# Synchronous reluctance motor: A proven path to magnet-free IE5 efficiency levels

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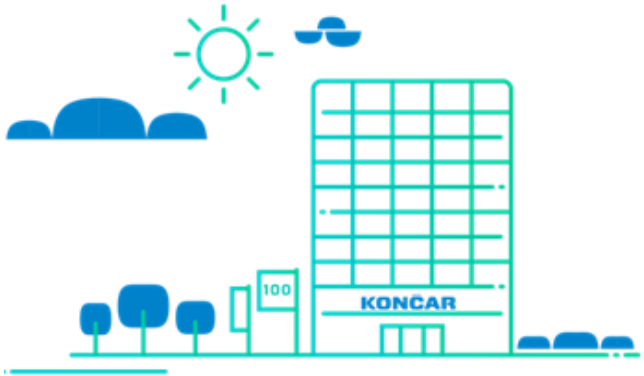
# Topics

- What are current motor efficiency requirements?
- Are IE5 motors a good investment?
- Technology for IE5 motors: with or without magnets?
- IE5 synchronous reluctance motor technology brief overview.
- Technology test results: motor with asynchronous aluminum rotor VS synchronous reluctance rotor.

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# 1

# Efficiency requirements

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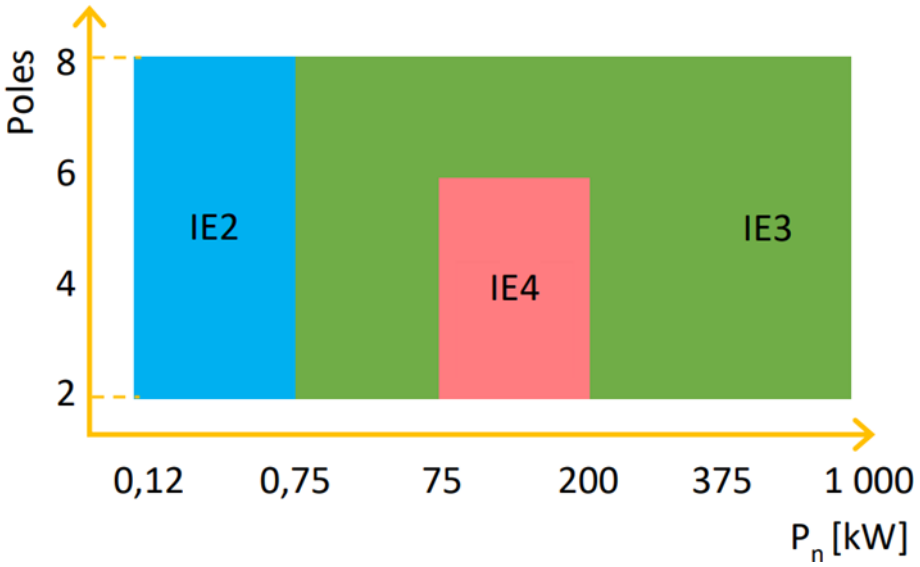
# IE4 requested for 75-200kW




- Regulation (EU) 2019/1781, in force since 07/2023.
- IE4 required for power range 75-200kW.
- Most commonly requested: IE4 induction motors.
- IE5 efficiency levels are not required by current regulation, BUT IE5 can deliver significant savings.

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# Are IE5 Motors a Good Investment?

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# Energy consumption is main cost of ownership


Typical life cycle costs of a motor installation over 25 years. Source link.

Cost of ownership = € + > + II

Purchase | Cost of running | Cost of not running

- The lifespan of electric motors is very long.
- Large number of old, inefficient motors are still in operation.
- Main component of total motor ownership cost is energy.

