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Optimization of 12S-14P Brushless DC Motor for Drone Application

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Abstract: Brushless Direct Current (BLDC) motor drone has gained worldwide popularity. BLDC motors have become the main motor for use in all low and high-performance in electric vehicles such as drone. The problems of this motor are cogging torque undesirable aspect of some brushless direct current (BLDC) motor. The excessive torque cause motor to produce acoustic vibration such as noise, speed ripple that can cause noise and damage to the structure. This research is to design and analyse BLDC motor using JMAG software designer for drone application, to optimize torque and power density ratio of the design BLDC motor using local parameter method and to compare performances of the initial and optimization design. The method that uses is local parameter every parameter must be adjustment and must keep same volume each parameter with the initial when adjust the parameter to optimize design. To investigate the maximum torque and power that performances of the BLDC motor can be achieve. At the end of the result, analyse the torque and power initial and optimize the improvements of the motor that optimize design give better performances without any noise to the structure of the motor.

Keywords: Brushless Direct Current, Cogging Torque, Local Parameter Method

1. Introduction

A DC motor is one of a class of rotary electrical motors that converts to mechanical energy into direct current electrical energy. The forces generated by magnetic fields depend on the most common forms. Almost all types of DC motors have some internal function, electromechanical or electronic, in order to alter the current direction periodically in the part of the motor [1]. Brushless DC motor (BLDC) drawbacks are less stable in control at lowest speeds, physically larger than other engines generating equal torque, considered high maintenance and vulnerable to dust that reduces performance. They reflect a major leap forward in technology since brushless DC motors have no brushes to get worn out. Brushless engines have a substantially higher efficiency and durability and a lower sensitivity than their brushed equivalents to mechanical wear [2]. The benefits of a higher torque-to-weight ratio of the Brushless DC motor, increased torque per watt of power input or increased performance, increased

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reliability and lower maintenance requirements, and decreased operating and mechanical noise [3]. A brushless DC motors have been for electric propulsion, cranes, paper machines and steel rolling mills [4]. DC motors using electronic speed controller devices have displaced brushed motors for many applications. Brushless DC motor has the characteristics of general DC motor, the ratio of instantaneous torque rated is very high which has excellent dynamic response characteristics. High output performance is the most required machine to be applied in heavy duty application such as in electric vehicle, aircraft and drone [5]. Brushless DC motor is an advantage in acceleration and deceleration, operation and control because it maintains high efficiency over a wide operating range. It is also approximately to a general permanent magnet synchronous motor (PMSM) with environment is less constrained, has high reliability and reduce cost of maintenance. It is also, used in a wide range of applications from large motor applications to small servo systems. From the researches have been reported, Brushless DC motor show a suitable method to use in these applications. Many researches on Brushless DC motor still carried out to optimize the exciting performances. In this project, Brushless DC motor with a combination of slots and poles 12/14 the goals are to design and analysis the performance [6] Brushless DC motor based on parameter, specifications and performances of the developed slot and poles. The focus of this proposal is optimization to optimize the power density by reducing the back EMF harmonics by selecting the optimal pole ratio in motor.

First of all, there are some problem regarding the structure of Brushless Direct Current (BLDC) which contained too many permanent magnets in structure. Therefore, the cost of construction of drone is very high due to permanent magnet (PM) material. The PM may be limited due to high temperature environment and possibility of demagnetisation at high current condition. Next, the issues are to optimize and compare performances (initial and optimize) design torque and power of design BLDC motor using local parameters are developed motor of Brushless Direct Current (BLDC) that has high cogging torque and non-sinusoidal back EMF. This cogging torque is an undesirable characteristic of some magnet motor design. That undesirable torque makes motor produce vibration acoustic noise, possible resonances, speed ripple that may cause noise and structure damage [7]. Moreover, another problem is the back EMF or induce EMF of BLDC are not in sinusoidal waveform that affect the harmonic distortion. Figure 1 shows the back emf waveform of developed BLDC of a combination of slots and poles 12/14 with to high harmonic content. Thus, the structure needs to be improvised to have better performances. Indeed, optimization BLDC motor for drone application is selected as the best candidate when compared with other design to optimize torque and power density. To design and analyse BLDC motor using JMAG software are to optimize the performance of the existing result. such as optimize torque and power ratio of the design BLDC and to compare the result of performances of the BLDC with others design. To get a more efficiency result and can improve to the future result and make more the efficiency higher in term torque and power density with existing result. This implies a lower magnetic flux rate that involves several harmonic components of the flux linkage, which makes it easier to produce torque variations and basic iron loss increases, which are additional drawbacks.

