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# Comparative analysis of various rotor types BLDC motor for residential elevator application

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**ABSTRACT**

Brushless DC (BLDC) motors are widely used in applications where high efficiency is crucial. With advancements in permanent magnet technology, BLDC motors are increasingly suitable for high-torque applications such as residential elevators. Known for their high efficiency, low maintenance, and excellent controllability, BLDC motors are ideal candidates for this research. However, the challenge lies in identifying the most efficient rotor structure that can deliver the required torque for residential elevator applications while maintaining cost-effectiveness and compact design. This paper addresses this problem by simulating various rotor types of BLDC motors using the finite element method (FEM), Ansys Maxwell. four different rotor structures have been analyzed to evaluate their back electromotive force (EMF) and torque. The model generating the highest torque will be selected for manufacturing as a motor for residential elevators. Among the models studied, BLDC-ERA rotor structures produced the highest torque of 28 Nm, while BLDC-HR type generates the lowest torque. To ensure practicality and cost-effectiveness of installing elevators in double-story houses or smaller residences, the selected motor must be compact and affordable, enabling senior citizen to maintain their independence. This research not only aids other researchers in designing suitable motors for elevator applications but also contributes to societal well-being by promoting accessibility and independence for the elderly.



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## 1. INTRODUCTION

The evolution of urban living has placed a significant emphasis on the development of efficient and reliable residential infrastructure. Elevators, as a critical component of multi-story buildings, necessitate advanced motor technologies to meet the modern living [1]. Nowadays, most housing developers tend to build double-storey or even higher landed houses [2], [3]. Therefore, a small-size and low-cost elevator system called domestic elevators is required in order to make sure it is affordable and practical to be installed at least for a double-storey house to promote independent living to the elderly. Residential elevators play a crucial role in enhancing accessibility and convenience within modern homes, offering vertical transportation solutions for individuals with mobility challenges and optimizing space utilization [4]. The motor system employed in residential elevators significantly influences their performance, robustness, reliability, and energy efficiency [5], [6]. There are several types of motors that can be used as the domestic elevator system electric motor, including linear motors and rotational motors. The current domestic elevator system uses either rotational type induction motors (IM) or permanent magnet synchronous motors (PMSM) as the electric motors [7]. The use of the IM or the PMSM requires additional room called the motor room that is located near the motor and its control panel. Usually, an additional floor is required on top of the top floor, which is uneconomical in terms of space occupancy. Based on some studies, the conventional elevator system occupies about 30% of the total floor space for buildings over 250 meters tall [8].

Commonly, they used the traditional induction motors as an electric motor for residential elevators [9]–[13]. Despite being very common, the traditional induction motors frequently lack precise control and energy efficiency. As a consequence, brushless DC (BLDC) motors present a better option due to their high efficiency, low maintenance, and remarkable controllability. BLDC motors, characterized by their electronic commutation and absence of brushes, reduce friction losses and wear, making them highly durable and efficient. Because of these features, BLDC motors are especially well-suited for applications where energy efficiency and reliable performance are critical [14]–[17]. BLDC motors offer an attractive solution for residential elevators that need smooth operation, accurate speed control, and reliable torque output under a range of load conditions.

There are some researchers designing an electric motor that is suitable for an elevator system. In the research by Amini *et al.* [18] involves designing two types of permanent magnet (PM) motors for use in an elevator system and analyzing their significant failure modes for lifetime analysis. The authors state that while induction motors (IMs) are commonly used in elevators, PM motors could be a suitable alternative due to their efficiency, controllability, and power density. The authors compared between interior IPMSM and PM-assisted synchronous reluctance motor (PMA-SynRM) in terms of reliability and lifetime. The results suggest that PMA-SynRM has higher fault tolerability and reliability than the IPMSM in the same operating time. Therefore, the authors recommend the PMA-SynRM for elevator usage from a reliability viewpoint. However, they also note that the PMA-SynRM has manufacturing challenges and higher torque ripple compared to IPMSM. Yetis *et al.* [19] discussed the proposed gearless elevator system driven by IPM compared to surface-mounted PMSM (SPM). The IPM motor with ferrite magnet and NdFeB NdFeB-based SPM motor have been comparatively investigated. Different slot/pole combinations and the number of flux-barrier layers in the IPM motor are analyzed to reduce torque ripple while minimizing cost and weight. The results suggest that gearless elevator systems driven by PMSM are more advantageous in all respects, even if the efficiency of ferrite-based designs is low. The most economical solution for a gearless elevator system driven by PMSM is the Ferrite based on IPM motors.