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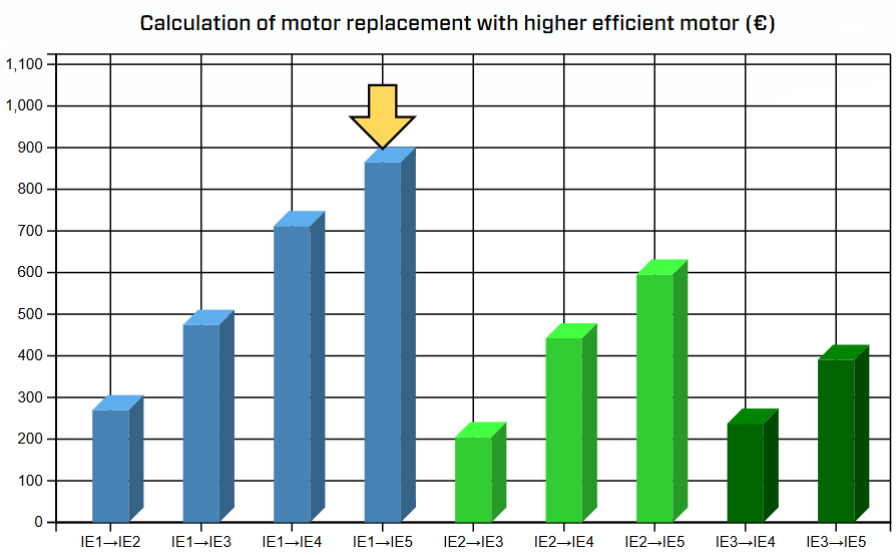
# Return on investment for the motor only


- The average non-household electricity price in the EU for 2024 is €0.19 per kWh (Source: Eurostat).
- Based on two work shifts totaling 4000 running hours per year for a 4 pole, 15kW motor.
- If old IE1 motor is replaced with new IE5 motor complete return on investment is achieved in just **1 year and 6 months**.
- **VSD not included in calculation!**




Source: savings calculator.

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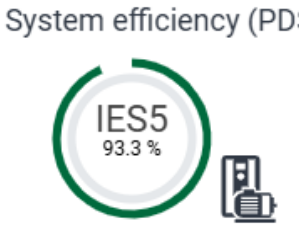
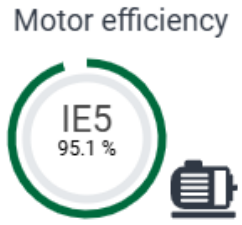
# ROI including motor and VSD


- The IES classification is determined by adding the losses of the Complete Drive Module and the losses of the motor at the operating point 90% speed and 100% torque.
- If an old IE1 motor is replaced with new IE5 motor, as in previous case, and a premium VSD is used, a complete return on investment is achieved in **5 years and 10 months**.




System efficiency determined according to IEC61800-9-2, 2023


Drive efficiency determined according to IEC61800-9-2, 2023




Motor efficiency determined according to IEC 60034-30-1

Source: https://energy.mydrive.danfoss.com/

# 25-Year energy cost comparison


| Motor | Eff | 25 year energy |
|---|---|---|
| **IE1 DOL** | 88,7% | € 321,300 |
| **IE5 VSD** | 93,3% | € 305,475 |
| **Savings** | | € 15,825 total<br>**€ 634 yearly** |
| **ROI** | | **5 years 10 months** |

| Motor | Eff | 25 year energy |
|---|---|---|
| **IE1 DOL** | 88,7% | € 321,300 |
| **IE4 DOL** | 93,9% | € 303,514 |
| **Savings** | | € 17,786 total<br>**€ 711 yearly** |
| **ROI** | | **2 years 6 months** |

| Motor | Eff | 25 year energy |
|---|---|---|
| **IE1 VSD** | 87,4% | € 326,086 |
| **IE5 VSD** | 93,3% | € 305,475 |
| **Savings** | | € 20,611 total<br>**€ 824 yearly** |
| **ROI** | | **4 years 6 months** |

- IE5 energy cost (excluding VSD): €300k (for 100%-efficient VSD)
- When possible, invest upfront in machinery with IE5 or IE4 motors. Also, whenever possible, replace old motors.
- Calcualtions are at full load, but VSD can improve system efficiency at partial loads.

