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FEA-based optimization of switches for reluctance motors

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ABSTRACT

Switched reluctance motors (SRMs) are considered one of the important machines used in industry sectors due to their simple structure, robustness, and high-speed capability. However, the performance is often limited by high torque ripple and acoustic noise due to the uneven magnetic flux distribution. This paper presents an optimization study for improving flux distribution by shape design modifications of the stator and rotor geometry using finite element analysis (FEA) combined with the whale optimization algorithm (WOA). More specifically, FEA is utilized to calculate the magnetic field behavior, torque characteristics, and core losses for different structural geometries of the proposed design, while WOA systematically searches for the optimum values of shape parameters. Thus, the simulation results show that the proposed approach significantly improves the uniformity of flux distribution, hence reducing torque ripple and improving the efficiency. The integration of FEA with the WOA provides a practical and effective way to achieve better SRM performance without further complication of control algorithms.

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1. INTRODUCTION

Reluctance motors have a widely recognized advantage of simple structure, robustness, and the possibility to work at high speed in the absence of permanent magnets. These features put them in an advantageous position in a variety of industrial drives, electric vehicle applications, and industrial adjustable speed drive (ASD) applications. However, switch reluctance motors (SRMs) inherently face a non-uniform distribution of magnetic flux, which often leads to high torque ripple, localized saturation, acoustic noise, and reduced efficiency [1], [2]. This flux path is inherently unbalanced, and it forms a basic design challenge that restricts broader applications of SRMs in noise-sensitive and high-performance applications [3].

Geometric design modifications have been one such approach to improve flux distribution. Optimizing stator and rotor pole arcs, which directly govern the variation of permeance with rotor position, constitutes one such widely studied approach. The adjustments of pole-arc combinations have managed to balance many competing objectives such as torque density, torque ripple, and efficiency [4]. Moreover, general shape optimization methods have been studied to refine the pole geometry in order to reduce torque ripple while still maintaining torque density. Another design methodology involving airgap shaping and pole-tip modification has been developed and implemented. The introduction of non-uniform air gaps, chamfers, and small notches may effectively redistribute the magnetic flux and reduce local saturation at aligned positions. The use of a uniform air gap with rotor perforations can minimize torque ripple without penalizing the average torque. Such techniques are highly reliant on finite element analysis (FEA) in order to predict the flux paths and verify any improvement in performance [5]. Since torque ripple and uneven flux also excite radial forces producing vibration and acoustic noise, researchers have integrated structural and acoustic models with FEA. It is feasible that the geometrical construction optimization through multiphysics FEA simultaneously lowers torque ripple and reduces sound pressure levels, giving more complete improvement to SRM performance [6].

More innovative topologies have also been proposed beyond conventional designs, such as segmented-rotor SRMs, which improve flux uniformity. Such machines reduce flux paths and flux reversals in the stator, hence improving torque density and efficiency. Xu *et al.* [7] reviewed the advantages of SSRMs, whereas Widmer *et al.* [8] optimized an 80-kW automotive-scale SSRM; torque density competitiveness and reduced ripple were attained compared to conventional designs. Moreover, similar strategies are investigated for bearing-less SRMs, where pole shaping has been applied to simultaneously boost torque and minimize ripple under combined electromagnetic and force requirements [9]. Recent studies also highlight advanced optimization methods, which combine parametric modeling with optimizations, or hybrid time-efficient FEA models, to accelerate the evaluation of many design variables [10]. Multi-objective optimization methods are also investigated to obtain higher output power and torque in SRMs [3]. To evaluate the electromagnetic and vibro-acoustic trade-offs [11], a hybrid acoustic prediction model has been proposed. Meanwhile, improvements in flux distribution must be co-designed with current excitation strategies to achieve robust torque-ripple minimization [12].

On the other hand, many existing works studied the investigation and optimization of the geometry of the SRMs, focusing on a single target, such as torque ripple reduction, without simultaneously accounting for efficiency and acoustic performance [6]. Others focus on specific design variables while neglecting manufacturability constraints, lamination robustness, or performance consistency under different operating conditions such as voltage variation, thermal effects, and high-speed transients [13]. In this paper, SRM is modeled and simulated using the parametric method. More precisely, the stator, rotor, and air gap design are further improved by applying the white whale algorithm and integrated with Ansys Maxwell software. Consequently, the predicted results show a better motor design, where the distribution and flow of magnetic flux between its different parts improved, raising the torque and subsequently, the overall efficiency.

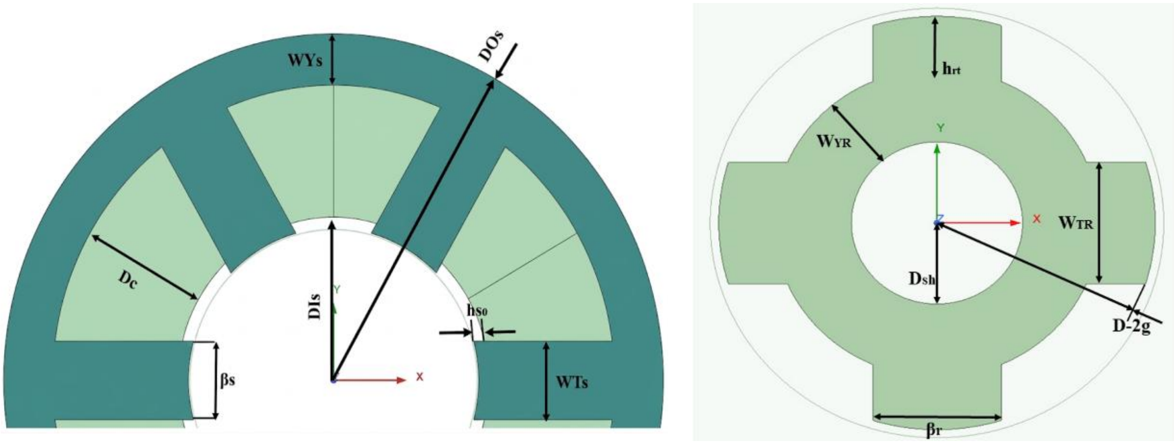
2. A FUNDAMENTAL DESIGN METHOD FOR THE SRM

The SRM design process focuses on the determination of the main geometric dimensions, especially the inner and outer diameters, which will be used as the basis for a more detailed design of both stator and rotor. This is followed by geometric definition; the performance evaluation is verified in terms of electromagnetic torque and overall efficiency. Multi-variable interdependencies inherently affect the efficiency of the motor, such as electromagnetic and core losses due to the internal configuration, selected construction materials, stator winding technique, and geometrical shaping of the peripheral rotor edges [13], [14]. To ensure accuracy in performance prediction, ANSYS MAXWELL software is employed to perform two-dimensional finite element analysis (FEA), using the developed motor model with the characteristics specified in Table 1. Moreover, the whale optimization algorithm (WOA) is integrated into the design framework to search for the optimal values of the key design variables.

