Computationally Efficient Optimization Approach of Synchronous Reluctance Machines Using Variance-Based Sensitivity Analysis

IEEE ENERGY CONVERSION CONGRESS & EXPO Nashville, TN | OCT.29-Nov.2
ECCE 2023

Paper #233

UCLouvain
Institute of Mechanics, Materials and Civil Engineering

Christophe De Gréef, Bruno Dehez

Institute of Mechanics, Materials and Civil Engineering (iMMC), Université catholique de Louvain (UCLouvain), Belgium

Context

Optimal design of SynRM involves

- Maximizing the **mean torque**
- Ensuring the **structural integrity**
- Limiting the **torque ripple**

$$\max_{\mathbf{x}} \ \overline{T}(\mathbf{x}) \quad \text{s.t.} \quad \max(\sigma_{\mathrm{VM}}(\mathbf{x})) < \sigma_y, \quad \widetilde{T}(\mathbf{x}) < 10\%$$

But also

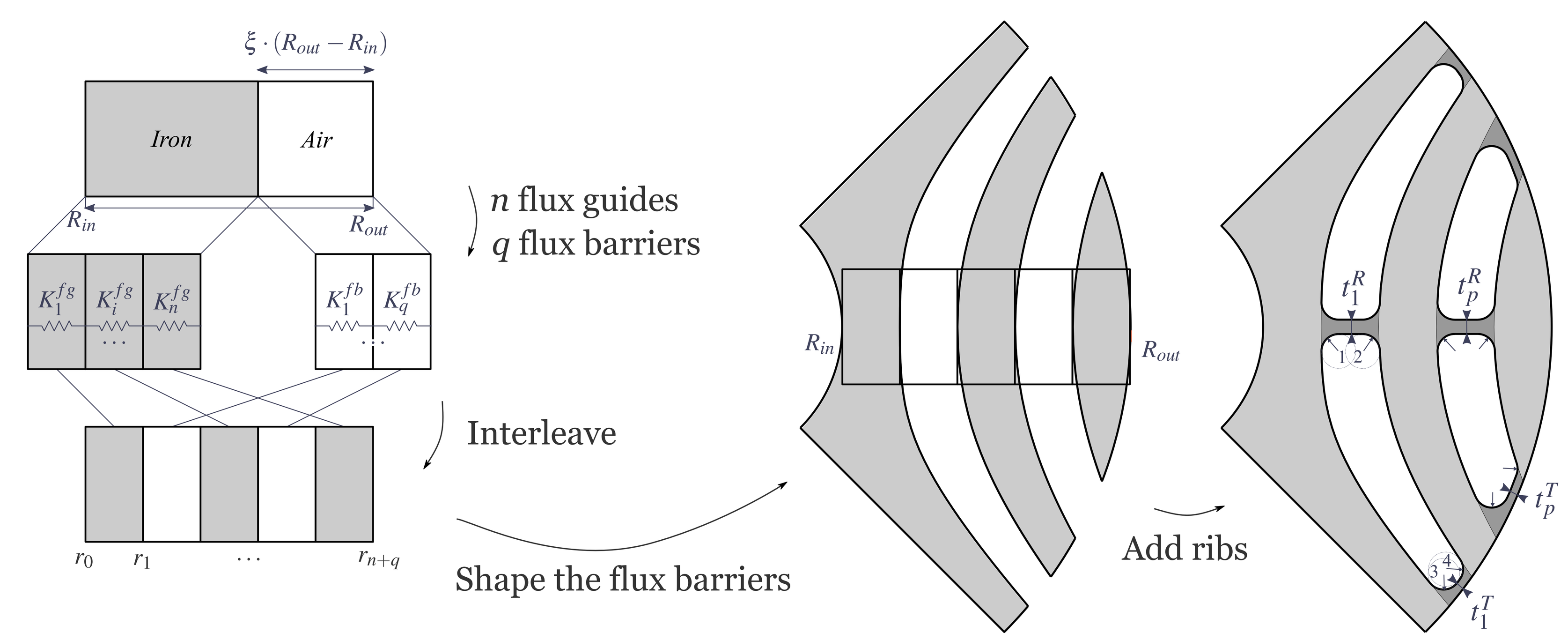
- A high number of parameters
- Costly FEM evaluations

⇒ **Consequent optimization time** (200 hours).