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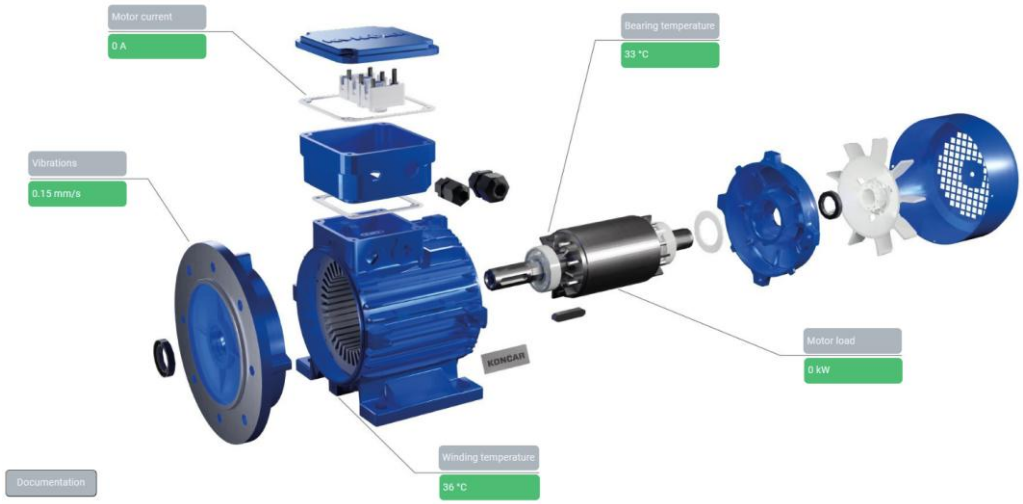
# Variable speed drive can bring additional benefits


- Higher upfront investment, but better efficiency at partial loads and variable speeds.
- Improved power factor – less reactive power.
- Opportunity to further optimise drive system for additional savings.
- Starting point for cost effective predictive maintenance.

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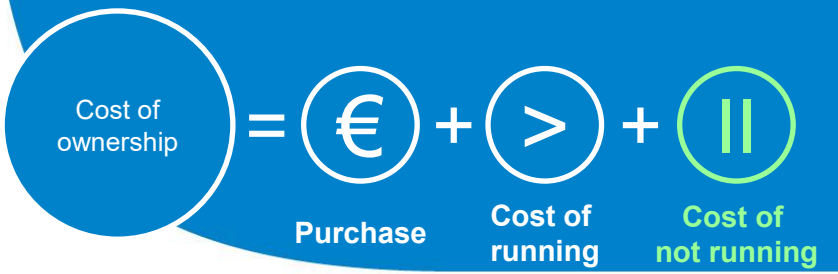
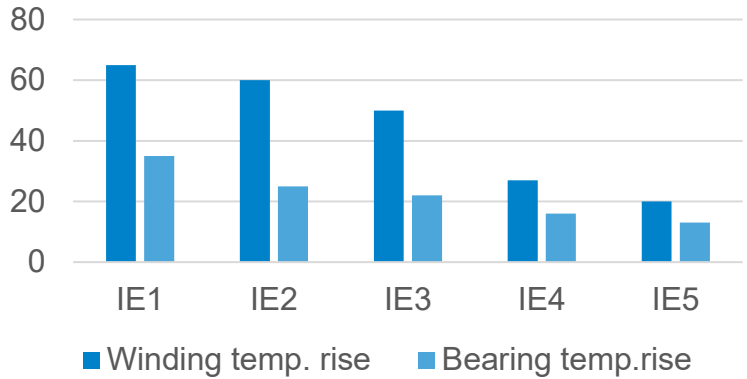
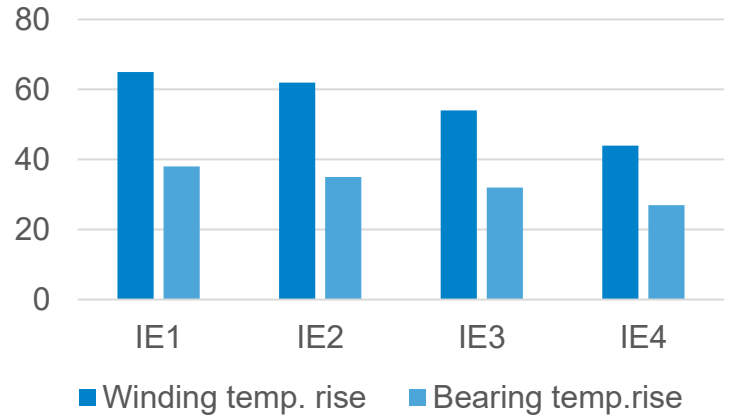
# Reduced downtime

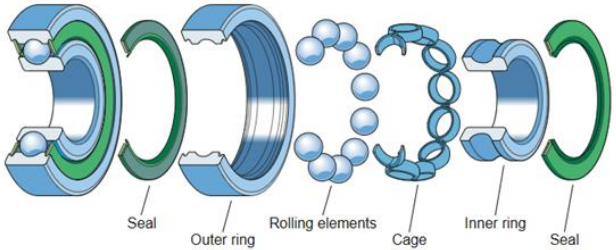



- Low bearing and winding temperature rise.
- Increased bearing replacement interval.