The geometry of the stator and rotor laminations significantly affects the magnetic performance and efficiency of switched reluctance motors (SRMs). Optimized profiles can reduce core losses, improve flux distribution, and enhance torque [15]. The stator and rotor were modeled in Maxwell software using the parametric method and relevant mechanical design equations. The rotor shape, which determines reluctance torque, is designed to align with energized stator poles, minimizing magnetic resistance and improving overall performance [16], [17]. Figure 1 shows a cross-section of stator and rotor geometry.

Table 1. Characteristics of the developed motor model

Motor information	Value	Unit
Rated output power	0.75	KW
DC terminal voltage	500	V
Peak value of the phase current	3.14	A
Rated speed	1500	rpm
Rated torque	4.77	N.m
Stack length	70	mm
Air gap length	0.45	mm
Ratio of stack length to bore diameter	0.73	-
Efficiency	79.1	%



(a) (b)

Figure 1. Machine cross-section: (a) stator geometry and (b) rotor geometry

Accordingly,

$$D = \sqrt[3]{\frac{D^2 L}{AR}} \tag{1}$$

$$L = AR * D \tag{2}$$

$$W_{Ts} = D * \sin\left(\frac{\beta_s}{2}\right) \tag{3}$$

$$W_{Ys} = WTs * \gamma_{wys} \tag{4}$$

$$\beta_s = \frac{2\pi}{mN_r} \tag{5}$$

$$W_{TR} = 2 * \left(\frac{D}{2} - g\right) * sin\left(\frac{\beta_r}{2}\right) \tag{6}$$

$$W_{YR} = WTR * \gamma_{wyr} \tag{7}$$

$$Ripple\ Torque\ (\%) = \frac{T_{max} - T_{min}}{T_{avg}} * 100 \tag{8}$$

Where D_{os}: stator outer diameter, D_{Is}: stator inner diameter, D_c: depth of the coil, D: bore diameter, L: stack length, W_{Ys}: width of stator tooth arc, W_{Ts}: width of stator tooth, γ_{wys}: the ratio of WYs/WTs, γ_{wyr}: per-unit rotor yoke width, W_{YR}: width of rotor yoke, W_{TR}: width of rotor tooth, h_{s0}: height of stator tooth, h_{rt}: height of rotor tooth, βs: stator tooth arc, AR: aspect ratio, N_r: number of rotor teeth, m: number of phases, g: air gap length, βr: rotor tooth arc, T_{max}: maximum torque, T_{min}: minimum torque, and T_{avg}: average torque.

The yoke width of both the stator and rotor is considered a critical parameter that directly influences the performance, efficiency, and mechanical characteristics of SRMs. Meanwhile, a narrower stator tooth yoke can help reduce noise, vibration, and magnetizing current, whereas an excessive increase in its width may introduce unnecessary mass and negatively impact efficiency. Similarly, the rotor tooth yoke width is one of the important parameters that determines magnetic behavior and torque production. While reducing this dimension can lower the magnetizing current and decrease the saliency ratio, it can also increase the static weight of the motor due to the additional mass in the rotor, which may alter the balance of performance given earlier [18].

3. FEM METHODS AND MAXWELL EQUATIONS

The finite element method (FEM) is one of the most adopted numerical techniques in electrical machine analysis due to its accuracy in solving nonlinear magnetic field problems when the analytical methods fall short [17]. ANSYS MAXWELL is a software that models the geometry, captures the non-linear flux density

– field strength (B-H) material behavior, and predicts the performance of a machine under changing load and excitation conditions [19]. This computational framework allows designers not only to estimate static and dynamic torque but also to analyze losses, efficiency, and thermal interactions more precisely [20] by applying material properties and setting boundary conditions in several steps, as illustrated in Figure 2 [21].

FEM-based simulations can be integrated with optimization algorithms such as WOA to explore large design spaces and identify optimal geometrical configurations that improve flux distribution and efficiency [22], [23]. The proposed model, shown in Figure 3(a), is analyzed using nonlinear material characteristics, while the corresponding mesh generation used for the FEA is illustrated in Figure 3(b). The optimization process focuses on key design parameters, including stator and rotor yoke widths, slot geometry, and air gap length, to enhance the electromagnetic performance and overall efficiency of the SRM.

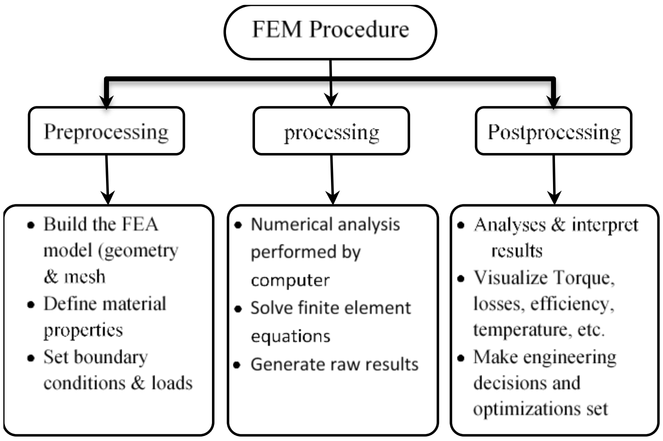


Figure 2. FEM steps

(a)

(b)

