# Modeling and Simulation Techniques for Optimizing Electric Motor Performance

**Priyanka Das**

MEng Electrical Engineering, CEAS, University of Cincinnati
priyanka14das@gmail.com

**Abstract**
**This paper focuses on the analysis of modeling and simulation and the practices to enhance electric motor performance. It describes different techniques: analytical approach, numerical approach, and combined approaches. Analytical modeling offers simplified mathematical models of electric motor dynamics, which can be helpful in the first design evaluations and control system design but fails when capturing some nonlinearities. Analytical methods provide general concepts of a problem and lead to approximate solutions, while numerical methods, including finite element analysis (FEA) and computational fluid dynamics (CFD), provide more detailed information about the physics of a problem and the geometry of the structures involved, at the cost of increased computational time. Hybrid modeling uses analytical and numerical approaches to be precise in calculation and time efficient. Since these computational possibilities develop, applying these modeling approaches remains to progress. It will enhance the construction of efficient electric motor systems and inspire the entire industry's sustainability.**

**Keywords**: **Electric Motors, Modeling Techniques, Numerical Simulation, Analytical Modeling, Hybrid Approaches, Rotor Eccentricity, Linearization, Electromagnetic torque**

## Introduction

Modeling and simulation techniques are widely applied to organizational and operational systems and have proven valuable in designing, constructing, analyzing, and optimizing physical systems. The main idea behind modeling and simulation is reconstructing an existing or future system – for example, a design concept and using it in tests to see how it performs different operations, assess management strategies, and decide on a better course of action. In addition to the deductive and inductive approaches, modeling and simulation technologies are gradually being recognized as the third approach to scientific investigation. Various modeling and simulating methods are used to assess the motor's performance, find areas that may be optimized, and check design modifications prior to actual application. This essay discusses different modeling and simulation techniques and how to optimize Electric motor performance.

## Modeling and Simulation Techniques

Modeling and simulation are the methods of replicating the behavior of a system or event using a comparable model, scenario, or device, either to acquire information more efficiently or to teach workers [8]. Organizational and operational systems make heavy use of modeling and simulation techniques, which are also helpful in designing, building, analyzing, and improving physical systems [9].Various modeling and simulation techniques exist, including analytical, numerical, and hybrid.

***Analytical Modeling Techniques***

Analytical modeling methods provide a deep understanding of the mechanisms of operation of electric motors by using simple mathematical models of their physical properties. These techniques employ equivalent circuit concepts and depict the motor as a sum of resistors, inductors, and other related circuit components. In their general work, electric motors transform the electrical input power into mechanical output [3]. Therefore, a model that can express the nature of the electrical input and electromagnetic torque is always required[3]. The modeling strategies used in electrical engineering and mathematics allow designers to understand the relationships in essential specifications, such as torque, speed, or efficiency, and to develop formulas to describe motor behavior.

As mentioned, analytical models are an effective tool for initial investigation, control system implementation, and fine-tuning for electric motor design because they have a lower order of computational complexity than numerical methods. Analytical models are unique for every type of electric motor. At the same time, training sets can be somewhat large, meaning there is much work for electric motor design engineers. This computational efficiency is most beneficial in analytical modeling during the design conceptualization stage of the motor design process, where there are numerous opportunities for configuration modification. However, analytical models are simple to solve, and hence, the derived equations are easy to interpret, which is a plus for designers when understanding the motor's performance.

However, analytical models also face a few disadvantages,which are as follows:Many of these models rely on assumptions and linearization, which may lead to the degradation of models when the operating conditions deviate from their base values [3]. In cases where more complex nonlinear phenomena such as magnetic saturation and rotor eccentricity are involved, limitations of purely analytical methods are evident. This model faces difficulties reproducing the measurement outcomes from a suggested loss model due to the non-linear relationship of cut-edge distance, loss, permeability, and core-loss density [3]. The difficulty is in capturing such detailed and complex nonlinear processes within the confines of analytical models, pointing to the necessity of using numerical modeling methods to obtain a more extensive picture of electric motor behavior in a broader range of operating conditions. Thus, the synergistic application of analytical modeling with other approaches allows designers to open opportunities for innovative thinking and further advancements in electric motor performance and related electric propulsion systems.