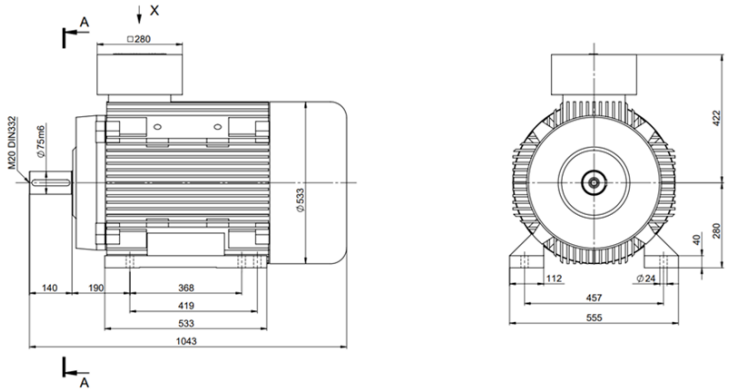




- Grease life doubles for every 15 °C reduction in temp.
  Source: Evolution - technology magazine from SKF
  (Reductions below 55 °C do not provide same benefit).



# Dimensions – main concern during replacement

- IE5 synchronous motors have same shaft, flange and foot dimensions, so mounting and coupling remain unchanged.
- Maintenance tasks and parts also must be the same (e.g., bearings sizes).
- Can we use a variable-speed drive (VSD) in the current process? If not, choose an IE4 induction motor, which can also match dimensions of the existing motor.

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# Example of replacement scenarios

- **IE1 asynchronous motor + VSD -> IE5 synchronous motor + VSD**
  VSD is already in use, so it is possible to replace both old VSD and motor without additional process issues.

- **IE1 asynchronous motor DOL -> IE5 synchronous motor + VSD**
  VSD can be integrated into the existing electrical design. As previously noted if only fixed speed is needed and if load is well optimised in that case better option is IE4 asynchronous motor.

- **IE1 asynchronous motor DOL -> IE4 asynchronous motor DOL (Cu rotor)**
  When it is not possible to integrate VSD in actual electrical design and when fast ROI is requested.

VSD = variable speed drive
DOL = direct on line starting (without VSD)

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# IE5 synchronous motors: with or without magnets?

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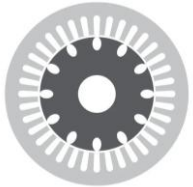
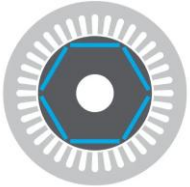
# Comparison of potential technologies for IE5

- Comparatively good
- Comparatively medium
- Comparatively poor





| | Induction motor | Synchronous reluctance | Permanent magnet |
|---|---|---|---|
| Torque / power density | ● | ● | ● |
| High speed operation | ● | ● | ● |
| Resistance to high temp. | ● ● | ● | ● |
| Raw material & manufacturing | ● | ● | ● |
| Partial load efficiency | ● | ● | ● |
| Rated current | ● | ● | ● |
| Major advantage | Easy control - VSD not required. | Efficient with low material cost. | Lighter for the same efficiency |
| Major disadvantage | For IE5 efficiency one or even two IEC sizes larger compared to IE3. | Requires advanced control algorithms. Higher rated current. | High cost of magnets, maintenance and recycling. |

# Why is the type of material used for efficiency important?

- Not all materials are the same!
- Rare earths require intensive mining operations, which increase cost of motors.
- Potential problems with supply chains.
- Upcoming regulatory review will address resource efficiency requirements, including the identification of rare earths in permanent magnet (PM) motors.
- There are strong indications that IE5 synchronous reluctance motors will easily comply with future ecodesign regulations!

