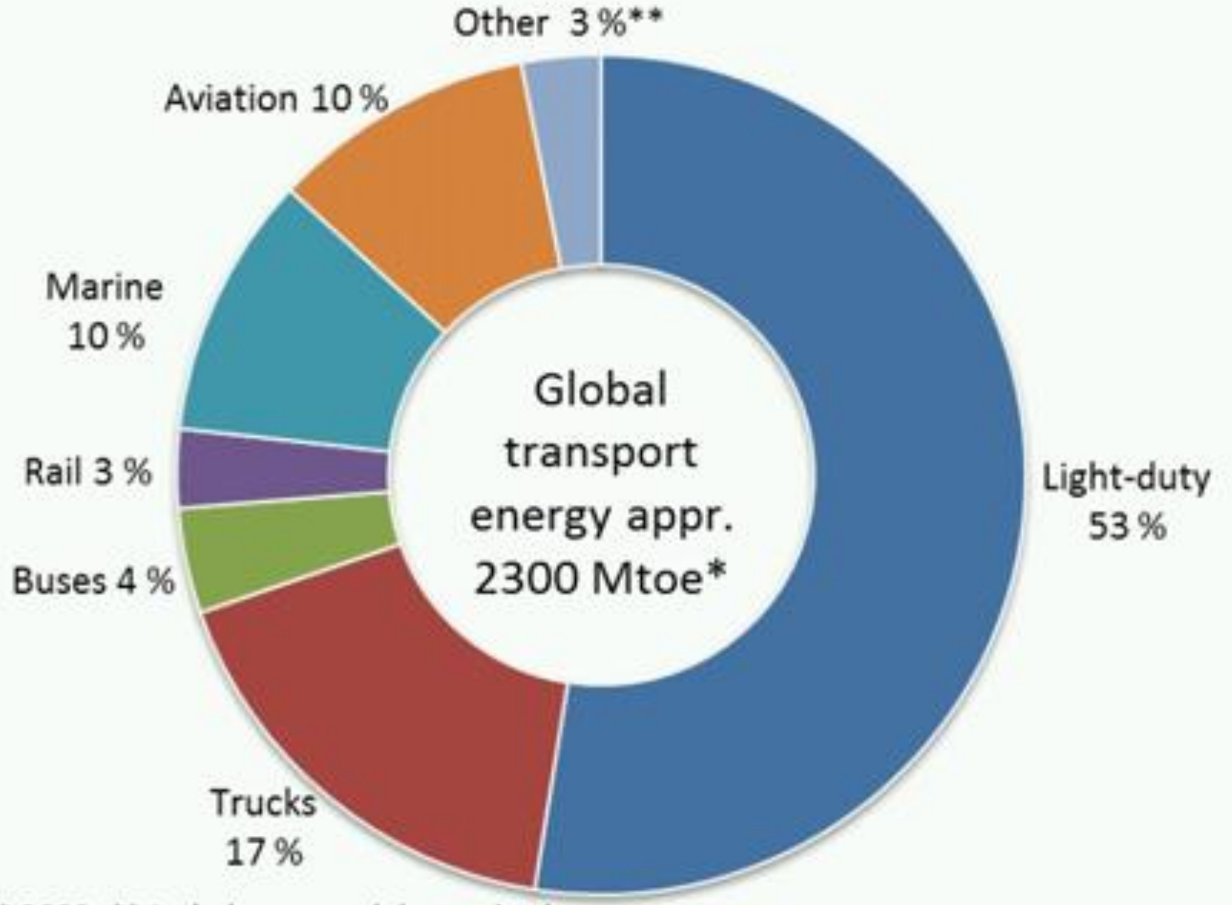
Motor Systems Optimisation (MSO) Expert Training
(2020 Egypt Edition)

Samir Khafagui
Siraj Williams

Discussed Topics

- Electric vehicle architecture
- Total supply chain efficiency for EVs
- Motor technologies used by EV manufacturers
- EV Motor Loads as Energy Storage to Balance Grid Supply
- EVs in the Public Transport Sector

Relative weight of each transport sub-sector in energy consumption (IEA, 2012).



* 2009 ** Includes two and three wheelers.
Data from World Economic Forum 2011 and IEA WEO 2011. Figure by IEA-AMF (A-S 2012).

Electric Vehicles (EV) and Sustainable Development

Electric mobility deals with means of transportation (two-wheel vehicles, cars, trucks, buses, trains, ships, airplanes) in which electricity is used to supply electric motors to provide, partially or totally, the mechanical power required to produce motion.

- **E--mobility a key solution for sustainable transport**
- Electricity as a fuel leads to more sustainable transport:
  - Reducing CO_2 emissions
  - Improving air quality
  - Increasing energy efficiency
  - Reducing oil dependence
- Environmental performance of EVs will further improve due to commitment to carbon-neutral electricity by 2050

Electric Mobility – 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

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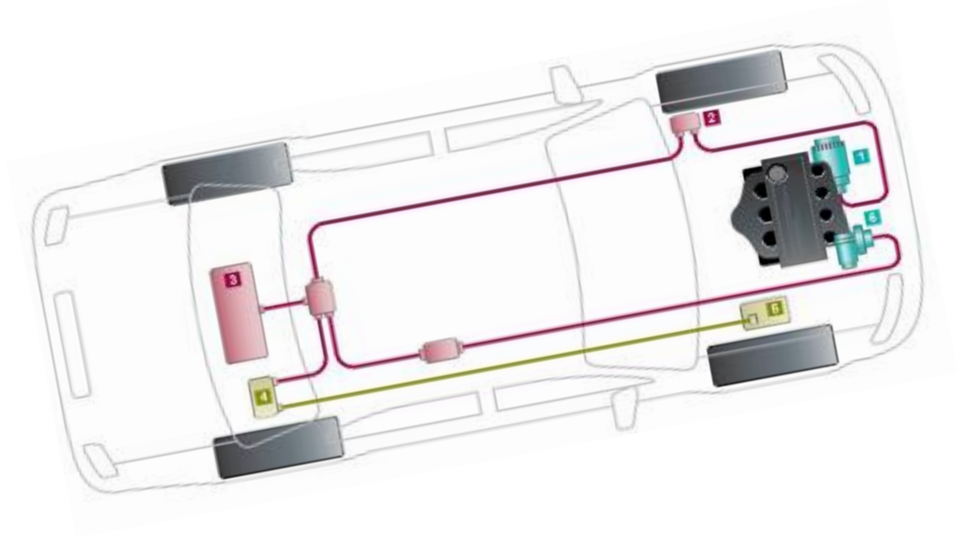
Mild Hybrid Vehicles

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

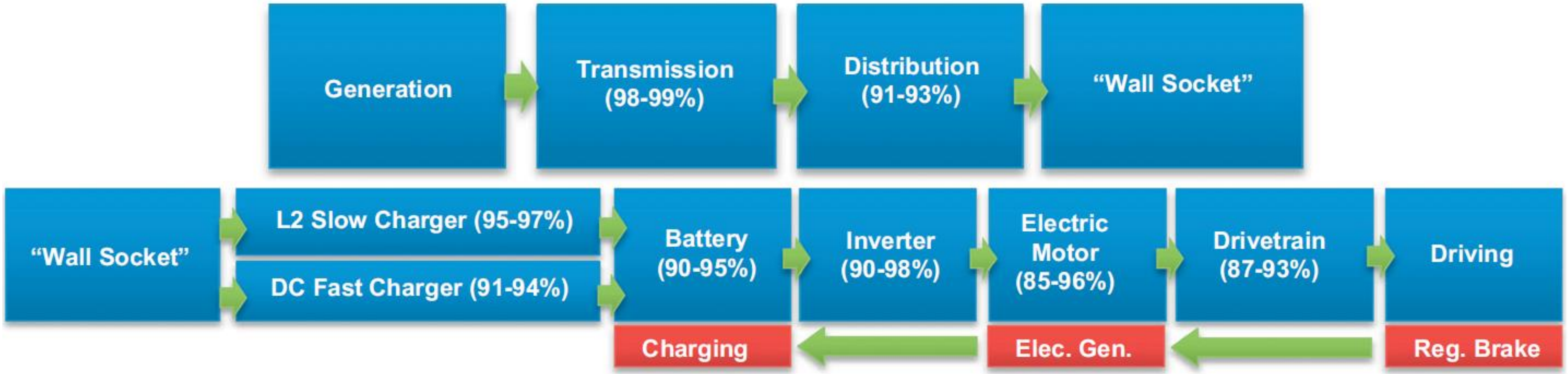


10 kW (or higher) starter motor/generator:

- 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



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

Comparison of Motor Technologies for EVs

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

Regenerative Braking

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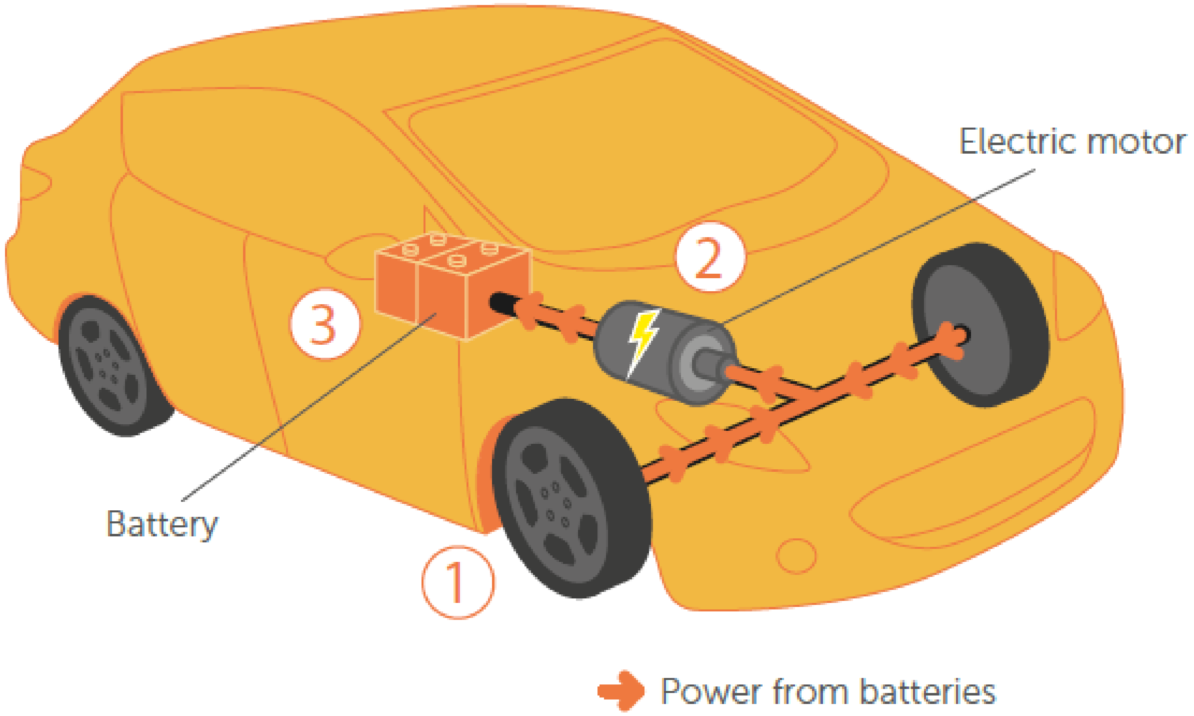
1. As the car brakes, the energy of motion from the wheels is transferred to the electric motor
2. The electric motor acts as a generator, producing electricity
3. This electricity is sent to the battery where it is stored