Another research by Avsar e*t al.* [20] discussed the design and optimization of a 4.5 kW inner rotor permanent magnet synchronous motor (PMSM) with 400 rpm nominal speed for a belt drive elevator system. The authors aimed to design a motor that provides efficiency and passage comfort, two critical criteria in elevator traction motors. The authors used electrical and magnetic modelling of PMSM and optimized parameters such as the slot opening, magnet thickness, embrace, stator tooth thickness, and air gap using the 2D Finite Element Method (FEM) and genetic algorithm. The authors also highlighted that using gearless PMSMs instead of induction motors with gears in the elevator system can save about 30%-50% energy. This has led to an increase in the usage rate of gearless PMSMs in the industry.

In research by Bakhtiarzadeh *et al.* [21] design PMSM can significantly increase the efficiency of elevator systems and reduce mechanical tension. The paper presents a comprehensive design of a PMSM for gearless elevators using the FEM. The authors analyze and evaluate various aspects of the motor design, such as fractional pitch slots, the number of slots, and harmonic components. They also compare the performance of their newly designed motor with an existing 4 kW PMSM in the market by analyzing and comparing the torque and efficiency performance of both motors using simulation and test results. They propose a new winding design and validate its performance through FEM and analytical calculations. In conclusion, the authors suggest that well-designed PMSM can offer a more efficient and environmentally friendly alternative to traditional elevator systems, and that further optimization of motor design can lead to even better performance.

Based on previous researchers, most of them design electric motors for elevator applications using PMSM. Thus, it will be the research gap for this research. The advantage of PMSM for elevator application is smooth operation, like torque, lower noise, and precise speed control, but difficult to control like a BLDC motor [22]–[24]. However, since there hasn't been much research on BLDC motors for elevator applications, this paper will concentrate on BLDC motors since the construction between PMSM and BLDC motors is quite similar. The advantage of the BLDC motor compared to the PMSM motor is smooth speed control and less maintenance cost [25], [26]. In terms of cost efficiency, BLDC motors generally have a simpler design and control mechanism, thus it will be more cost-effective compared to PMSM motors. Other than that, BLDC motors are typically more compact and lighter than PMSM motors, which can be beneficial in residential elevator applications where space and weight are critical factors.

In this paper, there are four types with different rotor structures of BLDC motor have been analyzed for residential elevator applications. FEM is used as a tool to solve electromagnetic field problems for given models with appropriate materials, boundaries, and source conditions, applying Maxwell’s equations over a finite region space (Ansys 2016). As mentioned by [27], [28], FEM can provide magnetic analysis with high accuracy because it gives an approximation on a microscopic scale. The simulation result of back electromotive force (EMF) and torque had been identified for such an investigation. Based on the result, the model that produced the highest torque will be chosen to be fabricated as a motor for a residential elevator. A small-size and low-cost elevator, called a domestic elevator, is required in order to make sure it is affordable and practical to be installed in at least a double-storey house to promote independent living to the elderly.

## 2. RESEARCH METHOD

### 2.1. Basic structure

The basic structure of a BLDC motor is shown in Figure 1. It consists of two main parts, which are the stator and rotor. There are four types of BLDC motor with different rotor structures as shown in Figures 1(a)-1(d), which are BLDC-ERA, BLDC-ERT, BLDC-HR, and BLDC-SR. The BLDC-ERA and BLDC-ERT are both embedded rotor types, but the difference is the material. The advantage of embedded rotor types is that it has a structure. Other than that, it will produce lower torque ripple and can produce high efficiency. Meanwhile, the BLDC-HR is a hollow rotor, and the BLDC-SR is a slotted rotor design. The BLDC-ERA models differ in that one uses an aluminum rotor while the BLDC-ERT uses a transil for the rotor. Meanwhile, the BLDC-HR is a hollow rotor structure. The hollow rotor will have a lightweight design, which can reduce the overall weight of the motor, but the limitation is that these rotor types might exhibit higher torque ripple, leading to less smooth operation for the elevator. The material for this rotor is made from non-oriented silicon steel M250-35A with a lamination thickness of 0.5 mm each. Lastly, the BLDC-SR is a slotted rotor. The material for this rotor is the same as BLDC-HR, which is made up of non-oriented silicon steel. The slotted rotor BLDC motor can produce higher torque, but the disadvantage is it produces higher torque ripple as well. So, it will lead to less smooth operation of the elevator system. All of this BLDC motor is simulated for a residential elevator application. The stator consists of coils and lamination of slots, while the rotor comprises a permanent magnet. The stator is the stationary part where whereas the rotor is the rotating part of the motor. The BLDC motor is designed for 18 slots and 20 poles arranged in three-phase. The permanent magnet is arranged back to back to each other so that the magnetization direction will be symmetrically distributed [29].

