Better Plants
U.S. DEPARTMENT OF ENERGY

Motor Systems
Virtual INPLT Training & Assessment

Session 1

U.S. DEPARTMENT OF ENERGY

Motors Virtual INPLT Facilitator

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U.S. DEPARTMENT OF ENERGY

Acknowledgments

- Johnny Douglas, P.E.
- Gil McCoy, P.E.
- Dr. Hugh Falkner
- Dr. Anibal De Almeida, University of Coimbra, Portugal

- Many industrial clients – both in the US and internationally

Safety and Housekeeping

- Safety Moment
  - Motors can be dangerous, and caution should be used around them
  - Always use proper lockout-tagout when working on motors
- You are welcome to ask questions at any time during the webinar
- When you are not asking a question, please MUTE your mic and this will provide the best sound quality for all participants
- We will be recording all these webinars and by staying on-line and attending the meeting you are giving your consent to be recorded
  - A link to the recorded webinars will be provided, afterwards

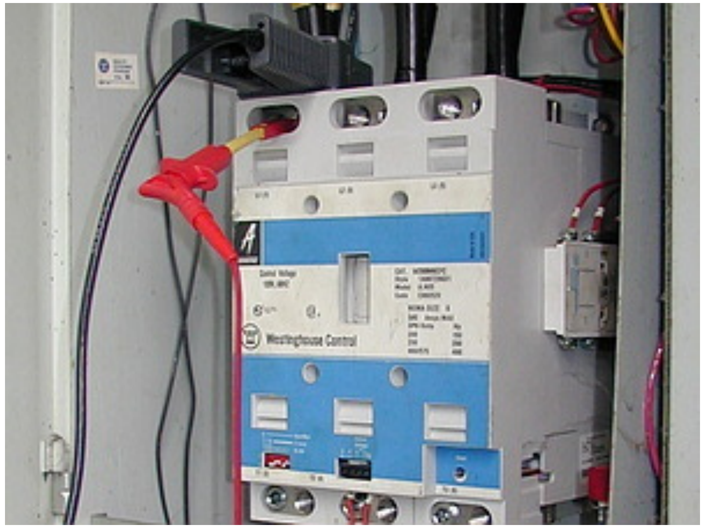
Learning Objectives

- Review motor system definition
- List 5 categories of motor losses.
- Review operating principle of AC induction motors.
- Describe advantages and disadvantages of “traditional” DC motors and key differences of their modern replacements.
- List advantages and disadvantages of switched reluctance motors.
- Describe AC motor characteristics from the motor nameplate
- List characteristics, advantages and disadvantages of Premium efficiency motors
- Describe how to create a motor inventory in MEASUR software

Big Picture Perspectives: Motor Systems

Industrial and commercial motor systems:

- Are the *single largest electrical end use* category in the American economy
- Account for 29% of U.S. electrical sales



Polling Question 1

Polling Question

2) What is your major function in your current role at your plant?

A. Process Engineering
B. Operations & Maintenance (Engineering / Technical)
C. Operations & Maintenance (Management)
D. Plant management
E. Corporate-level management
F. Independent consultant / contractor
G. Other

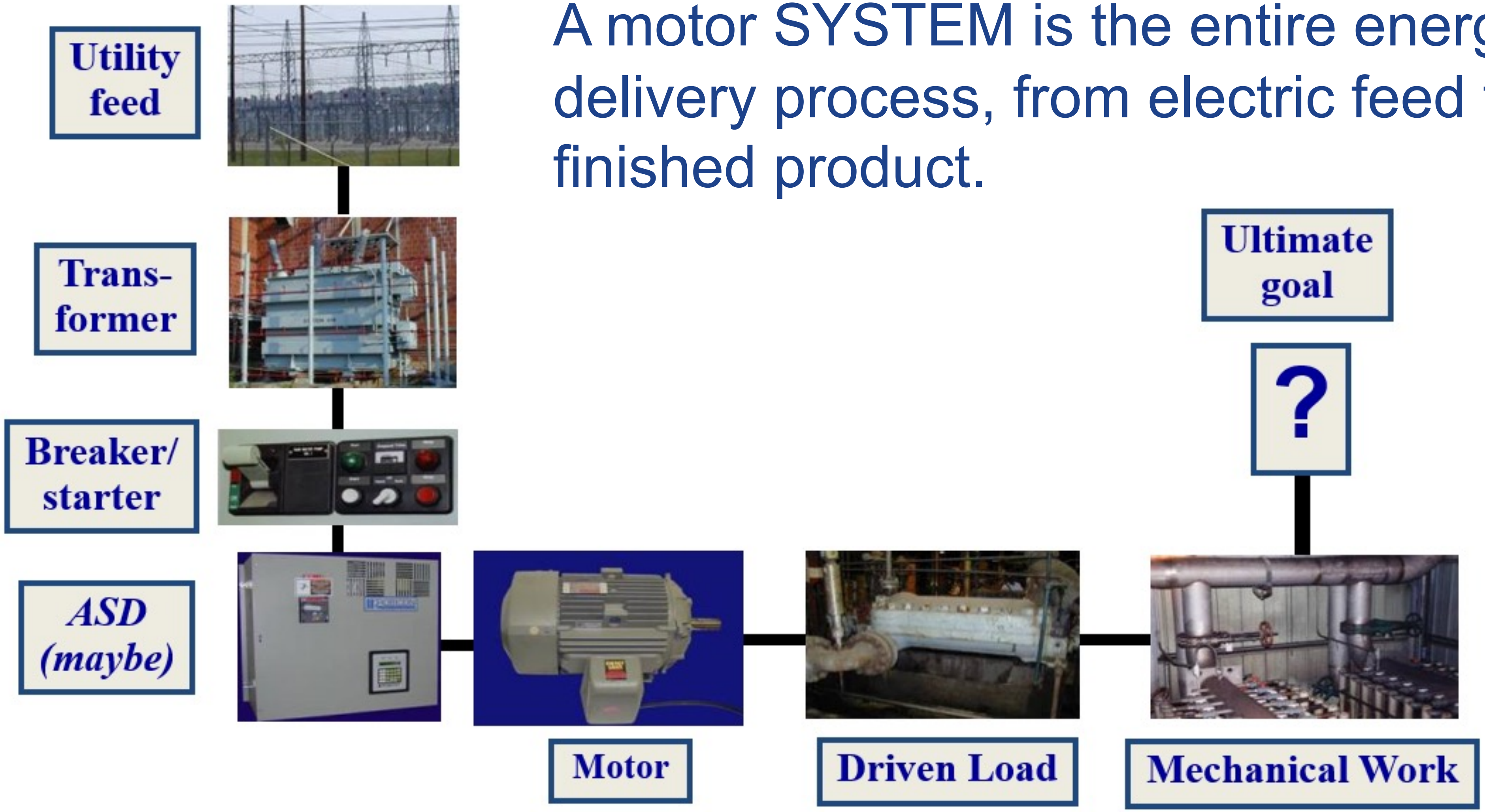
Polling Question 2

Polling Question

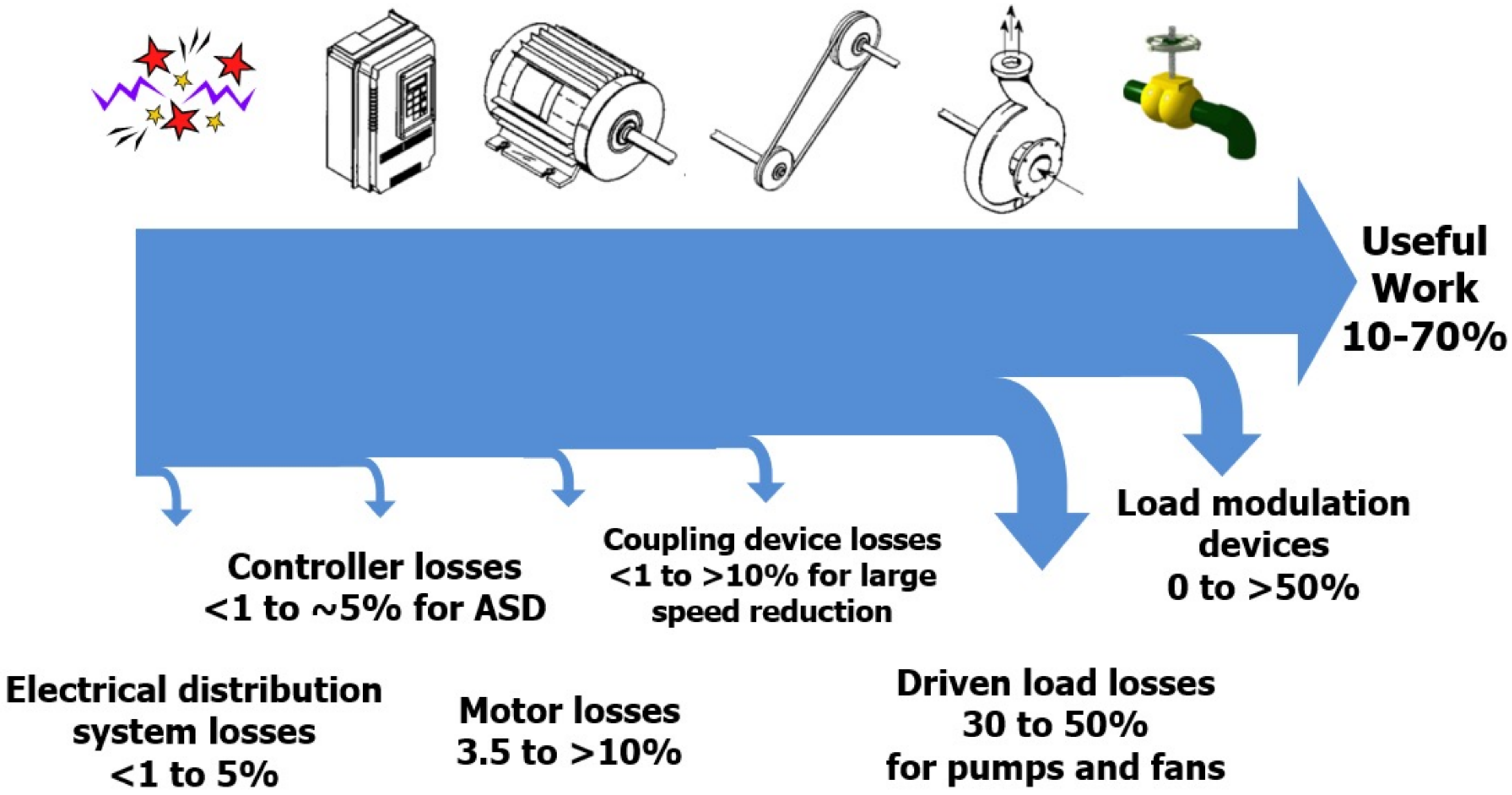
1) How many motors do you use at your facility?
   A. 1-49 motors
   B. 50-99 Motors
   C. 100-199
   D. More than 200

Motor System

A motor SYSTEM is the entire energy delivery process, from electric feed to finished product.