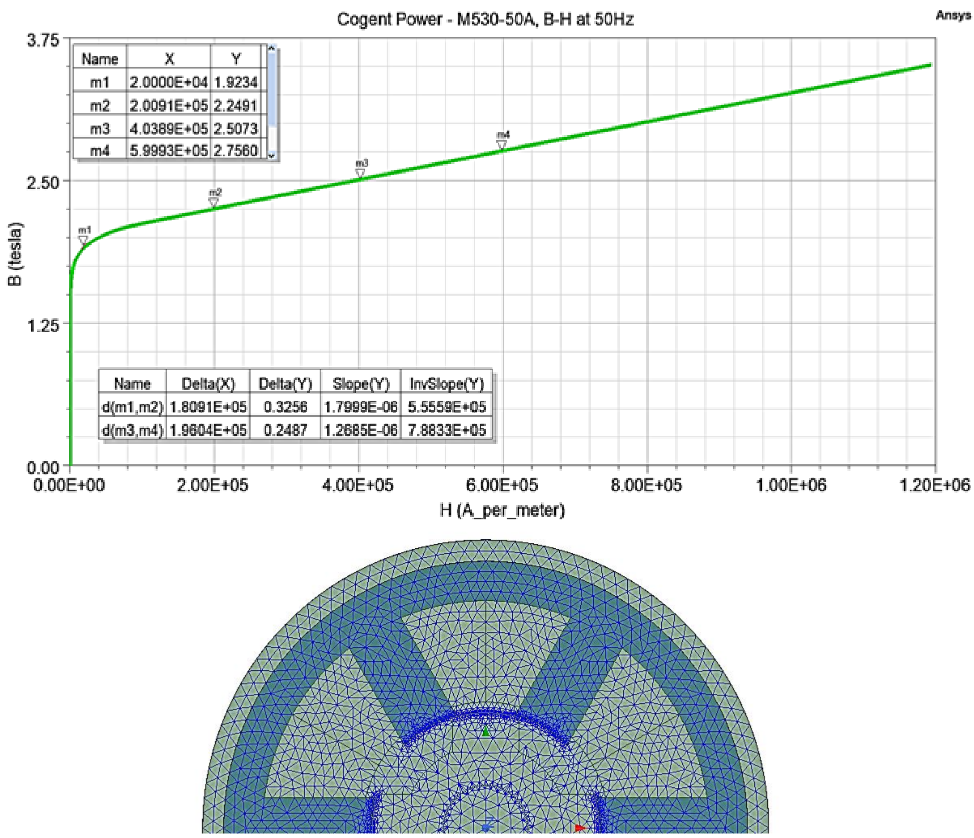


Figure 3. SRM proposed model: (a) nonlinear material characteristics and (b) meshing analysis for SRM

4. WHALE OPTIMIZATION ALGORITHM (WOA)

The proposed WOA is a recently introduced nature-inspired metaheuristic developed by Mirjalili and Lewis [24], which has been inspired by the bubble-net hunting strategy of humpback whales [25]. WOA has gained significant interest and broad consideration owing to its simplicity, effective global search ability, and its potential for balancing exploration and exploitation while solving complex engineering optimization problems [26]. In electrical machine design, the integration of the WOA with FEA has already been implemented for identifying optimal geometrical parameters capable of improving performance metrics regarding torque, efficiency, and flux distribution [27], [28]. Figure 4 illustrates the principles of operation of the WOA.

To implement WOA for the proposed SRM effectively, three critical design variables have been selected as optimization inputs. The first is stator yoke width, which is related to the carrying capacity of magnetic flux in the stator, preventing its core from saturation, and generally affecting torque production and efficiency [27]. The second is the rotor yoke width, defining the return path of magnetic flux and having a direct effect on torque capability and magnetic loading, plus overall efficiency in energy conversion. The third is the air-gap dimension, more decisive in shaping the flux linkage, inductance variation, and torque ripple, since even minor variation in this parameter strongly influences the smoothness of torque and efficiency in the machine [29], as illustrated in Table 2.

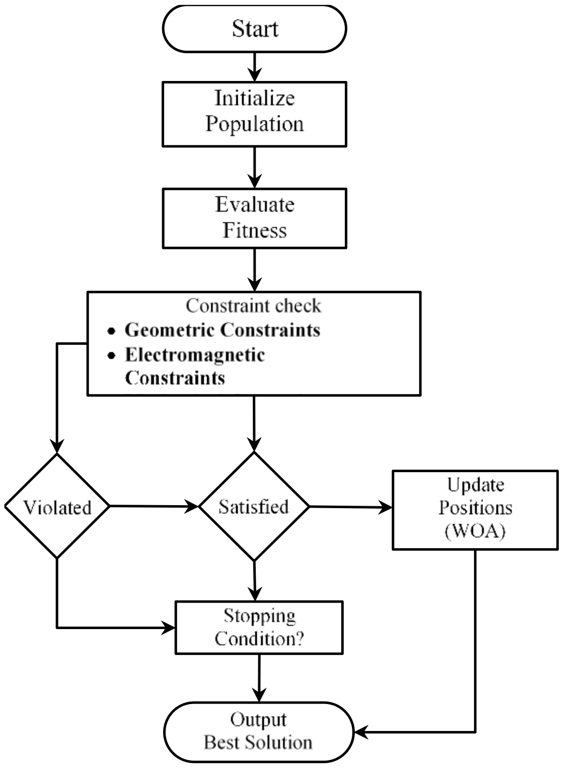


Figure 4. Algorithm flowchart for the proposed WOA

Table 2. The variable limitations for the proposed model

Variables	Symbol	Units	Ranges
Width of stator yoke	W_{Ys}	mm	$0.33 < W_{Ys} < 0.97$
Width of rotor yoke	W_{YR}	mm	$0.3 < b_{r2} < 0.9$
Stator tooth arc	W_{Ts}	mm	$0.19 < b_s < 0.9$
Rotor tooth arc	W_{TR}	mm	$0.15 < b_r < 0.95$
Air-gap	g	mm	$0.23 < g < 0.65$

5. OPTIMIZATION STRATEGY AND CONSTRAINTS

In the ANSYS Maxwell environment, the preliminary SRM geometry is first modelled and simulated, and its electromagnetic performance is measured in terms of torque waveform, output power, efficiency, power factor, and input current. The accuracy of this analytical model is then verified by performing FEA to ensure that the electromagnetic behavior under realistic conditions is faithfully represented. Following this validation, a multi-objective optimization framework is utilized that integrates the WOA with FEA evaluations to successively tune the chosen design variables in the search for the most promising setting. Efficiency is to be maximized, and torque ripple minimized in the optimization while keeping the machine stable. For ensuring feasibility, Table 3 defines the optimization constraints through specification of the bounds on the upper and lower limits of the variables and the ideal target values of the objectives, along with associated weight factors. These weights (w_i), within the ANSYS optimization environment, vary between 1 and 5 and are based on the priority ranking of the designer; that is, correspondingly larger weights (to be assigned to higher-priority objectives) dictate stronger emphasis during the search process.

Table 3. Optimization constraints for the proposed (WOA)

Description	Optimization constraint	Constraint equation	Wi
Efficiency % (η)	79 < η < 100	1 + (η-initial value) * target value/difference value	5
Torque (T)	4.77 < T < 9	1 + (T- initial value) * target value/difference value	4
B (Tesla)	2 < B <4	1 + (B- initial value) * target value/difference value	3

6. SIMULATION OPTIMIZATION RESULTS AND DISCUSSION

The initial parametric model is created in Ansys Maxwell, followed by variable analysis and an optimization process using the proposed white whale optimization algorithm implemented in MATLAB. The predicted results are then integrated back into the Ansys software for validation. It can be noticed that a significant increase in the value of the electromagnetic torque can be obtained, as shown in Figure 5. This increase is due to an improvement in the rotor yoke width, as the optimal value for the proposed design is 0.36 mm. Furthermore. An improvement in the distribution of magnetic flux transmitted from the stator to the rotor across the air gap can be achieved.

In addition to the improvement of the average torque, a significant reduction of the torque ripple is observed. From the obtained curves in Figure 6, it can be seen that the initial design has significant dips and oscillations in the torque, whereas the optimized design has smoother torque characteristics with fewer abrupt fluctuations. The results show that the optimized topology has a lower torque ripple value of 36.6% than the initial design value of 52%, which confirms the effectiveness of the proposed optimization approach. This reduction of torque ripple is mainly attributed to the better distribution of the magnetic flux and the smoother variation of the phase inductance with the rotor position. Thus, the proposed design not only improves the torque production but also reduces the vibration, acoustic noise, and mechanical stress, which improves the overall SRM performance.