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# Notes from regulators

## New framework '*Ecodesign for Sustainable Products Regulation*' (ESPR) (EU) 2024/1781

- **In force since July 2024**
- **Replaces** the current Ecodesign directive (EU) 2009/125 covering energy-related products ("ErPs")
- Covers almost **all categories of physical goods** placed on the EU market.
- **Wide range** of requirements to be considered, including:
  - energy efficiency and resource efficiency
  - product durability, reusability, upgradability and reparability
  - presence of substances that inhibit circularity
  - recycled content, remanufacturing and recycling
  - carbon and environmental footprints
  - information requirements, including through a Digital Product Passport
- **Improves** the current framework on various aspects (e.g. market surveillance etc.)
- **Provides a transitional regime**

General info:
Ecodesign for Sustainable Products Regulation - European Commission

Electric Motors and variable speed drives:
Electric Motors - European Commission

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# SynREL future proof for new regulations?

- Comparatively good
- Comparatively medium
- Comparatively poor

| | Induction motor | SynREL | SynPM |
|---|---|---|---|
| Energy efficiency and resource efficiency | ● | ● | ● |
| Product durability, reusability, upgradability, **reparability** | ● | ● | ● |
| Presence of substances that inhibit circularity | ● | ● | ● |
| Recycled content, remanufacturing and recycling | ● | ● | ● |
| Carbon and environmental footprints | ● | ● | ● |
| VSD is essential for operation | ● | ● | ● |

- IMPORTANT NOTE: The impact of the VSD is not included, but its manufacture also requires some resources.

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# 4

# Brief technical details of synchronous reluctance motors

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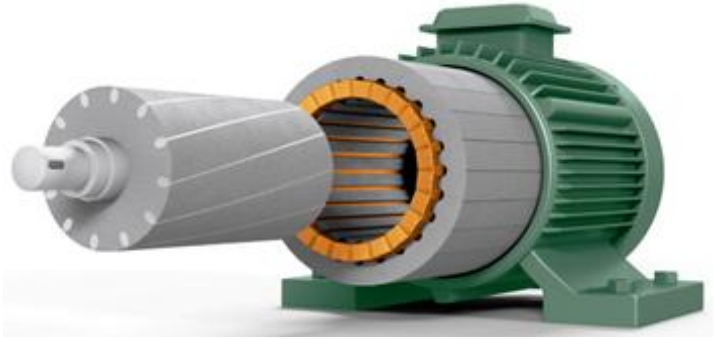
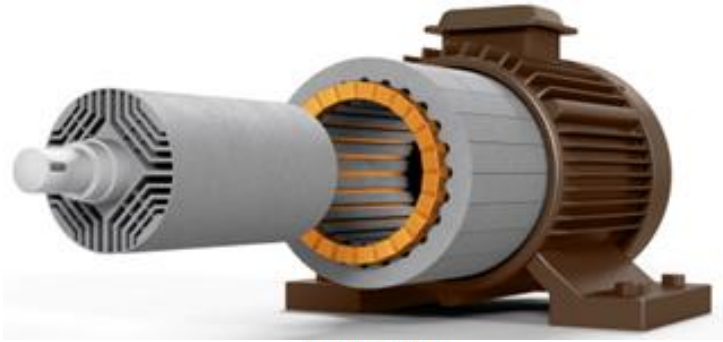
# SynREL construction comparison with asynchronous motor

- Same type of stator winding.
- Same housing, terminal box and shaft.
- Same production procedures and tools.
- Same level of repairability, with the same maintenance and recycling procedures.
- The main and only difference is in the design of the active part of the rotor.

