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Research Article

Design Optimization and Analysis of Radial Flux Permanent Magnet Generator Using Local Optimization Method

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Abstract : Recently, Permanent Magnet Generator has been widely used due to its ability to have simple structure yet high efficiency. To maximize the output performance of the generator advances and trends in mathematical modelling and computer simulation using optimization techniques have opened the way to a new approach to electrical machine design. In this paper, a Radial Flux Permanent Magnet Generator (RFPMG) configuration was examined and optimized throughout sizes and weight using the Local Optimization Method as an iterative process in order to achieve optimal output. By utilizing the LOM technique as an optimization process, the output voltage of RFPMG increased by 13.64% from the initial results. With a corresponding increase in output voltage performances, the configuration geometry adjustment additionally helps in expanding the generator's operational area. Hence, this paper presents the contributions of advancement resulting in an increment of the back-electromotive force value and with the reduction in the permanent magnet volume after the optimization process.

Keywords : Optimization, Radial Flux Permanent Magnet, Generator.

1 Introduction

Economic growth is fundamentally dependent on electricity as a source of energy and ensuring the generation of renewable energy sources is crucial to achieving the goal of sustainability [1]. The development of renewable and alternative energy sources must be considered in addition to spreading knowledge of energy conservation through education. Perhaps, it is necessary to boost instrument energy consumption efficiency or generator efficiency in order to slow down the depletion of fossil fuels.

One of the well-known energy-sufficient generators has been introduced to this field which is the permanent magnet generator [2, 3]. Recently, Permanent Magnet Generator has been widely used due to its ability to have simple structure yet high efficiency [4], [5]. For small-scale industrial and commercial industries, permanent magnet generators are one type of sustainable energy that is frequently employed in ordinary routines. Permanent magnet (PM) generators are widely utilized in small-scale generation systems due to their prevalence. However, the ongoing pursuit of enhanced efficiency, power density, and reliability necessitates the adoption of contemporary electric generators. One of the ways to improve the performance of the generators is by adjusting every part size name as an optimization method. Optimization is a well-known method among researchers in order to achieve the high performance of the proposed generator.

During designing a generator or machine structure, optimization is crucial for achieving excellent performance, whether that performance is measured in terms of efficiency or robustness [6, 7, 8]. The optimization issue is then structured utilizing each of the three mathematical elements related to variables, constraints, and cost functions. It is known that the optimization design should aim to minimize the topology's overall impact in terms of size, weight, and length [9, 10, 11]. Besides, It is required to develop a mathematical function that specifies the electric efficiency as a function of the structure in order to accomplish the optimization of the methodological design[12].

Hence, this paper focuses on using the Local Optimization Method (LOM) to optimize the radial-flux permanent magnet generator. The LOM algorithm is performed by changing the design sensitivity parameters in one sequence directly, part by part, and repeated over until the design achieves the highest performance of output voltage, power, and efficiency [13]. These methods offer good accuracy when compared with initial measurements that will be described in the next section.

2 Optimization Algorithm of RF-PMG

Recently, the optimization method has been used widely by researchers. Optimization methods bring up new modelling, algorithm, and configuration to solve the overcome engineering problems [10, 14, 15]. To maximize the output performance