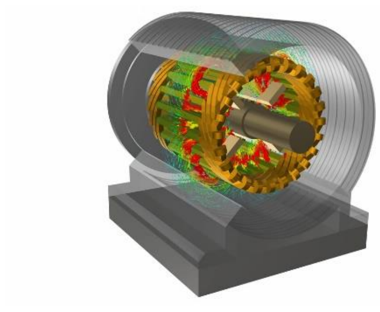

**Fig1: Stator and rotor Design**

***Numerical Modeling Approaches***

Applying numerical methods to model and simulate electric motor performance includes finite element analysis (FEA) and computational fluid dynamics (CFD). These techniques include discretizing the motor geometry and the governing equations into a computational mesh, which is then used to solve the problem in an iterative manner using high-order numerical solutions. Physical phenomena of a lower hierarchical level, such as electromagnetic fields, thermal effects, and fluid dynamics, can be described in numerical models, allowing the opportunity to consider motor behavior in detail.

The strengths of numerical modeling include the consideration of geometries and nonlinear behaviors, which would otherwise be hard to capture analytically. For instance, FEA can simulate complex shapes of rotors and stators, magnetic saturation, and eddy currents [2]. The FEA tool is highly significant for determining the complicated physics of the machine design, especially in electric drives. FEA allows engineers to design and analyze complex mechanical parts and systems with precision that can be used for simulation and optimization on the computer [1]. Through the incorporation of first-order harmonic FEM models in the dynamic simulations, control techniques can be designed by the engineers for the fault conditions. For low-frequency electromagnetic modeling, the dominant numerical technique is the finite element (FE) method, mainly in the field of electrical machines. The Finite Element approach is widely used by specialists in such cases; however, the potential to develop new applications in various fields is rather promising.

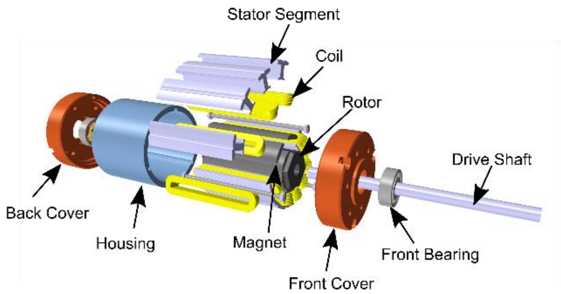


**Fig 2: Structure of a motor**

Conventionalsimulation approaches typically use reduced-order models and do not include some essential transient phenomena and losses; therefore, they cannot optimize the drive performance [2]. FEA has a crucial advantage for modeling that considers the variation in the geometry, material properties, and boundary conditions, resulting in a better representation of the behavior of machines [2]. This capability is handy when dealing with the nonlinear dynamics that manifest under different operation conditions. Therefore, FEA is an indispensable tool in modern machine design and control algorithm design.

It is, therefore, possible to use CFD to determine the cooling performance of the motor and modify the cooling system to improve the motor's efficiency. Consequently, as a time-dependent continuum formulation, CFD has played immense roles both in industrial plants and academia since its inception in the mid-twentieth century [10]. By applying fluids together with the basics of mechanics, one may create a system of connected non-linear PDEs. These equations are utilized analytically to address most of the engineering issues [10]. When establishing mathematical models, the physical properties of the fluid, including the law of conservation of mass, momentum, and energy, have to be taken into account in the domain of interest [10]. The numerical models can be time-consuming, especially for three-dimensional simulations or for design analysis involving changes in parameters. This can be disadvantageous in real-time control applications or where the design is to be quickly optimized.

### *Hybrid Modeling Techniques*

There has been a creation of dual approaches, where both the numerical and the analytical models are integrated to benefitfrom the two. In these techniques, the motor is divided into severalsub-domains, and then a best-suited technique is used for modeling each of them. For instance, the electromagnetic field in the air gap of the motor is analyzed analytically. At the same time, the geometries and nonlinearities of the rotor and stator are modeled using the FEA method. The results of the various sub-models are combined to deliver an integrated picture of the motor's operation.

Electromagnetic performance can be numerically predicted using finite element methods, especially if magnetic material nonlinearity is considered. With this method, one may expect a high saturation level in the air gap or the tooth core,giventhe high field concentration effect [6]. However, this procedure is rather time-consuming - most notably when defining the first electrical machine size is necessary. Hence, it appears to bea fundamental design need and a real difficulty to build an analytical model for early performance calculations [6]. As genetic algorithms develop, the indicated analytical approach may apply optimization strategies.

Their use can result in models with reasonable accuracy and relatively low computational demands, making it possible to analyze a given problem in greater detail than possible with analytical methods while not necessarily employing pure numerical simulations. This approach is precious in design optimization, where the applicable variation of the design can be evaluated at a high speed.