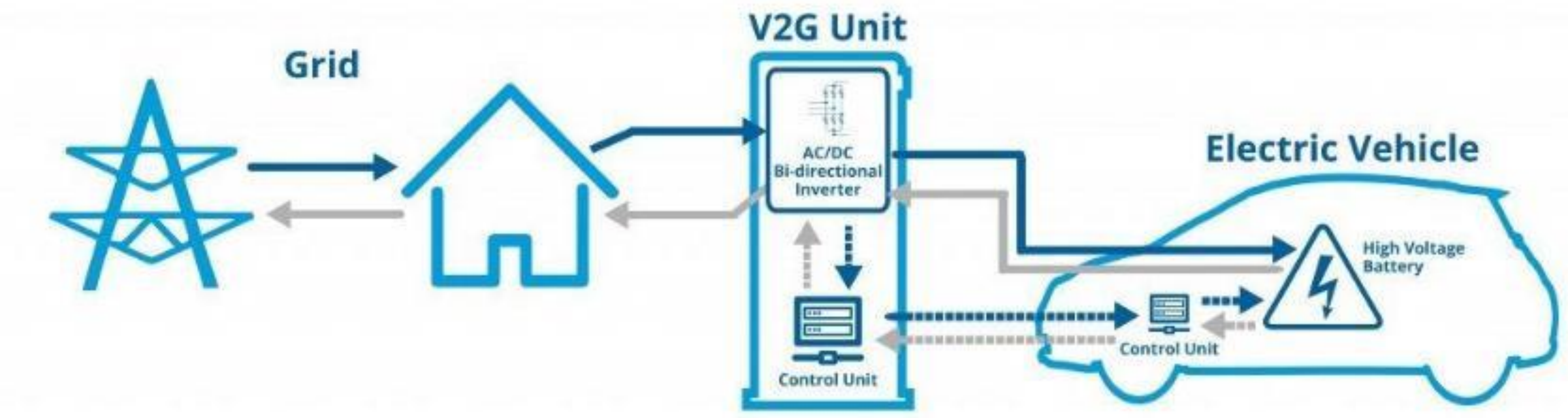


EVs and the Smart Power System

- 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

The Future of EV Recharge Stations

Electric Trucks - Scania

Permanent Magnet Synchronous Motor ~
-295 kW Peak power Peak Torque 2.200 Nm
-230 kW Continuous power Continuous Torque 1.300 Nm

Batteries - up to 300 kWh, with 130kW Fast charger

Autonomy -250 to 350 km dependending on driving cycle

Electric Buses

Cities around the world are introducing electric buses (e-buses), driven by growing concerns on air quality, CO_2 emissions and potential operational cost savings.

Electric Buses

Egyptian program for promoting Industrial Motor Efficiency
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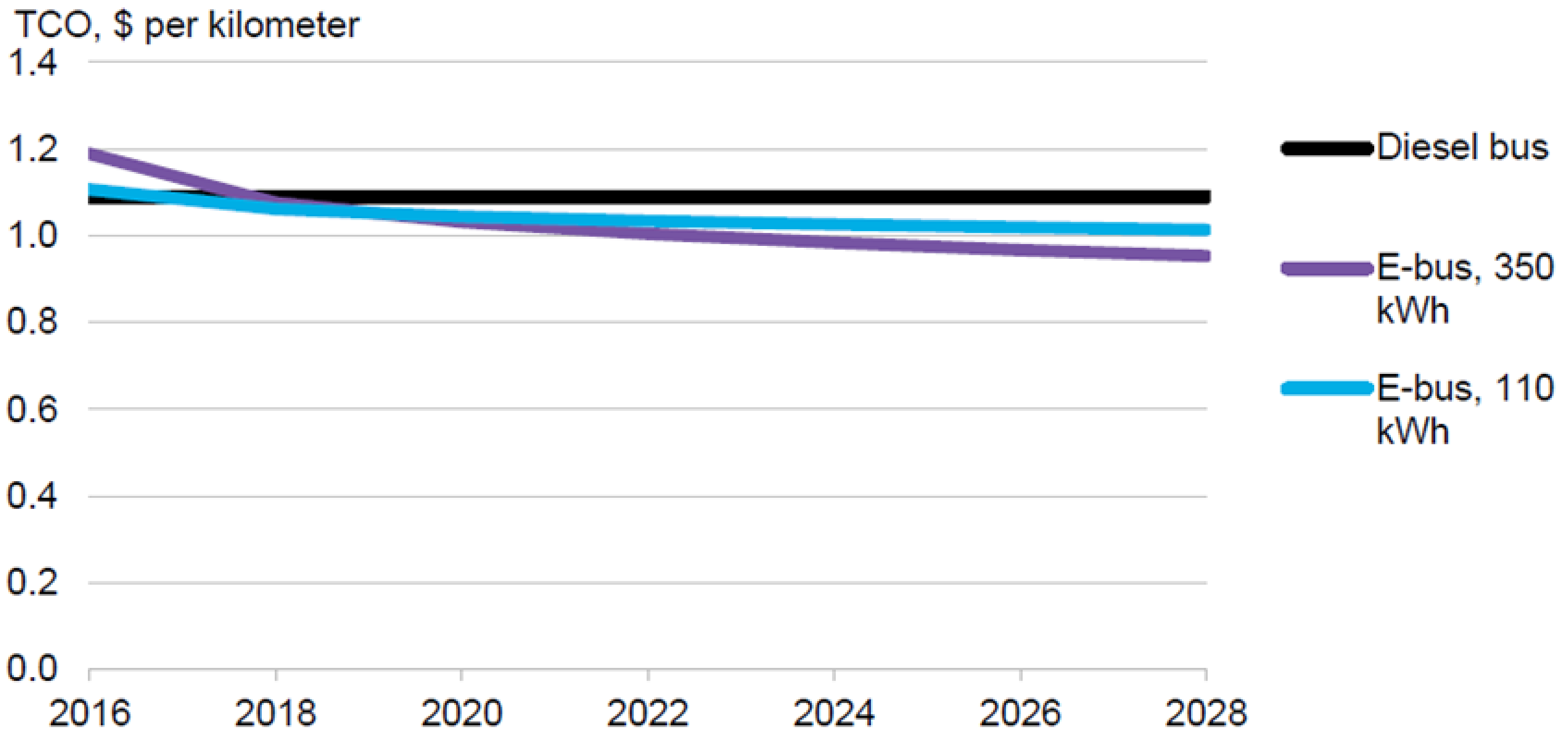
Beyond improvements in air quality, there are other factors that will further help to push the adoption of e-buses:

- 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.

E-bus Total Cost of Ownership



E-bus Total Cost of Ownership (TCO) forecast, assuming that the e-bus runs on average 56,000 kilometres per year.

Source: Bloomberg, 2018

Electric Buses – Made in Uganda

Egyptian program for promoting Industrial Motor Efficiency
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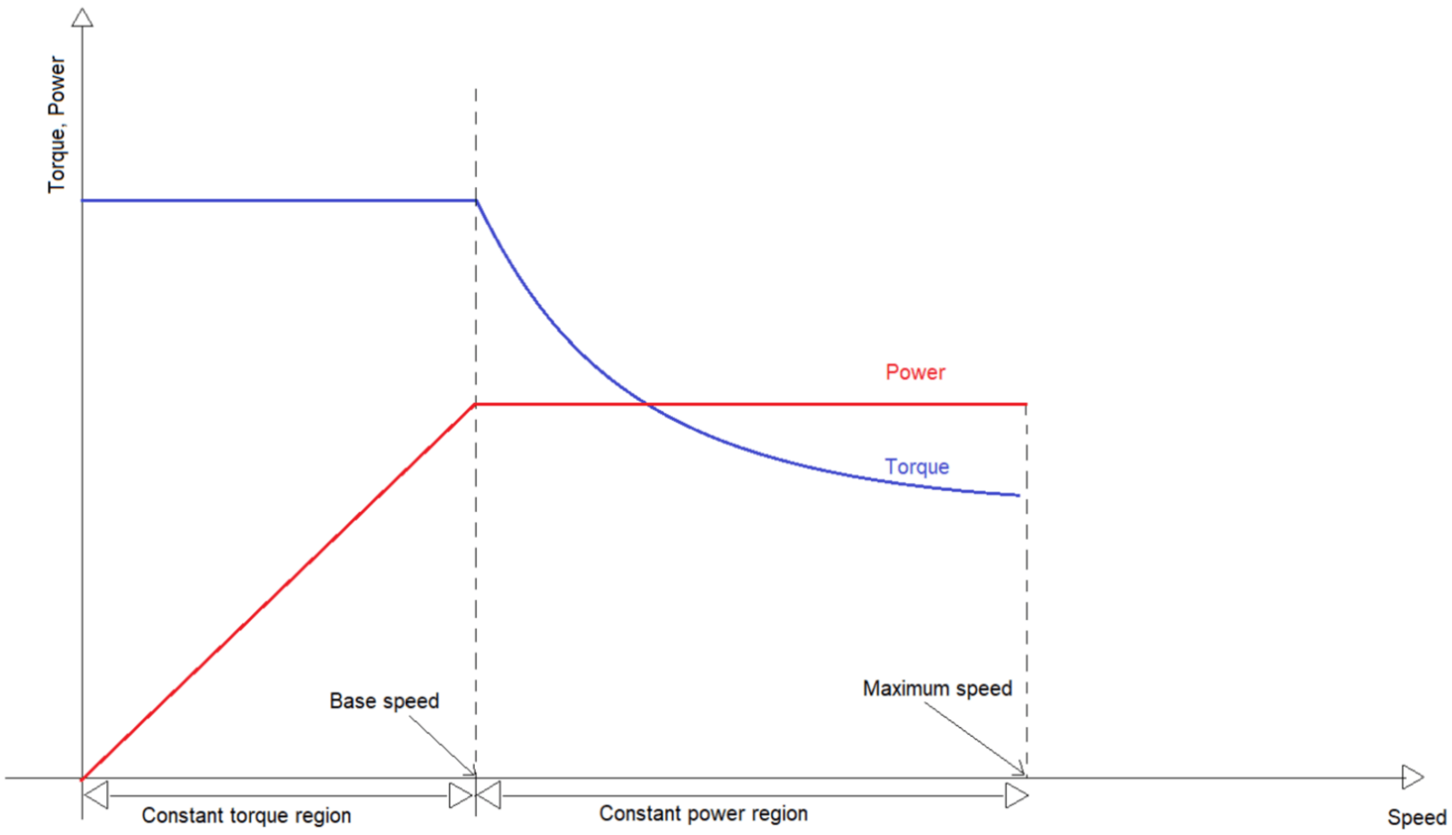
A good example for other countries to follow