In ECCE2021, we reported that **optimizing** the ribs **separately** from the flux barriers significantly **lowers the optimization time**, preserves the mean torque, but **fails to** consistently **limit the torque ripple**. This is due to **unaccounted parameter interactions**.

In this study, we perform a **global sensitivity analysis** to better understand the interaction between parameters by **decomposing the variance** of the outputs, using Sobol indices.
⇒ From this analysis, we **propose an optimization strategy**.

Parametrization

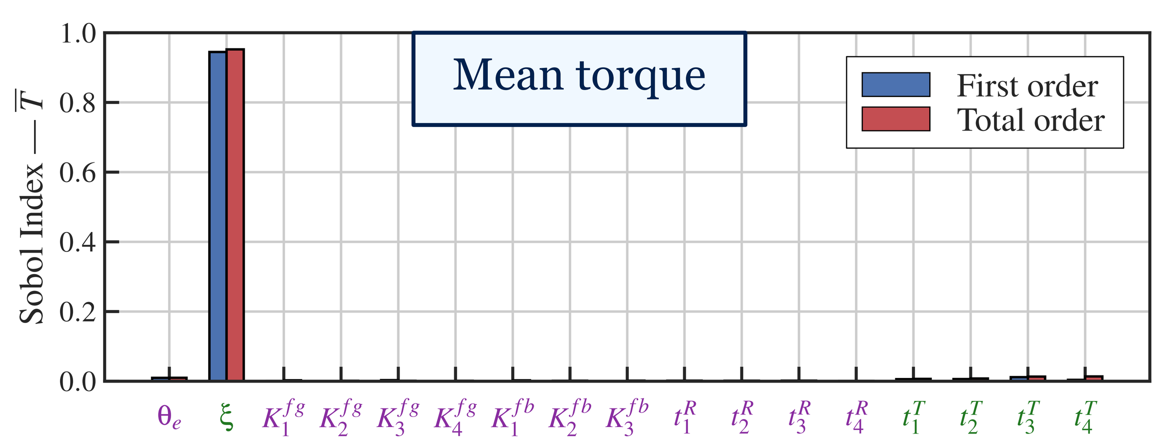


This parametrization highlights the **main factors** impacting the **mean torque**.

For **4 flux barriers**, there are **33 parameters**:

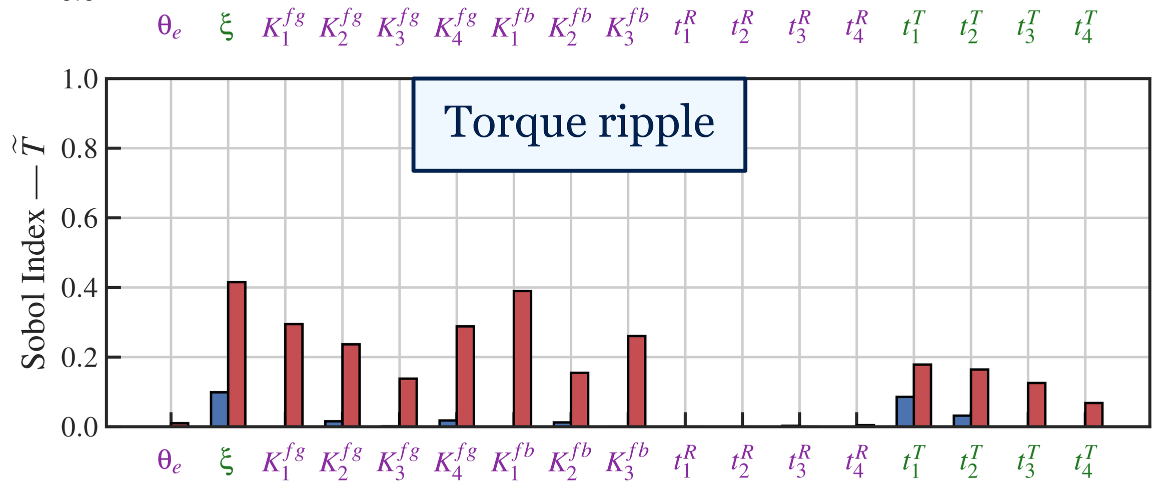
- 1 for the air-to-rotor ratio, 1 for the electric angle
- 4 for the flux guides, 3 for the flux barriers
- 4 for the thicknesses of the radial ribs, 4 for the tangentials
- 16 for the fillets (proven negligible by the sensitivity analysis)