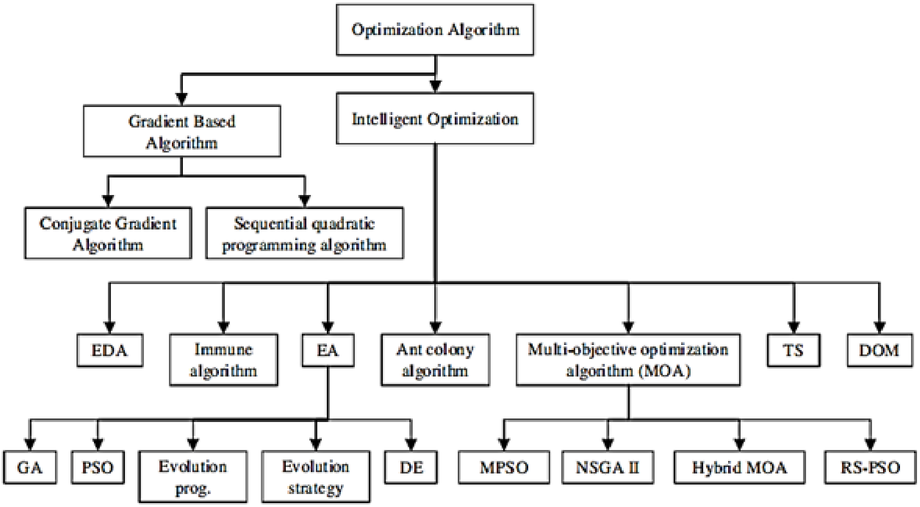

Figure 1: Optimization algorithm for electrical machine configuration

Table 1: Initial design parameter of RF-PMG

Specifications	Parameters
Inner Rotor Diameter (mm)	266
Outer Rotor Diameter (mm)	284
Inner Stator Diameter (mm)	264
Outer Stator Diameter (mm)	180
Stack length (mm)	30
Air gap (mm)	1
Number of poles	24
Number of slots	36

of the generator, advances, and trends in mathematical modelling and computer simulation using optimization techniques have opened the way to a new approach to electrical machine design. Recently, modern optimization methods had a potential growth of interest for industry year after year due to their massive penetration into the design chain [16]. Figure 1 illustrates optimization algorithms for the design optimization of electrical machines as well as other electromagnetic devices [17], [18]. According to the figure, eighteen types of optimization algorithms have been used in electric machine designs, such as conjugate gradient algorithm (CGA), sequential quadratic programming (SQP) algorithm, estimation of distribution algorithm (EDA), immune algorithm, evolutionary algorithm (EA), evolution programming, evolution strategy, and ant colony algorithm. Based on previous research, the conjugate gradient algorithm (CGA), sequential quadratic programming (SQP) algorithm, Tabu Search (TS), and deterministic optimization method (DOM) are the most widely used optimization algorithms among researchers [19]. Moreover, there are two categories of optimization that can develop analytical solutions: gradient-based algorithm (GBA) and intelligent optimization algorithm (IOA). This paper utilizes the Local Optimization method which is categorized under IOA to optimize the proposed design to ensure the operating principle and performance of the generator.

3 Design Optimization Parameters of RF-PMFSG

The illustration configurations of RF-PMG as shown in Figure 2. The configurations consist of four main parts which are 36 stator slots, 24 rotor poles, a permanent magnet, and an armature coil. The permanent magnets are made of 1kg rare-earth material which is Ferrite Br (0.4)T with 5000 kg/m3 density. The initial design parameters of RF-PMG are shown in Table 1. Hence, the number of turns for the armature coil changes based on the effective area during the optimization process. Equation 1 shows the formula to calculate the number of turns. The fluxes produced are controlled through each armature coil, and each coil flux is contrary.

$$\text{No. of turns} = \frac{A_{\text{effective}}}{A_{\text{coil},2\pi r}} \tag{1}$$

Where the number of turns is set according to the phase, $A_{\text{effective}}$ is the armature coil area with filling factor, and $A_{\text{coil},2\pi r}$ is the size of the coil used.