Typical Motor System Losses



Motor Systems

Measure	Saving Potential as % of Motor End-use Fraction	Assumptions
Energy-Efficient Motors	1-9 % for applicable motors	96 % of motor load has energy-efficient replace-ments available
Improved Drivetrains, Lubrication, and Maintenance	3-7-% for all motor load	
Improved Electric Supply	1-5 % for all motor load	
Adjustable Speed Drives	15-40 % for applicable motors	25-75 % of pump, fans, compressor, and conveyor loads are applicable sites
Pump and Fan Efficiency	2-10 % for end-use motor load	
Reduced Compressed Air Leaks	50-75 % reduction in leaks	compressed air leaks are 15 % of compressor load
Compressor Controls	3-7 % for compressor load	
Air Compressor Efficiency	4-20 % for applicable load	50 % of compressor load is applicable for equipment efficiency improvement
Refrigeration Equipment Efficiency	10 % for refrigeration load	

Courtesy Anibal T. De Almeida and Hugh Falkner and UNIDO

Motor Systems

Plan ahead so you can upgrade when a failure occurs.

- The picture changes dramatically when failures occur.
- If the system is out of commission and needs to be rebuilt, then you might be able to do it more efficiently instead of replicating the old.
- The upgrade may cost less than replicating the old.

Motor Systems Management Plan

Elements of a good motor systems management plan

- Includes a preventive and predictive maintenance program.
- Applies best practices for selecting repair shops and ensuring quality repair.
- Implements a replacement and new motor purchase plan to ensure minimum cost over the life of each motor by considering:
  - Initial cost
  - Matching performance to load requirements
  - Operational reliability
  - Operating efficiency

All Motors

Devise Standard Policies and Procedures (P/P) for smaller and seldom used motors, e.g.:

- Schedule preventive maintenance like cleaning and lubrication.
- Scrap all failed motors under 50 HP.
- Use NEMA Premium™ replacement motors.
- Identify sources for upgrading specialty motors when they fail.

Moderate Priority Motors

- Includes larger or more important motors.
- Track inventory of all moderate priority motors.
- Implement preventive maintenance.
- Investigate the systems to determine if there is energy efficiency improvement potential.
- Are there problems or capacity mis-match?
- Is an upgrade or better replacement available?
- Have a contingency plan for upgrades ready for quick action when the system breaks down.
- Enable staff to avoid replicating old mistakes.

Highest Priority Motors

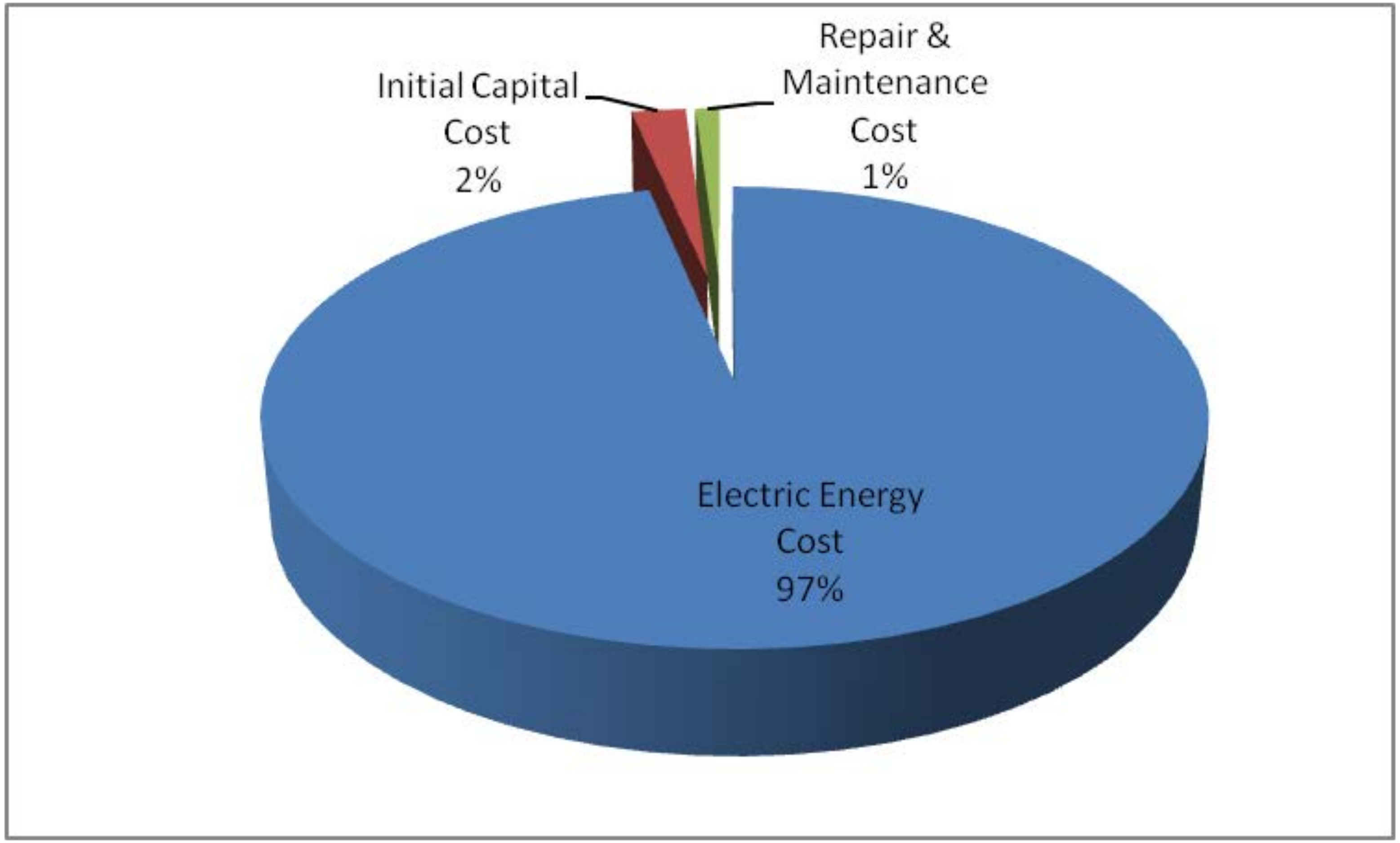
- Large (>100 or 200hp) centrifugal loads
- Production critical process
- “Bad Actor” systems
- Over 2000 hours per year utilization
- Implement predictive and preventive maintenance.
- Study the systems to determine if there is energy efficiency improvement potential.

Squirrel-cage Induction Motors Lifecycle Cost

- In Industry, an induction motor can consumer 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/maintenance.

Motor Systems Energy Use



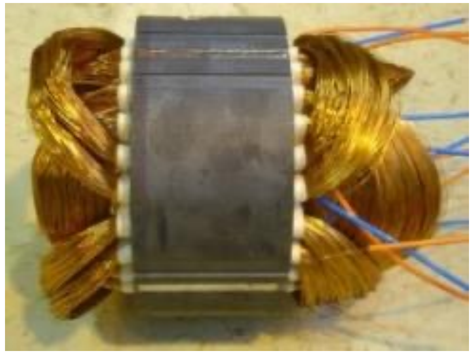
11 kW IE3 Motor, 4000 operating hours per year, 15 years life cycle 0,0754 €/kWh
Source: ISR – University of Coimbra

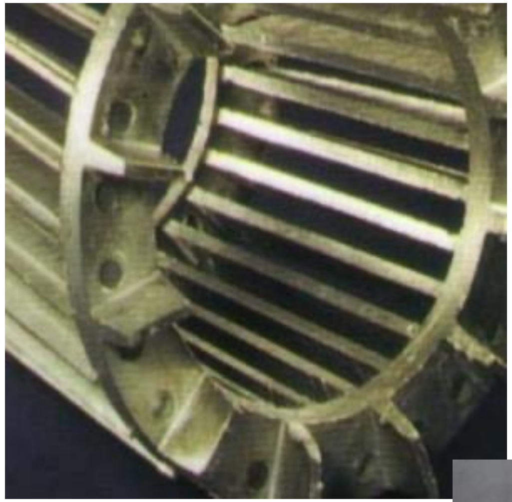
Before Screening

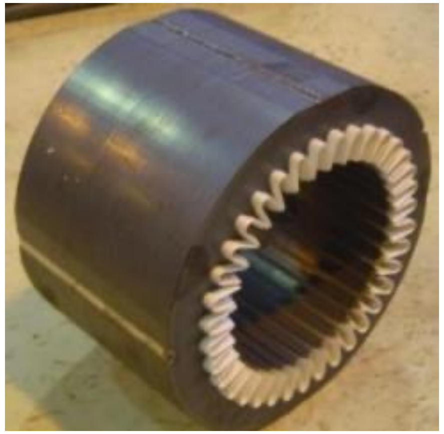
- For any motor-driven piece of equipment, ask yourself “Can it be turned off?”
- It is an amazingly common action, particularly in systems with multiple or parallel pieces of equipment.
- Savings are guaranteed to be 100%.