First objectives are to design and analyses BLDC motor using JMAG software designer for drone application. Second, to optimize torque and power density ratio of the design BLDC motor using local parameter method and thirdly, to compare performances of the problems BLDC motor with initial and optimize design.

Firstly, structure of the motor is designed by using JMAG-Geometry Editor while the analysis is implemented using JMAG designer software. Both JMAG-Geometry Editor and JMAG designer are released by JSOL Corporation. Secondly, the proposed design of BLDC is based on the parameter and specification of BLDC as listed in Table 1. Thirdly, along the project implementation analyses will focus to the performance cogging torque, back EMF, speed leakage torque and power density. Lastly, the performance motor will be compared with number of slots, pole and air gap to obtain the best candidate for further improvement.

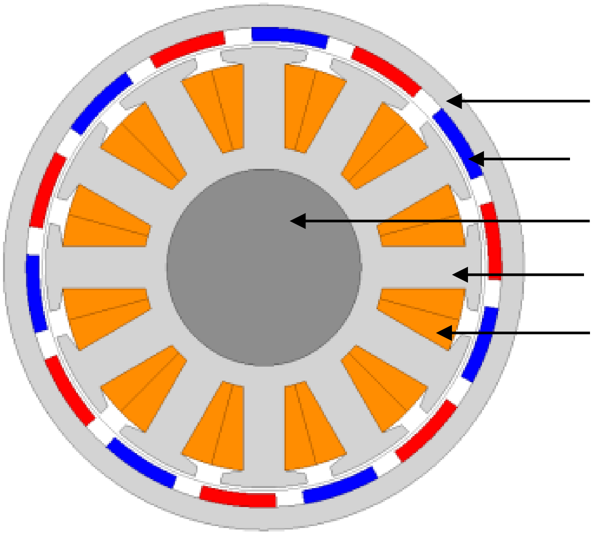


Figure 1: Sectional View of BLDC Motor Initial Model

Table 1: Parameter of Initial Design Motor

Parameter	Value	Unit
Number of phases	3	-
Number of slots	12	-
Number of poles	14	-
Air gap Length	0.5	mm
Rated speed	500	rpm
Rotor outer / Inner diameter	24/22.5	mm
Stator outer / Inner	5.5/4	mm
Shaft diameter	0.75	mm
Permanent Magnet gap	0.366	mm
Permanent Magnet length	4.31	mm
Armature coil width	1.131	mm
Armature coil thick	1.13	mm
Permanent magnet volume	130.40	g

2. Method Design and Analyses BLDC Motor

JMAG Geometry editors used to design each part of the engine separately as FEM, rotor, stator, and armature coil. For each engine part and the engine simulation that has been created, the JMAG-designer is used to integrate the condition setting and materials

2.1 Material Setting

Table 2 indicates the material environment for the Internal Permanent Magnet Synchronous Motor parts. The materials are chosen from the library of materials located on the right side of the screen.

Table 2: Material for Condition Motor Parts

Parts	Material used	Conditions
Rotor	35H210	Motion: Rotation Torque: Nodal Force -
Stator	35H210	-
Permanent Magnet Radial	Neomax35AH	Motion: Rotation Torque: Nodal Force -
Permanent magnet circumferential	Neomax35AH	-
Armature Coil	Copper	FEM Coil

2.2 Method Optimize Design BLDC Motor

Using a local optimization method is to boost higher engine torque and strength, recognize possible parameters that can be optimal value for the local optimization process, rotor, stator, permanent magnet and coil armature sizing. four design-free parameters that are responsive to machine performance changes are specified on the sides of the rotor yoke. The design parameter is split into three classes, such as those associated with the shape of the rotor center, which includes rotor yoke (L1), the PM shape including PM gap (L2) and stator shape including stator tooth width (L3) and Stator back teeth width (L4) will affect the width of armature coil. Figure 2 shows the parameter should be modify to optimize design.

