Drone Power System Design and Build

Design Document

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Content

1. Introduction

1.1 Problem and Solution Overview

In the realm of large drone development, a significant bottleneck exists in the form of power systems. Currently, there is a dearth of efficient and reliable power systems capable of meeting the high-thrust demands for large drones' takeoff and sustained flight. This shortfall directly impacts the performance of large drones. Drone manufacturers face the risk of power-related failures during flight, which not only compromises the safety of the drones but also leads to increased production costs and potential losses. For end-users in industries such as delivery and surveying, the lack of a suitable power system results in limited flight time, reduced payload capacity, and suboptimal overall performance of large drones, hampering the efficiency and effectiveness of their operations.

To address these issues, our project aims to design and construct an electric power system tailored for large drones. The system is engineered to generate 5 kg of thrust at ground level, effectively resolving the thrust insufficiency problem. It is designed with high-efficiency power conversion components to minimize energy loss, ensuring that the power is utilized optimally during flight. Advanced control algorithms are integrated for real-time power management, enabling the system to adapt to diverse flight conditions, such as varying altitudes, wind speeds, and payloads.

Furthermore, the system is designed with modularity in mind. This modular design allows for easy replacement of components in case of failure or wear and tear, reducing maintenance time and costs. It also facilitates system upgrades, enabling users to keep up with technological advancements and improve the performance of their drones over time. In terms of functionality, the power system will convert electrical energy into mechanical thrust to power the large drone. It will manage power distribution across different components, ensuring a stable voltage supply and maintaining optimal power levels throughout various flight phases.

1.2 High-level requirements list

- Motor control must be able to perform higher than 1000 W(1000W-2000W).
- Motor control device must properly connect with motor and motor should properly connect with propeller.
- Motor should be strong enough to perform at least 3500 RPM
- Propeller should have the capability to provide 5kg thrust.