Figure 7(a) shows the distributed magnetic field density for the basic model with a maximum value of (2.2687 T), indicating a relatively lower magnetic flux density. In contrast, Figure 7(b), the second image, exhibits a higher maximum value of (3.3316 T) for the optimal model, suggesting a stronger magnetic field with a more uniform distribution and intensity in Figure 8. Consequently, the optimized model can be considered as the superior design for improved performance of the switch reluctance machines.

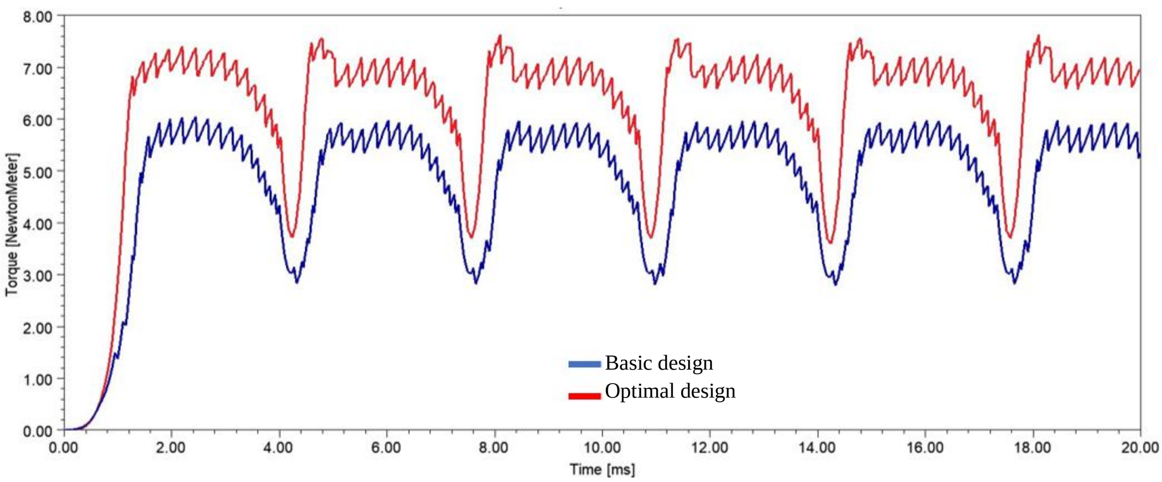


Figure 5. Comparison of torque results for basic and optimized models

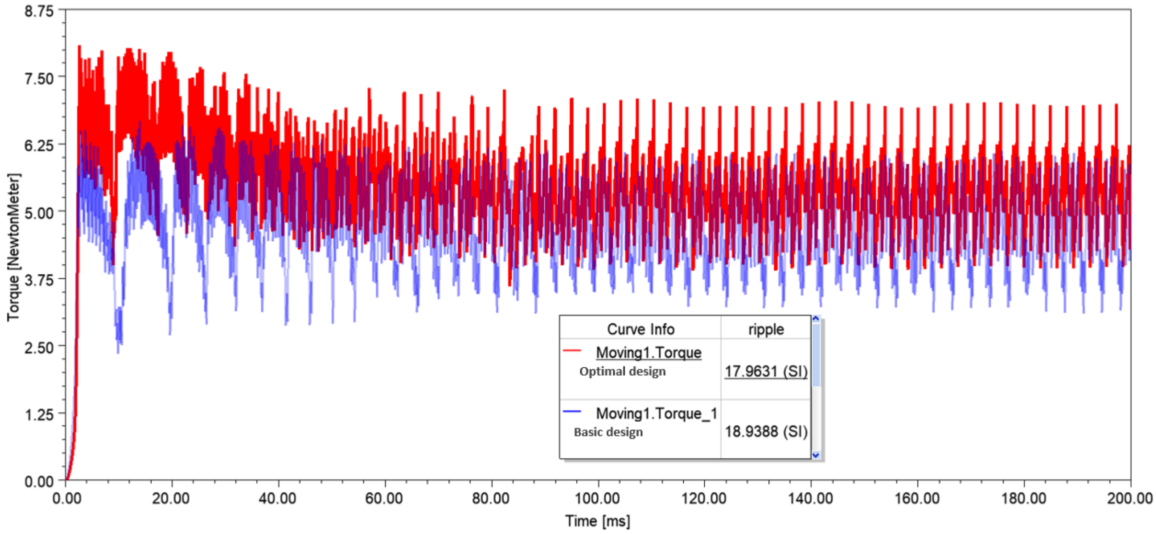
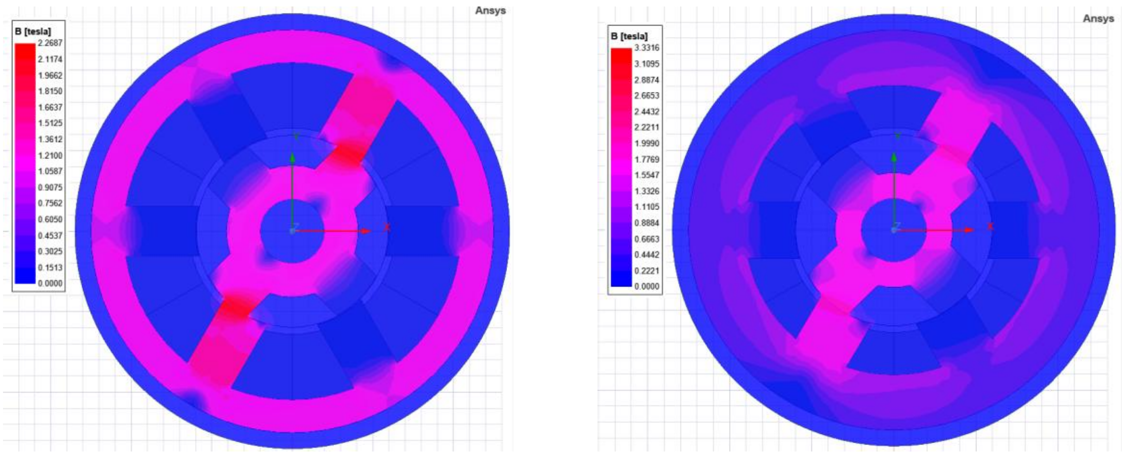


Figure 6. Comparison of ripple torque results for basic and optimized models



(a) (b)