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

Motors for Electric Vehicles

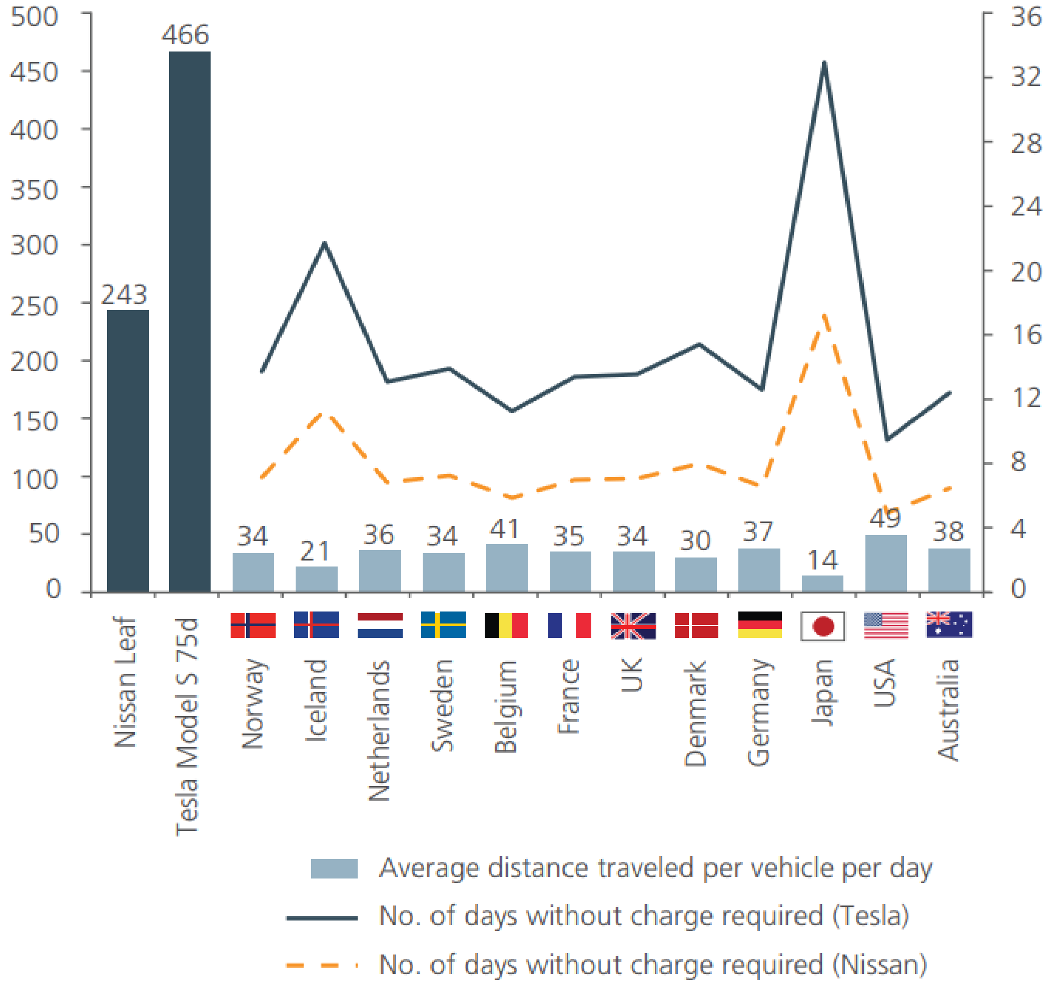


- The performance of the motor is determined by the torque-speed and power-speed characteristic of the traction motor.
- The constant torque operating region is important at low speed to provide a good start and up-hill drive. The constant power region determines the maximum EV speed on flat surfaces.

EV Travel Distances

Average distances traveled daily in several countries versus current EV autonomies and number of days between recharges.

As the battery technology improves, the number of days between recharges increasing, providing more freedom for EVs



- Any questions?

16. Demand Response and Smart Grids

Motor Systems Optimisation (MSO) Expert Training
(2020 Egypt Edition)

Samir Khafagui
Siraj Williams

Discussed Topics

- Sustainable Development, Energy Use and the Electricity Sector
- Demand Side Management and Demand Response
- Motor Loads as Flexible Loads to Balance supply and Demand

IEA – 2050 Sustainable Development Scenario

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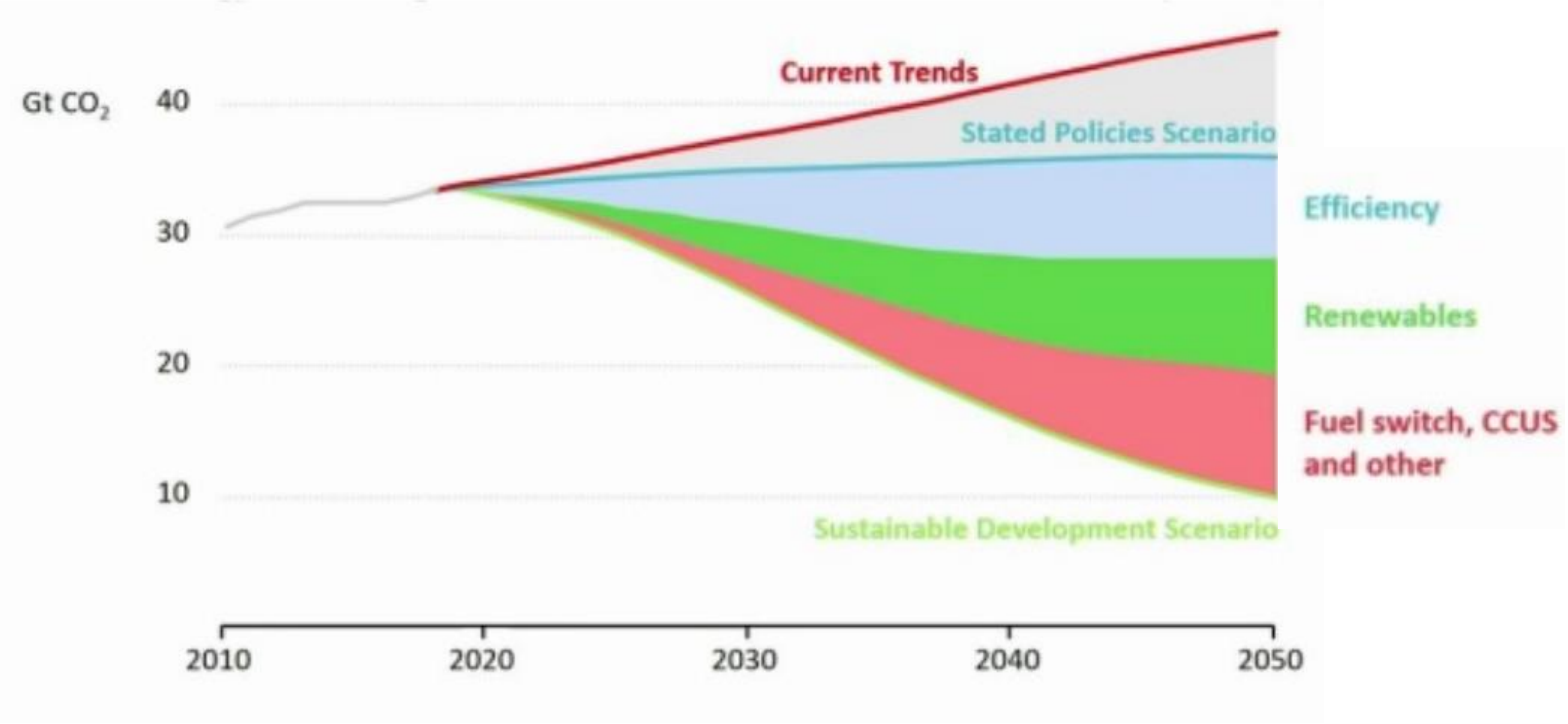
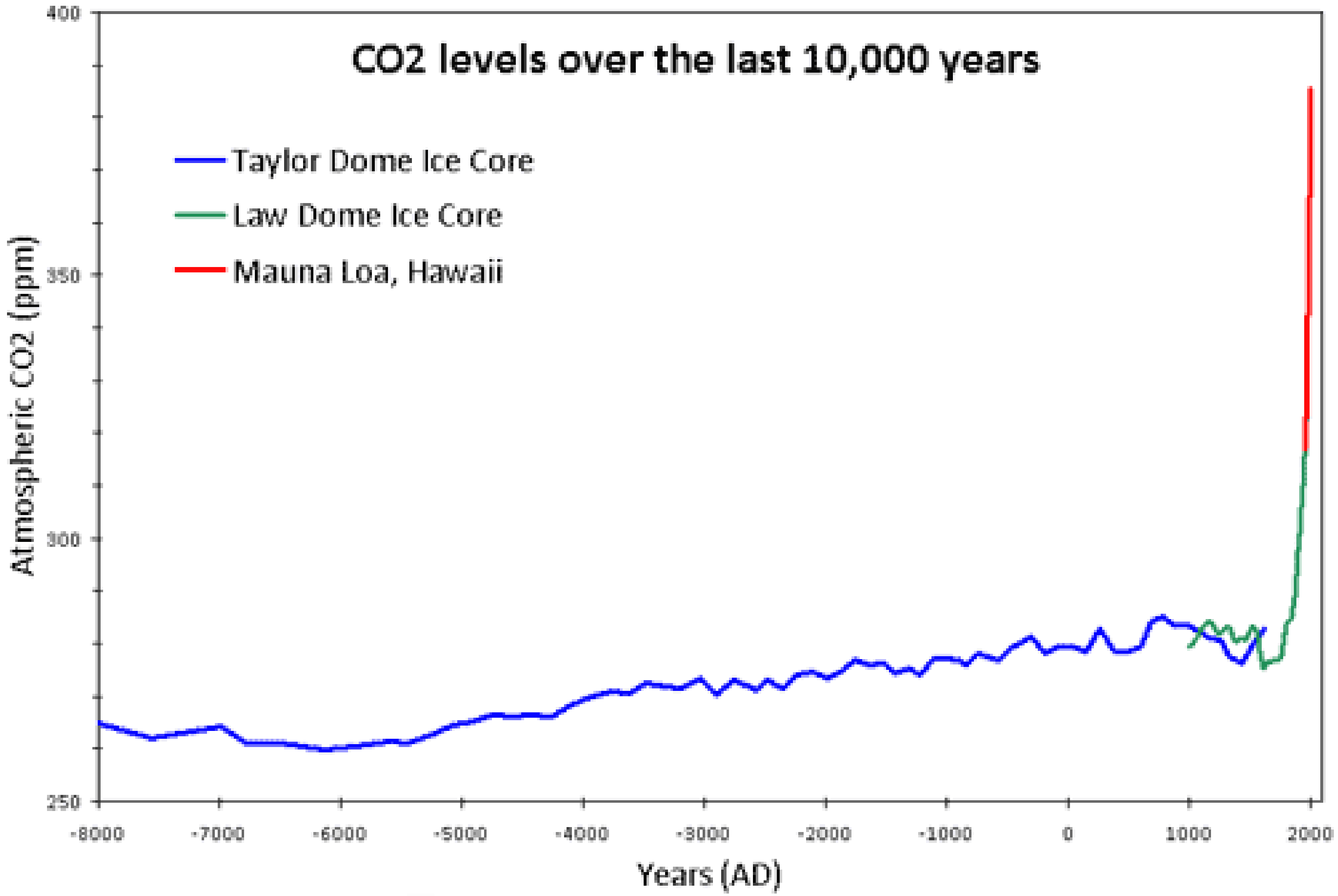


Is it necessary for carbon emission reduction?