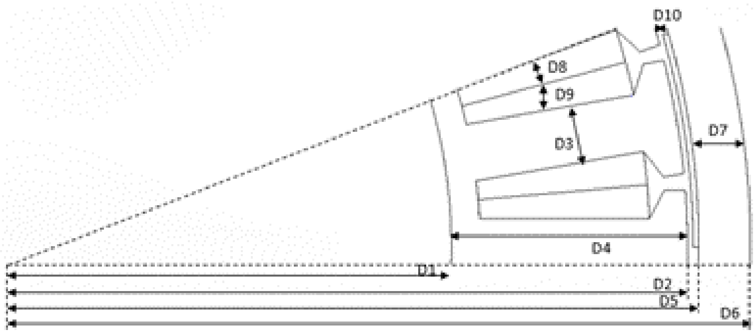

Figure 2: Illustration parts of RF-PMG

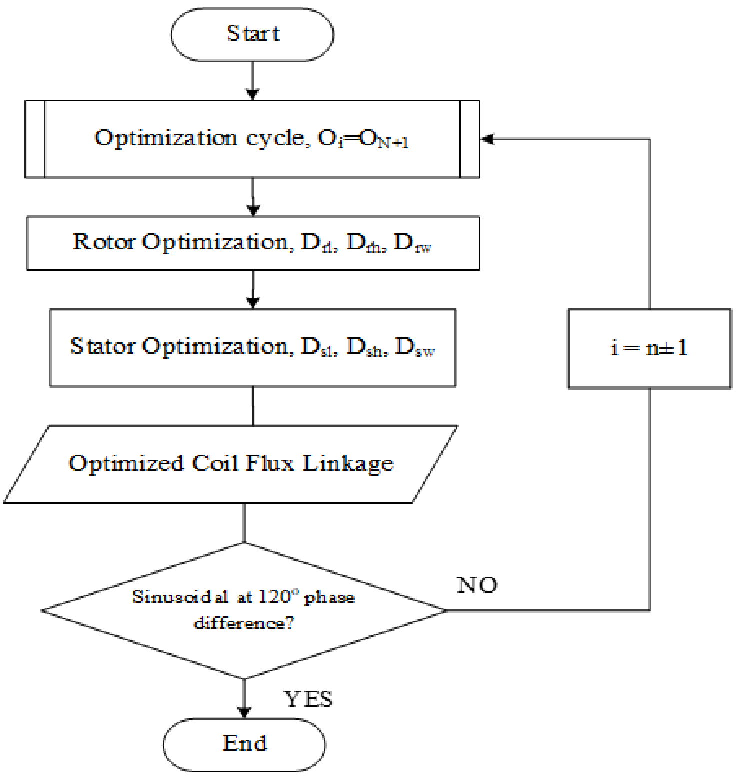

Figure 3: Optimization flowchart

LOM is then used to optimize the parameters of two main parts of the proposed generator which are rotor and stator including armature coils. The optimization cycles of the parameters including their rotor width D_7, rotor length D_6, rotor height D_5, stator width D_3, stator length D_4, and stator height D_2 will be done by parts as depicted in Figure 3. The optimization will be repeated for all generator parts until it reaches the optimum output performance with a 0.1 scaling factor. Moreover, the remainder of this article pertains to the structure of parameters in the RFPMG, and the technique for designing is based on the fundamentals as shown in the following equations for the initial RFPMG structure. The length of the generator's air gap is identified initially to ensure that the structure does not exceed the maximum value of the air gap density.

In addition, it is important to highlight that the dimension of a rotor might have an impact on the stability and consistency of the rotational system. The stability of a generator is typically enhanced by the incorporation of a longer rotor, as this results in a greater moment of inertia. This increased moment of inertia effectively opposes any modifications that are in the generator's rotational speed. The maintenance of a consistent pace is of crucial importance in several applications, particularly those involving power generation or high-precision machines. Therefore, the dimensions of the rotor and stator can be determined through the utilization of the mathematical expression specified in Equation 2 during the optimization process.