Sensitivity Analysis



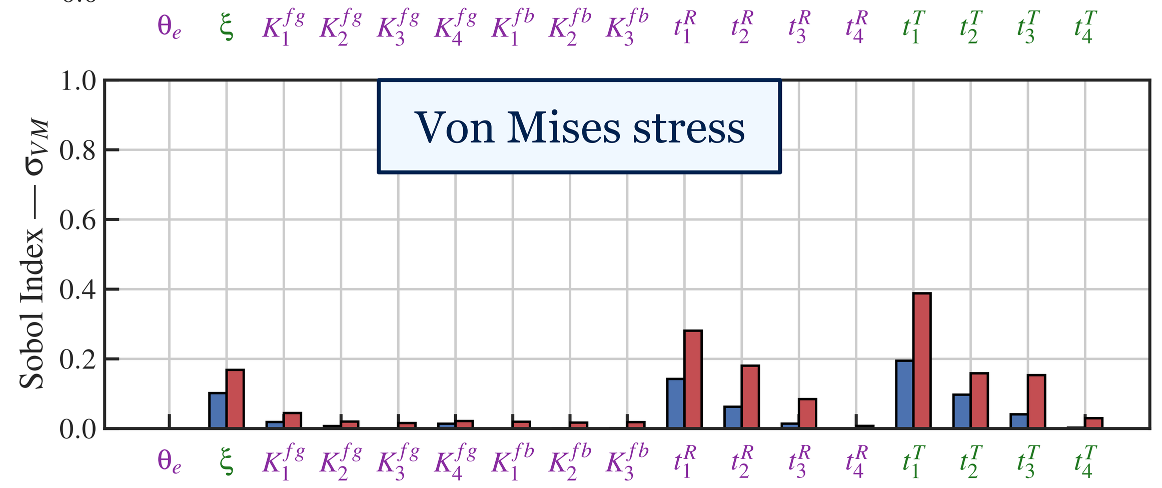
Maximize the mean torque, using the most significant parameters

$$\mathcal{P}_1 = \max_{\mathbf{x}_1 = \{\theta_e, \xi\}} \overline{T}(\mathbf{x}_1)$$



Minimize the torque ripple, by redistributing the flux barriers and the flux guides

$$\mathcal{P}_3 = \min_{\mathbf{x}_3 = \{K_i^{fg}, K_j^{fb}\}} \widetilde{T}(\mathbf{x}_3)$$