2 Design

2.1 Block Diagram

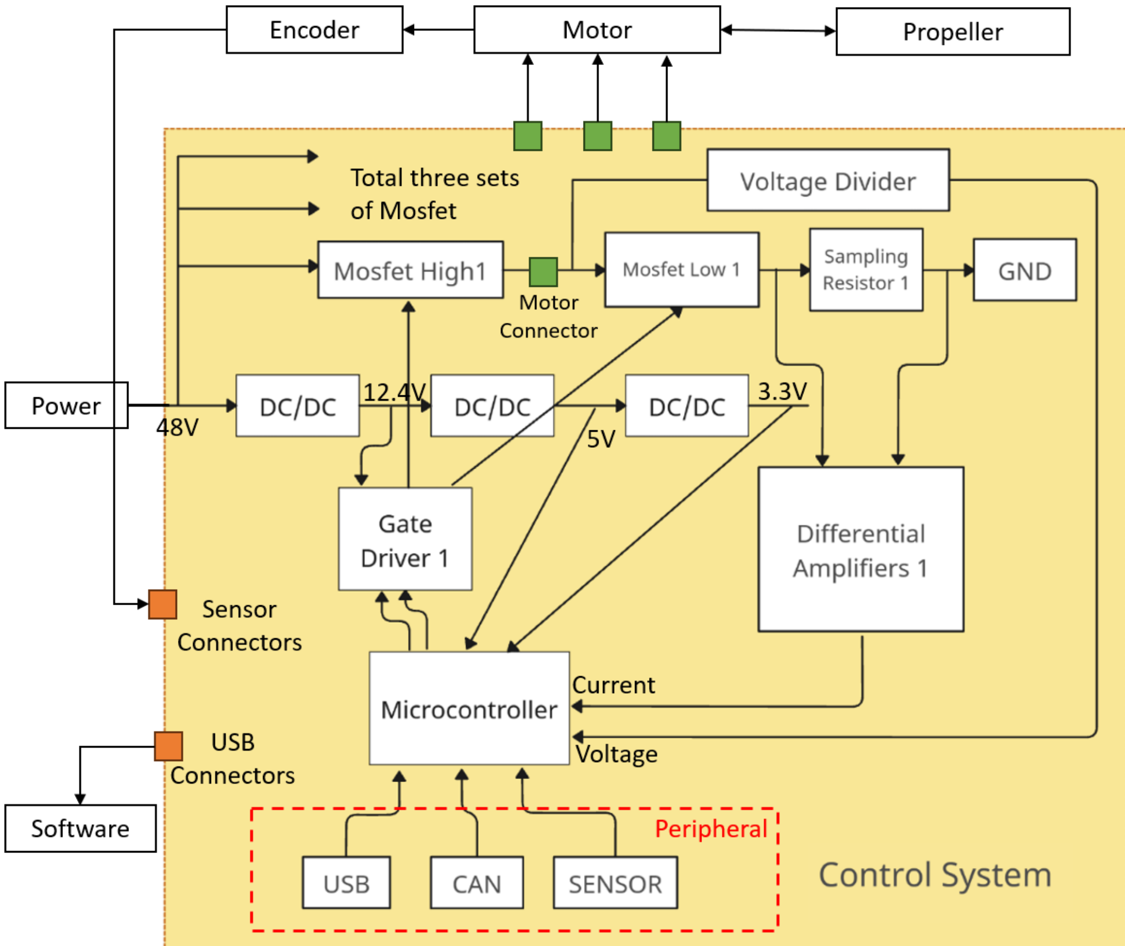

Figure 1: Overview Block Diagram

The block diagram illustrates a comprehensive power management architecture designed to meet the demanding requirements of a drone power system capable of generating up to 5 kg of thrust. At its core, the system begins with a high-voltage 48 V power input, typically sourced from a robust battery pack or dedicated power supply. This high voltage is then intelligently distributed into several voltage levels through multiple DC/DC converters. For instance, stepping down to 12.4 V caters to higher-powered components such as motor drivers and other actuators, while further conversion to 5 V and 3.3 V supplies power to low-voltage electronics including microcontrollers, sensors, and communication modules. Critical elements like voltage dividers are incorporated to precisely monitor and ensure that all voltage rails remain within their optimal operating ranges.

In addition to efficient power conversion and distribution, the diagram emphasizes the integration of closed-loop control systems that are essential for both stability and performance during flight. Feedback signals from various sensors are processed and managed by a central controller, which dynamically adjusts power distribution and modulation signals to the motors. This real-time regulation ensures that the power delivery is both consistent and responsive, even under varying load conditions experienced during flight. Collectively, these design strategies ensure that the system can reliably sustain the power output necessary to achieve the targeted thrust, making it a solid foundation for advanced drone applications.

2.2 Physical Design

The physical design in this project mainly involves the combination of the propeller (rotor) part and the motor part, and determines the application and fixation of the connecting components.

Figure 2: Physical design model diagram

2.3 Motor Control Board Subsystem

2.3.1 Motor Control Board Design General Plan

Controlling high-power motors with a dedicated control board presents several technical challenges. Since our system is designed to deliver 5 kg of thrust and requires over 1500 W of power, issues such as managing high current fluctuations, efficient heat dissipation, and ensuring electrical safety (including proper insulation and electromagnetic interference reduction) become critical. The board must be capable of accurately monitoring current, dynamically responding to load variations, and reliably maintaining performance under rigorous operating conditions.

While there are many available solutions—such as simpleFOC—for motor control, most of these target low-power motors below the 500 W range. Their control algorithms, hardware tolerances, and thermal management strategies are typically insufficient for high-power applications like ours. Consequently, the simpleFOC approach does not meet the demanding requirements of our system.

We decided to adopt the VESC solution for several compelling reasons:

1. **High-Power Capability:** One of the key products in the VESC lineup supports motor control at up to 75 V and 200 A, which directly addresses our requirement for high power handling. This ensures that our power supply demands are met with a reliable and robust control strategy.
2. **Adjustable Firmware Flexibility:** Due to limitations in domestic hardware acquisition, some official products face challenges such as prohibitively high shipping costs or unavailability. VESC's open and adjustable firmware parameters provide the flexibility to select alternative hardware components, enabling us to optimize both system performance and cost-effectiveness.
3. **Mature Interface and Tooling:** VESC offers a well-developed interface along with the official VESC Tool. This free software provides powerful functionality for real-time motor monitoring, parameter adjustment, and fault diagnostics. The mature interface significantly simplifies system integration and upper-level control, making motor operation management more intuitive and reliable.

Based on these advantages, we have designed our control board on the foundation of official VESC hardware [1]. This choice not only meets our high-power requirements but also provides the flexibility and robust interface needed for the long-term success and scalability of our system.