$$P_{AC} = P_S + 2P_R + P_{PM} \tag{2}$$

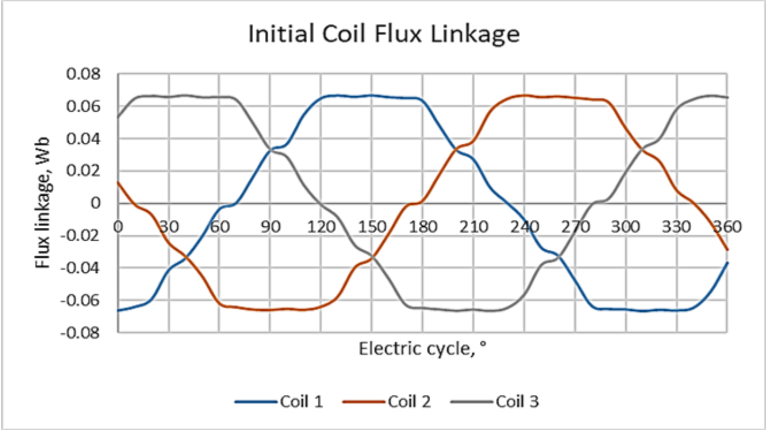

Figure 4: Initial coil flux linkage

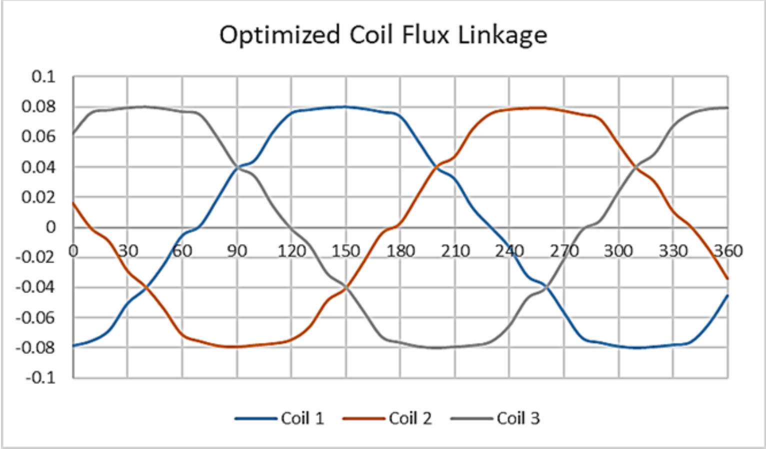

Figure 5: Optimized coil flux linkage

Where P_{AC} is the armature coil pole pitch, P_S is the stator pole pitch, P_R is the rotor pole pitch, and P_{PM} is the permanent magnet pole pitch respectively. However, the length of each slot structure is determined by the filling factor and the lateral area on each side of the coil.

4 Optimization Results Comparison

The final dimensions of the RF-PMG were obtained by determining the initial machine specifications by utilizing local optimization procedures using the finite element method. The initial topology of RF-PMG has been designed utilizing 2-dimensional Finite Element Analysis (FEA). Both of the design has been analyzed under the same speed and material which is 600rpm. Figure 4 illustrates the initial coil flux linkage and Figure 5 shows the optimized flux linkage. Based on both figures, flux linkage on optimized design shows 0.08Wb which is higher than the initial flux linkage value which is 0.065Wb. Besides, it is crucial to achieve the highest magnetic flux combined with the maximum amount of conductors in series in order to maximize the induced voltage for each coil due to the effect of the generator design on the induced voltage waveform.

The winding phase obtains a current of electricity throughout the excitation phase, which magnetizes the machine's core. The energy from the prior process's magnetic core storage as well as the energy from the mechanical power generated by the machine shaft are given to the load throughout the electricity production stage that brings the back EMF and transforms mechanical power into electrical power [20]. Therefore, 36 slots with 24 poles have been observed at 600rpm and achieved 224V as shown in Figure 6. From the figure, the initial result before the optimization is compared with optimization results where it obtained 151V. In addition, this fundamental value of the induced voltage is commonly calculated and used for bigger size of generators to achieve optimal output performance results.

The comparison of the cogging torque value of the initial design and the optimized design is shown in Figure 7. When compared to the initial configuration, it can be observed that the maximum values of cogging torque have a 63% reduction. The maximum peak-to-peak cogging torque value of the initial design is 0.99Nm and becomes 0.36 after optimization respectively.