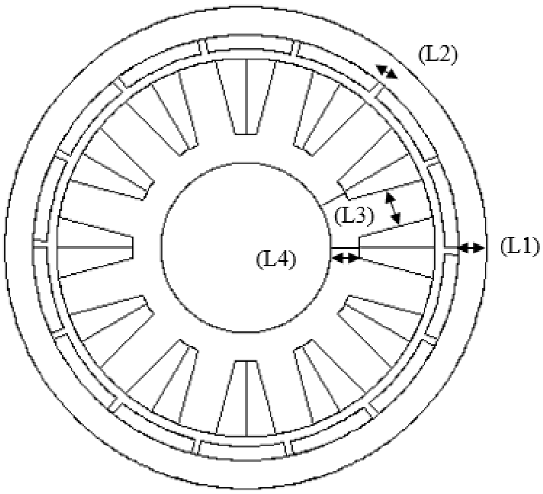


Figure 2: Parameter Modify to Optimize

2.3 Method Comparison Initial Design and Optimize Design BLDC Motor

Using analysis torque and power method this approach, compare the initial and optimization design no load until load analysis that give the better improvement for the performances motor such as torque and power of the 12S-14P BLDC motor design. Figure 3 shows the flow chart overall of this project.

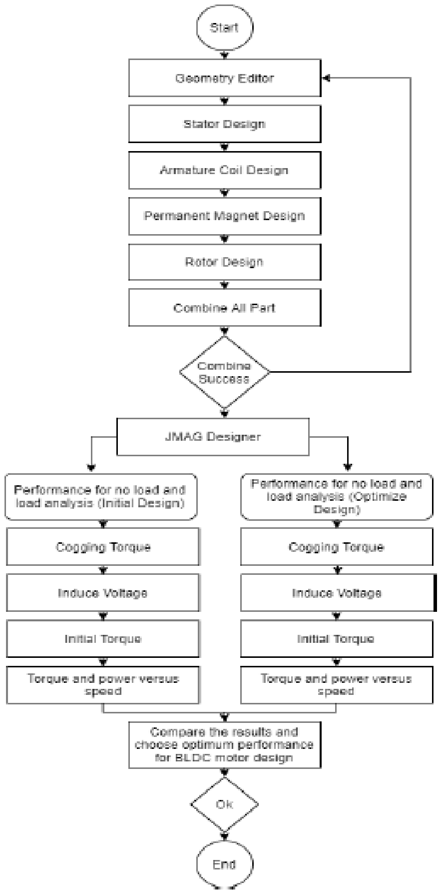


Figure 3: Flow Chart Operation Overall Project

2.4 Comparison BLDC Motor Optimization and Improvement Design

The research difference between optimization design and other research such as improvement design are different but same aim to increase the torque to get the optimum torque for the performances motor. The optimization design process to optimize design with modify parameter to get high performances such as speed and torque to get the better results of the performances. While, improvement design compares the other type filter with suitable capacitor to investigate which filter are makes improvement torque to get the optimum torque.

3. Results and Discussion

The results and discussion section present data and analysis of the study comparison performances of the initial and optimize design to give better performances such as torque and power. The pattern grouped as follow W, U and V phase. The three-flux linkage in which PM generates the source under open circuit conditions at no load. At load analysis the initial design average torque is 0.565Nm and power is 49.88kW. While, the optimize design the average torque is 0.575Nm and power 50.72kW. The improvement of the performances motor optimize design is 1.8%.

3.1 Results

The results reflect the flux linkage, torque and power between phase which defined as W, U and V respectively for comparison initial and optimize design. The following graphs show the three-phase flux and the difference design initial and optimization design.

3.2 Comparison of U Phase Cogging Torque

Figure 4 displays initial design and optimizes design BLDC motor the configuration of the cogging torque for drone application. This graph is plotted when there is no current supply of 0Arms/mm2 to the armature coil. It is demonstrating that in BLDC motor rotation, the rotor. The cogging torque of the initial generated is the maximum peak to peak of 0.0081Nm. Otherwise, after optimization the cogging torque reduces to 0.007Nm. The value of the cogging torque shows the performance improve of the motor due to distortion which is vibration to the motor is reduce. Even though the value of cogging torque for optimized is lower compared to initial design because it reduces the excessive torque cause motor to produce acoustic vibration noise, speed ripple that can cause noise and damage to the structure. The results analyse that when do an optimization the design of BLDC motor it will give a better performances.