Projected Global Emissions

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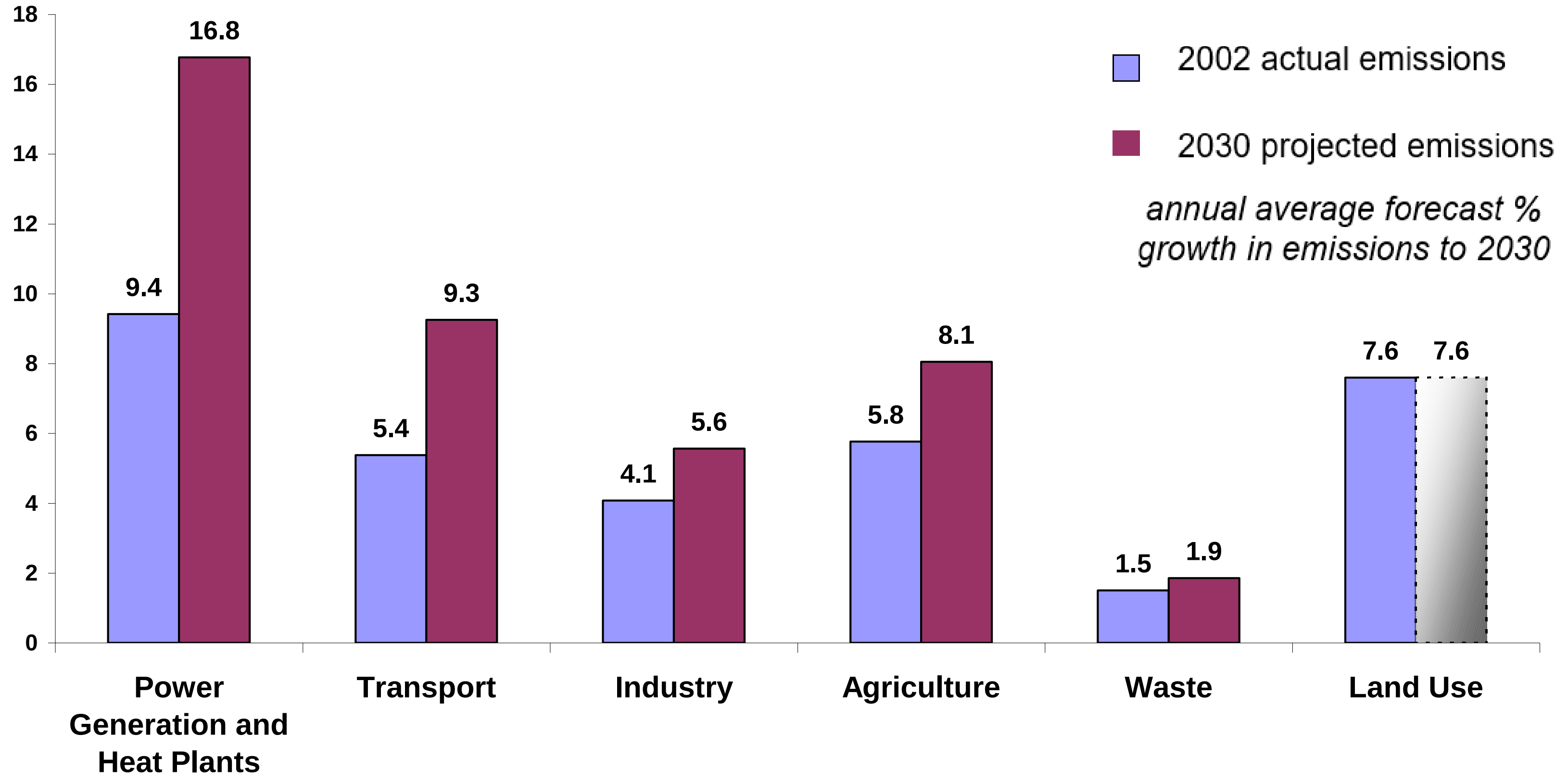
Global emissions are forecast to grow from all sources transport & power generation growing fastest



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IEA – Electricity Generation Projections

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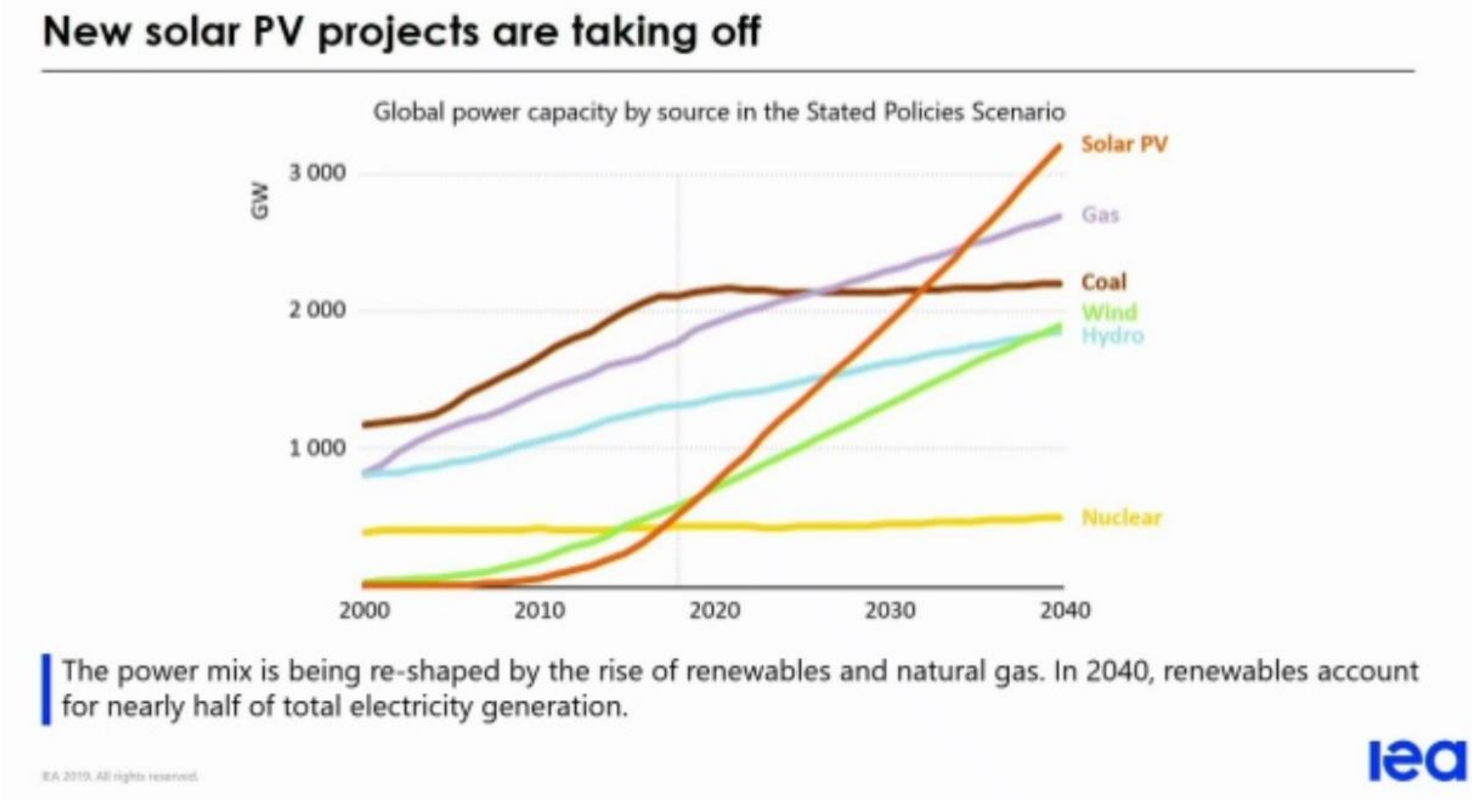
- Solar power becomes dominant - cheapest generation
- Very low cost – currently around 1.3 cents (US) / kWh