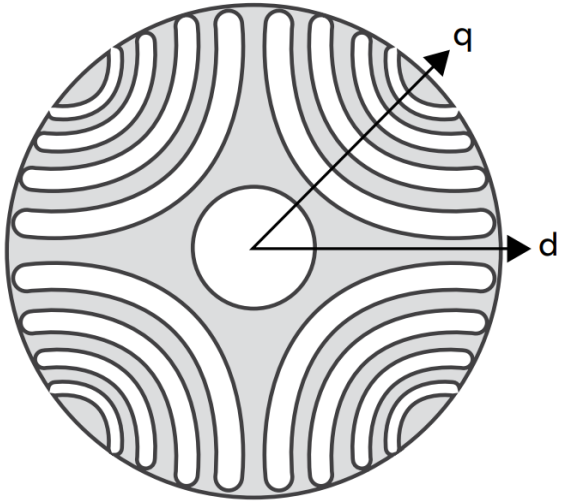


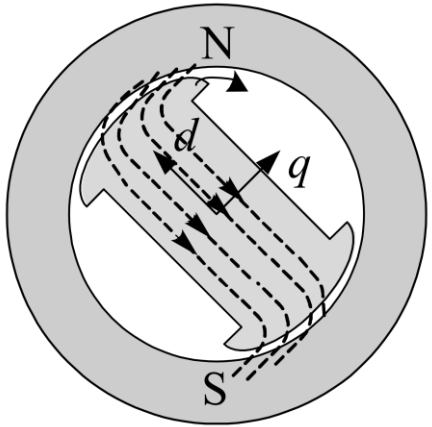


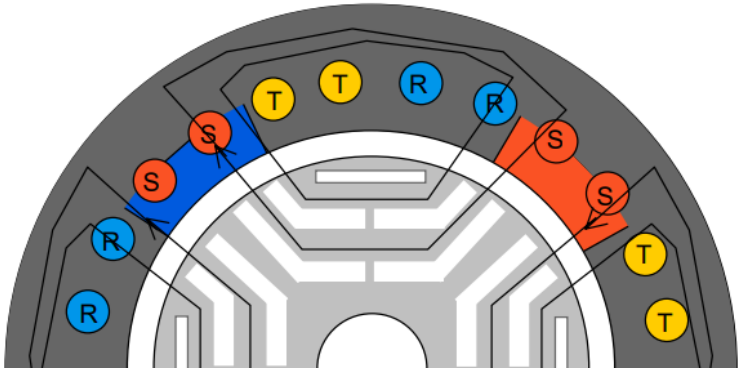
Graphic source: Danfoss Drives

# SynRM principle of operation

- Utilizes magnetic reluctance for torque creation.
- Magnetic field (lines) tend to follow the path of least magnetic resistance (reluctance).
- Magnetic field lines have a tendency to reduce their length.

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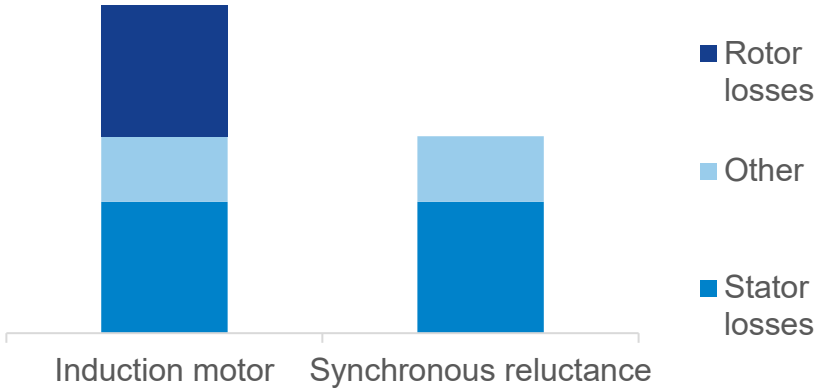
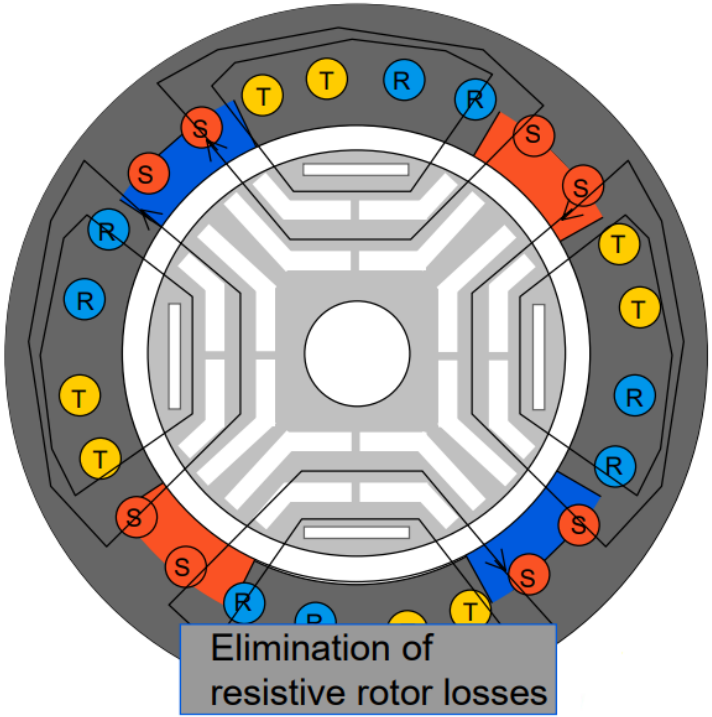
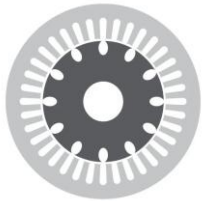
# Why is synchronous reluctance motor efficient?