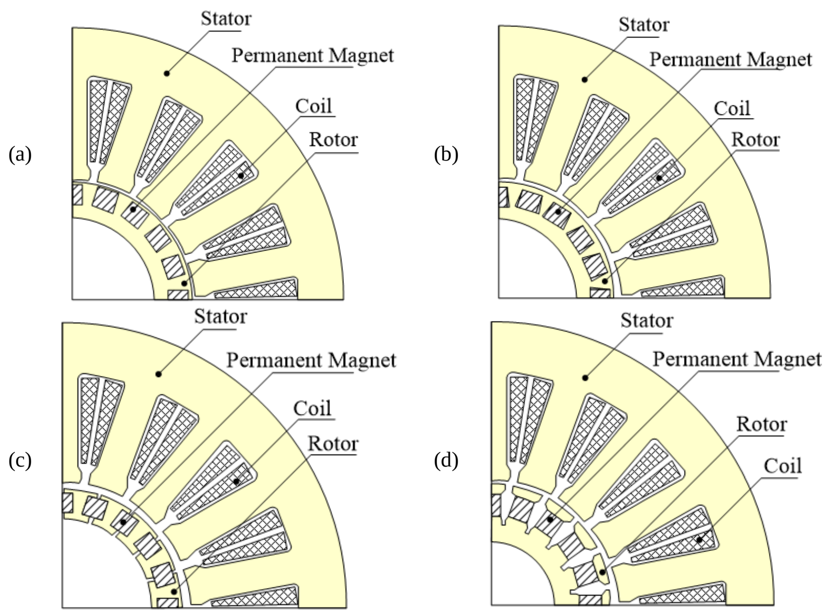


Figure 1. Basic structure of BLDC motor with different types of rotor structures:
(a) BLDC-ERA, (b) BLDC-ERT, (c) BLDC-HR, and (d) BLDC-SR

Table 1 shows the material for the stator, rotor, and permanent magnet for each type of BLDC motor. Some of the rotor structures are made up of either ferromagnetic or non-ferromagnetic material. It is still necessary to fix the mechanical air gap even though the rotor's material is different. It is to make sure every model has the same amount of magnetic energy. Figure 2 shows the B-H curve for non-oriented silicon steel M250-35A. It shows that the ratio of flux density to field strength (B/H) is not constant but varies. The flux density increases in proportion to the field strength until it reaches a saturation value. The flux density saturation for this material is about 2.0 Tesla. But to achieve an optimum result, 1.5 Tesla is the best selection. This B-H curve is imported into Ansys Maxwell properties. Table 2 shows the motor specification of the BLDC motor for this research. Since this research is focusing on a lab scale, the target torque specification for this motor is 25 Nm. The lab scale is designated at a ratio of 1:6 from the actual size.

Table 1. Material for parameter BLDC motor

| Parameter | BLDC-ERA | BLDC-ERT | BLDC-HR | BLDC-SR |
|---|---|---|---|---|
| Stator | Non-oriented silicon steel (M250-35A) | | | |
| Rotor | Non-ferromagnetic | Ferromagnetic | Ferromagnetic | Ferromagnetic |
| Permanent magnet | Neodymium Boron Iron (NdFeB42) | | | |
| Coil | Copper | | | |