2.3.2 Power Supply management for Control Board

The control board requires different voltages to supply different components. So, in our case we use three sets of DC/DC module to supply 12.4V, 5V, 3.3V voltages to gate drivers and microcontroller pins.

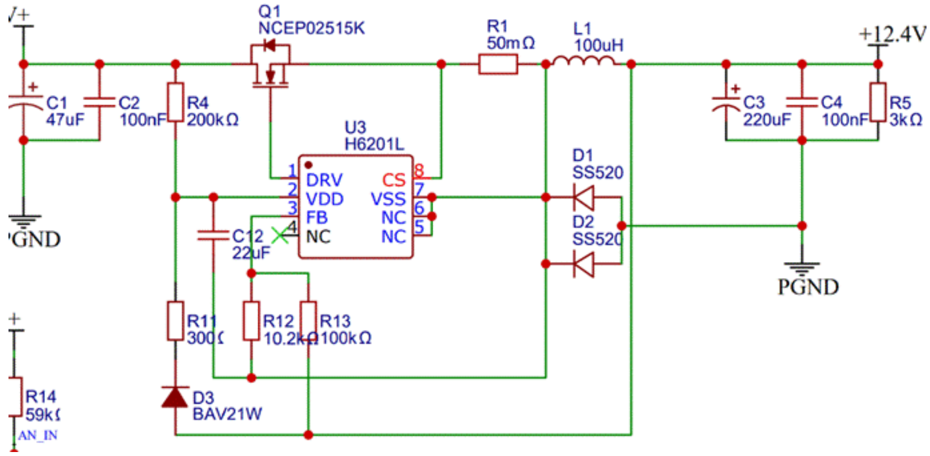

Figure 3: DC/DC component 1

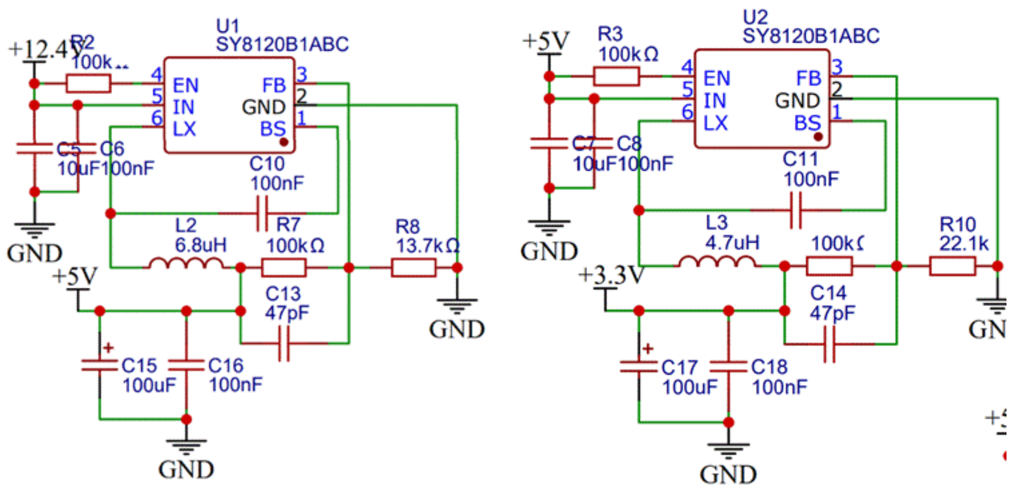

Figure 4: DC/DC component 2&3

The results can be calculated by:

$$Vout1 = 1150mv * (1+R13/R12) = 12.4V,$$

$$Vout2 = 600mv *(1+R7/R8) = 5V,$$

$$Vout3 = 600mv *(1+R9/R10) = 3.3V,$$

Table 1: Drone dynamic configuration

Requirement	Verification
1. First DC/DC outputs 12.4 V	Test the board pins to see if they output the right

2. Second DC/DC outputs 5V 3. Third DC/DC outputs 3.3V	voltage.

2.3.3 Half-Bridge Driving Circuit

We use a half-bridge driving circuit to supply power to the load (motor). For each phase, we parallel two MOSFETs on both the high side and the low side to reduce the current burden on each individual MOSFET. Additionally, we employ a gate driver to control the gate voltage. By utilizing a bootstrap circuit, the high-side Vgs can reach up to Vdd, which is the 12.4 V we obtained from the DC/DC converter in the previous section. Essentially, the gate driver encodes the gate control signals from the microcontroller as follows:

- **Hi_encoded = a * Hi + SH**
- **Lo_encoded = a * Lo**

Table 2: Half-Bridge Driving Circuit

Requirement	Verification
1. Control the mosfet based on gate voltage	1. Give each mosfets a direct gate voltage and observe the current amplitude
2. Mapping the gate voltage from microcontroller signals through gate driver	2. Give a direct Hi and Lo signal by ourselves and see what are Hi_encoded and Lo_encoded.