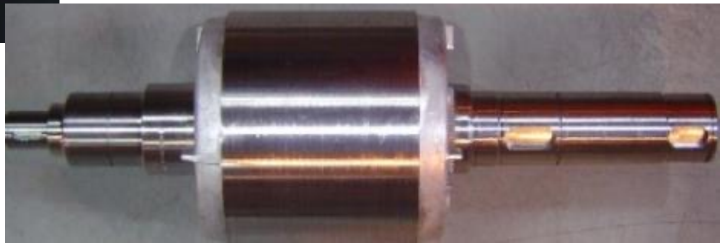
Squirrel-Cage Induction Motors

- Good efficiency and high reliability (reduced maintenance)
- Low cost (when compared to other motor types)
- Easy to control speed using a VFD









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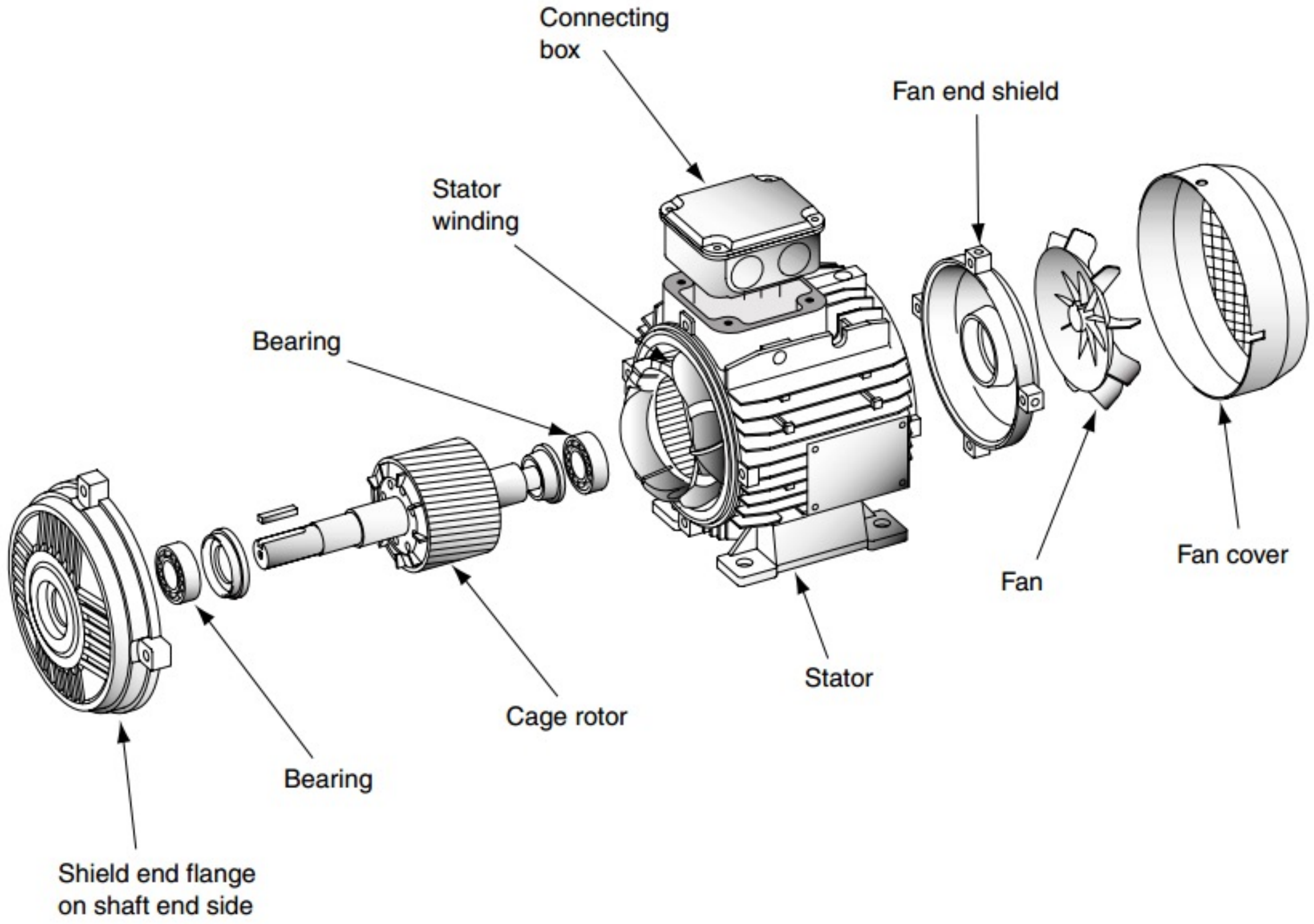
Squirrel-Cage Induction Motors



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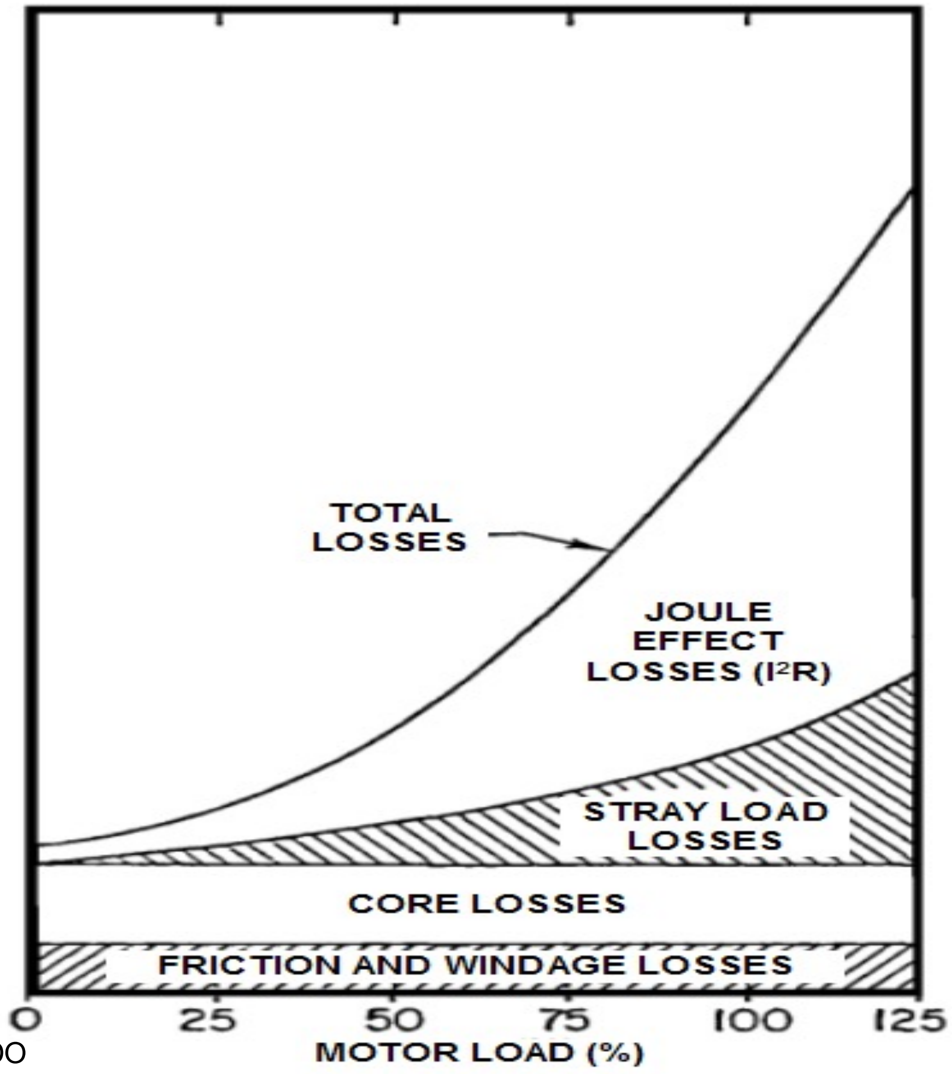
Motor Losses

- **Electrical** – I^2R Heat generated by electric resistance in the windings and in the rotor conductor bars and end rings.
- **Core or Magnetic** 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 flux-density.
- **Mechanical** are due to friction in the bearings and fan.
- **Stray load** 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.
- **Brush contact (only for motors with brushes)** the voltage drop between the brushes and commutator, including friction losses.

Motor Losses



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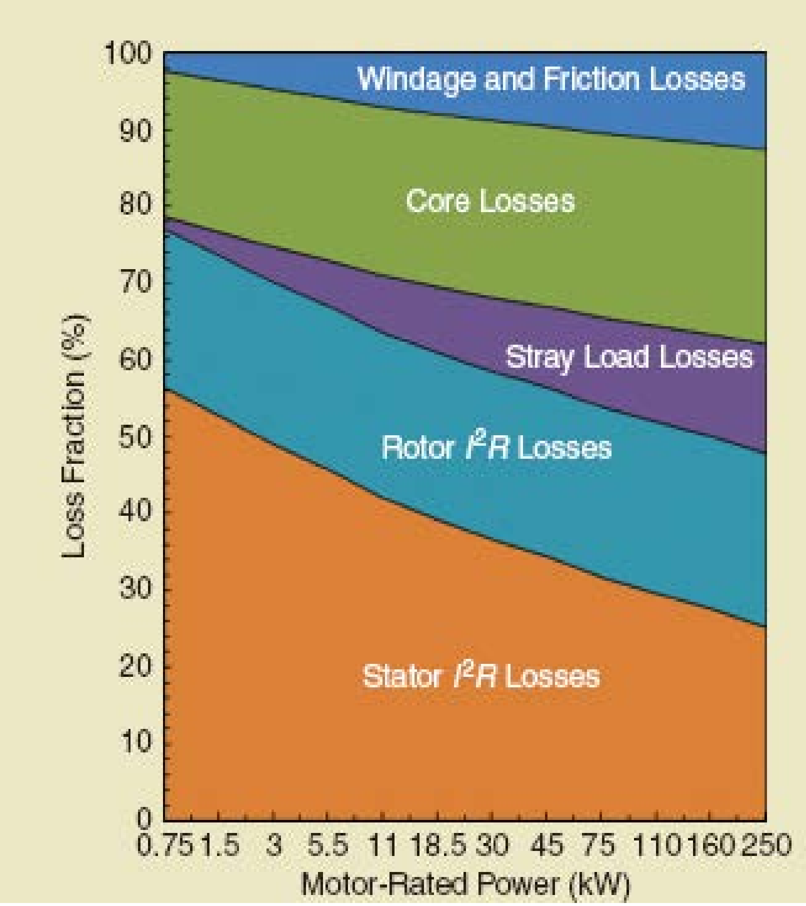
Motor Losses