The results comparisons of the magnetic flux distribution of RF-PMG are shown in Figure 8. The maximum magnetic flux

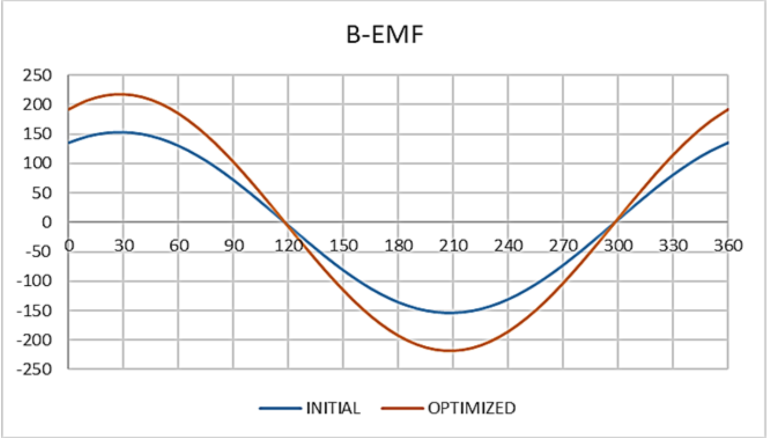

Figure 6: Comparison of back electromotive force

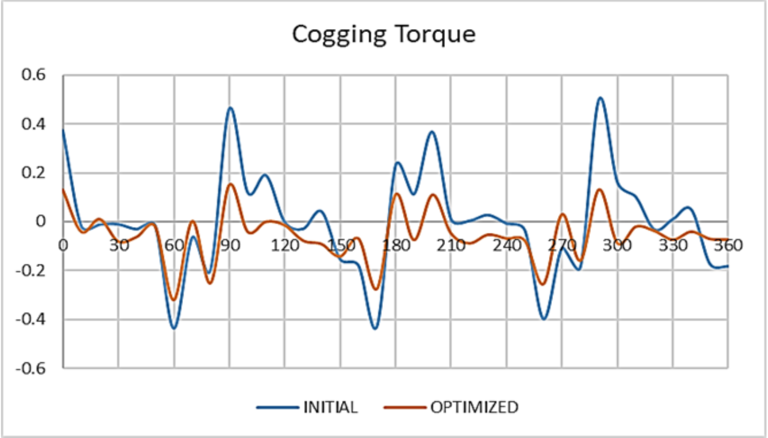

Figure 7: Comparison of cogging torque

density decreases after the optimization process. The most significant area of the air gap flux density that corresponds to the stator slots regions has average values of 1.7631 T and 1.7383 T, respectively. It is observed that whenever the magnetic field polarity shifts at the stator tooth part areas, the air-gap flux density radial component can rapidly shift.

5 Conclusion

In conclusion, this paper presents the design optimization using the Local Optimization Method (LOM) for a Radial Flux Permanent Magnet Generator. According to the results obtained, output voltage shows a 13.64% increase with a 63% reduction of cogging torque after the optimization process. It can be concluded that this method can be used for the optimization process to achieve better performance of the generator.

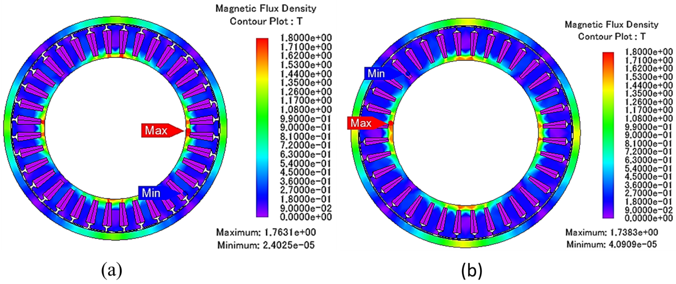

Figure 8: Comparison of flux distribution (a) initial design (b) optimized design

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Authors' Contributions

Therefore, this study makes a valuable contribution towards improving the RFPMG performances in terms of permanent magnet weight reduction and back-electromotive force. The optimized generator has achieved a weight reduction of 0.9kg compared to the initial design. By implementing this approach, the generator's weight has been reduced which results in enhanced generator's robustness. Hence, all authors made contributions to the design, optimization, and analysis of the study. The final draft of the work has been reviewed and approved by all authors.

Competing Interests

The authors declare that they have no competing interests.

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