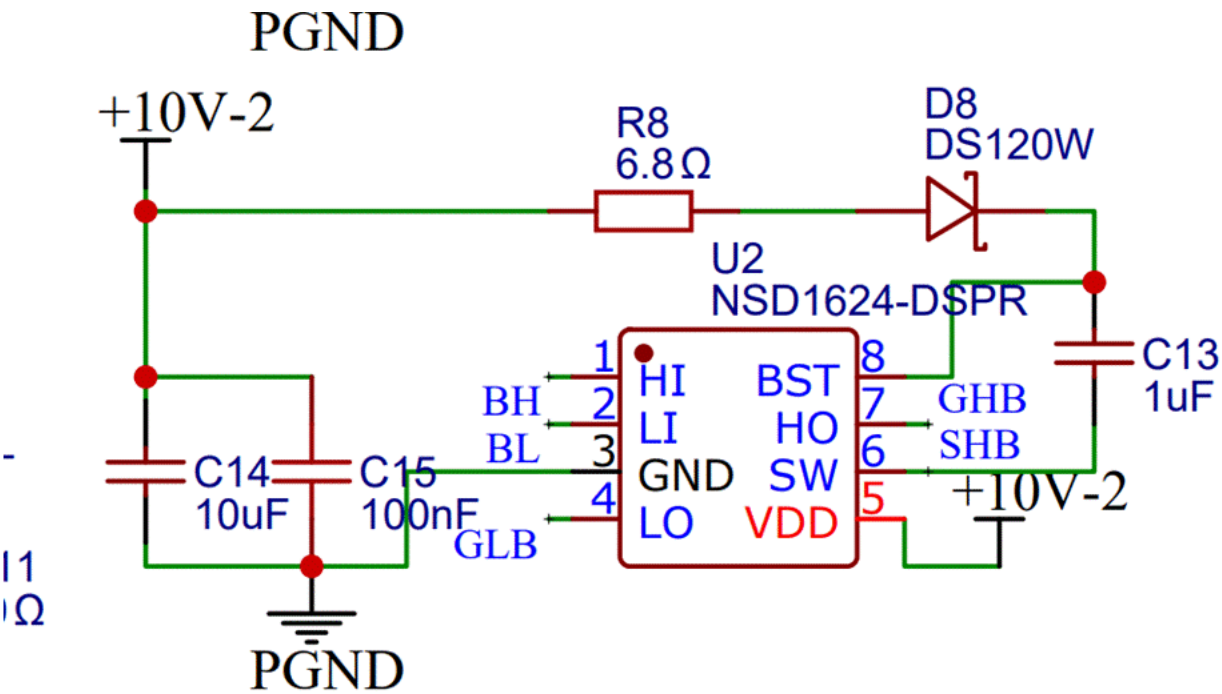

Figure 5: gate driver

2.3.4 Current and voltage feedback

Next, I'll describe the current and voltage feedback mechanisms, starting with current feedback. A sampling resistor is placed at the source of the low-side MOSFET. The two sides of the power supply are connected to the positive and negative inputs of a differential amplifier, thereby amplifying the voltage difference across the sampling resistor. This amplified signal is then fed into the microcontroller.

In addition, the voltage at the source of the high-side MOSFETs is scaled down by a resistor divider network, which reduces the voltage by a predetermined ratio before feeding this signal into the microcontroller. By fine-tuning the value of the sampling resistor, adjusting the gain of the amplifier, and modifying the resistor values in the voltage divider within the firmware, these signals can be accurately decoded by the microcontroller. This process forms a closed-loop control system that ensures proper feedback for both current and voltage measurements.