Typical fraction of losses in 50-Hz, four-pole IMs

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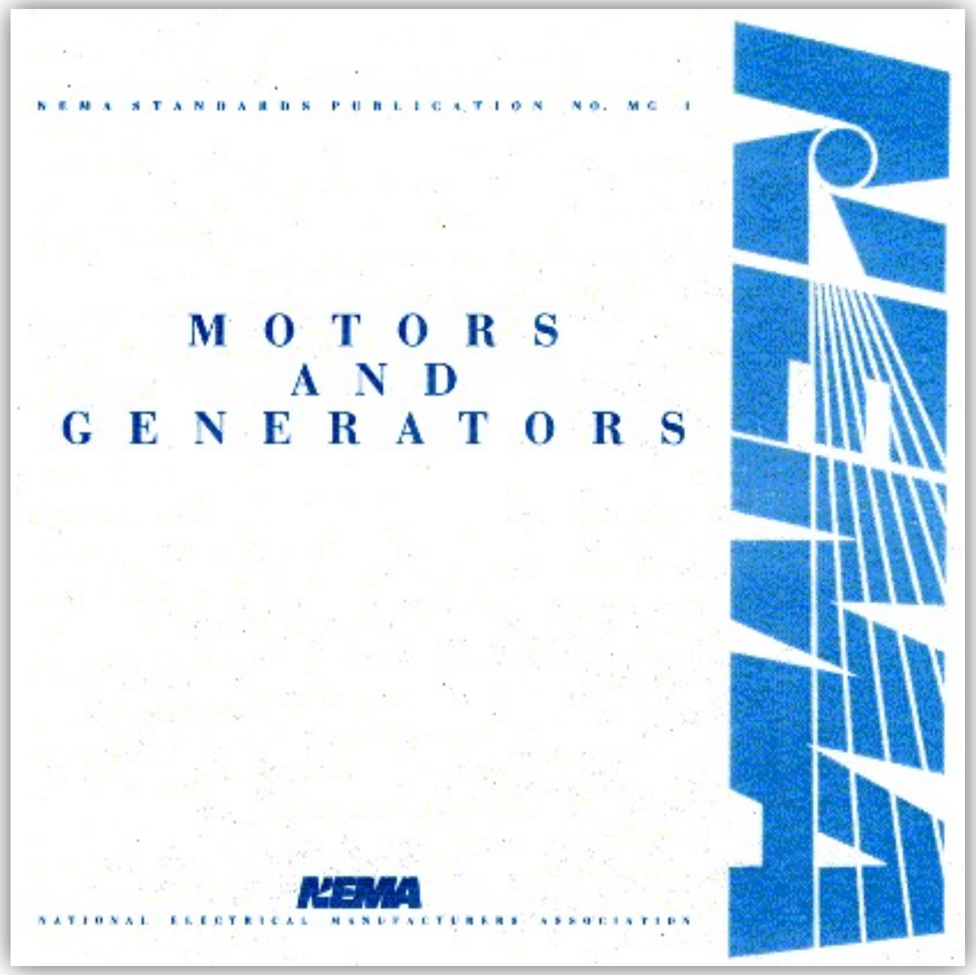
Motor Standards and Definitions

National Electrical Manufacturers Association promulgates standards for electric motors in its NEMA Standards Publication MG 1.



Purpose: NEMA Classification

General Purpose

- Induction motor under 500 hp designed according to NEMA standards to meet a broad variety of applications.

Definite Purpose

- Motor produced in *standard* ratings with *standard* operating characteristics for *particular* applications or other than usual service conditions.

Special Purpose

- Motor designed with *special* operating characteristics for particular applications.

Enclosures: Cooling and Protection

NEMA Current:

- Totally Enclosed Fan-Cooled (TEFC)
- Open Drip-proof (ODP)
- Explosion Proof
- Quite a few other less common types

Induction Motor Design NEMA Designation Letters

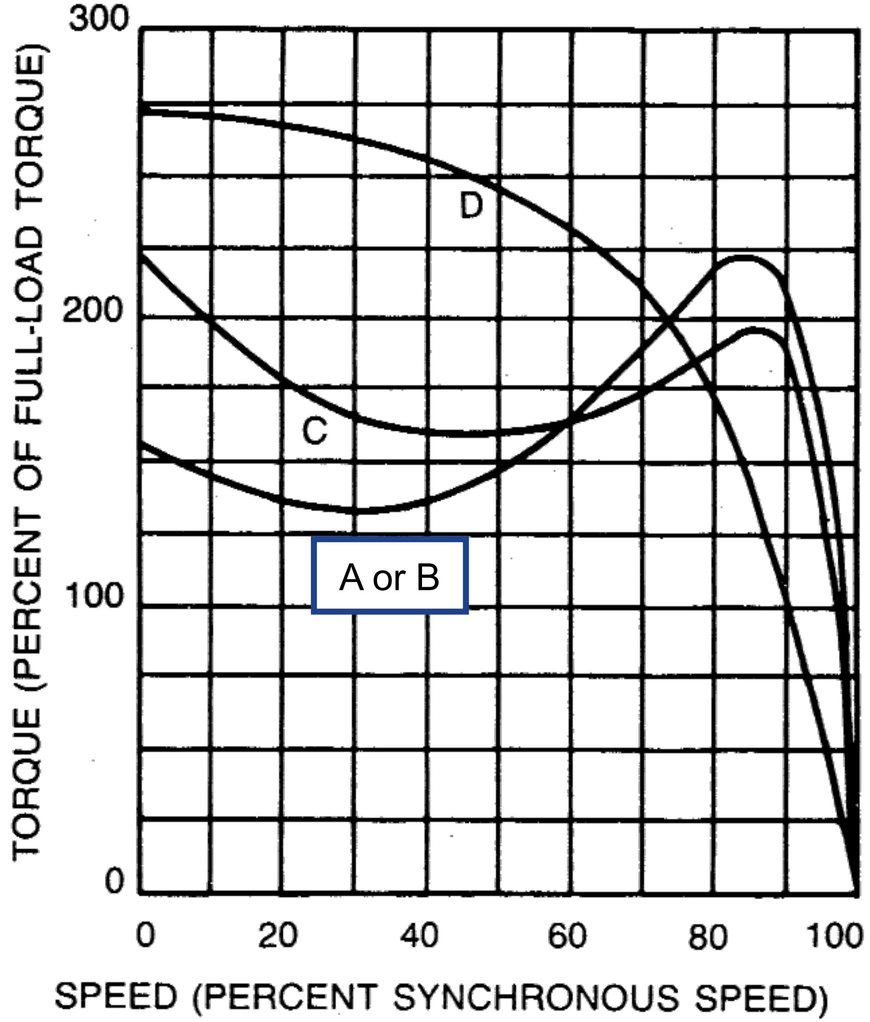
- **Design B:** Most common design. NEMA specifies minimum locked rotor, breakdown, and pull-up torque and maximum locked rotor current.
- **Design A:** Less common than B. Identical to B, except locked rotor current has no upper limit.
- In applications where Design B works and starting current is not a concern (stiff wiring, soft start or VFD), search for the most efficient motor among both Designs A and B.

Induction Motor Design NEMA Designation Letters

- **Design C:** Higher starting and accelerating torque than Designs A and B. Same limits on slip and locked rotor current.
- **Design D:** Designed for loads with flywheel like punch presses and oil well pumps. Slip higher than 5%, sometimes much higher. Very high locked rotor torque. Efficiency low.

Induction Motor Design NEMA Designation Letters

- Accelerating torque curves vary for different motor designs.
- In most cases, Designs A or B will provide sufficient torque. They also tend to have the highest efficiencies.



Nameplate Information

- Frame Type/Size
- Voltage
- Rated Horsepower
- Amps, Rated Load
- Time Rating, i.e. Duty
- Maximum Ambient Temperature
- RPM at Rated Load
- Insulation Class
- Design Letter
- Service Factor
- Frequency
- Number of Phases
- Locked Rotor Code, MG1 Part 10.37
- Efficiency, Rated Load
- Other Optional Information


RELIANCE ELECTRIC
DUTY MASTER®
841XL™
SEVERE DUTY AC MOTORS
I.D. NO.
MODEL NO.
FRAME SIZE 324TS
HP 40
VOLTS 575
PHASE 3
DESIGN B
TYPE P
RPM 3560
AMPS 36.3
HZ 60
AMB 40 °C
SF 1.15
DRIVE END BEARING 55BC03J30X
DUTY CONT
INSUL CLASS F
OPP D.E. BEARING 55BC03J30X
ENCL TEFC
CODE G
D.E. BRG. DATA 6311
POWER FACTOR 87.6
NEMA NOM EFFICIENCY 94.1
O.D.E. BRG. DATA 6311
MAX CORR KVAR 07.5
GUARANTEED EFFICIENCY 93.6
3/4 LOAD EFF. 94.5
NEMA NOM/CSA QUOTED EFF AT 100% LOAD
MEETS IEEE STD 841-1994
MOTOR WEIGHT 630 LBS.
RELIANCE ELECTRIC INDUSTRIAL CO. CLEVELAND, OHIO 44117
PLANT 010
MADE IN U.S.A.

Service Factor

- Some motors can exceed their power rating by a factor of 1.15 or 1.25.
- **Service factor** represents allowable overload.
- Specify motors sufficiently large that service factor operation will occur infrequently.
- Power factor, efficiency and life expectancy are reduced by overloading the motor into its service factor.

What is efficiency?