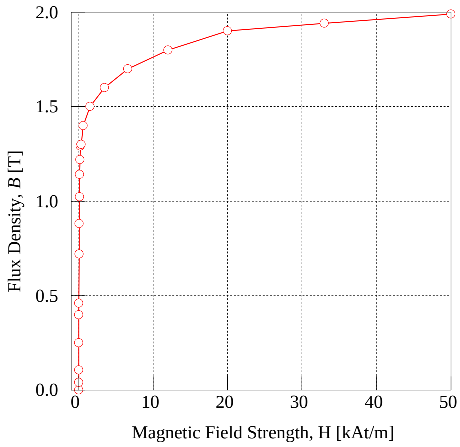


Figure 2. Non-oriented silicon steel M250-35A B-H curve

Table 2. Motor specifications used in simulation

| Item | Unit | Value |
|---|---|---|
| Outer diameter stator | [mm] | 300 |
| Outer diameter rotor | [mm] | 149.2 |
| Permanent magnet volume | [$m^3$] | $8.112\times10^{-5}$ |
| Number of turn | | 200 |
| Copper size | [mm] | 1.0 |
| Stack length | [mm] | 26 |
| Mechanical air gap | [mm] | 1.0 |
| Rated torque | [Nm] | 25 |
| Rated voltage | [V] | 36 |
| Maximum current | [A] | 10 |
| Rated power | [W] | 360×3 |
| Rated speed | [rpm] | 30 |
| Efficiency | [%] | 98-99 |

### 2.2. Parameter for analysis

In this research, the BLDC motor is modeled using SolidWorks software and analyzed using FEM. The analysis includes flux lines, flux density, back electromotive force (EMF), and torque characteristic. FEM is used because it can provide magnetic analysis with high accuracy. The FEM is used as a tool to obtain all the results. The size of copper used in this study is 1.0 mm. In order to calculate the number of turns that can fit, Equation 1 will be used. Due to the coil pattern, which is in cylindrical shape, during the winding process, there will be some overlap of the coil, especially at the vertical axis, a coil factor is introduced. Figure 3 shows the overall analysis flowchart for the BLDC motor.

$$N = \frac{w_c}{d_c} \times \frac{h_c}{d_c} \times 0.6 \tag{1}$$

Where $N$ is the number of turns, $w_c$ is the width of the coil in [mm], $h_c$ is the height of the coil in [mm], and $d_c$ is the size of the coil diameter in [mm]. In (1), coil factor for the number of turns is fixed at 0.6 as well as 60 %. After the number of turns is calculated, the resistance can also be calculated. Current injected into the motor is varies from 2 A to 10 A.

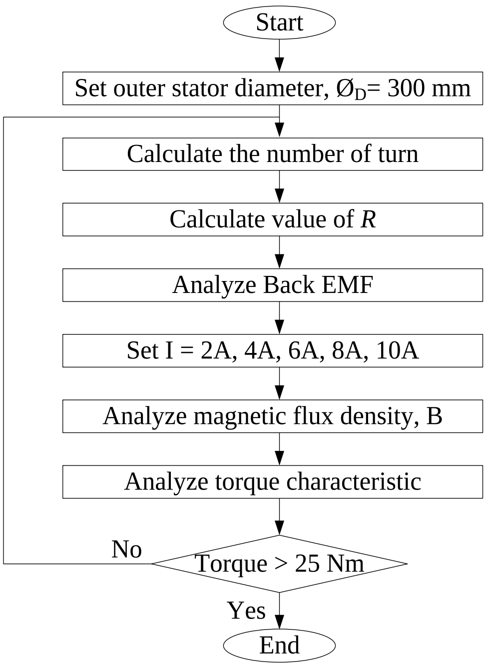


Figure 3. Overall analysis flowchart

## 3. RESULTS AND DISCUSSION

### 3.1. Finite element analysis

Figure 4 shows the example magnetic flux lines and flux density for all types of BLDC motors. A complete path of flux for phase A circulates around the stator, rotor core, and permanent magnet. As can be seen from Figure 4, the flux flows from the N pole permanent magnet through the air gap into the stator yoke teeth and travels along the stator yoke as well as the stator core. Then, the flux flows through the adjacent stator yoke to the air gap and rotor core. This rotor structure is chosen because it produces less flux leakage. The magnetic flux distribution, such as flux lines and density, was an important factor that should be considered in the BLDC motor design. Figure 4 shows the magnetic flux density inside the model with different colors and tones. The magnetic flux produced by the permanent magnet (PM) in the BLDC motor. Each tone of the color represents a different intensity of flux inside the machine. It is known that red color represents the highest flux density for the corresponding simulation in a particular area. Hence, the magnet is flux in that area tends to be saturated first. On the other hand, cold color such as blue has low flux density.