Figure 7. Magnetic field distribution: (a) basic model and (b) optimal model

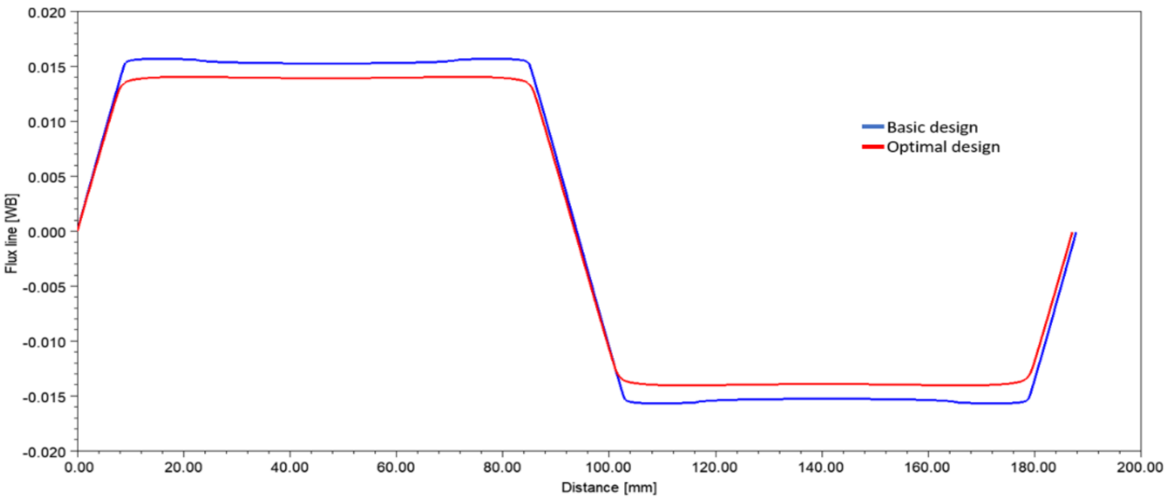


Figure 8. Air gap flux line path

On the other hand, the analysis of current waveform characteristics is presented in Figure 9. The predicted results demonstrate improved stability and performance of the optimized model. The peak value of the current in the optimized model is reduced to 5.1645 A compared to 5.4605 A in the basic design. This reduction in peak current effectively minimizes current fluctuations and contributes to a significant enhancement in efficiency. Moreover, the peak current reduction decreases the switching stress in the power semiconductor devices, which leads to improved reliability and reduced thermal loading. Furthermore, smoother current transitions would have the advantage of reduced electromagnetic interference (EMI), which is an important issue in SRM drive systems. Thus, the proposed geometric optimization can not only improve the motor electromagnetic performance, but also enhance the overall efficiency and stability of the corresponding power electronic converter [30].

The efficiency of switched reluctance motors (SRMs) is greatly affected by different types of power losses inside the machine. The losses are usually classified into copper losses, core (iron) losses, and stray losses. Copper losses are related to the resistance of the stator windings and are directly proportional to the magnitude and waveform of the phase current [31]. Core losses are caused by hysteresis and eddy current effects in the magnetic materials and are very sensitive to the flux density distribution and switching frequency. Moreover, leakage flux, harmonic components, and non-ideal electromagnetic effects cause stray losses, which are hard to accurately model but contribute to the overall efficiency degradation. A better flux distribution and smaller current peaks in SRMs can greatly cut down copper and core losses, thus increasing efficiency and thermal performance [32].

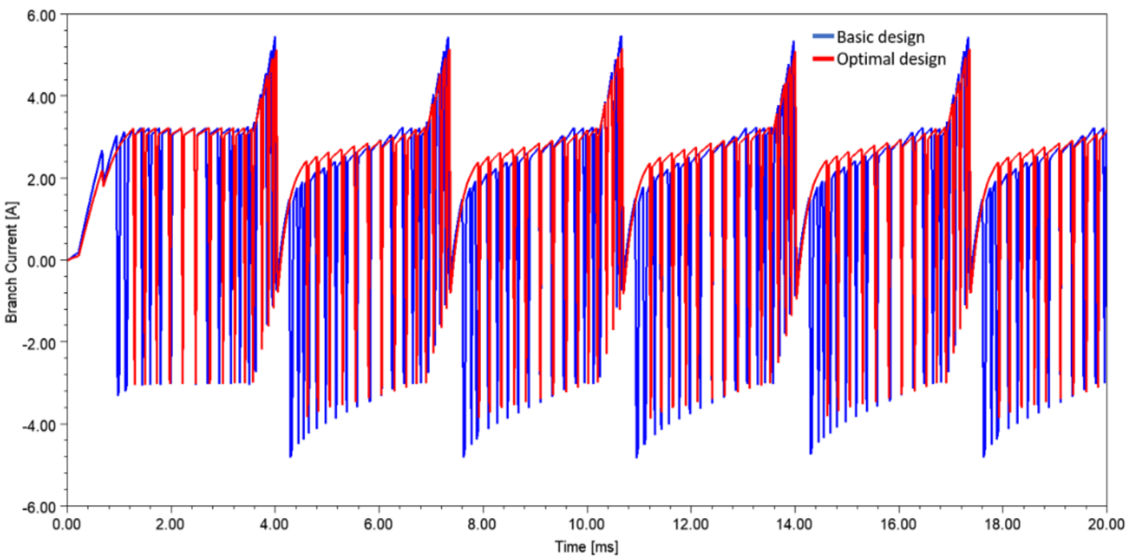


Figure 9. Line current of SRM

Figure 10 compares the predicted copper losses between the basic and the optimized design. The optimized design shows a reduction in the copper losses to (122.9 W), with the peak value for the basic design reaching (116.3 W). Figures 11 and 12 depict the predicted results for the stranded and core losses of the basic and the optimum proposed models, respectively. Stranded losses reduced from (43 W) to (23.1 W) in the optimal model; this reduction in losses indicates improved efficiency and better thermal management in the optimized motor design.

Figures 13(a) and 13(b), the basic model has an efficiency of 79% and shows a great deal of variation, meaning that the operational stability is poor, particularly at low and medium speeds. However, the optimized design gives a higher efficiency of around 84%, which implies a more efficient energy conversion. The gains are due to the improvement of magnetic flux distribution and low core loss and ensure a more stable performance of the SRM under variable-speed operation.

Table 4 compares the performance characteristics of the basic and optimized models in detail, which shows the overall improvement obtained using the proposed optimization technique. It clearly indicates the improvements of key parameters like electromagnetic torque, efficiency, and loss reduction. These results verify the effectiveness of the optimization approach to improve the overall performance and stability of the SRM.