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

Importance of Demand Flexibility

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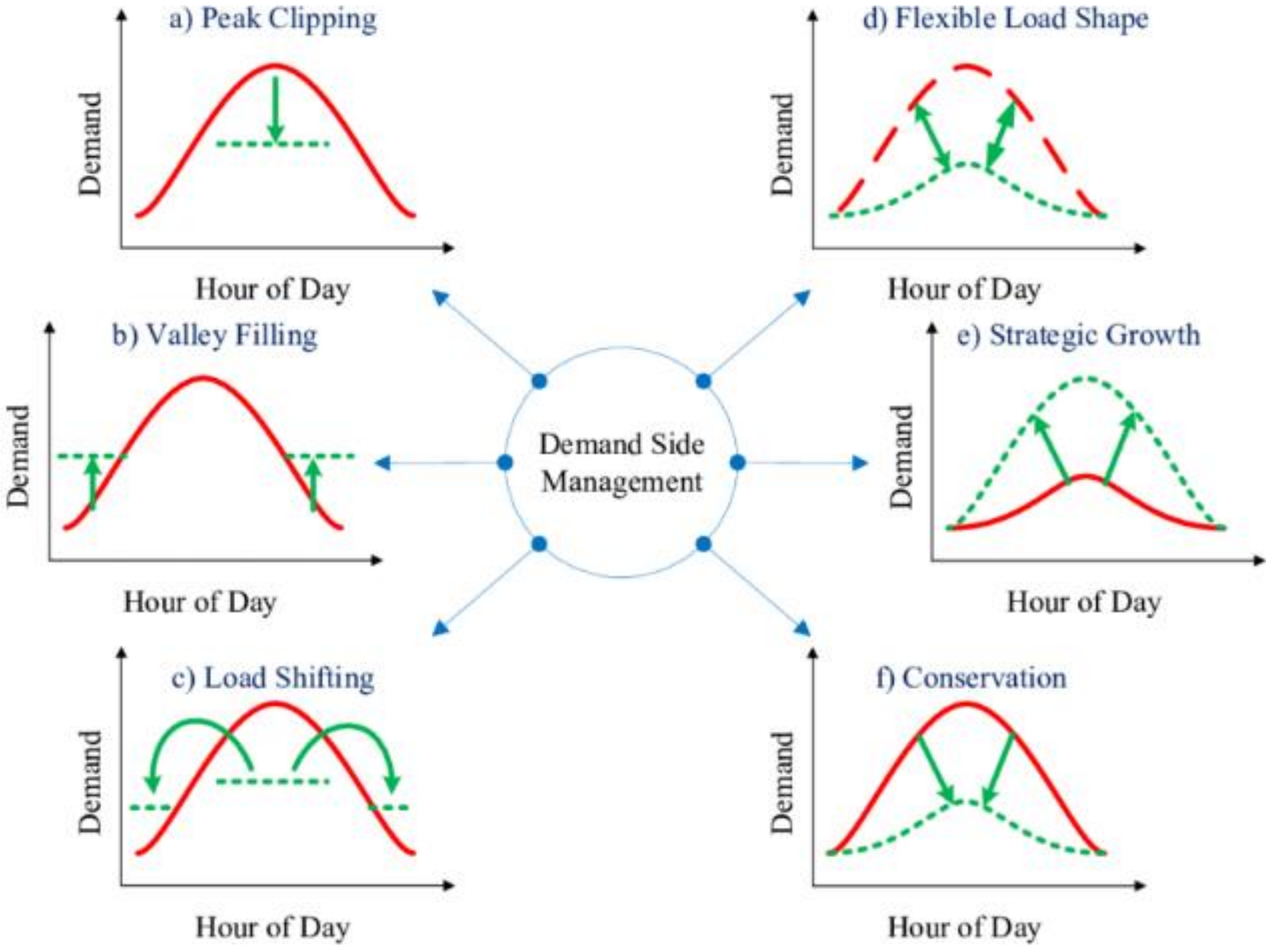
FUNDAMENTAL VALUE DRIVERS OF DEMAND FLEXIBILITY

CATEGORY	DEMAND FLEXIBILITY CAPABILITY	GRID VALUE	CUSTOMER VALUE
Capacity	Can reduce the grid's peak load and flatten the aggregate demand profile of customers	Avoided generation, transmission, and distribution investment; grid losses; and equipment degradation	Under rates that price peak demand (e.g., demand charges), lowers customer bills
Energy	Can shift load from high-price to low-price times	Avoided production from high-marginal-cost resources	Under rates that provide time-varying pricing (e.g., time-of-use or real-time pricing), lowers customer bills
Renewable energy integration	Can reshape load profiles to match renewable energy production profiles better (e.g., rooftop PV)	Mitigated renewable integration challenges (e.g., ramping, minimum load)	Under rates that incentivize on-site consumption (e.g., reduced PV export compensation), lowers customer bills

Essential for the integration of intermittent renewable generation (Solar PV + Wind)

Demand-Side Managment Strategies



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

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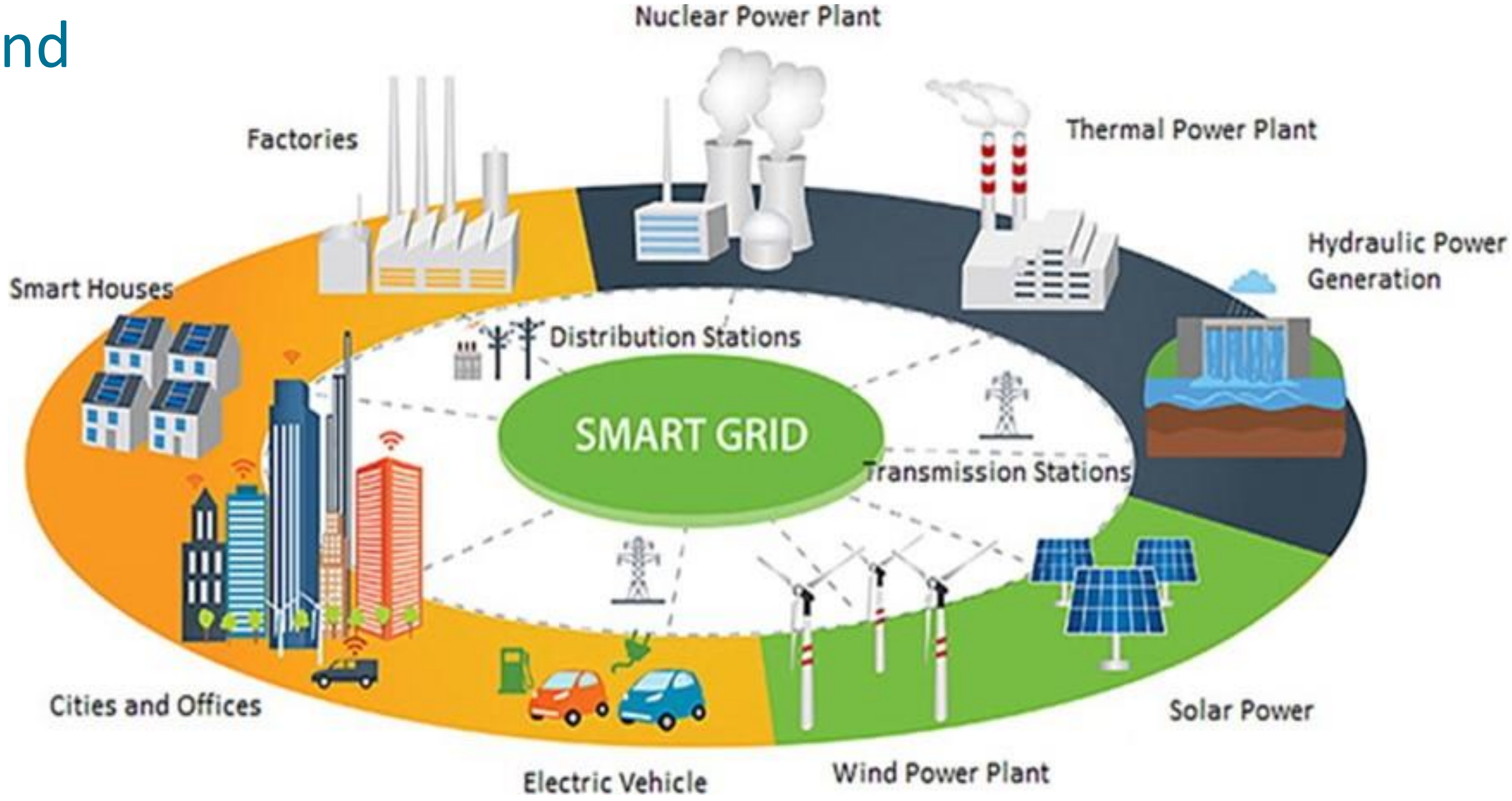
Integration of renewable energies and flexible loads



Large Flexible Motor Loads

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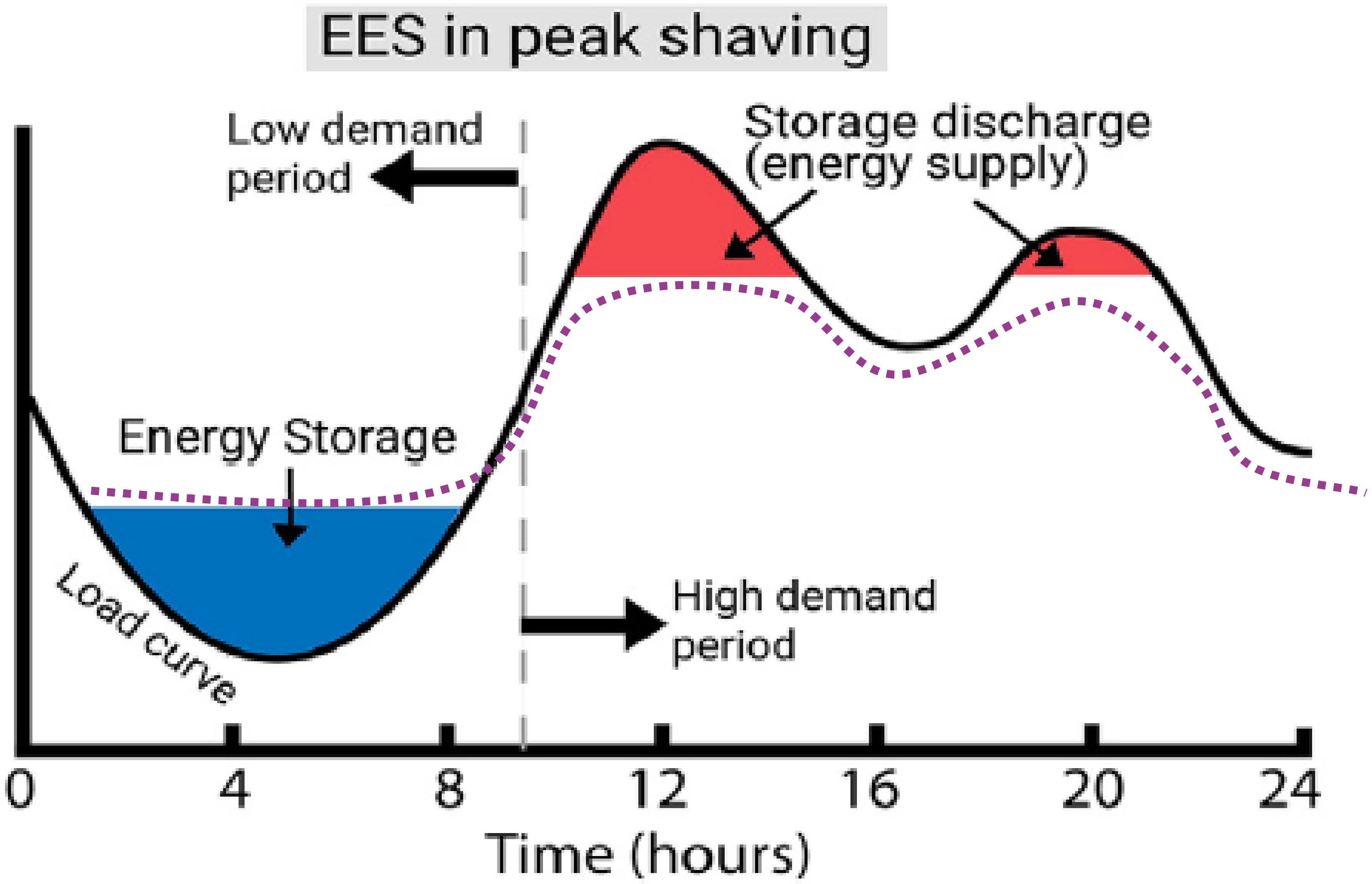
- Materials processing in industry (e.g. cement mills, mining industry)
- Refrigeration wharehouses
- Air conditioning loads with cool storage
- Large data centres
- Irrigation, namely to take advantage of solar power
- Sea water desalination, namely to take advantage of solar power, using water reservoirs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