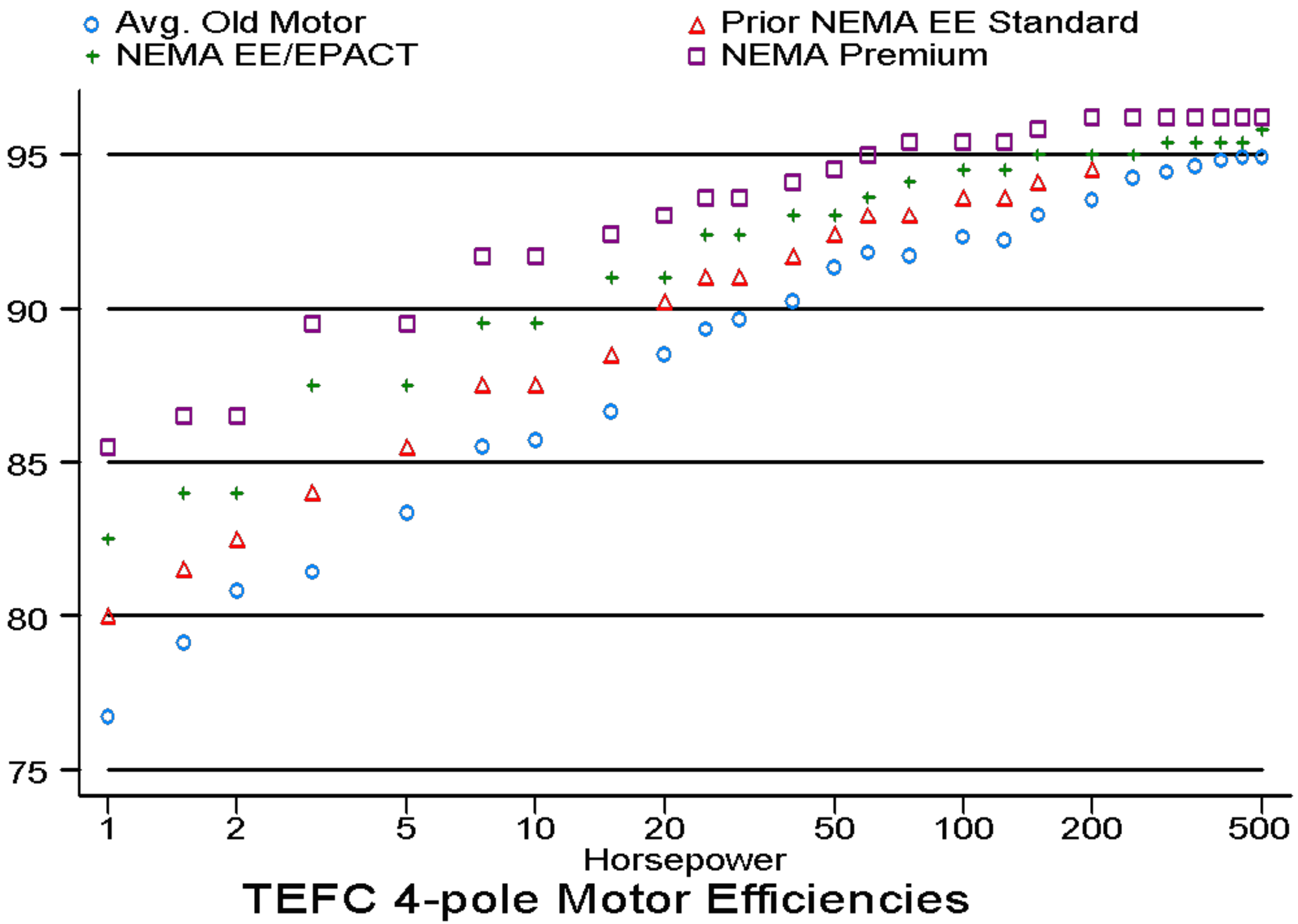
- Efficiency = Output / Input
- Efficiency = (Input – Losses) / Input
- Efficiency = Output / (Output + Losses)

- They’re all mathematically equivalent.

Motor Efficiency Definitions

- IEEE Std 112-1996 Test Procedures
- NEMA older “Energy Efficient” set efficiency values for different size motors
  - US adopts NEMA “EE” as federal standard
- NEMA “NEMA Premium”
  - US adopts “NEMA Premium” in 2010

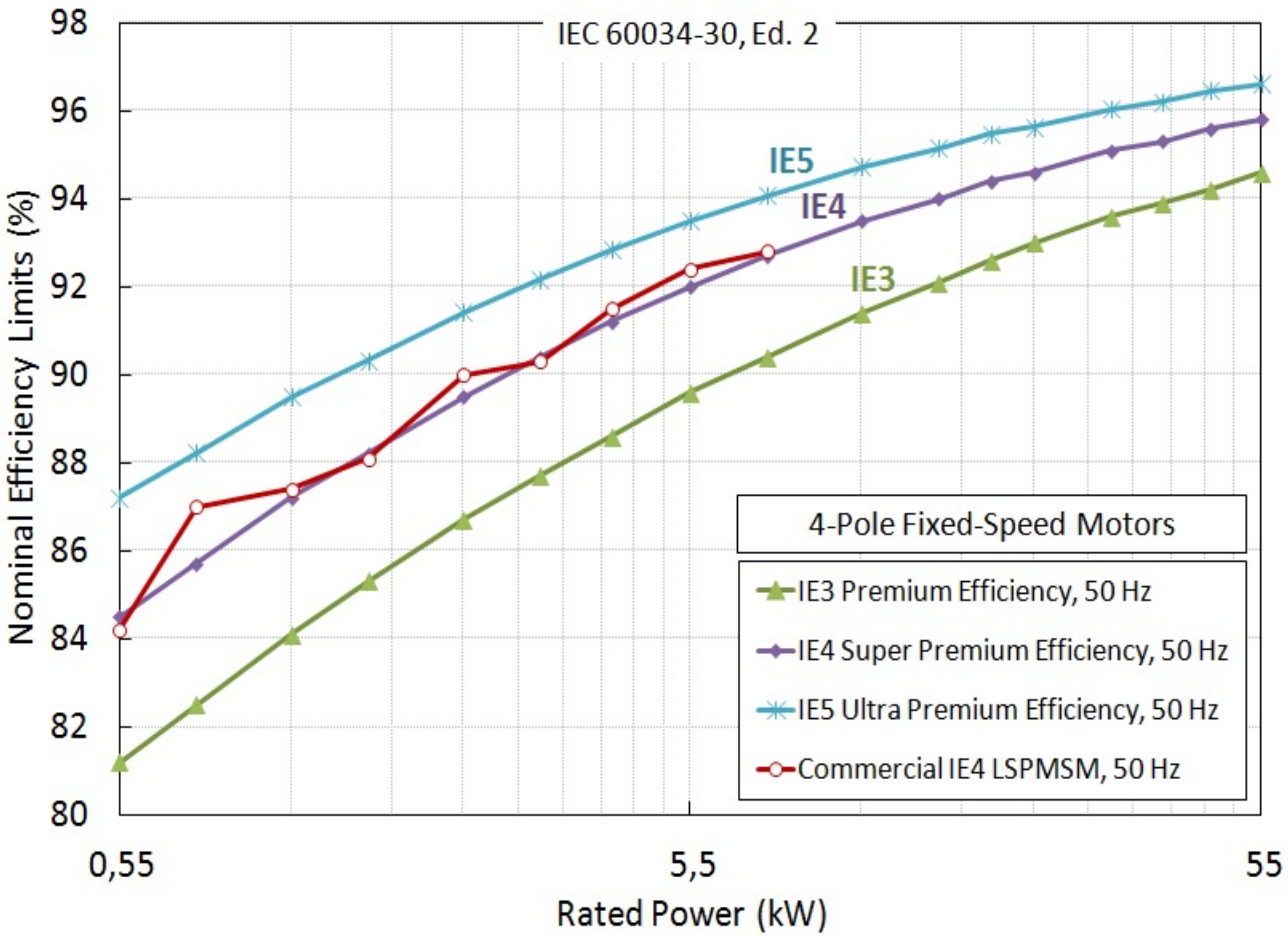
Motor efficiency comparison by class



IE4 Super-Premium Efficiency Induction Motors

- International Electrotechnical Commission (IEC) Voluntary Standard
- Includes standards for both 50 Hz and 60 Hz motors.
- Single speed, one or 3 –phase, low voltage.
- 2-, 4-, 6-, and 8-pole (3600, 1800, 1200, and 900 RPM) with a rated shaft output between 0.12 and 1000 kW.
- Offered in the U.S. at 1-500 hp, by three manufacturers.
- Two efficiency bands above NEMA Premium (IE3) motors.
- 20% reduction in motor losses compared to premium-efficiency
- Efficiency gains are larger for smaller motors
- Greatest energy savings in applications where the motor is fully-loaded, operates constantly, and is a replacement for an old, standard-efficiency motor.

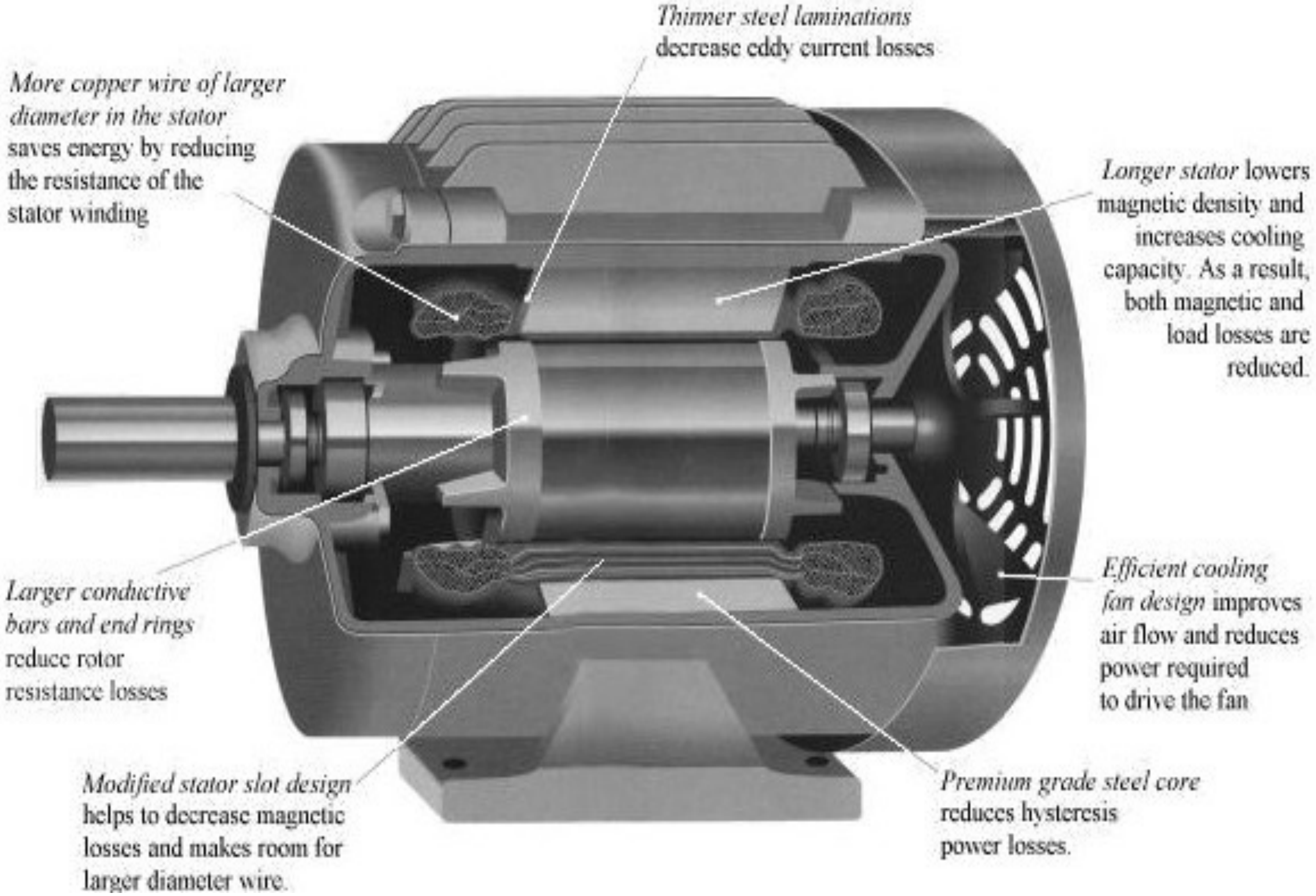
Super-Premium Motors
IEC 60034-30 Standard



Are NEMA Premium™ efficient motors…

- More or less reliable?
  - Not necessarily correlated. But some manufacturers offer a premium line that may combine better efficiency with other aspects.
- More fragile?
  - No. Nothing in their design is inherently more or less though.
- Bigger?
  - No. The same standard frame sizes are available.

