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Design Optimization Algorithm: A Novel Method for Design Optimization of PMSM

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Abstract

The performance evaluation of the Permanent Magnet Synchronous Motors (PMSMs) is done with varying operational conditions such as power, voltage & speed, different rotor and stator diameters, magnetic materials. This analysis is accomplished by the MATLAB-based algorithms. This investigation evaluates and graphically represents the crucial performance metrics: magnetic flux, cogging torque and torque. Through variable critical considerations and relating magnetic resources like Ferrite, SmCo, Alnico and NdFeB understandings are graphically presented as torque characteristics, magnetic flux behavior and effects of cogging. The outcomes are useful for enhancing PMSM design in industrial usance requiring smooth operation, high efficiency and high performance.

Keywords: Cogging Torque; Design Optimization; MATLAB; PMSM; Rotor and Stator Configuration.

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Introduction

The process of design optimization of rotating machines for a particular operation is long-lasting and accurate. Recently, different algorithms have been developed to make the accurate and user-friendly design optimization process. Artificial Hunting Optimization (AHO) algorithm is available as a strong and novel methodology that addresses real challenges in PMSM optimization. Its comparative performance analysis, validation with both FEA and experiments and dual-objective framework demonstrate practical utility [1]. The design of permanent magnet synchronous motors with external rotor (ER-PMSMs) is improved using a novel nonlinear analytical model (NAM) embedded within an optimization framework. The suggested technique indicates exactness in the stator core by exhibiting saturation of magnetic flux with high current loading conditions. Pareto-optimal design solutions are generated by employing a multi-objective ant colony (MOAC) optimization algorithm which are authenticated through finite element analysis (FEA) and investigational measurements. A robust framework for early-stage motor design — with strong FEM and experimental backing is the result of integration of material saturation, efficient magnetic circuit solving and MOAC-based optimization. A well-executed, computationally efficient and physically validated methodology can be used for optimizing the design of ex-ternal rotor PMSM using a novel nonlinear analytical model [2]. The structural bene-fits of cup winding in reducing axial height and iron losses and recommends amalgam enhancement approach combining back-propagation artificial neural networks (BP-ANNs), genetic algorithm (GA) and multi-objective particle swarm optimization (PSO) can also be used to maximize efficiency and minimize volume through multi-variable design optimization, validated by finite element method (FEM) simulations [3]. This study introduces a robustness-oriented design optimization (RDO) method focused on reducing cogging torque in permanent magnet synchronous motors (PMSMs) used in high-precision uses for example robotics and CNC machinery. It addresses uncertainties introduced in mass production by proposing a physical-based surrogate model combined with a data-driven layer enabling accurate and computationally efficient prediction of cogging torque variations caused by magnet tolerances [4]. A novel design and optimization methodology for permanent magnet synchro-nous motors (PMSMs) used in water pump (WP) applications. Here, methodology begins with the hydraulic characteristics of the application and aims to customize the PMSM performance via a torque-speed-efficiency map unlike conventional approaches that start with fixed motor topologies or preexisting designs. The methodology employs a novel similarity-based optimization objective function and combines with ultrafast magneto-static finite element analysis (FEA) with d-q electrical modeling [5]. A study proposes a novel multi scenario Parameter Optimization method for Active Disturbance Rejection Control (MSPO-DRL) using Deep Reinforcement Learning (DRL) for permanent magnet synchronous motors (PMSMs), targeting applications in More Electric Aircraft (MEA). The method enhances Active Disturbance Rejection Control (ADRC) by optimizing its parameters through a series of functional environments (scenarios), addressing challenges of parameter coupling and nonlinearity in conventional ADRC tuning [6]. Hybrid Excitation Double Stator Permanent Magnet Synchronous Machine design is tailored for electric vehicle applications along with a multi-objective optimization methodology. The field windings and permanent mag-nets are combined in this design to enhance magnetic regulation. The structure with double stator splits armature and excitation windings to improve power and torque density. The Kriging modeling, analysis based on sensitivity and solution refinement optimizes the design and focuses on the magnetic losses, unwanted torque and torque at the output [7]. The PMSM used in Fly-Gen type Airborne Wind Energy Systems with optimized design enhances the power density and efficiency. The genetic algorithm is used for optimization with integration of electromagnetic, thermal, and mechanical analyses within an analytical multi-physics framework. The designed ma-chine operates as a generator to harvest the energy and as a motor to take off with high starting torque. The ANSYS Maxwell 2D simulations and Motor CAD validated the design [8]. The optimized Interior PMSM is used for belt-driven elevator systems. Here, the proposed PMSM design reduces the complexity and cost. The need of chassis frame is also eliminated if the motor is directly mounted to the rail system. The design emphases on attaining high efficiency and minimal torque ripples with step-skewing [9]. The design objectives: high output torque and low torque ripple achieved in proposed Surface and Interior Hybrid Permanent Magnet Synchronous Motor using a novel Halbach magnetization structure and an improved Taguchi method enhanced by fuzzy logic theory [10].