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

Types of Energy Storage

- **Mechanical**
  - Pumped Hydro (PHS)
  - Compressed Air (CAES)
  - Flywheel (FES)
- **Electrochemical**
  - Electrochemical Batteries
    - Lead Acid
    - Nickel-based
    - Sodium-based
    - Li-ion
  - Flow Batteries
    - Redox Flow
    - Hybrid Flow
- **Electrical**
  - Supercapacitors
  - Superconducting Magnetic (SMES)
- **Chemical**
  - Hydrogen (Fuel cell)
- **Thermal**
  - Low Temperature
    - Aquiferous
    - Cryogenic
  - High Temperature
    - PCM
    - CSP

Storage Technologies Comparison

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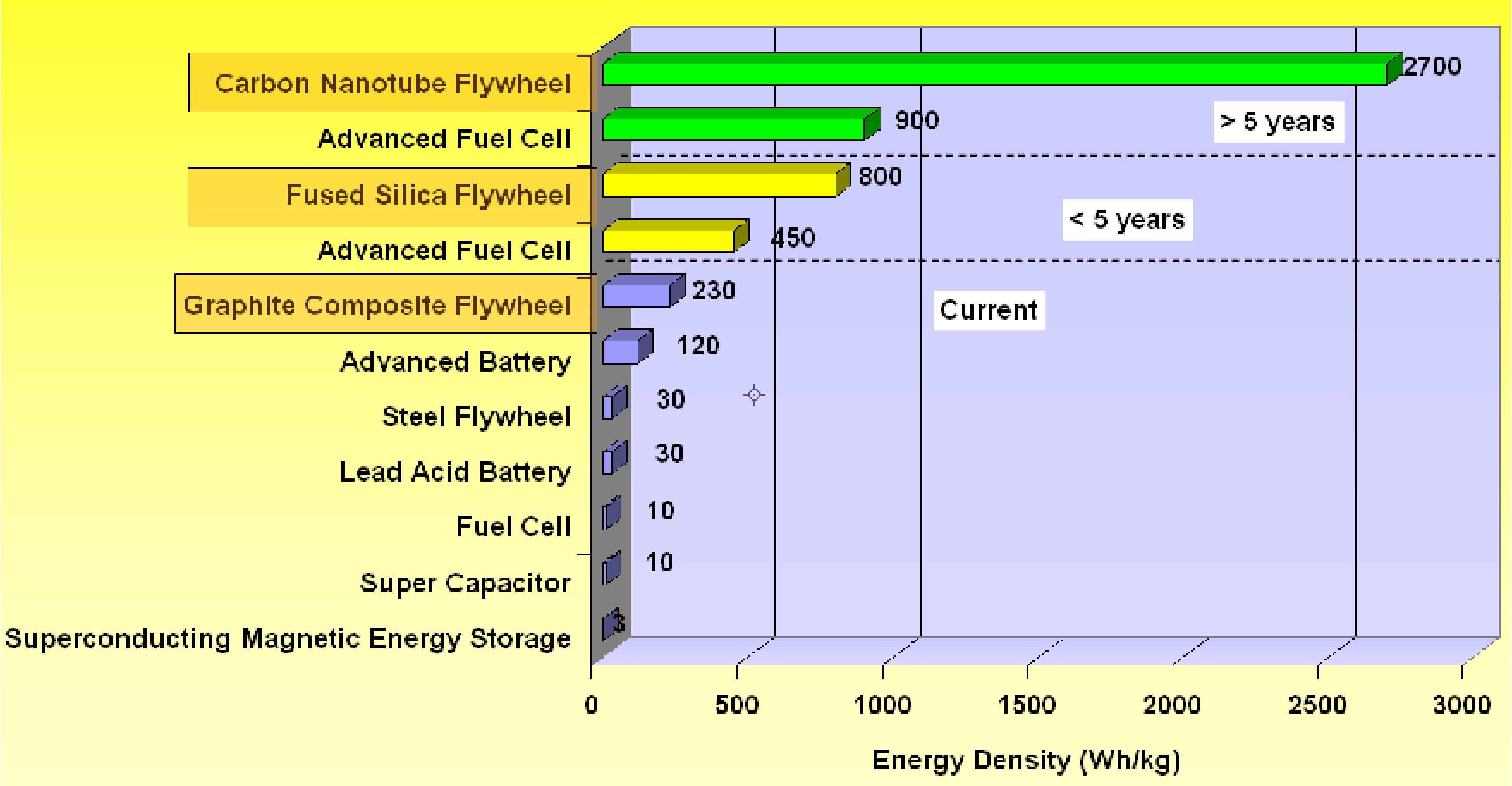
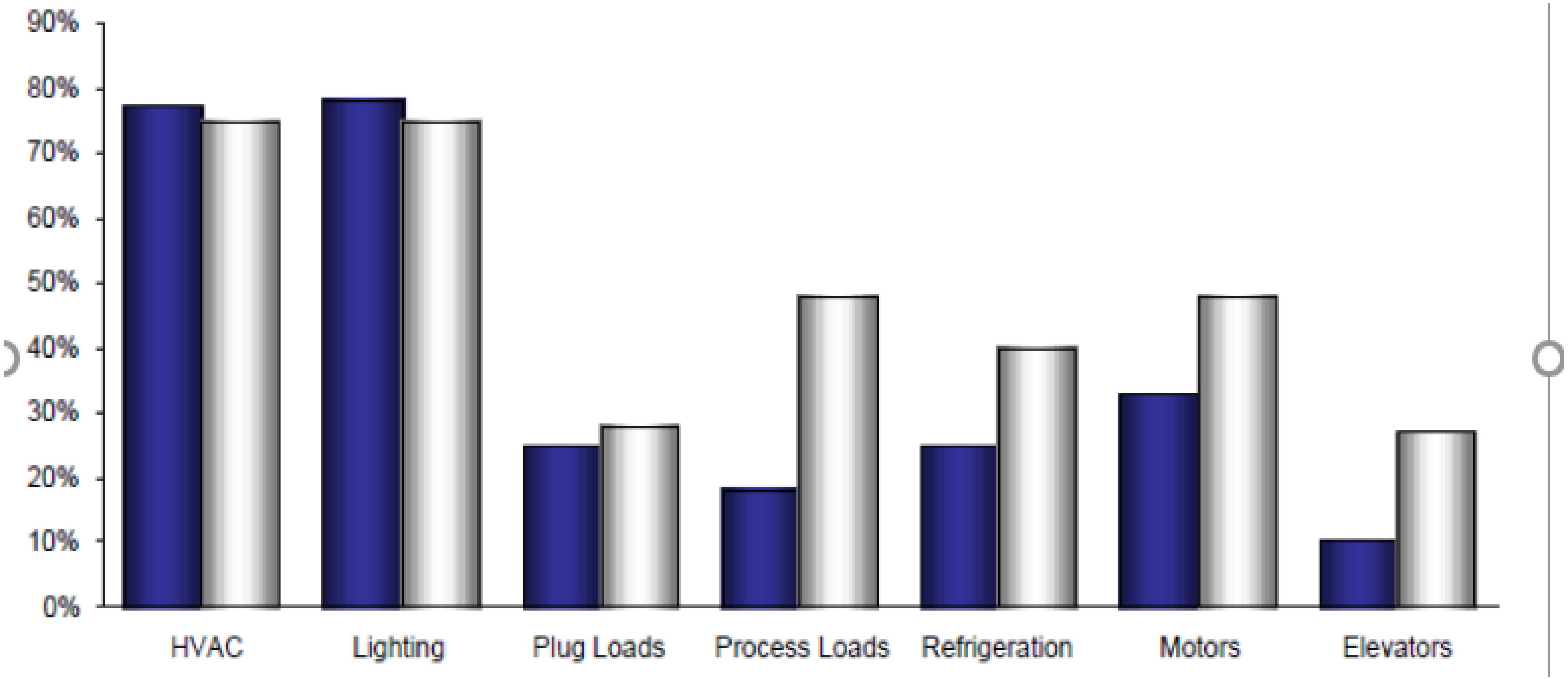
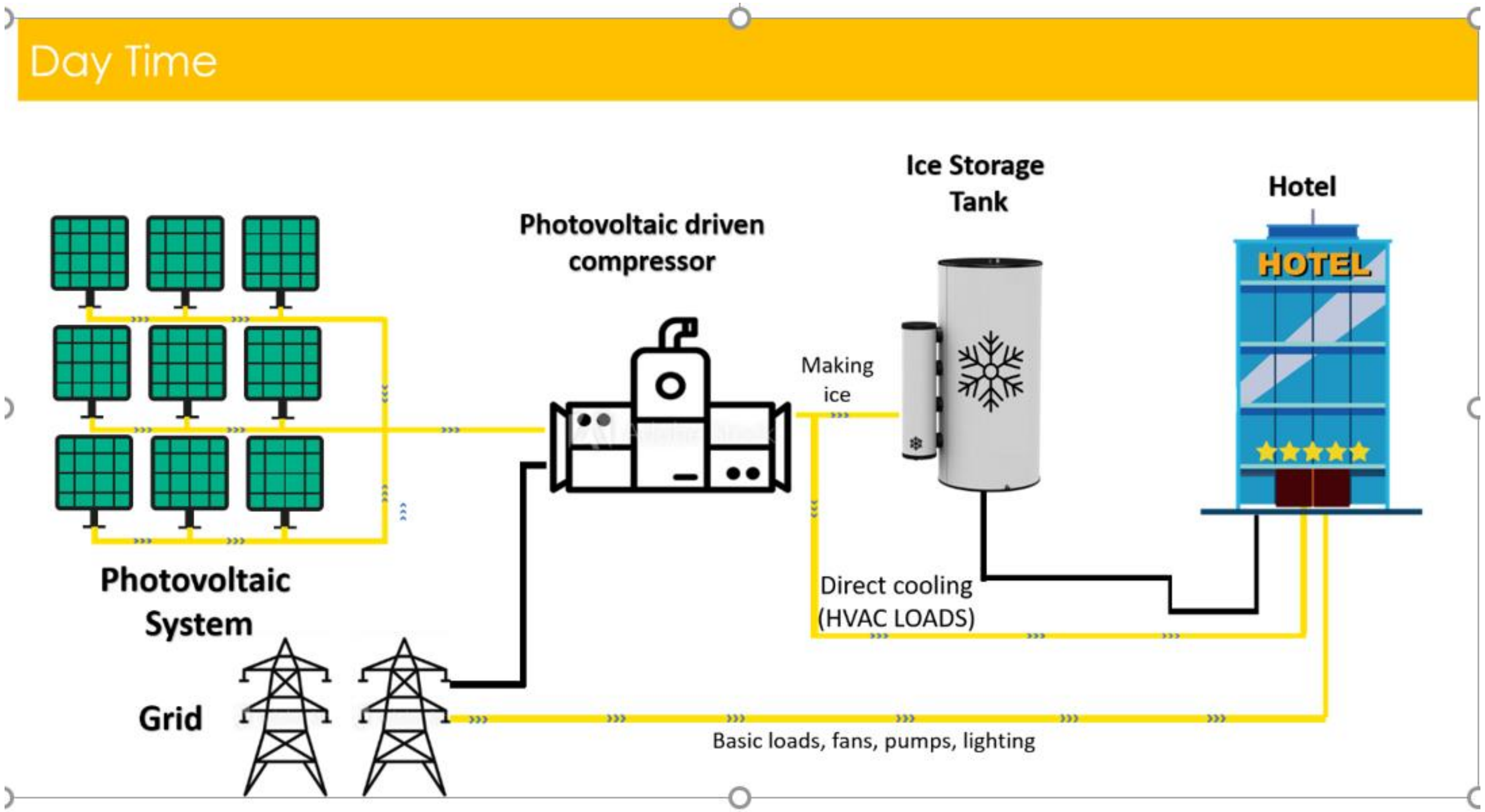