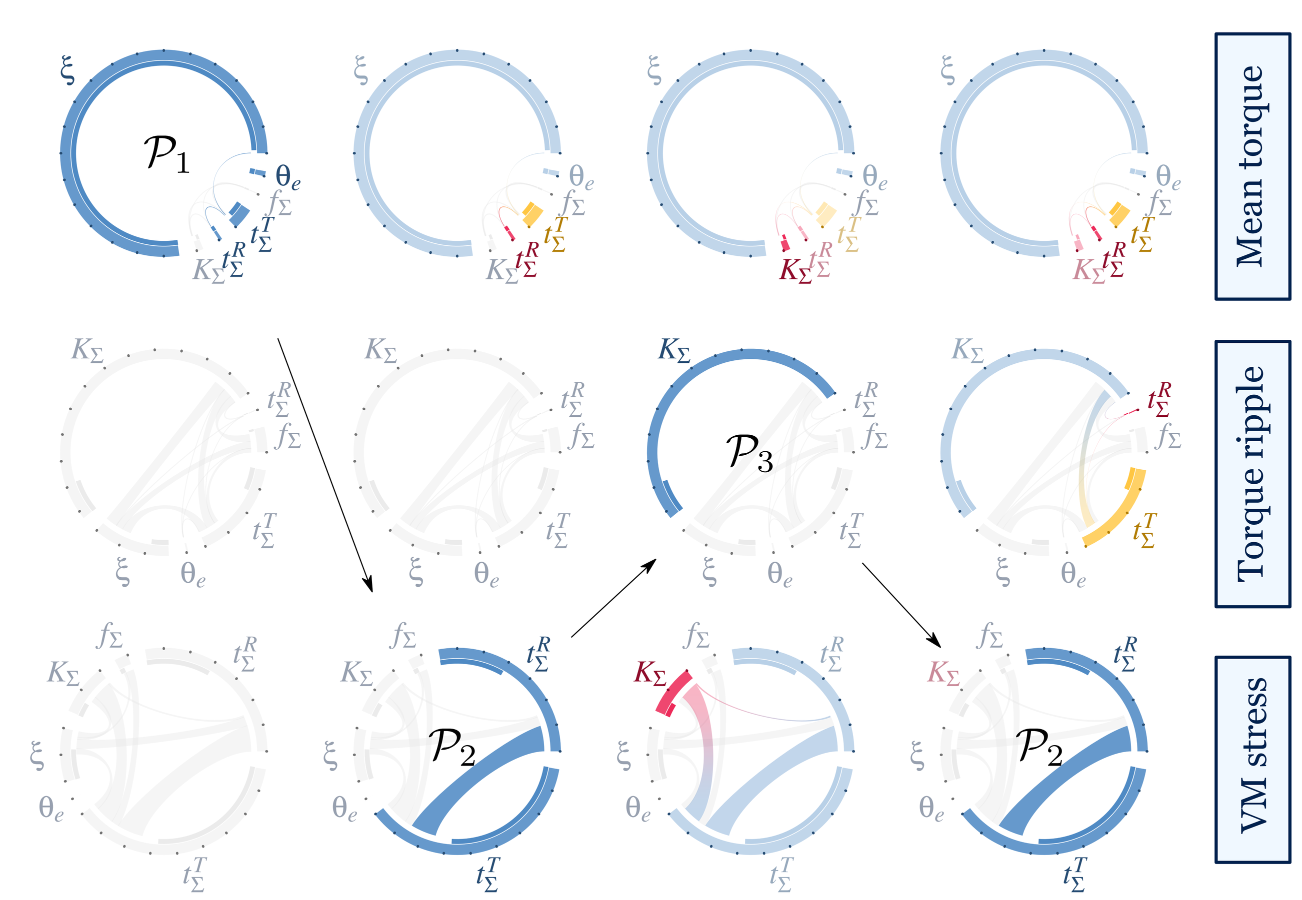


Ensure the structural integrity, while minimizing the changes on the tangential ribs

$$\mathcal{P}_2 = \left\{ \begin{array}{l} \min\limits_{\mathbf{x}_2 = \{t_j^R, t_j^T\}} \sum_{j=1}^{q} \mathrm{abs}\left(t_j^T - t_j^T|_0\right) \\ \text{s.t.} \quad \max(\sigma_{\mathrm{VM}}(\mathbf{x}_2)) < \sigma_y \end{array} \right.$$

- Parameter x affects a **single** output
- Parameter x affects **several** outputs