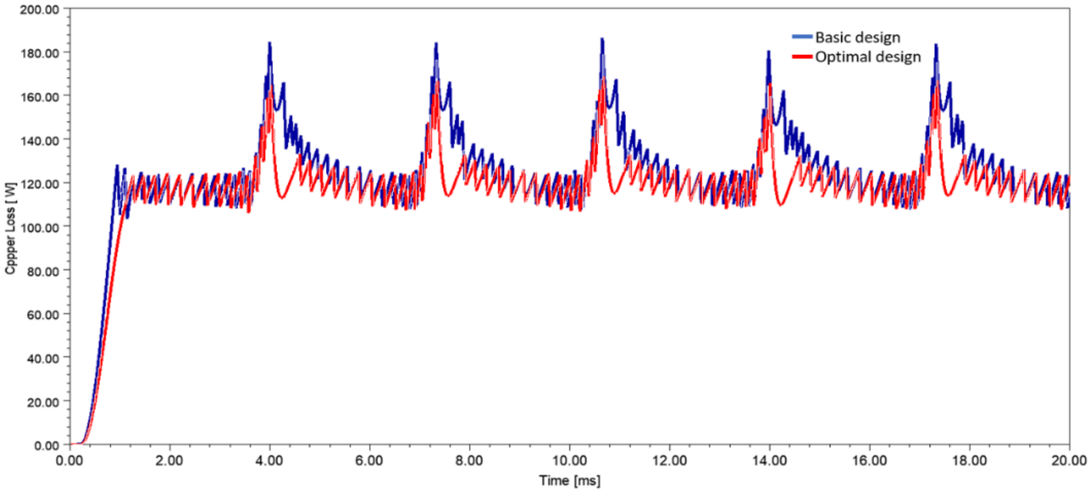


Figure 10. SRM copper

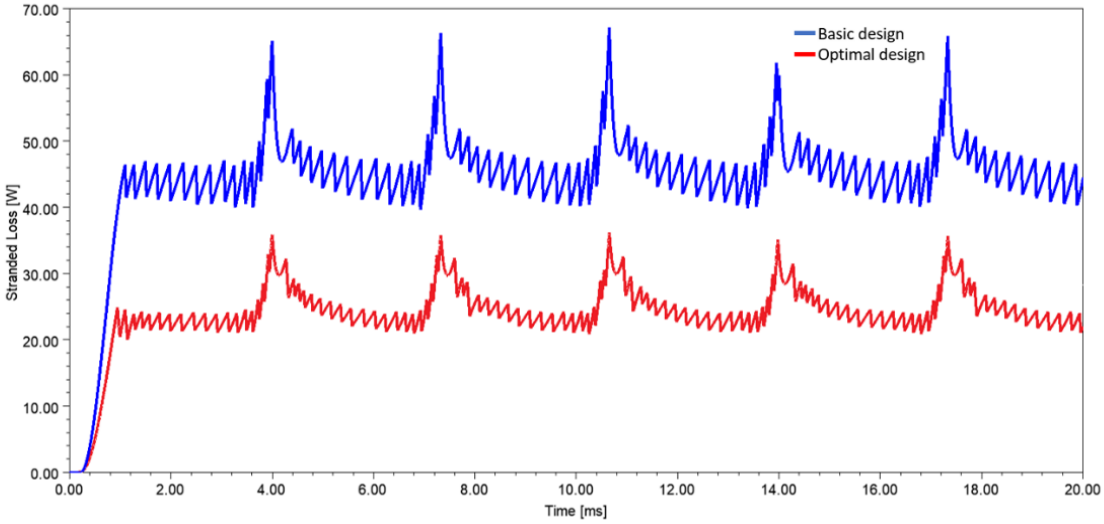


Figure 11. SRM stranded losses

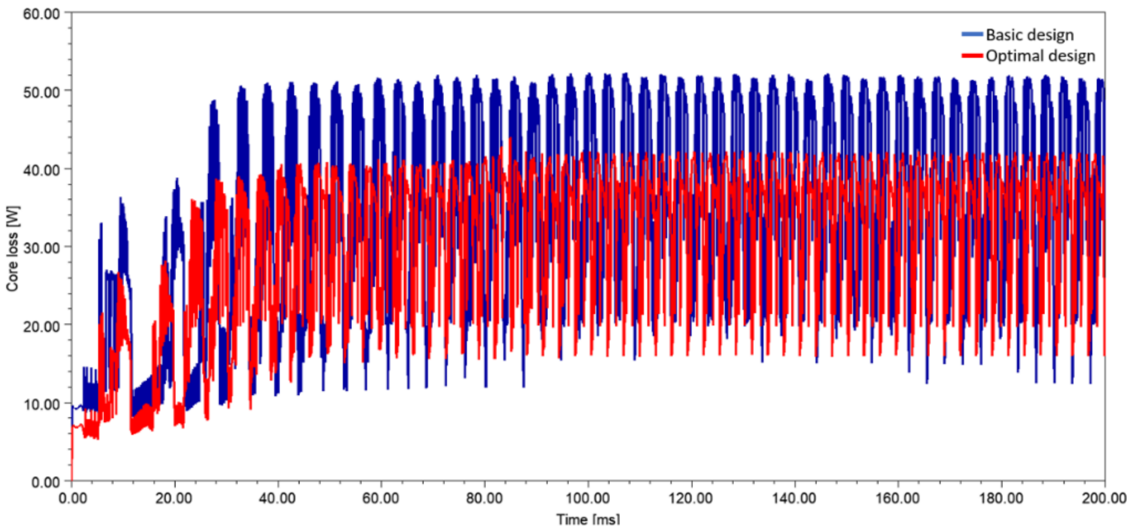
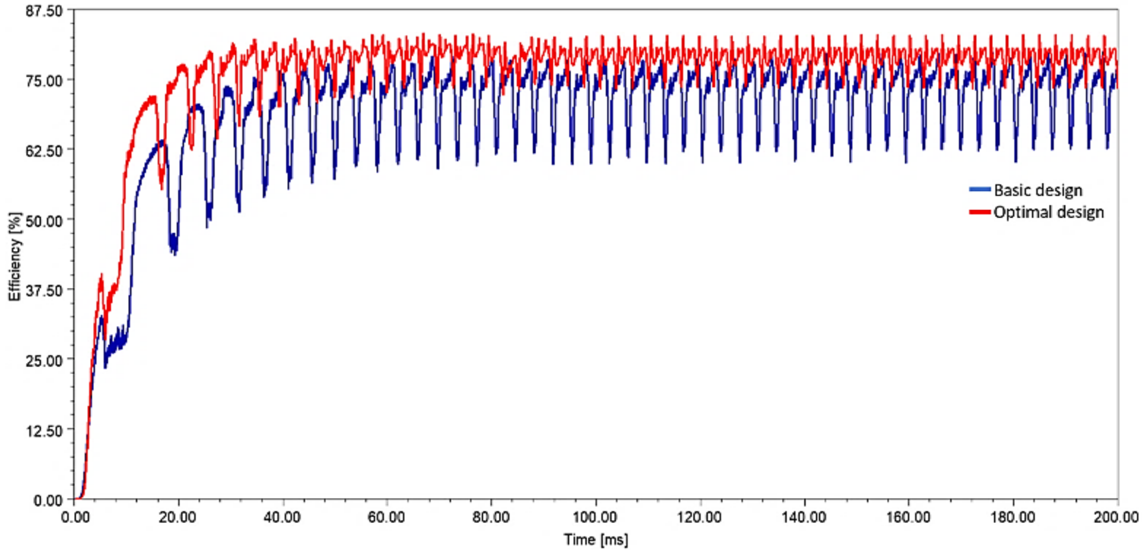
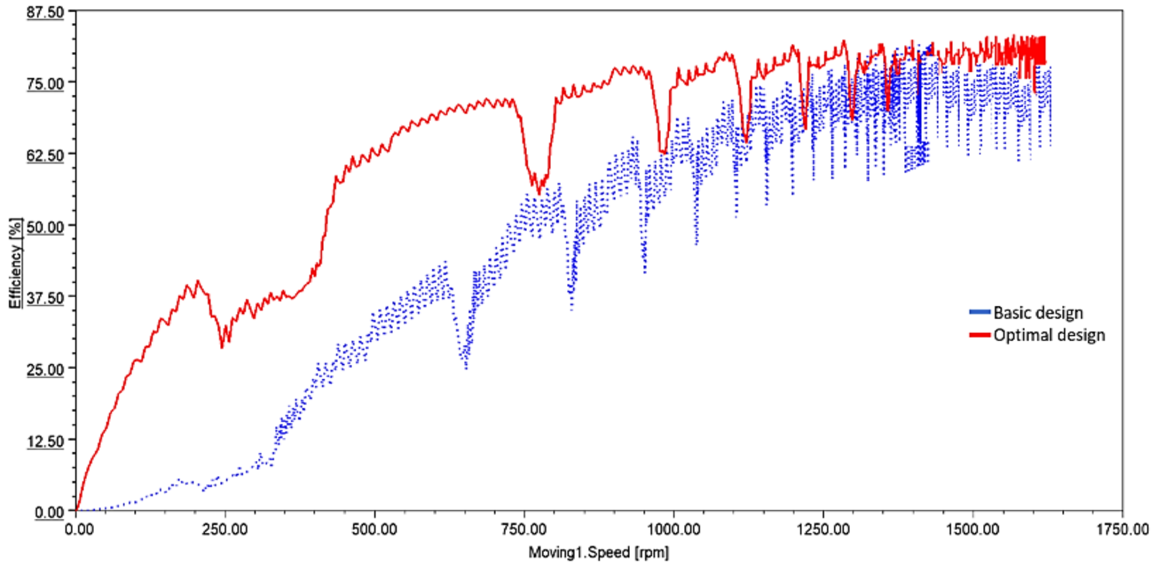