Premium Induction Motors

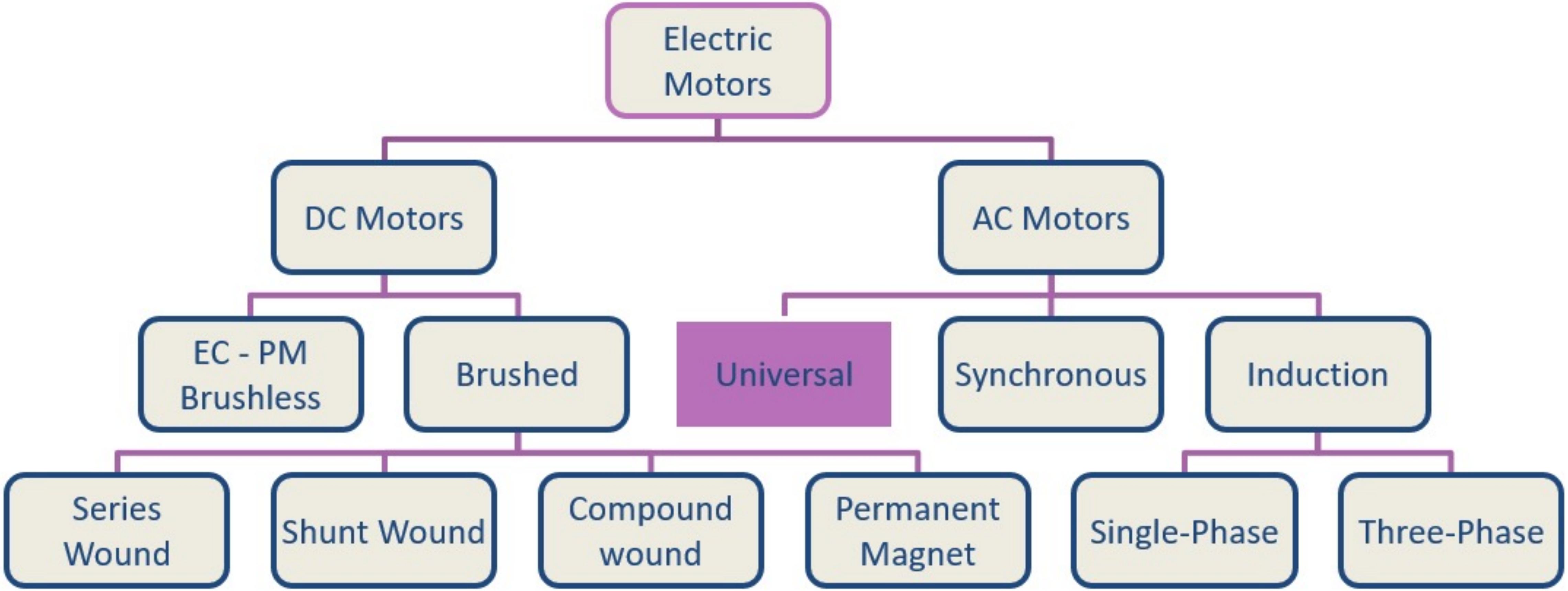


Courtesy Anibal T. De Almeida and Hugh Falkner and UNIDO

NEMA Premium™ "Traps"

- Check inrush current.
  - May need stronger fuse.
- Check motor size.
  - Premium motors sometimes hang further off the "back end."
- Check Rotational speed.
  - Premium motors often 10 or 20 rpm faster
  - Change pulley ratio on fans
  - Trim pump impeller
  - 1% increase in speed = 3% energy increase

Motor Types



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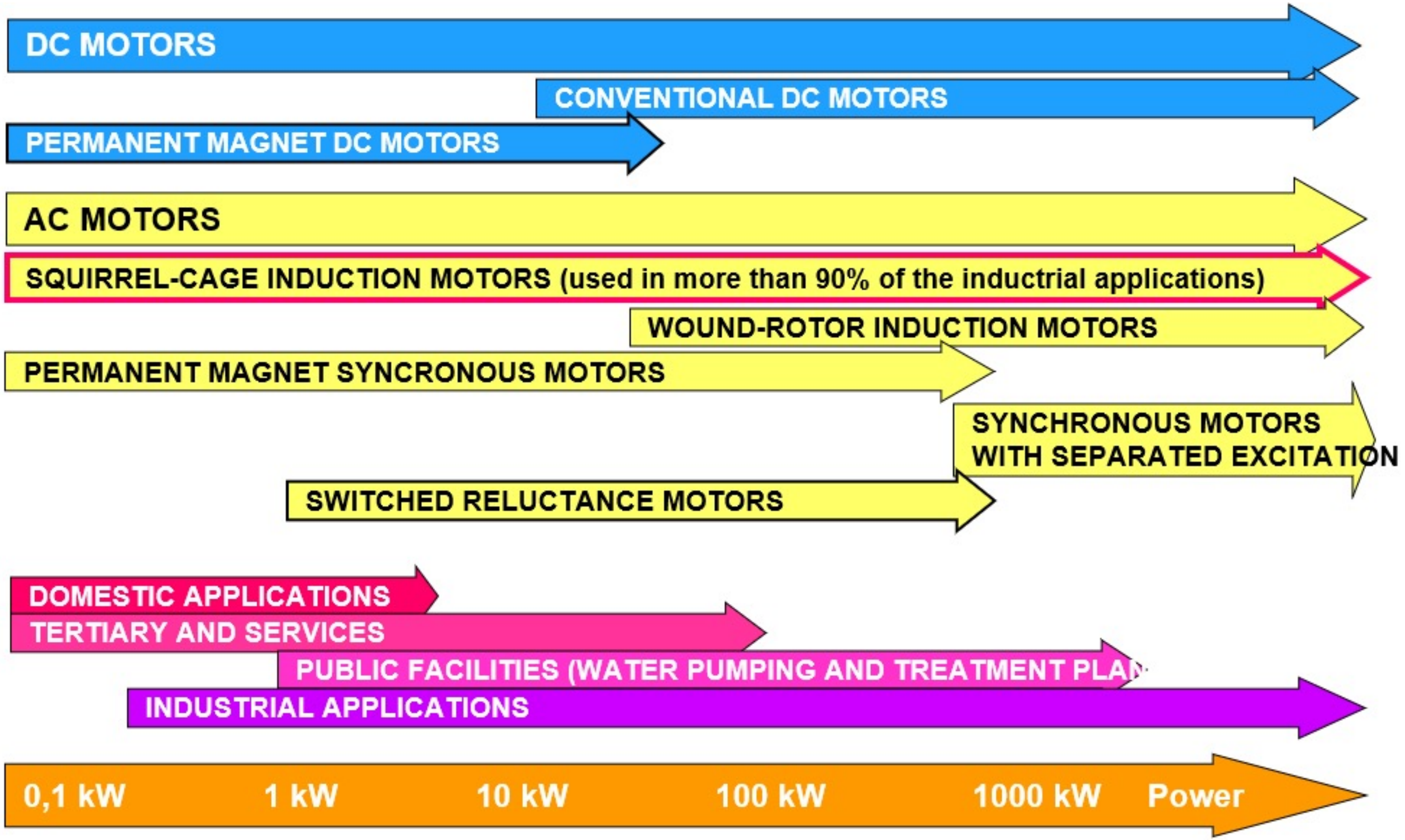
Motor Types and Applications



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Polling Question 3

Polling Question

1) In addition to AC induction motors, are you using any of these other types of motors? (select all that apply)
   A. DC motors
   B. AC Synchronous motor
   C. Brushless DC motors (or EC Electronically Commutated motors)
   D. Copper rotor motor
   E. Switched reluctance motor

Synchronous Motors

- Synchronous motors operate at synchronous speeds, i.e. 3600, 1800, 1200, 900.
- No speed drop over the working load range.
- Use when exact speed is required.
- Synchronous motors can generate reactive power to correct power factor.
- When supplying reactive power, they are said to be operating at a leading power factor.
- Synchronous motors are often more energy efficient than induction motors, especially above 1000 hp.
- Not very many new ones being installed – handful of old ones