Figure 4 illustrates the proper distribution of flux lines among the BLDC motors, which consequently results in higher torque and improved efficiency. Among all the BLDC motor models, the BLDC-HR exhibits greater flux leakage compared to others. This increased flux leakage in BLDC-HR means that a significant amount of magnetic flux does not contribute to torque production. As a result, the effective magnetic fields interacting with the rotor is reduced, leading to lower torque output.

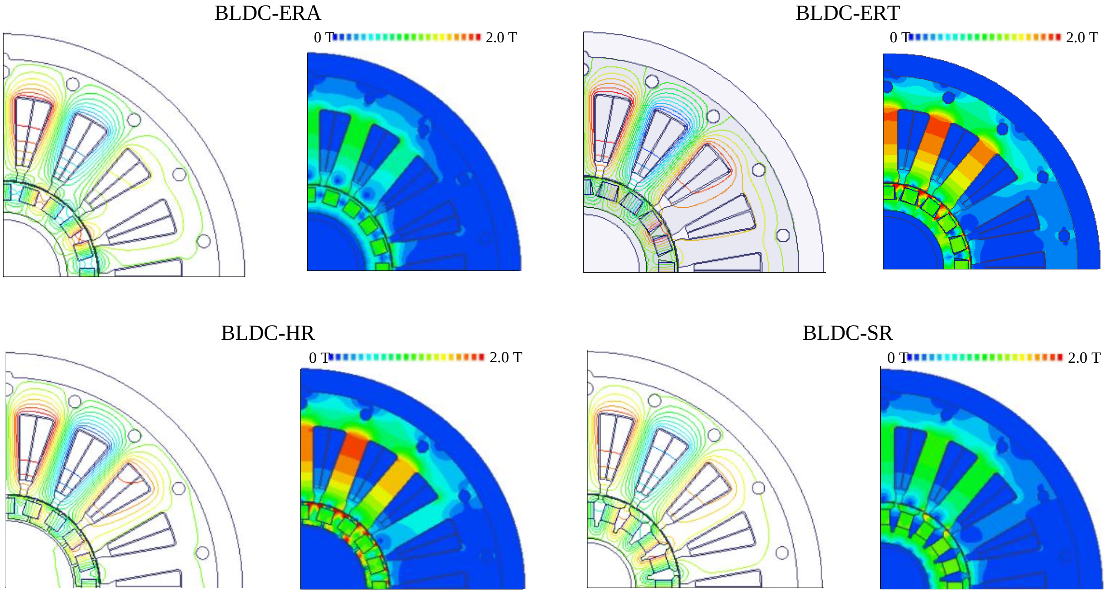


Figure 4. Magnetic flux analysis

Figure 5 shows the sampling data of the FEM simulation for back EMF and torque. Figure 5(a) shows the result of the back EMF. The back EMF is obtained when there is no current supply to the motor. The back EMF in this figure captures the per-phase value of the BLDC motor. The back EMF is the result of the permanent magnet flux crossing the air gap in radial direction and cutting the coils of the stator at a rate proportional to the rotor speed. In the further discussion, only the average is being discussed by integrating the value of back EMF. Before calculating the average of back EMF, the negative polarity of back EMF is shifted upward in order to get the positive polarity. In this case, only one phase is selected because the other phases produce the same pattern.

Meanwhile, Figure 5(b) shows the result of the electromagnetic torque for the BLDC motor. The electromagnetic torque is generated by the stator winding currents and rotor magnet field interaction. The torque refers to the amount of torque produced at a speed of 15 rpm of rotation with a load applied. This torque is produced when the AC current is injected into the motor. In this research, the average will be considered. This is due to the torque produced being in a transient mode, not stable; thus, the area under the graph is required in order to estimate the torque of the motor.