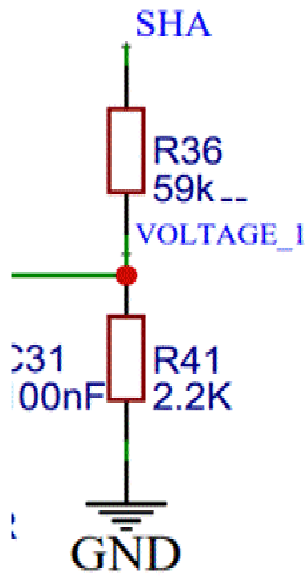

Figure 6: voltage divider

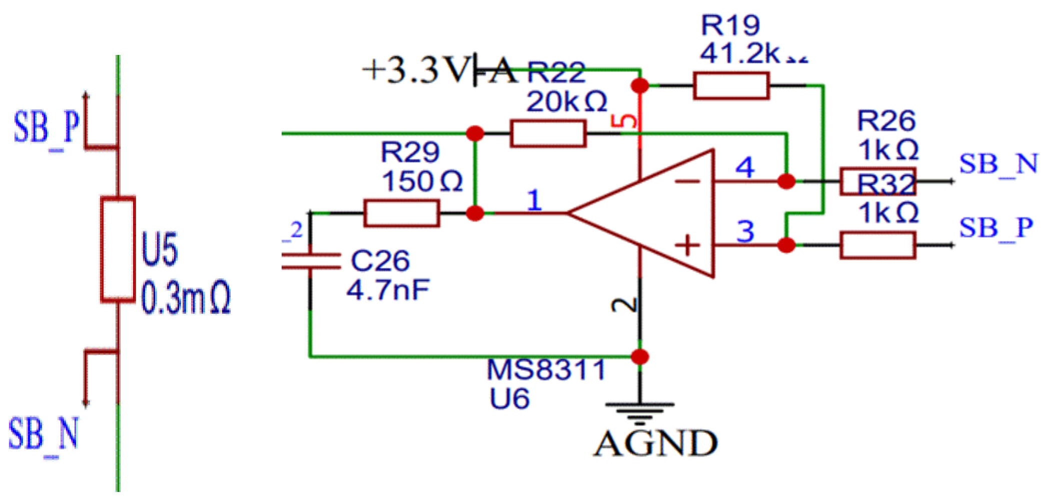

Figure 7: Sampling resistor and differential amplifier

Calculation for the amplifier

V4 = (Vout - SP_N)*(1/20.15) + SB_N;

V3 = (3.3 – SB_P)*(1/41.2) + SB_P

V4 = V3 => delta(SB_P – SB_N)*20.15 = delta(Vout)

```
//The voltage dividing acquisition circuit on the Makerbase VESC motherboard is 560K and 21.5K resistors.
#ifndef VIN_R1
#define VIN_R1                  560000.0        makerbase-motor, 17 months ago • Add files via upload
#endif
#ifndef VIN_R2
#define VIN_R2                  21500.0
#endif

#ifndef CURRENT_AMP_GAIN
#define CURRENT_AMP_GAIN        20.0
#endif
#ifndef CURRENT_SHUNT_RES
#define CURRENT_SHUNT_RES       (0.0005 / 3.0)
#endif
```

Figure8: Interface for firmware modification

Table 3: Voltage and current feedback

Requirement	Verification
1. Successfully output current signal	1. See if delta(V_amplified)/delta(V_sampling_res) = 20
2. Successfully output voltage signal	2. Should work correctly because it is simple circuit.

2.3.5 Microcontroller and peripheral

Microcontroller pins are already defined in VESC official documents and as well as HALL sensor, USB and CAN, so we can directly use them.

Table 4: Microcontroller and peripheral

Requirement	Verification
1. Successfully initialized	1. Observe if all the pins have correct voltage, if

	we can successfully download the firmware and communicate through CAN in VESC tool

2.4 Motor Subsystem

Figure 9: Motor Components Model

2.4.1 Electromagnetic Core and Wiring

The electromagnetic core is based on a 36-slot stator and 40-pole rotor configuration, selected to ensure high torque density and smooth torque output, suitable for drone propulsion applications. According to the design in Motor-CAD, the stator has a diameter of 83 mm, a slot depth of 10 mm, and a slot shoulder height of 30 mm, optimizing space for windings. The rotor integrates N52-grade NdFeB magnets [2], each 3 mm thick and extending across a 140° arc, delivering strong, uniform magnetic fields. The air gap is set to 1 mm, and the shaft diameter is 54 mm, balancing torque output, mechanical strength, and magnetic efficiency. The windings use AWG 23 copper wire, arranged in 3 strands with 8 turns per phase, supporting up to 68 A current, while minimizing thermal rise and power loss. The motor is expected to deliver at least 6.5 Nm torque, with an efficiency ≥ 80%, and a maximum speed above 3500 rpm.