Typical Loads Penetration for Demand Response*

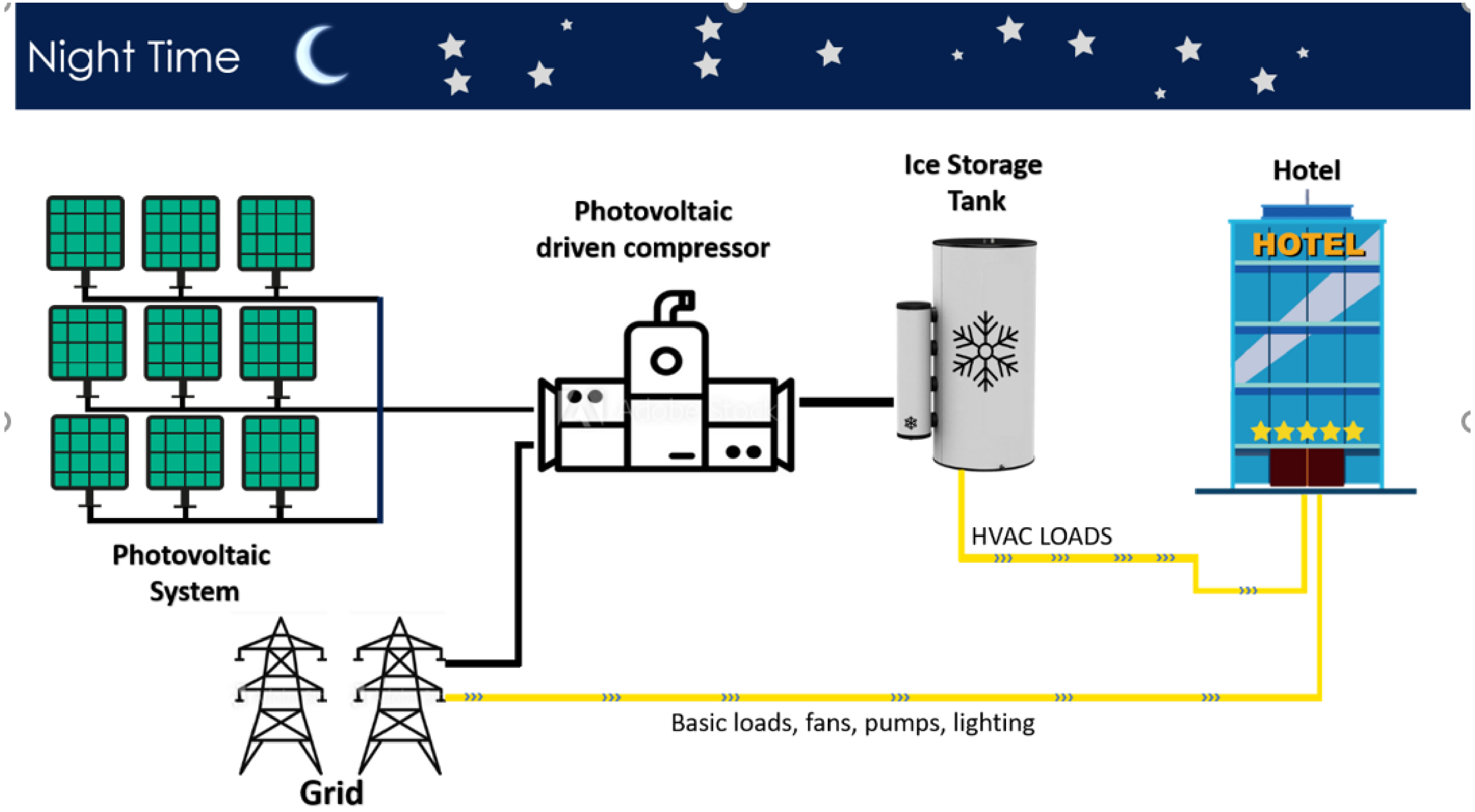


* For State of New York and California

Solar Plus Grid Hotel Air Conditioning



Solar Plus Grid Hotel Air Conditioning



Cement Mill Load Shifting

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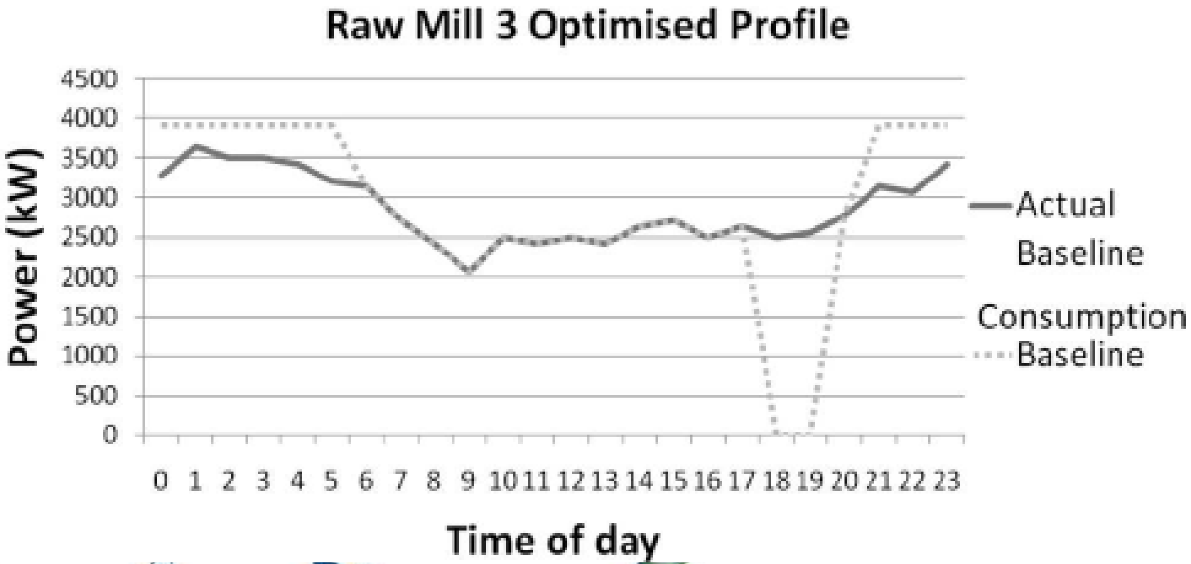
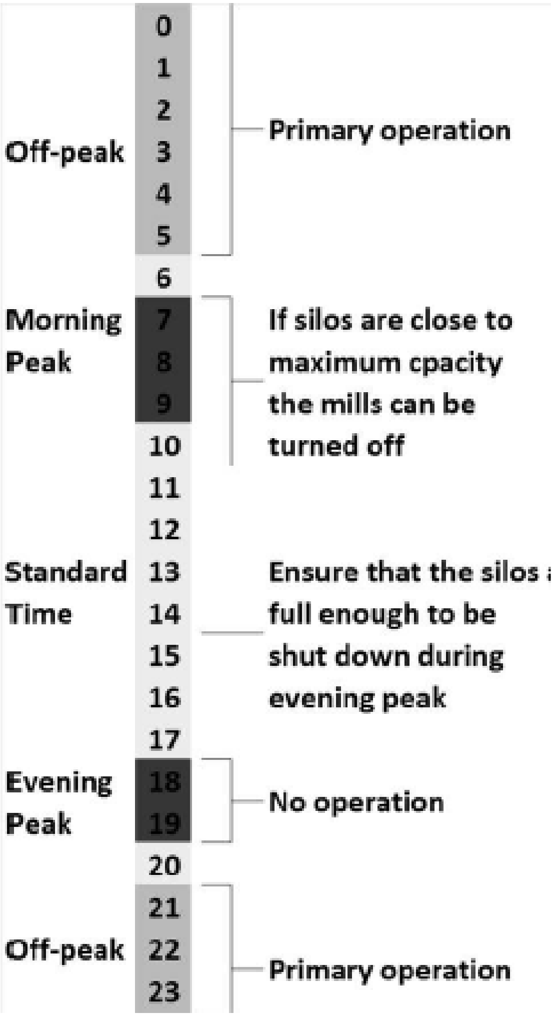
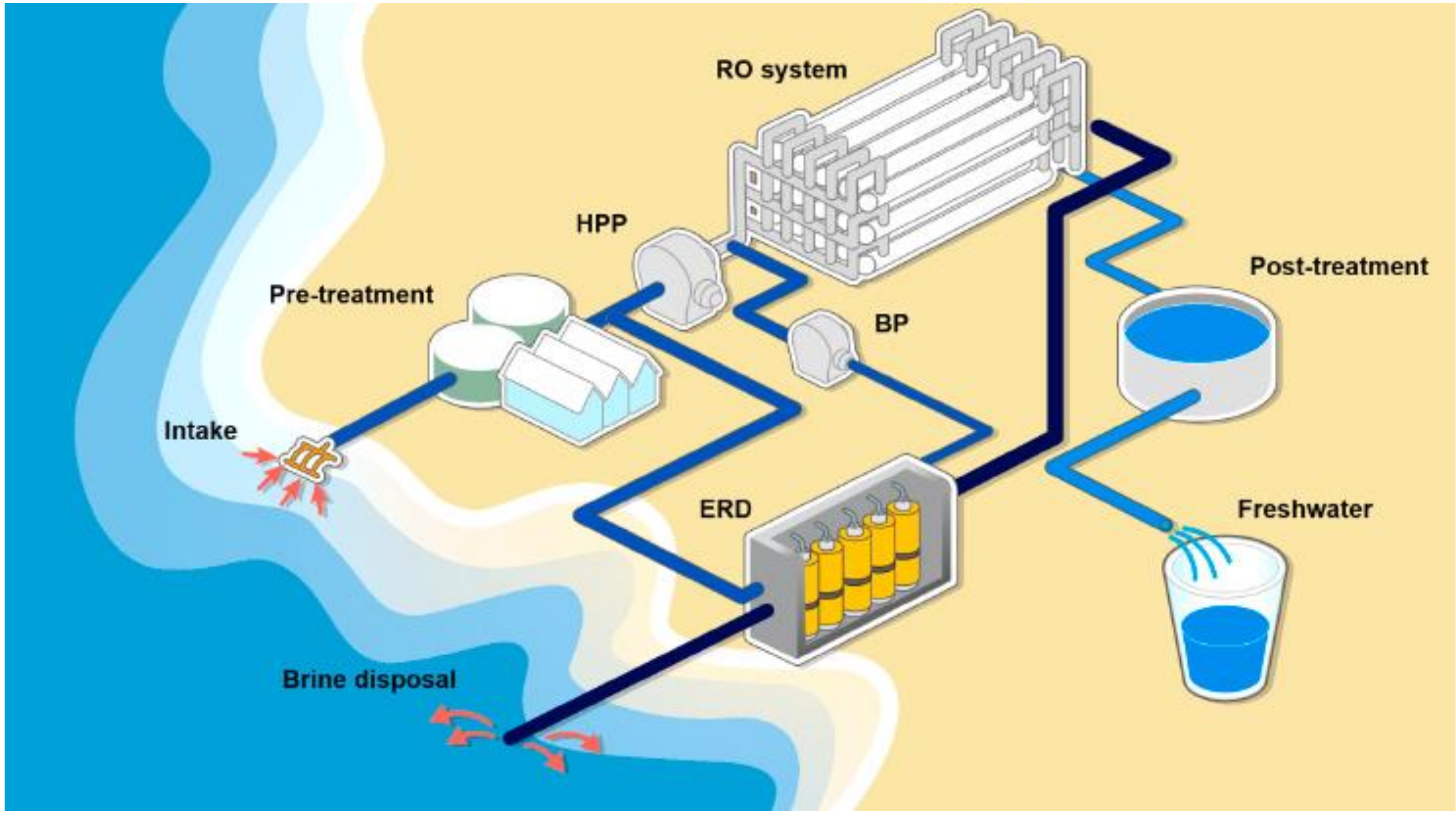