Algorithm and Methodology

MATLAB Algorithm of PMSM

Algorithm of Permanent Magnet Synchronous Motor (PMSM) is designed for parameters: Varying Magnetic Materials, Rotor and Stator Diameters and Operating Conditions. The MATLAB program computes magnetic flux (Φ), electromagnetic torque (T) and cogging torque (Tcog) for combinations of magnetic materials, voltage (48V – 440V), speed (100 – 3000 RPM) and power (750 – 3000 W) with varied rotor and stator diameters. Flux is computed as $\Phi = B * A * \cos(\theta)$, torque as $T = (P * 9.549)/N$, and cogging torque as $Tcog = -0.5 * \Phi^2 * (dR/d\theta)$.

Program Description

This MATLAB program simulates various performance characteristics of a Permanent Magnet Synchronous Motor (PMSM) by iterating over different values for material properties, rotor and stator diameters and operating conditions such as speed, power and voltage. The following calculations are performed for each configuration.

- Magnetic Flux Calculation: This method calculates the magnetic flux based on the magnetic material, rotor cross-sectional area, and angle θ.

- Torque Calculation: Computes the torque generated by the PMSM using input power and speed values.
- Cogging Torque Calculation: Calculates the cogging torque, considering the magnetic flux and change in reluctance concerning angle θ.

Key Variables

- Efficiency range: Efficiency range (0.4 to 0.95).
- Voltage range: Voltage values from 48V to 440V.
- Speed range: Motor speed ranges from 100 RPM to 3000 RPM.
- Power range: Power values from 750W to 3000W.
- Stator diameters: Range of stator diameters (in meters).
- Rotor diameters: Range of rotor diameters (in meters).
- Materials: Types of magnetic materials considered (Alnico, NdFe, SmCo, Ferrite).
- Magnetic flux density: Flux densities for each material.

Algorithm

Efficiency, voltage, speed, power, stator/rotor diameters

- Efficiency range = 0.4:0.2:0.95; % Efficiency ranges from 40 % to 80 %
- Voltage range = 40:100:440; % Voltage ranges from 48V to 440V
- Speed range = 100:1000:3000; % Speed ranges from 100 RPM to 3000 RPM
- Power range = 750:1500:3000; % Power ranges from 750W to 3000W
- Stator diameters = 0.08:0.02:0.2; % Stator diameters in meters
- Rotor diameters = 0.079:0.02:0.15; % Rotor diameters in meters

```
% Magnetic materials and their flux densities
materials = {'Alnico', 'NdFe', 'SmCo', 'Ferrite'};
agnetic flux density = [0.12, 1.2, 0.95, 0.35]; % Tesla (T)
% Constants
P = 2; % Number of poles, assuming 2 for PMSM
theta = pi / 4; % Angle theta in radians (example 45 degrees)
dR_dtheta = 0.001; % Example value for dR/theta (Ohms per radian)
% Loop through ranges of stator and rotor diameters
for sd = stator_diameters
    for rd = rotor_diameters
        if rd > = sd % Ensure the rotor is smaller than the stator
            continue; % Skip this combination if the rotor is larger than the stator
        end
        % Loop through the magnetic materials
        for m = 1: length(materials)
            % Calculate magnetic flux (Φ = B * A * cos(θ))
            B = magnetic_flux_density(m); % Magnetic flux density (T)
            A = pi * (rd/2)^2; % Cross-sectional area of rotor (A = π*r^2)
            flux = B * A * cos(theta);
            % Loop through ranges of speed and power
            for N = speed_range
                for power = power_range
                % Torque calculation (T = (P * 9.549) / N)
                    torque = (power * 9.549) / N;
% Cogging torque calculation
(Tcog = -0.5 * Φ^2 * (dR/dθ))
cogging torque = - 0.5 * flux^2 * dR_dtheta;
 % Display results for this combination
fprintf ('Material: %s, Stator diameter: %.2f m, Rotor diameter: %.2f m\n', materi-als{m}, sd, rd);
```

```
fprintf ('Speed: %d RPM, Power: %d W\n', N, power);
fprintf ('Magnetic flux: %.5f Wb, Torque: %.5f Nm, Cogging torque: %.5f Nm\n\n', flux, torque, cogging_torque);
            end
          end
        end
      end
    end
```