Optimization strategy



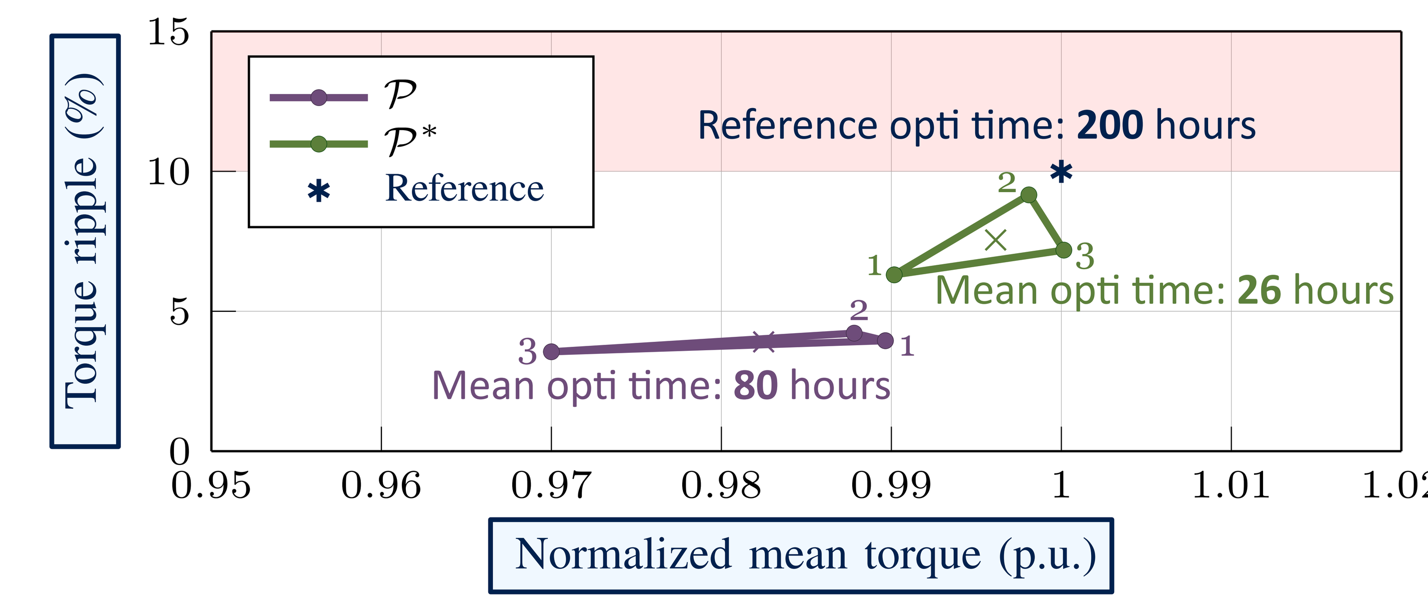
$$\mathcal{P} = \mathcal{P}_1 \rightarrow \mathcal{P}_2 \rightarrow \mathcal{P}_3 \rightarrow \mathcal{P}_2$$

$$\mathcal{P}^* = \qquad \xrightarrow[\widetilde{T}(\mathbf{x}_3) \leq 10\%]{} \mathcal{P}_2$$

Ribs are predimensioned before minimizing the torque ripple, to minimize the effects of the last optimization