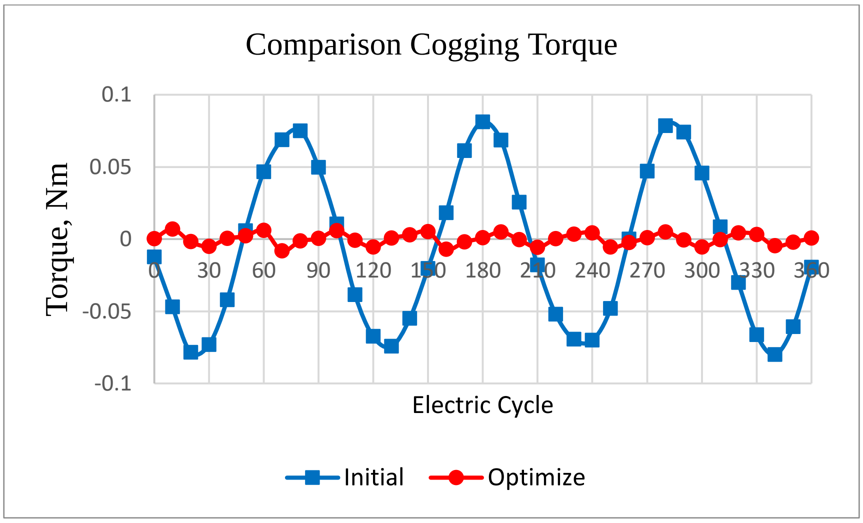


Figure 4: Comparison Cogging Torque Initial and Optimize Design

3.3 Comparison Induce Voltage

Figure 5 shows the graph for back electromotive force (emf) for initial design and optimization design BLDC motor for drone application. As a result, shows that, the initial design has the maximum value of 19.42V at angle 240º while optimized design has the maximum value of 18.21V at angle 60º. It also showed that the induce voltage are reduce and it will be good performance and improvements of the motor performances the configuration of waveform computed by optimized design is more favourable as it has the sinusoidal waveform.

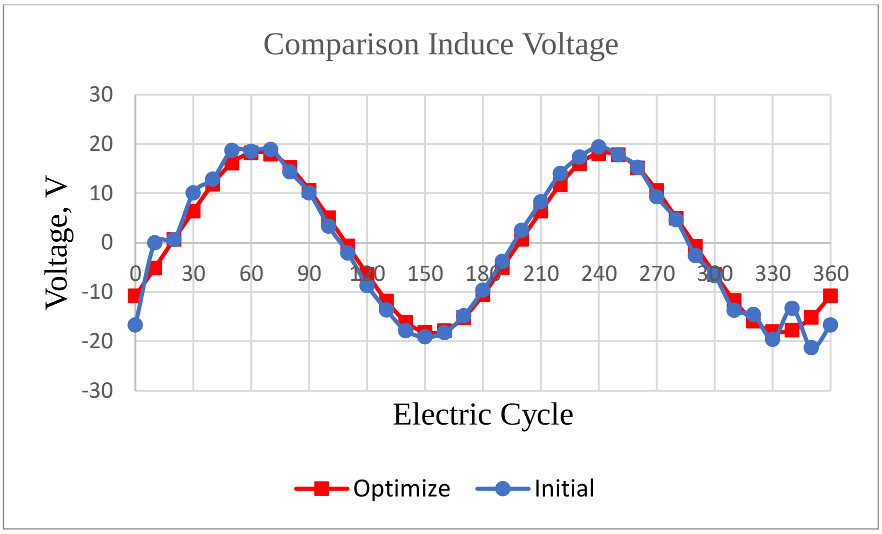
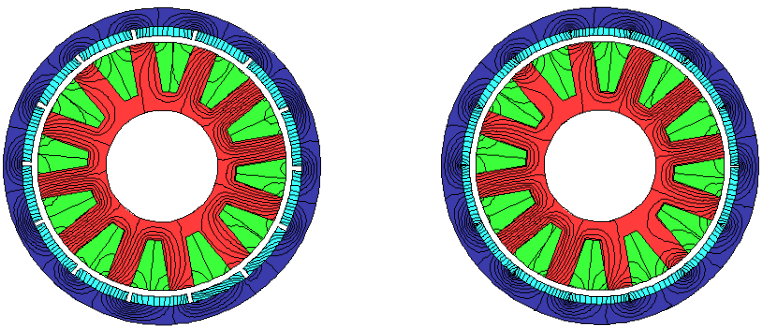


Figure 5: Comparison Induce Voltage Initial Design and Optimize Design

3.4 Comparison of Flux Line Analysis

The flux flow of the permanent magnet and armature coil for initial and optimized design BLDC motor for drone applications at Ja=0 Arms/mm2 are showed in Figure 6 (a) initial flux line analysis design and it is obvious that most of the flux flow to the stator. Meanwhile, Figure 6 (b) optimization flux line analysis design it produces flow of flux path to the stator around the permanent magnet. Then, it can be observed that the flux in initial design is slightly packed compared to the optimized design. It is improving the flux line because there are many extra empty areas where there will be more spaces for flux could to occupy.

