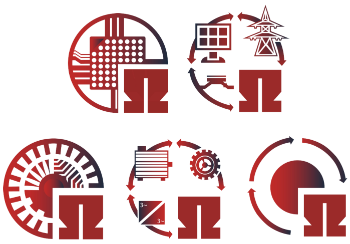
ELSYS Note



Untapped Capability of the SynRM

In low-pole, sub-10 kW applications without field-weakening, synchronous reluctance machines (SynRMs) unlock performance limited in induction motors (IMs) by rotor losses. Experiments show a 5,5 kW → 9 kW uplift and a 16 K cooler stator under identical conditions, illustrating the thermal headroom of the SynRM. A simple rule emerges: a SynRM can reach about 1,5× the IM's power in the same frame.

Introduction

The induction motor (IM) is the universal workhorse of industry. It is robust, manufacturable at scale and tolerant to almost any application environment. Yet these advantages come with a drawback: the squirrel-cage rotor generates heat that must cross the airgap and stator yoke before reaching the cooling system. This thermal path often limits the power that can be extracted from a given frame size.
In contrast, the synchronous reluctance machine (SynRM) operates with negligible rotor loss. In applications with **no field-weakening requirement**, **low pole-pair number** and **sub-10 kW power** ratings, this characteristic leads to a simple but powerful consequence:

The stator, not the rotor, becomes the dominant thermal constraint.

This ELSYS Note highlights that, in this specific operating region, the SynRM exposes *untapped capability* within standard IM frames.

More Output per Frame

A clear illustration is the well-known conversion of a 5,5 kW induction motor into a synchronous reluctance machine [1]. The stator frame remained unchanged; the rotor and stator topologies were optimised.

$$5{,}5\,\text{kW} \longrightarrow \approx 9\,\text{kW}$$

This corresponds to a 1,6 × **increase in power** inside the same mechanical frame. Remarkably, this also aligns with the rule-of-thumb that PMSMs typically reach > 1,5× the power density of IMs. Yet here it was achieved *magnet-free*.
The mechanism behind this uplift is straightforward: without rotor copper losses, the thermal bottleneck of the IM is removed. The stator can operate at the same temperature but transfer more electrical power before reaching its thermal limit.

Thermal Headroom: Experimental Proof

The disappearance of rotor heat can be demonstrated directly. In a historic 110 kW comparison [2], the IM stator was reused and the rotor converted to a pure SynRM. Both machines delivered 110 kW, but under identical stator current and cooling the SynRM exhibited a:

16 K lower stator temperature rise

Since stator copper losses were equal, the only possible source for this temperature difference is the missing rotor I^2R loss. The experiment therefore confirms:

Same stator, same current, same cooling – the SynRM runs cooler.

This is the thermal headroom that enables the 5,5 kW to 9 kW uplift.
Tab. 1 serves as a practical frame of reference. The SynRM occupies the middle ground: completely magnet-free like the IM, but capable of IM-matching or IM-exceeding output when rotor losses are removed.

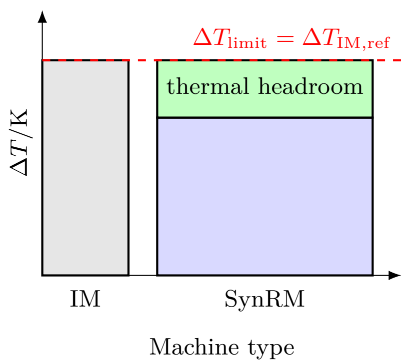


Fig. 1: Measured temperature rise showing the SynRM's thermal headroom due to negligible rotor losses.

Table 1: Machine Types in Context

Machine type	Magnets	Power density (vs. IM)	Typical role
IM	none	1,0 (reference)	universal workhorse
SynRM	none	$\approx$ 1,0 to > 1,0 (can exceed IM)	magnet-free alternative when no FW is required
PMSM	yes	$\geq$ 1,5× IM	high power density, but cost & supply risk

Synthesis of Evidence

Across multiple identical-stator comparisons, the trend is consistent:

1. When the stator is fixed, **SynRMs match or exceed** IM output power.
2. The absence of rotor I^2R loss introduces **thermal headroom**.
3. A documented case reached **PMSM-class power density without magnets**.

These findings are not limited to a single study. Comparable conclusions were reported in [3, 4], all of which reused industrial IM stators and showed higher torque or output density when only the rotor was replaced by a reluctance design.
These observations apply most strongly in the specific operating region considered here: low pole count, no deep field-weakening, and sub-10 kW frames.

A Rule of Thumb

Based on measured results and consistent trends, a compact engineering estimate emerges. Simple rules of thumb are valuable in early design phases, where quick frame-size judgements are needed long before detailed FEM optimisation is available. Such estimates provide a quick engineering judgement: not exact, but reliable enough to guide practical decisions.

SynRM output
$\approx$ **1,5× IM output**
in the same frame

This rule holds when:

- field-weakening requirements are small,
- the pole number is low (2–4 poles), and
- the cooling boundary conditions are comparable.

The 5,5 kW → 9 kW uplift and the 16 K thermal reduction provide direct experimental justification.

Conclusion

For low-pole, sub-10 kW machines without field-weakening demands, the SynRM reveals a simple but powerful advantage: rotor-loss elimination frees thermal headroom that is unavailable to the IM. This enables the SynRM to act not merely as an alternative, but as a **magnet-free upgrade path** capable of delivering up to 1,5× the IM's power in the same frame size.
The capability is not theoretical. It has been demonstrated experimentally at both small and large ratings, and the underlying mechanism is clear. In the appropriate application region, the SynRM taps into performance that remains inaccessible to the induction motor.

References

[1] M.J. Kamper, F.S. Van der Merwe, and S. Williamson. "Direct finite element design optimisation of the cageless reluctance synchronous machine". *IEEE Transactions on Energy Conversion* 11.3 (1996), pp. 547–555. DOI: 10.1109/60.537006.

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[3] Aldo Boglietti, Andrea Cavagnino, Michele Pastorelli, David Staton, and Alfredo Vagati. "Thermal Analysis of Induction and Synchronous Reluctance Motors". *IEEE Transactions on Industry Applications* 42.3 (2006), pp. 675–680. DOI: 10.1109/TIA.2006.873668.

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