Results and Discussion

Algorithm Results

The output of script of Algorithm 1 is the magnetic flux, torque and cogging torque for each configuration, which can be used to analyze motor performance under various operating conditions.

Table 1. *Design variable parameters and their level*

Material	Stator Diameter (m)	Diameter (m)	Speed (RPM)	Power (W)	Magnetic Flux (Wb)	Torque (Nm)	Cogging Torque (Nm)
Ferrite	0.08	0.08	100	750	0.00121	71.6175	-0.000
Ferrite	0.08	0.08	100	2250	0.00121	214.852	-0.000
Ferrite	0.08	0.08	1100	750	0.00121	6.51068	-0.000
Ferrite	0.08	0.08	2100	750	0.00121	3.41036	-0.000
Ferrite	0.10	0.10	100	750	0.00191	71.6175	-0.000
Alnico	0.10	0.10	100	750	0.00065	71.6175	-0.000
Alnico	0.10	0.10	100	2250	0.00065	214.852	-0.000
Alnico	0.10	0.10	1100	750	0.00065	6.51068	-0.000
Alnico	0.10	0.10	2100	750	0.00065	3.41036	-0.000
Alnico	0.12	0.08	100	750	0.00042	71.6175	-0.000
NdFe	0.10	0.10	100	750	0.00653	71.6175	-0.000
NdFe	0.10	0.10	100	2250	0.00653	214.852	-0.000
NdFe	0.10	0.10	1100	750	0.00653	6.51068	-0.000
NdFe	0.10	0.10	2100	2250	0.00653	10.2310	0.0000
NdFe	0.12	0.08	1100	750	0.00416	6.51068	-0.000
SmCo	0.10	0.10	100	750	0.00517	71.6175	-0.000
SmCo	0.10	0.10	100	2250	0.00517	214.852	-0.000
SmCo	0.10	0.10	1100	750	0.00517	6.51068	-0.000
SmCo	0.10	0.10	2100	750	0.00517	3.41036	-0.000

The result shown in table 1 provided the data based on which we can analyze the magnetic flux, torque characteristics and cogging torque of different magnetic materials used in motors with varying rotor and stator dimensions, speeds and powers. Here's a summary of observations and the following insights:

Magnetic Material Impact: NdFe consistently achieves the highest magnetic flux (0.00653 Wb for a 0.10m diameter rotor and stator) and torque values at different RPMs and power levels, indicating high efficiency for high-performance applications. The magnetic flux with SmCo has lower values than NdFe.

Ferrite and Alnico: The magnetic flux with Ferrite and Alnico also has lower values. The flux is 0.00121 Wb for smaller diameters and 0.00191 Wb for larger stators and rotors with Ferrite. The flux has the lowest values with Alnico.

Effect of Speed and Power: The motor with high RPMs with the constant power resulted to low torque values across all materials. Applications: The motor can be used where requirement is high motor speeds and low torque.

Cogging Torque: The cogging torque is 0.0 Nm with all materials. It indicates no cogging torque in this configuration. Applications: The motor can be used where requiring smooth and uninterrupted rotation. Example; in precision or quiet motor applications.

Conclusion

The paper concludes that the material SmCo shows periodic torque with negligible cogging torque, proposing it for loads that require constant torque with minimal magnetic resistance. Furthermore, the operational requirements for precision applications like servomotors is achieved by the step variations in magnetic flux. In high-performance magnetic applications, the steady flux behavior and low cogging of the material SmCo, make it promising.

In minimal magnetic interference applications, the Ferrite material shows stable torque with very low cogging torque. However, Ferrite exhibits a lower magnetic flux range compared to SmCo.

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