Older DC Motors

- Brushes with stator winding
- Brushed with Permanent Magnet

Simple to control speed

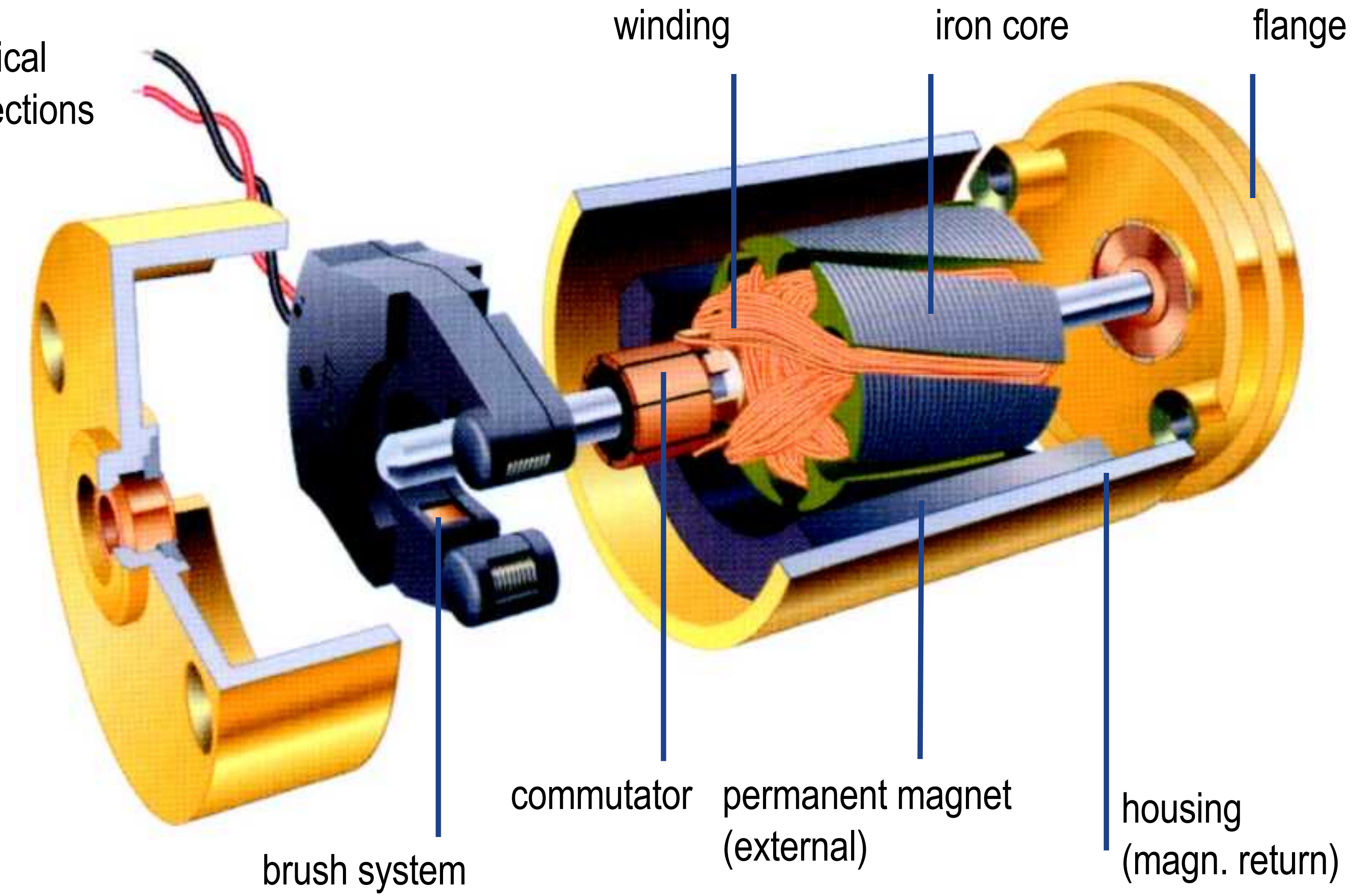
High maintenance requirements

Poor reliability

Direct Current Motors

- When precise speed control is required (DC speed control simpler & less costly than AC speed control).
- High starting torque
- High over-torque capability
- Can be run from Batteries
- Need DC power source (older motor-generator sets not very efficient).

Conventional Permanent Magnet DC Servo Motor



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Brushless DC Motors / EC Motors

- Names:
  - EC motor (electronically commutated)
  - BLDC motor (Brush-Less Direct Current)
  - PM Synchronous motor (Permanent Magnet)

Brushless DC Motors / EC motors

Advantages:

- Excellent torque-speed curve
- Excellent dynamic response
- Variable Speed
- High efficiency
- High reliability
- Longer lifetime
- Low acoustical noise
- High speed capability
- High torque/volume ratio or high-power density.

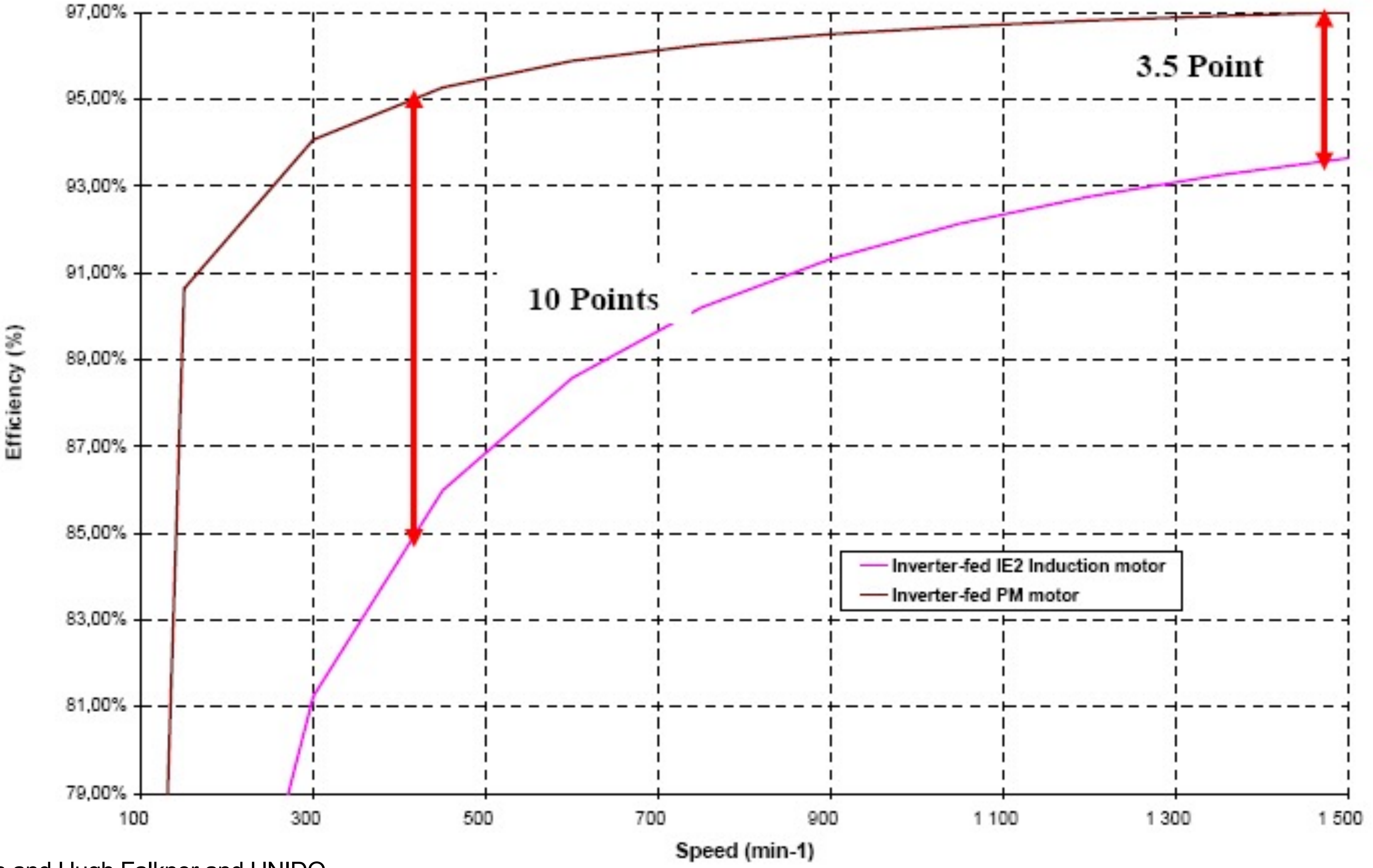
Disadvantages:

- Higher cost than AC induction motor
- Dedicated controller required

Line-Start Permanent Magnet (LSPM)

- Stator practically the same as regular induction motor.
  - Same power ratings
  - Same frame sizes up to 10 hp
- Rotor made from high energy permanent magnets (NeFeB).
- Use with 3 phase electricity or VFD.
- Uses high density magnetic mineral found primarily only in China.

PM Motor Part-Load Efficiency



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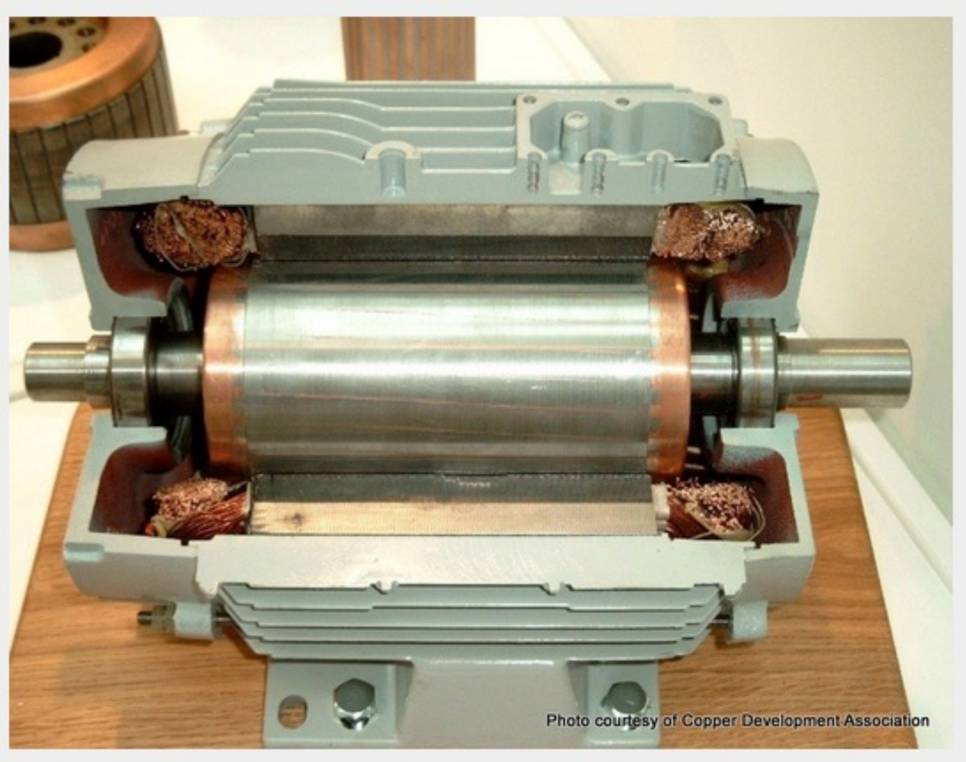
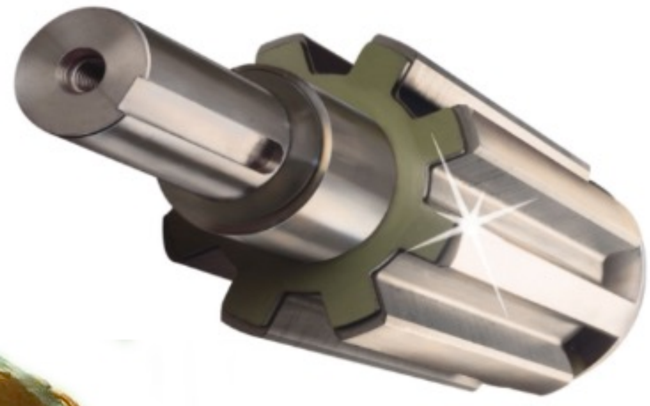
Copper Rotor Motors