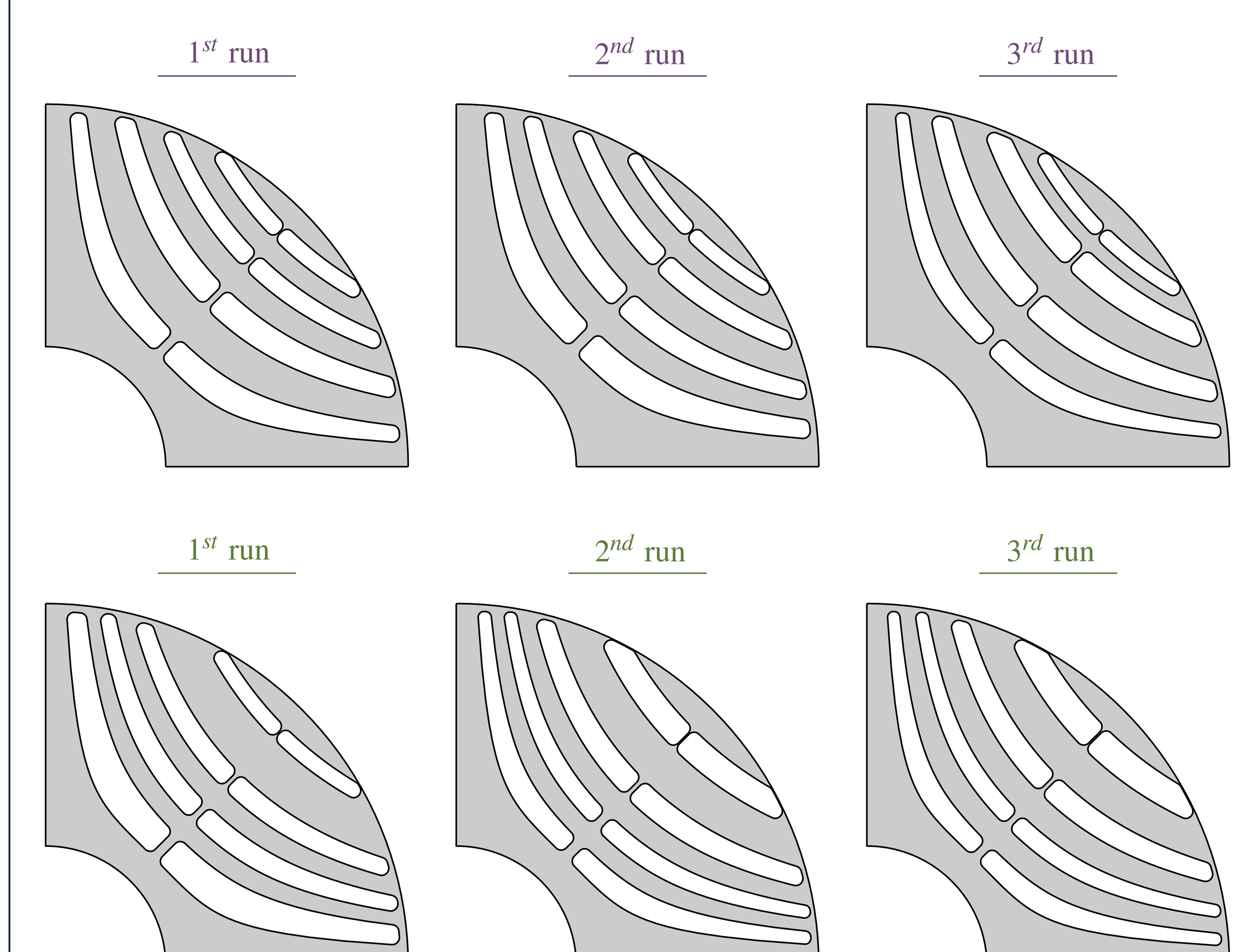
The torque ripple optimization can be aborted once the constraint is satisfied → Alternative strategy $\mathcal{P}^*$

Results & Discussion



To account for the **stochasticity** of the optimization algorithm, the **repeatability** of the strategies is tested by performing **3 independent runs**. The obtained designs are very similar in their geometrical configurations and electromagnetic performance.

Using the proposed approaches, the **torque ripple** has been brought **lower than the reference design**, for an **eighth of the total optimization time** and an equivalent output torque.



Conclusion

Sensitivity analyses can be used to propose a **sequencial optimization** strategy that **satisfies the constraints with minimal impact on the main objective**, while showing **good repeatability.**