Desalination with Water Storage

- Main load is high pressure water pump
- Water production from grid and solar depending on time of day
- No production during peak periods



Flexible Solar Plus Grid Desalination

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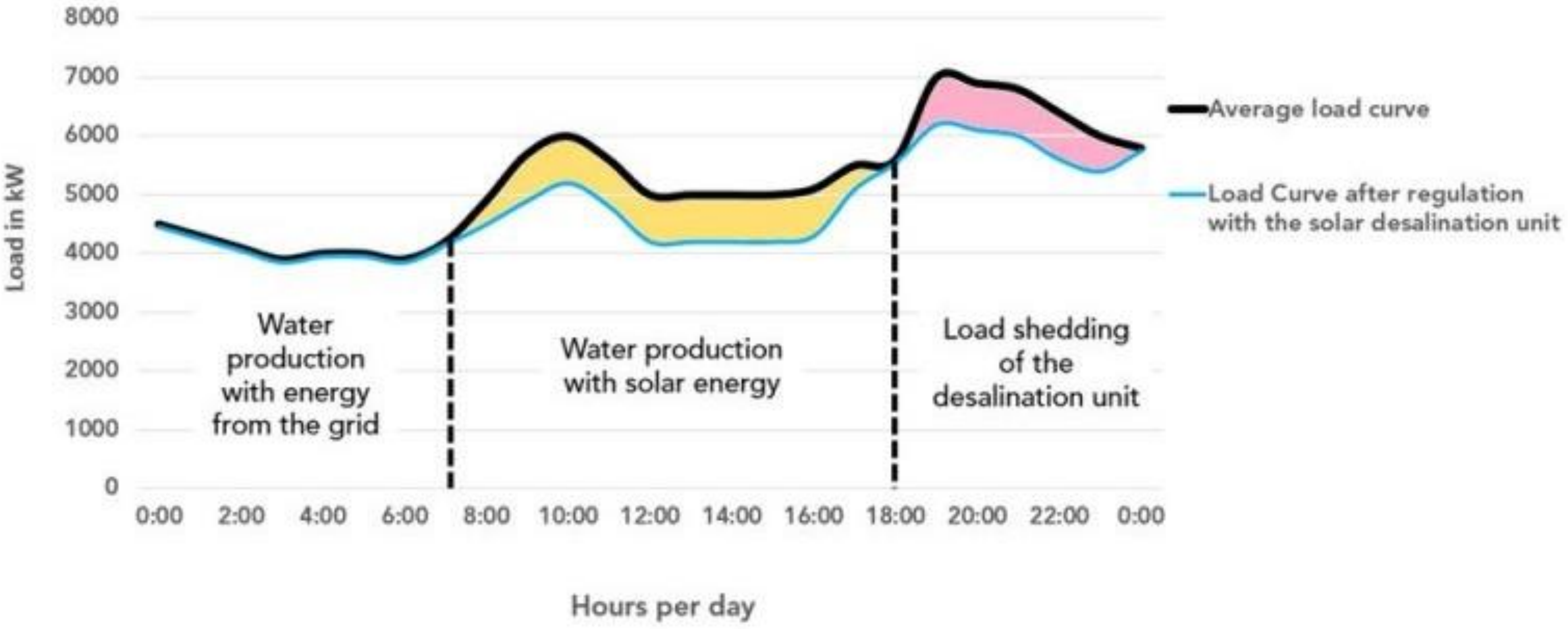

17. Site Visit

Motor Assessment

Motor Systems Optimisation (MSO) Expert Training (2020 Egypt Edition)

Samir Khafagui
Siraj Williams

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Site Programme

- Welcome
- Introduction to Plant
- Induction (Safety, PPE)
- Plant overview
- MSO systems overview
- Conducting an MSO assessment
- Measurement and data collection
- Analysis of data collection
- Development of opportunities and recommendations

18. MSO Training and Certification

Conclusion

Motor Systems Optimisation (MSO) Expert Training (2020 Egypt Edition)

Samir Khafagui
Siraj Williams

The MSO Training Cycle

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PREPARATION

- Companies commit and agree to host energy system assessment.
- Awareness sessions delivered to executive teams.
- Participants enrolled into programme.
- Energy measurement equipment is procured.

2-3 MONTHS

USER TRAINING (2 DAYS)

Targeted to facility engineers, operators and maintenance staff of enterprises, as well as equipment vendors and service providers.

Subjects covered include:

- System optimization approach applied to motor-driven systems.
- Basic principles of energy efficient design in motor-driven systems.
- Selection of energy efficient motors & technologies.
- Best-practices in operations, control, maintenance & performance assessment.
- Analysis of energy & cost savings for energy efficiency improvement measures.

EXPERT TRAINING

Theory & demonstration of industry assessment (5-6 DAYS)

- In-class training on theory of energy assessment & optimization of motor-driven systems.
- Onsite demonstration & practice of energy performance assessment.
- Demonstration of measurement equipment.
- Baseline data collection and analysis.
- Presentation of preliminary results to the company management.

Individual industry assessments (3-6 MONTHS)

- Onsite practice of motor-driven systems' energy performance assessment.
- Implementation support for low cost/ no cost energy saving measures.
- Identification of capital intensive energy saving opportunities.
- Regular webinars to discuss progress with international experts.

Reportings & presentations (3-4 WEEKS)

- Preparation of assessment reports with recommendations for energy efficiency improvements for participating companies.
- Presentation of the results & recommendations to companies' management.

PROGRAMME COMPLETION

Final assessment (2-3 WEEKS)

- Exam (3 hours).
- Assessment of individual assessment reports.
- Participants qualified as motor-driven systems experts.

Revision & lessons learned (1 DAY)

- Participants discuss, present findings, share knowledge & lessons learned.
- Revision of motor-driven system optimization theory & practice in preparation for exam.

Graduation ceremony (1 DAY)

Certificates awarded to participants.

COMMUNICATION & DISSEMINATION

- Case studies generated.
- Results communicated widely.
- Knowledge sharing workshops facilitated.
- Establishment of peer-to-peer exchange platforms, networks and learning circles.

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MSO Certification Options

- Attendance Certificate
  - For participants who are interested in motors and would like to increase their knowledge in motor systems
  - Attendance of User training course (at least 75% attendance)
  - Attendance of theoretical (classroom) part of Expert training (at least 75% attendance)

- Expert Certificate
  - For participants who intend to complete the user and full expert training in motor systems assessments
  - For participants who would like to become motors systems trainers and facilitators

MSO Expert Certificate

Requirements:

- Attend the User training (2 day).
- Write and pass the User training class test achieving at least 70%.
- Attend the Expert training (5 day).
- Actively participate in the class discussions, practical demonstrations, and presentations.
- Complete an individual MSO assessment at a plant.
- Attend progress webinars as arranged.
- Write and pass a final examination based on the coursework covered, obtaining a minimum pass mark of 70%.
- Obtain an overall final pass mark of 70% based on the individual report, final examination and class participation.

MSO Trainers and Facilitators

- Purpose
  - To enable continued transfer of knowledge
  - Local capacity building for self sustainability

- Requirements
  - **Training skills** – ability to engage and communicate with participants
  - **Knowledge** – of subject matter, ability to think critically, analyse challenges and synthesise solutions
  - **Attitude** – professional conduct and behaviour couple with ethics and values regarded by UNIDO

Duties of MSO Facilitator

- Subject matter expertise and development of course material
- Presentation of course material
- Technical support for class tests and examinations
- Support in selecting host and candidate plants
- Technical support to participants throughout the MSO programme

Desirable Characteristics for a Facilitator

- Self-confidence
- Awareness of environment
- Ability to build bridges - relate old to new
- Organizational skills
- Desire to learn
- Ability to listen
- Sense of humor
- Communication & theatrical skills
- Flexibility
- Patience
- Cool head & warm heart

Review & Discussion

- Any questions?

End of Course

Thank you for your participation

Please complete the course evaluation

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