To determine the required torque capability, the torque output is estimated using the average torque equation of surface-mounted PMSMs Which is ideally ≥6.5 Nm torque to be feasible with margin:

$$T_{\text{avg}} = \frac{3}{2} \cdot \frac{P}{2} \cdot \psi_m \cdot I_q$$

For electrical design, AWG 23 copper wires (diameter ≈ 0.573 mm) are selected. The winding uses 8 turns per phase with 3 strands in parallel, reducing the effective resistance and enhancing current capacity. The equivalent wire area is:

$$A_{\text{eff}} = 3 \cdot \pi \left(\frac{0.573}{2}\right)^2 \approx 0.775 \text{ mm}^2$$

Assuming copper resistivity $\rho = 1.68 \times 10^{-8}\ \Omega \cdot \text{m}$, and effective winding length per phase of $l \approx$ 1.2 m, the total resistance per phase is:

$$R = \frac{\rho \cdot l}{A_{\text{eff}}} \approx \frac{1.68 \times 10^{-8} \cdot 1.2}{0.775 \times 10^{-6}} \approx 0.026\ \Omega$$

Then we can use the following equation to measure the cu loss

$$P_{\text{cu}} = I^2 \cdot R$$

Given the rated power of around 2000 W, the copper loss should be verified well below 10%, satisfying the thermal efficiency constraint.

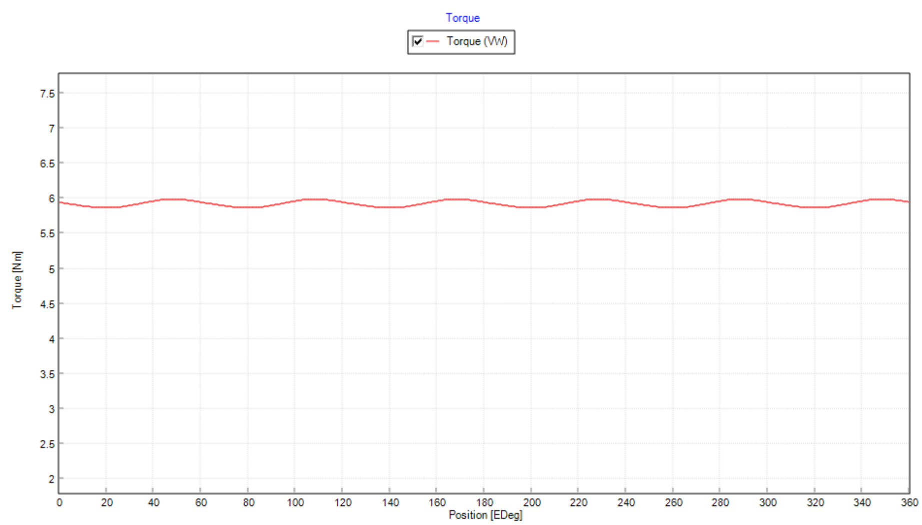

Figure 10: E-magnetic simulation of Torque

Table 5: Electromagnetic Core and Wiring Requirements and Verifications

Requirement	Verification
1. The motor must generate ≥6.5 Nm torque, with efficiency ≥ 80%, and maximum speed > 3500 rpm. 2. The stator and rotor must be configured as 36-slot / 40-pole, with dimensions: stator diameter 83 mm, rotor diameter 54 mm, slot depth 10 mm, air gap 1 mm. 3. Windings must be 8 turns/phase, 3 strands of AWG 23 copper, supporting 68 A current, with copper loss < 10% and wire temperature < 80°C.	1. a. Mount motor on a dynamometer system. b. Power with 48V from the control board and apply 42 A load. c. Record torque, speed, and compute efficiency. d. Verify speed stability above 3500 rpm. 2. a. Inspect physical structure or cross-sectional CAD model. b. Confirm dimensions using calipers and 3D measurement tools. c. Validate 36N40P topology via tooth and magnet count. 3. a. Power windings with 42 A current for 5 minutes. b. Monitor coil surface temperature using thermocouple or IR camera. c. Measure resistance and calculate $P_{cu} = I^2R$; verify it is below 10% of rated power. d. Confirm temperature < 80°C.