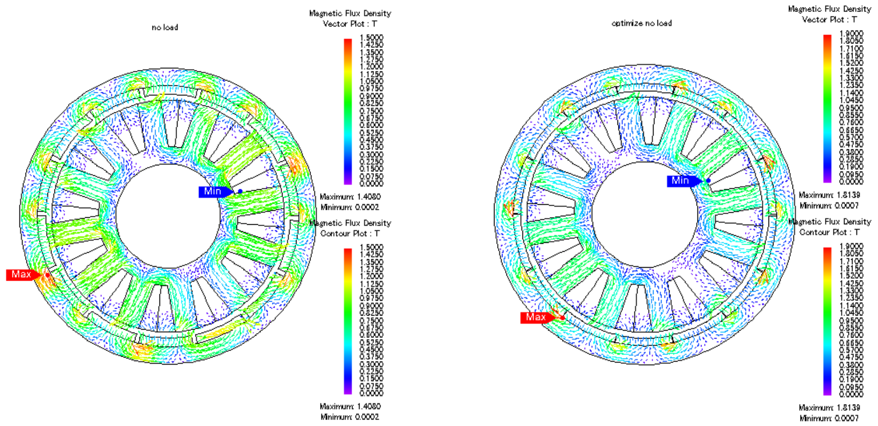


(a) Initial Design BLDC Motor **(b) Optimization BLDC Motor**

Figure 6: Comparison of Flux Line Analysis (a) Initial Design and (b) Optimization Design

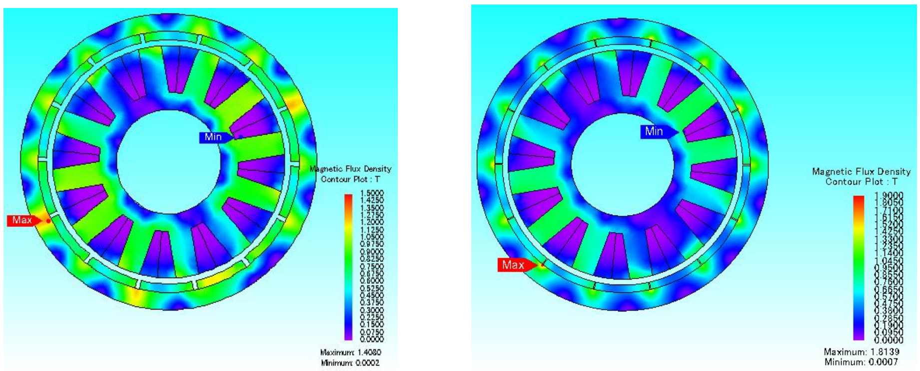
3.5 Comparison of Flux Line Distribution and Density

The comparison of flux line distribution and density is also investigated for the initial design and optimized design at Ja= 0 Arms/mm2. As shown for initial design in Figure 7(a) and 8(a), the initial flux line distribution and density design of BLDC motor maximum magnetic flux density is 1.4080Nm and the minimum value is 0.0002Nm. Meanwhile, slightly increase flux density from the 7(b) and 8(b), the optimization of flux line distribution and density from PM flow to the stator. The maximum magnetic flux density is 1.8139Nm and the minimum value was 0.0007Nm.



(a) Initial Flux Distribution Design **(b) Optimization Flux Distribution Design**

Figure 7: Comparison Initial and Optimization Flux Distribution Design



(a) Initial Flux Density Design **(b) Optimization Flux Density Design**

Figure 8: Comparison Initial and Optimzation Flux Density Design

3.6 Comparison Torque and Power Versus Speed Design

The initial design torque and power versus speed characteristics of the initial design 12S-14P BLDC for drone applications is illustrated in Figure 9 at based speed of 1419.2 r/min, the average torque obtained is 0.565Nm, with corresponding power of 49.88kW. Since the target torque and power need to improve the performances. While, Torque and power versus speed characteristics of the optimization BLDC motor is illustrated in Figure 10, the result at base speed are 1419.2r/min. The average torque obtained is 0.575 Nm and corresponding power of 50.717kW. Based on the Figure above the design of the optimization improve the performances of the motor which are 1.8% from the initial model.