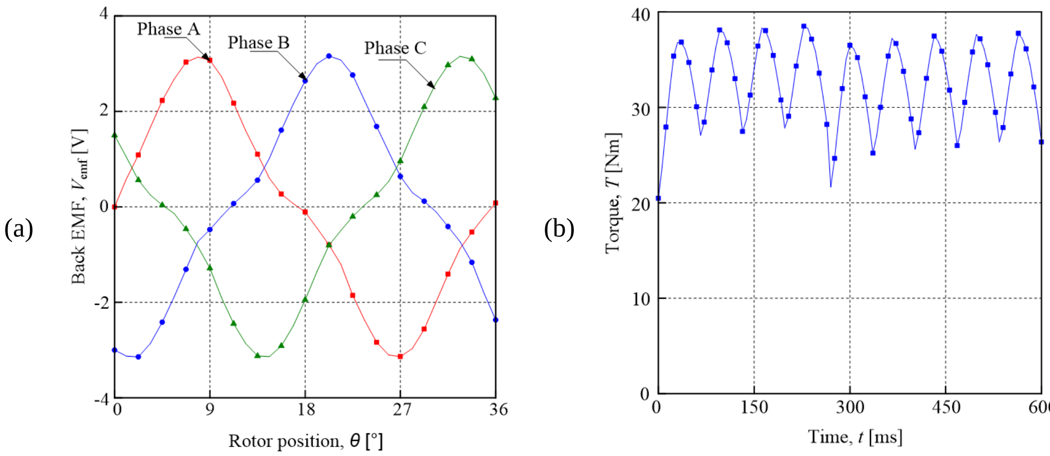


Figure 5. Simulation from FEM: (a) back EMF and (b) torque

Figure 6 shows the simulation result produced for all types of BLDC motors. Figure 6(a) shows the average back EMF produced by BDLC-ERA, BLDC-ERT, BLDC-HR, and BLDC-SR. The highest back EMF is generated by the BLDC-SR motor. It is about 6.5 V at a speed of 30 rpm. Meanwhile, the lowest is 3

V produced by BLDC-HR. It can be seen that the back EMF increases when the speed of the motor increases. The percentage difference between the maximum and the minimum values is about 54%. This is due to flux leakage produced by BLDC-HR being higher compared to others.

The torque produced by the BLDC motor is shown in Figure 6(b). When an injected current of 10 A is applied, the highest torque produced is about 28 Nm, which is generated by BLDC-ERA. The lowest torque is produced by BLDC-HR, which is 15 Nm at 10 A. The percentage difference between the highest and the lowest is about 46%. The torque is directly proportional to the current. When the current is increasing, the torque will increase. The torque for BLDC-SR is slowly dropping because the flux density for the material is almost saturated.

Figure 6(c) shows the torque ripple for all types of BLDC motors. The highest torque ripple is presented by BLDC-SR, and BLDC-ERA produced the lowest torque ripple. The difference between the highest and the lowest is about 4 Nm. The lowest torque ripple in a BLDC motor for residential elevators will provide a smoother, quieter, and more reliable operation. Besides that, when it produces low torque ripple, it will reduce the vibration as well. By minimizing the torque ripple, it will reduce vibrations, which lead to less wear and tear on the elevator components, thereby extending the lifespan of the system.

The efficiency of the BLDC motor is shown in Figure 6(d). The BLDC-ERA shows the highest efficiency, which is about 99.9%. The lowest efficiency is produced by BLDC-ERT. The highest efficiency will the highest energy savings. High-efficiency BLDC motors consume less power, leading to significant energy savings. Other than that, an efficient motor lowers the electricity bills and reduces the overall operating costs of the elevator systems.

Based on the analysis, the BLDC-ERA is chosen for the fabrication process since the torque produced meets the requirement, which is more than 25 Nm. The value of can be higher when the current increases. This is due to when the 10 A is injected into the motor, the flux density does not achieve the saturation level, so it can be injected higher value of current. The back EMF produced is 6 V. Other than that, BLDC-ERA produces lower torque ripple and higher efficiency compared to other types of BLDC motor. This is because the embedded rotor allows for a more optimized magnetic flux path, reducing losses and improving overall efficiency.