Figure 12. SRM core losses



(a)



(b)

Figure 13. Efficiency of SRM: (a) efficiency-time and (b) efficiency-speed

Table 4. Output characteristics for the basic and the proposed model of the motor

Motor characteristics	Basic model	Optimal model	Unit	Percentage of improvement
Electrical torque	4.77	6.1	N.m	27.88%
Line current	5.46	5.30	A	−2.93%
Copper losses	122.9	116.3	W	5.37%
Stranded losses	43	23.1	W	46.28%
Core losses	34.4	30.9	W	10.17%
Efficiency	0.79	0.84	%	5.06%
Flux line	0.0157	0.0140	W_b	10.84%
Magnetic field	2.2687	3.3316	Tesla	46.73%

7. CONCLUSIONS

This paper presented an effective optimization of a switched reluctance motor based on FEA. The optimization was performed by applying the whale optimization algorithm to improve the electromagnetic performance and the overall efficiency. The analysis focused on the key performance indicators, such as electromagnetic torque, energy losses, and efficiency, which provided a thorough understanding of the factors affecting the motor behavior. The obtained results show clear improvements in torque generation, reduction in different loss components, and an overall increase in efficiency. Most of these improvements are due to the optimized geometrical arrangement that results in a more uniform distribution of the magnetic flux and a better utilization of the magnetic circuit. Therefore, the optimized design exhibits more stable performance, particularly under variable-speed operating conditions. Subsequently, the study confirms that optimizing the SRM design through the use of FEA and metaheuristic optimization techniques is a legitimate strategy. The suggested method may be expanded to additional configurations and applications and offers a solid foundation for achieving high-performance motor designs. Overall, the findings demonstrate how the suggested strategy might aid in the creation of reliable and effective SRM-based drive systems.

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AUTHOR CONTRIBUTIONS STATEMENT

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Tamer Kamel						✓				✓		✓		

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article. Further inquiries can be directed to the corresponding authors.

REFERENCES

[1] P. Vijayraghavan, "Design of switched reluctance motors and development of a universal controller for switched reluctance and permanent magnet brushless DC motor drives," 2001.

[2] C. Lee, J. Lee, and I. G. Jang, "Shape optimization-based design investigation of the switched reluctance motors regarding the target torque and current limitation," *Structural and Multidisciplinary Optimization*, vol. 64, no. 2, pp. 859–870, Aug. 2021, doi: 10.1007/s00158-021-02897-0.

[3] O. Rahmani, S. A. Sadrossadat, S. M. Mirimani, and S. H. Mirimani, "Optimization of efficiency and output power of 8/6 switched reluctance motor using new neural network-based adjoint L p metric method," *IET Electric Power Application*, vol. 15, pp. 769–783, 2021, doi: https://doi.org/10.1049/elp2.12073.

[4] L. Liu, Y. Huang, M. Zhao, and Y. Ruan, "Parametric modeling and optimization of switched reluctance motor for EV," *The Applied Computational Electromagnetics Society Journal (ACES)*, vol. 37, no. 9, pp. 948–958, 2023, doi: 10.13052/2022.ACES.J.370904.