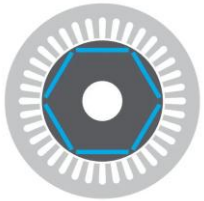
- No rotor bars through which current passes.
- Rotor speed is equal to synchronous rotating magnetic field of the stator.
- Rotor losses are eliminated.



# Main usage scenarios of different motor technologies





| Induction motor | Synchronous reluctance | Permanent magnet |
|---|---|---|
| Cranes | HVAC | E mobility |
| Marine applications (winches, etc.) | Pumps | Robotics |
| Mills | Conveyors | CNC machine spindles |
| Wood industry (saws) | Mixers and stirrers | Airplanes |
| Loads with extremely dynamic changes | Loads without extremely dynamic changes | Automation – high precision positioning systems |
| ATEX | ATEX | Marine applications |
| No synchronization problems and high maximum and starting torques | IE5 efficiency with low cost of non-critical raw materials | Used mainly when small size or weight is needed |

# Two examples of SynREL applications

- IE5 ATEX Explosion-Proof motors
- No magnets and no risk of demagnetisation in critical applications such as Ex zones.
- No additional magnetic field sources that could, in some cases, induce high voltages (e.g., during overspeed faults in cranes, etc.).
- EC transformer cooling fan – cooling on demand, resulting in significant energy savings.

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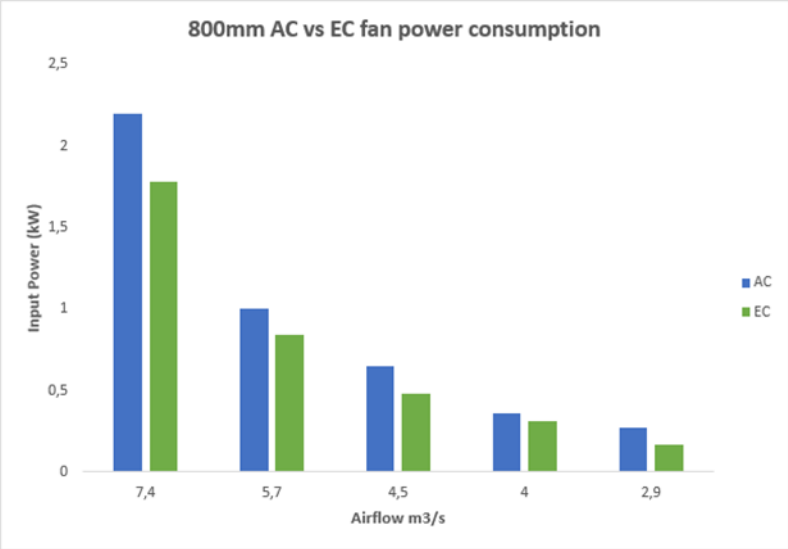
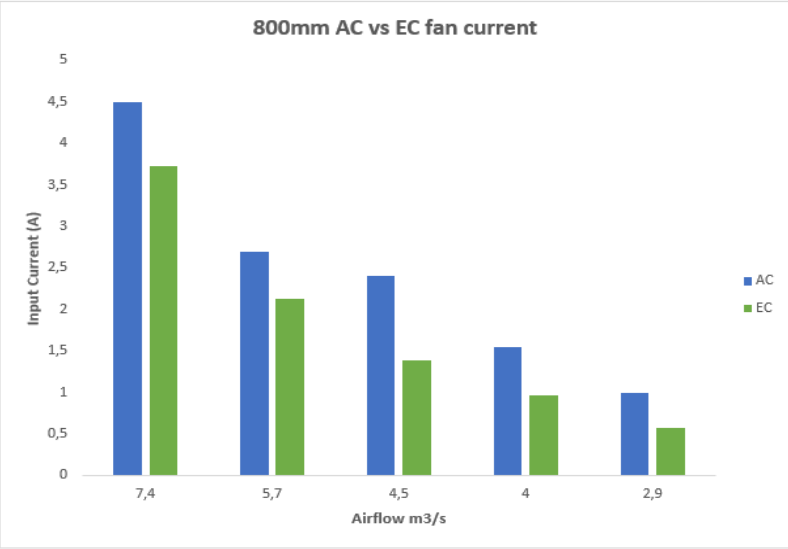
# HVAC application savings with SynREL