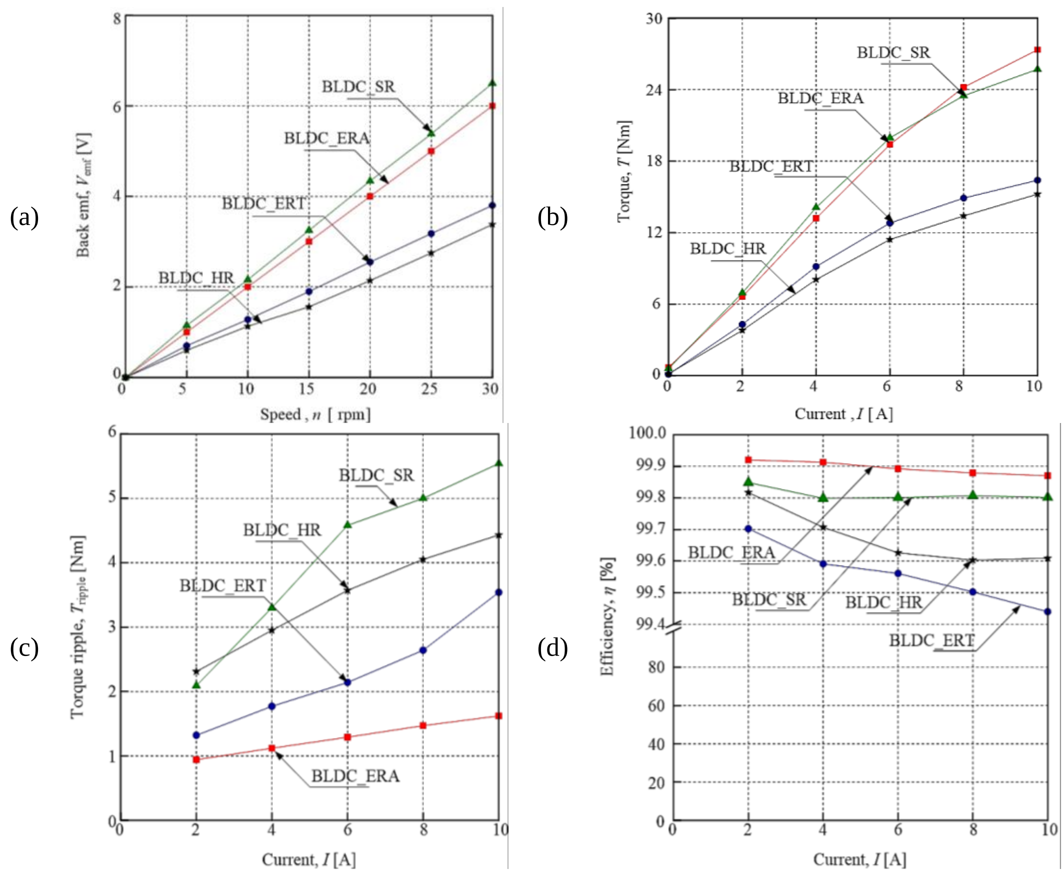


Figure 6. The simulation result of BLDC motor: (a) average back EMF, (b) torque, (c) torque ripple, and (d) efficiency

### 3.2. Performance trade-offs

The performance trade-offs in terms of cost-effectiveness, manufacturing complexity, torque and speed performance for all BLDC motors are shown in Table 3. Based on Table 3, BLDC-ERA will be chosen to undergo the fabrication process since the cost-effectiveness and manufacturing complexity is low but the torque and speed performance are good.

Table 3. Performance trade-offs

| Parameter | BLDC-ERA | BLDC-ERT | BLDC-HR | BLDC-SR |
|---|---|---|---|---|
| Cost-effectiveness | Low | Average | Average | High |
| Manufacturing complexity | Low | Low | Medium | High |
| Torque and speed performance | Good | Average | Poor | Good |

## 4. CONCLUSION

This paper presents a details simulation of four types of BLDC motors with different rotor structures that will be used in a residential elevator application. This BLDC motor had been studied for its performance, including back EMF and electromagnetic torque. The rotor is made up of ferromagnetic and non-ferromagnetic. The BLDC-SR produced the highest back EMF, and the BLDC-ERA produced higher torque. Meanwhile, BLDC-HR has the lowest back EMF and torque. Based on the simulation, the rotor with BLDC-ERA is chosen for further analysis because it is a simple structure to fabricate and easy to assemble. The BLDC-ERA rotor structure had achieved the target specification, which is 25 Nm. This BLDC motor will be used in the application of a residential elevator and will be used as a motor to take up less space.

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This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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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

## DATA AVAILABILITY

Data availability is not applicable to this paper as new data were created or analyzed in this study.

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