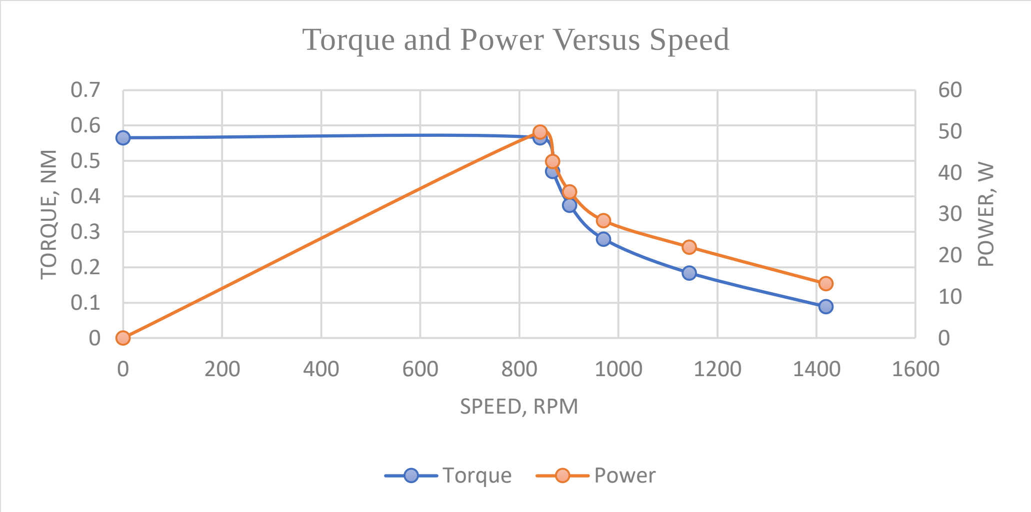


Figure 9: Torque and Power Versus Speed Initial Design

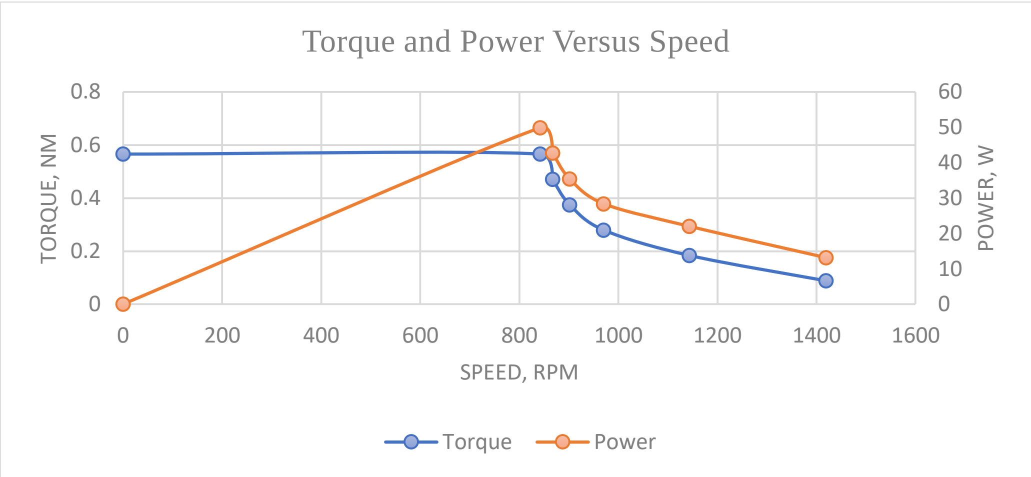


Figure 10: Torque and Power Versus Speed Optimize Design

4. Conclusion

A BLDC 12S-14P BLDC motor for drone application structure was proposed in this study. This work is divided into three parts which are initial design validation and analysis optimization and comparison between initial and optimize design. In the beginning initial design of 12S-14P BLDC motor for drone application has been validated and analyzed using JMAG designer version 14.0. After Succeed validating the coil test analyzes are carried out to examine the design operating principles. The performances have been tested with no load and load condition. Besides, optimization takes place where the main objective is to increase the torque. After the optimization process completed, the optimization 12S-14P BLDC motor for drone application achieved a torque increment from 0.565 Nm to 0.575 Nm which is increase 1.8%. Next, the cogging torque has decrease slightly from 0.0081 Nm to 0.007 Nm which is about 13.58% decrement and give better performance to the BLDC motor when optimize. Last but not least, the power has increase from 49.88kW to 50.72kW which makes about 1.68% it will improvement of the efficiency of the BLDC motor.

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