[5] G. F. Lukman and J.-W. Ahn, "Torque ripple reduction of switched reluctance motor with non-uniform air-gap and a rotor hole," *Machines*, vol. 9, no. 12, p. 348, Dec. 2021, doi: 10.3390/machines9120348.
[6] F. Juarez-Leon, N. Emery, and B. Bilgin, "Acoustic noise reduction in an 8/6 switched reluctance machine using structural design," *Energies*, vol. 16, no. 7, p. 3282, Apr. 2023, doi: 10.3390/en16073282.
[7] Z. Xu, T. Li, F. Zhang, Y. Zhang, D.-H. Lee, and J.-W. Ahn, "A review on segmented switched reluctance motors," *Energies*, vol. 15, no. 23, p. 9212, Dec. 2022, doi: 10.3390/en15239212.
[8] J. D. Widmer, R. Martin, and B. C. Mecrow, "Optimization of an 80-kw segmental rotor switched reluctance machine for automotive traction," *IEEE Transactions on Industry Applications*, vol. 51, no. 4, pp. 2990–2999, Jul. 2015, doi: 10.1109/TIA.2015.2405051.
[9] D. Marcsa and M. Kuczmann, "Design and control for torque ripple reduction of a 3-phase switched reluctance motor," *Computers & Mathematics with Applications*, vol. 74, no. 1, pp. 89–95, Jul. 2017, doi: 10.1016/j.camwa.2017.01.001.
[10] H. E. Aziz, A. K. Shanshal, and A. J. Ali, "Optimization of induction motor rotor bar geometry based on genetic algorithm," in *2023 International Conference on Engineering, Science and Advanced Technology (ICESAT)*, IEEE, Jun. 2023, pp. 127–132. doi: 10.1109/ICESAT58213.2023.10347297.
[11] S. Rani and R. Jayapragash, "FEA-based pole arc optimization and sensitivity analysis of 8/6 SRM for EV application," *Results in Engineering*, vol. 23, p. 102683, Sep. 2024, doi: 10.1016/j.rineng.2024.102683.
[12] M. J. Navardi, B. Babaghorbani, and A. Ketabi, "Efficiency improvement and torque ripple minimization of switched reluctance motor using FEM and seeker optimization algorithm," *Energy Conversion and Management*, vol. 78, pp. 237–244, Feb. 2014, doi: 10.1016/j.enconman.2013.11.001.
[13] Z. Jia, "Switched reluctance motor design and optimization," *Academic Journal of Science and Technology*, vol. 9, no. 1, pp. 219–221, Jan. 2024, doi: 10.54097/qjvj9791.
[14] B. Gecer and N. F. O. Serteller, "Understanding switched reluctance motor analysis using ANSYS/Maxwell," in *2020 IEEE 29th International Symposium on Industrial Electronics (ISIE)*, IEEE, Jun. 2020, pp. 446–449. doi: 10.1109/ISIE45063.2020.9152513.
[15] L. Jing, J. Cheng, and T. Ben, "Analytical method for magnetic field and electromagnetic performances in switched reluctance machines," *Journal of Electrical Engineering & Technology*, vol. 14, no. 4, pp. 1625–1635, Jul. 2019, doi: 10.1007/s42835-019-00167-0.
[16] S. Bhaktha B., S. Kumawat, J. Pitchaimani, and K. V. Gangadharan, "Design and performance analysis of a switched reluctance motor using finite element analysis and magnetic equivalent circuit model," *Defence Science Journal*, vol. 73, no. 1, pp. 39–50, Mar. 2023, doi: 10.14429/dsj.73.17828.
[17] Đ. M. Lekić and S. N. Vukosavić, "Finite element design of rotor permanent magnet flux switching machine with arbitrary slot, pole and phase combinations," *Electronics ETF*, vol. 22, no. 2, p. 93, Sep. 2019, doi: 10.7251/ELS1822093L.
[18] R. Krishnan, *Switched Reluctance Motor Drives Modeling, Simulation, Analysis, Design, and Applications*, Industrial. 2001.
[19] S. Sezen, E. Karakas, K. Yilmaz, and M. Ayaz, "Finite element modeling and control of a high-power SRM for hybrid electric vehicle," *Simulation Modelling Practice and Theory*, vol. 62, pp. 49–67, Mar. 2016, doi: 10.1016/j.simpat.2016.01.006.
[20] B. Ganji, J. Faiz, K. Kasper, C. E. Carstensen, and R. W. De Doncker, "Core loss model based on finite-element method for switched reluctance motors," *IET Electric Power Applications*, vol. 4, no. 7, pp. 569–577, Aug. 2010, doi: 10.1049/iet-epa.2009.0041.
[21] W. N. Fu, P. Zhou, D. Lin, S. Stanton, and Z. J. Cendes, "Modeling of solid conductors in two-dimensional transient finite-element analysis and its application to electric machines," *IEEE Transactions on Magnetics*, vol. 40, no. 2, pp. 426–434, Mar. 2004, doi: 10.1109/TMAG.2004.824127.
[22] G. R. Kiran, S. R. K. Raju, and M. K. Kumar, "A novel enhanced fire hawks optimization approach for improving the efficiency of converter-based controllers in switched reluctance motors," *Advanced Control for Applications*, vol. 6, no. 4, Dec. 2024, doi: 10.1002/adc2.234.
[23] A. H. Maray, S. Q. Hasan, and N. L. Mohammed, "Design and implementation of low-cost vein-viewer detection using near infrared imaging," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 29, no. 2, pp. 1039–1046, 2023.
[24] S. Mirjalili and A. Lewis, "The whale optimization algorithm," *Advances in Engineering Software*, vol. 95, pp. 51–67, May 2016, doi: 10.1016/j.advengsoft.2016.01.008.
[25] A. T. Ebrahem, N. K. Younis, A. W. Talab, Z. H. Al-Sawaff, and F. Kandemirli, "Developing a new algorithm to detect right thumb fingernail in healthy human," *International Journal on Recent and Innovation Trends in Computing and Communication*, vol. 11, no. 4, pp. 47–53, May 2023, doi: 10.17762/ijritcc.v11i4.6380.
[26] M. Mafarja *et al.*, "Evolutionary population dynamics and grasshopper optimization approaches for feature selection problems," *Knowledge-Based Systems*, vol. 145, pp. 25–45, Apr. 2018, doi: 10.1016/j.knosys.2017.12.037.
[27] Y. Özüpak, "Design and analysis of switched reluctance motor with FEM based Ansys-Maxwell," *MANAS Journal of Engineering*, vol. 10, no. 2, pp. 159–164, Dec. 2022, doi: 10.51354/mjen.1164604.
[28] N. Saha and S. Panda, "Cosine adapted modified whale optimization algorithm for control of switched reluctance motor," *Computational Intelligence*, vol. 38, no. 3, pp. 978–1017, Jun. 2022, doi: 10.1111/coin.12310.
[29] J.-W. Ahn and G. F. Lukman, "Switched reluctance motor: Research trends and overview," *CES Transactions on Electrical Machines and Systems*, vol. 2, no. 4, pp. 339–347, 2019, doi: 10.30941/cestems.2018.00043.
[30] X. Wang *et al.*, "A review of current control strategies for switched reluctance motor drives: performance evaluation across a wide speed range," *IEEE Open Journal of the Industrial Electronics Society*, vol. 7, pp. 136–156, 2026, doi: 10.1109/OJIES.2025.3647661.
[31] Š. Grbin, D. Vukadinović, and M. Bašić, "Model of a switched reluctance generator considering iron losses, mutual coupling and remanent magnetism," *Energies*, vol. 18, no. 10, p. 2656, May 2025, doi: 10.3390/en18102656.
[32] V. Madonna, C. M. Meano, S. Mafrici, and K. F. Hansen, "Copper vs. aluminium winding SRMs: a multidisciplinary performance assessment," *IET Conference Proceedings*, vol. 2023, no. 17, pp. 49–56, Oct. 2023, doi: 10.1049/icp.2023.1978.

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