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# Upgrade of existing motors IE3 motors?

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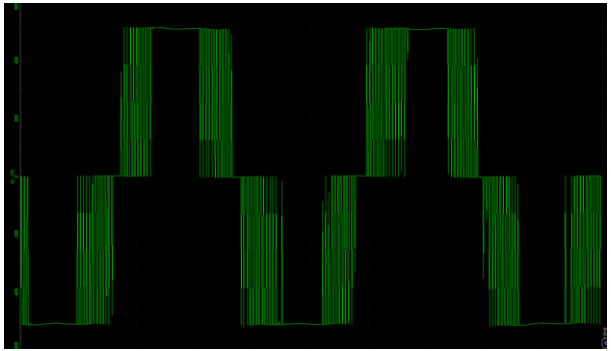
# Alternative to purchasing a completely new motor

- Replace the aluminum rotor with a synchronous reluctance rotor during regular maintenance.
- Synchronous reluctance rotor can be purchased from the motor manufacturer.
- In some cases, speed needs to be reduced to avoid overmodulation.
- Efficiency will improve, but it may not reach IE4, or IE5 just by rotor replacement.
- Suitable for upgrade of relatively new IE3 motors.
- The old aluminum rotor and shaft can be recycled.



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# Comparison of two technologies

| IE3 2p=4 with aluminum rotor | | |
|---|---|---|
| Output power | P2 (kW) | 3019 |
| Voltage | U (V) | 400 |
| Frequency | f (Hz) | 50 |
| Current | I (A) | 6,121 |
| Power factor | CosPhi | 0,811 |
| Rotation speed | n (rpm) | 1426 |
| Temp. Rise | K | 52,2 |
| Efficiency | η (%) | 87,78 (IE3) |

| IE4 2p=4 Upgraded with synchronous rel rotor | | |
|---|---|---|
| Output power | P2 (W) | 3006,5 |
| Voltage | U (V) | 389,9 |
| Frequency | f (Hz) | 50 |
| Current | I (A) | 6,27 |
| Power factor | CosPhi | 0,778 |
| Rotation speed | n (rpm) | 1500 |
| Temp. Rise | K | 35,7 |
| Efficiency | η (%) | 91,26 (IE4) |

3kW 2p=4: IE3 87,7% / IE4 90,4% / IE5 92,1%

Only rotor replaced – possible additional upgrades.
VSD efficiency should be taken into consideration if not already used.

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# Conclusion

- Replacement of old motors with IE5 synchronous reluctance motors is a great investment with short ROI even if current regulations do not require IE5 motor efficiencies.
- During replacement of old motors, dimensions should be kept the same. Two good options: IE5 SynRM motor with VSD or IE4 asynchronous motor with Cu rotor without VSD.
- Synchronous reluctance motors are future proof for IE5 efficiecny rating and future regulations due to good material cost efficiency and absence of rare earths.
- It is possible to upgrade existing IE3 motors with aluminum rotors to higher efficiency levels by using synchronous reluctance rotor or copper rotor.

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# Questions?


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