## Optimizing Electric Motor Performance

Various approaches can be utilized to enhance electric motor performance; one of the approaches in the preliminary design stage is using analytical models. Analytical models, with their simplified mathematical representations and equivalent circuit approaches, would be most appropriate during the early design stages of electric motors [5]. These models can directly read performance parameters such as torque and speed efficiency and give a quick idea of their interactions. Analytical approaches can give engineers a great deal of freedom to consider numerous design options, find the best one, and provide a basis for further optimization.

Another possible approach to improve electric motor performance is to use numerical modeling for detailed studies. However, analytical models present conclusions more efficiently for computation but provide less flexibility in conceiving nonlinear impacts. This is where numerical modeling techniques, finite element analysis (FEA), and computational fluid dynamics (CFD) are helpful[3]. These approaches can give a complete and more reliable picture of the motor's behavior, such as the impact of magnetic saturation, rotor eccentricity, and thermal properties at an acceptable level. Through numerical modeling, engineers can achieve what is best for this motor; it could even surpass expectations as far as the design is concerned.

Another method of optimality of Novikov's electric motor is achieving balanced accuracy and efficiency through hybrid modeling. In this regard, there is an opportunity to use both categories of models and combine them with the help of so-called mixed models. Since these sub-domains of the motor can be isolated and the most suitable technique applied to each of them, hybrid models can improve the accuracy and the detail of purely analytic models without the computational cost of numerical simulations. This approach is most beneficial in design space, where the capability to assess numerous design variants quickly is essential.

## Conclusion

Modeling and simulation techniques play a crucial role in the design and optimization of electric motors, allowing engineers to analyze complex physical phenomena, explore a vast design space, and validate design changes before physical implementation. The type of model, numerical, analytical, or combined, depends on the need of the application, the level of detail required, and the available computing power. Moreover, as computational power and the associated software tools are constantly improving, electric motor modeling and simulation methods are also developing, offering engineers a more comprehensive set of sophisticated and versatile tools to solve the problem of motor optimization. By applying these techniques, industry can design and produce higher efficiency and lower costs for electric motor systems that will benefit the world's future. Electric motor engineers can analyze motor behavior and systematically improve motor design and performance by applying each modeling and simulation approach, from analytical to numerical and mixed methods. By incorporating these methods along with computational optimization and thermal management in mind, it is possible to create electric motor designs that are efficient, reliable, and affordable.

## References

[1]. Abbas, Assad. "Finite Element Analysis in Mechanical Engineering: Simulation and Optimization." Osf.io, University of Leads Lahore, 2019, https://osf.io/3xrw6/download/?format=pdf

[2]. Bensalem, Yemna, and Mohamed Naceur Abdelkrim. "Modeling and Simulation of Induction Motor Based on Finite Element Analysis." International Journal of Power Electronics and Drive Systems (IJPEDS), vol. 7, no. 4, Dec. 2018, p. 1100, https://doi.org/10.11591/ijpeds.v7.i4.pp1100-1109.

[3]. Bilgin, Berker, et al. "Modeling and Analysis of Electric Motors: State-of-The-Art Review." IEEE Transactions on Transportation Electrification, vol. 5, no. 3, Sept. 2019, pp. 602–17, https://doi.org/10.1109/TTE.2019.2931123.

[4]. Brisset, Stephane, and Pascal Brochet. "Analytical Model for the Optimal Design of a Brushless DC Wheel Motor." Compel-the International Journal for Computation and Mathematics in Electrical and Electronic Engineering, vol. 24, no. 3, Emerald Publishing Limited, Sept. 2019, pp. 829–48, https://doi.org/10.1108/03321640510612952.

[5]. Olenev, N. MODELING and SIMULATION TECHNIQUES. Encyclopedia of Life Support Systems (EOLSS), www.eolss.net/sample-chapters/c15/e1-26-05-04.pdf

[6]. Yin, C., and A. McKay. "Introduction to Modeling and Simulation Techniques." Proceedings of ISCIIA 2018 and ITCA 2018, 1 Nov. 2019, https://eprints.whiterose.ac.uk/135646/

[7]. Zawawi, M. H., et al. "A Review: Fundamentals of Computational Fluid Dynamics (CFD)." A Review: Fundamentals of Computational Fluid Dynamics (CFD), vol. 2030, no. 1, 2018, https://doi.org/10.1063/1.5066893.