- AC induction motor.
- Super premium motor.
- Reduces I^2*R loss in rotor bars.
- Most rotor bars are aluminum which is easier to manufacture, but not as conductive or as tough as the copper rotor.
- Available up through 20hp.



Switched Reluctance Motors

- Iron rotor – no magnets
- Coils mounted diametrically opposite on stator poles.
- Energizing a phase pulls rotor to align with the coils
- Rotor position feedback
- Closed-loop operation
- Dedicated controller



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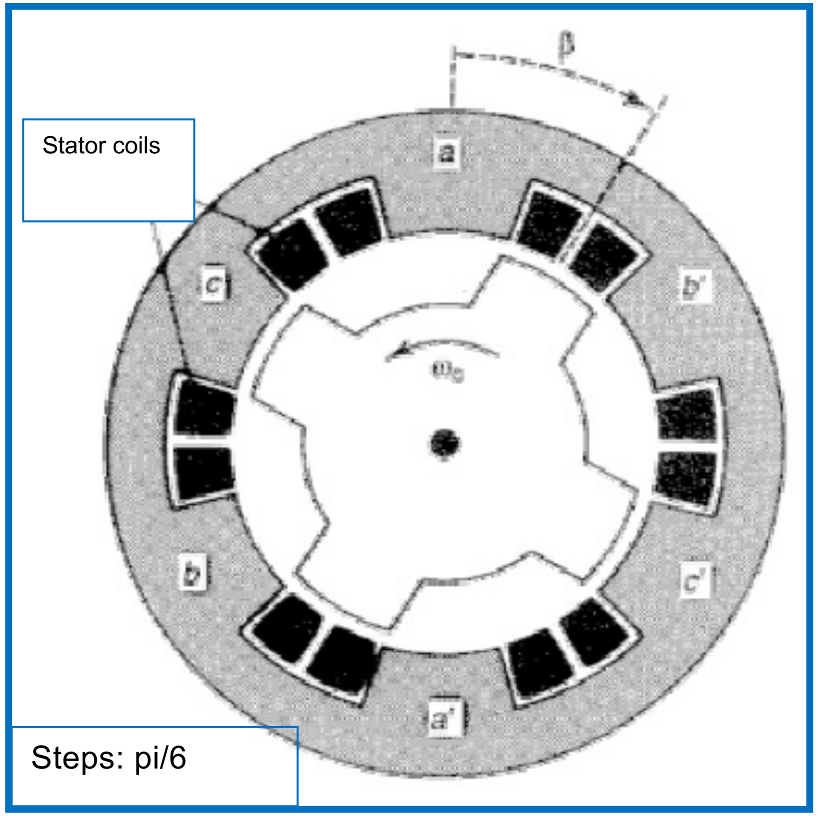
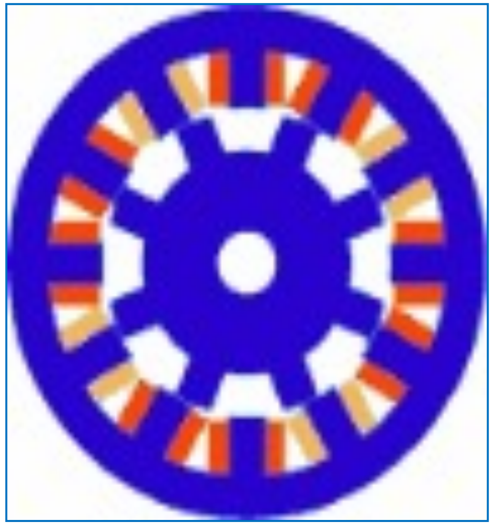
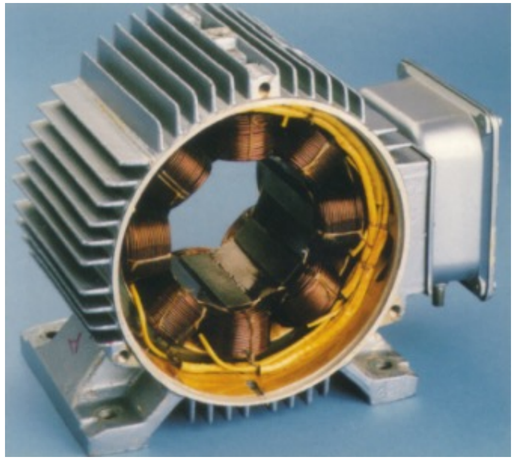
Switched Reluctance Motors

STATOR: 6 POLES (3 PHASES)

ROTOR: 4 POLES

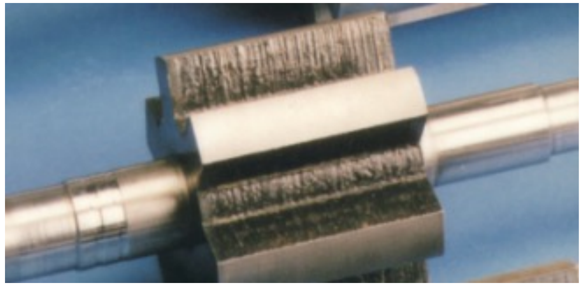






STATOR: 8 POLES

ROTOR: 6 POLES



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Switched Reluctance Motor Applications

- Available in 20 through 400 hp
- Compressors
- Washing machines
- Vacuum cleaners
- Vacuum pumps
- HVAC
- Machine-tools
- Automation
- Traction
- Many more

Switched Reluctance Motors

Advantages:

- High efficiency
- High torque
- High speed capability
- Simple robust construction
- High reliability and long lifetime
- Commercially available at low cost
- Simpler Controller
  - 1 power switch per phase
  - Much slower speed than VFD (one-tenth)
- High power density – could be in smaller frame

Disadvantages:

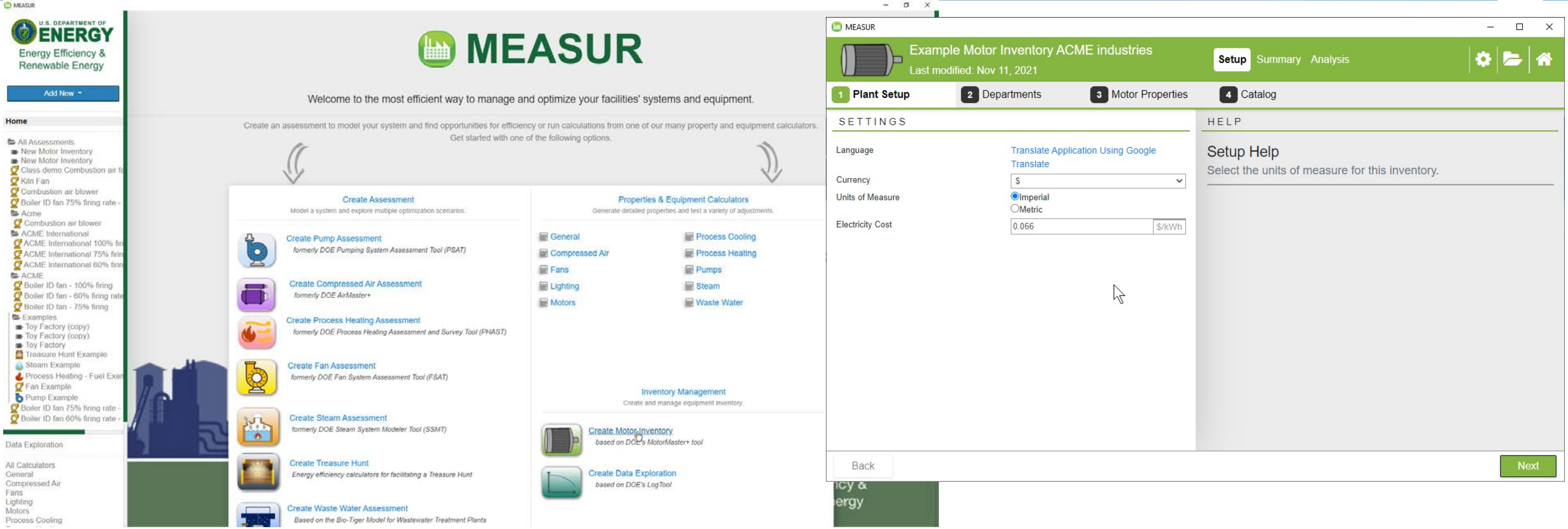
- Older design suffered from ripple torque and were noisy because of the vibration level
- Requires dedicated controller

Courtesy Anibal T. De Almeida and Hugh Falkner and UNIDO

Homework for next week

- Review your organizations’ motor systems management practices:
  - Does it include a spec for new motor purchases?
- Make a list of the top ten AC induction motors in your facility
  - Collect nameplate information for these motors
- Make a list of major motors that are over 20 years old
- Are there any applications that use
  - Synchronous motors
  - DC motors (or brushless DC)
- Can you think of any applications that might benefit from the use of newer motor styles such as switched reluctance or electronically commutated motors?

Switch to demonstration of MEASUR inventory tool



Thank you!

For Questions or Comments please reach out to the following:

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