2.4.2 Housing and Bearing

The motor housing is made of finned aluminum alloy, designed for effective thermal dissipation and structural integrity. It ensures passive cooling during continuous operation, keeping motor surface temperatures below 80°C. The 6205 angular contact bearings are used to support high-speed rotation with low noise and minimal wear. The full motor assembly is kept under 2 kg, meeting airborne system weight constraints. The housing must also withstand mechanical shock and vibration during takeoff, flight, and landing phases in aerial vehicles.

The steady-state heat transfer from the winding to the environment is modeled using Newton's law of cooling:

$$Q = h \cdot A \cdot (T_{\text{coil}} - T_{\text{amb}}) = h \cdot A \cdot \Delta T$$

This implies that forced convection or fin optimization is necessary to keep the system under thermal limits, which is achieved through the fin design shown in CAD. Mechanically, the housing must maintain a total weight under 2 kg, which can be verified via CAD model BOM weight analysis.

Table 6: Housing and Bearing Requirements and Verifications

Requirement	Verification
1. The housing must maintain **< 80°C** during full-load continuous operation. 2. The structure must keep the total motor weight **under 2 kg** and withstand vibration and shock loads. 3. The **6205 bearings** must sustain **3500+ rpm** with minimal friction and no visible damage after extended use.	1. a. Affix thermal sensors at casing hotspots. b. Run the motor at rated torque and current for 30–60 minutes in enclosed chamber. c. Log temperature data and verify it remains below 80°C. 2. a. Use a precision scale to measure the motor mass. b. Conduct mechanical durability testing (e.g., ISO 16750-3 vibration, IEC 60068 drop test). c. Inspect the housing and mounting points for cracks, deformation, or loosening. 3. a. Operate motor continuously at 3500 rpm for 6 hours. b. Record bearing temperature and noise

	levels. c. After disassembly, visually inspect bearings under microscope for pitting or wear.

2.5 Propeller Subsystem

In our project, the propeller subsystem is required to provide a pulling force of at least 5 kg. The design, modeling, and manufacturing of the propeller will be carried out by our group independently. The propeller needs to be well - adapted to the motor system to achieve high efficiency. The propeller subsystem consists of blades and blade clamps. The propeller part serves as the output component of the motor system.

2.5.1 Blades design and manufacture

Our propeller blades were modeled in Autodesk Fusion 360. Aerodynamic simulations and static structural analyses were conducted using Ansys. A prototype was manufactured using the vacuum-assisted resin infusion technique for testing. After the fracture test, the design was finalized and the finished products were manufactured.

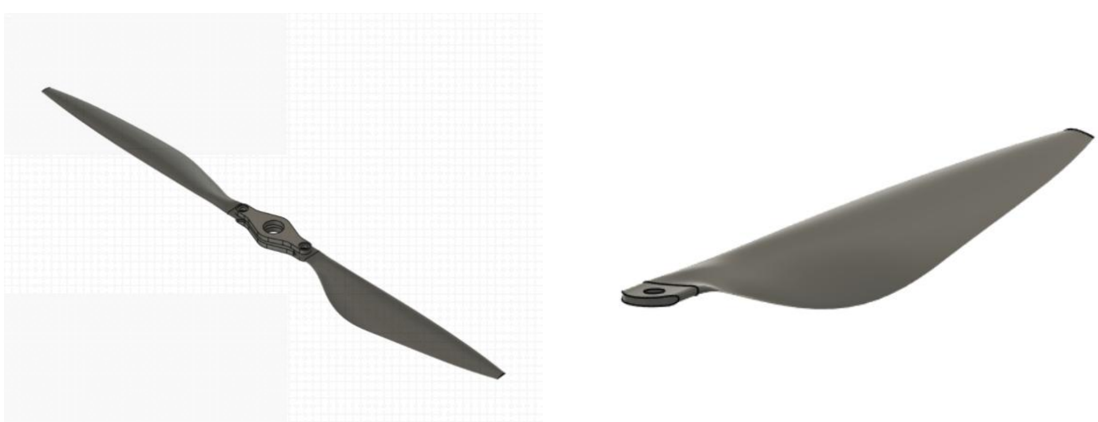

Figure 11: Rotor Blade

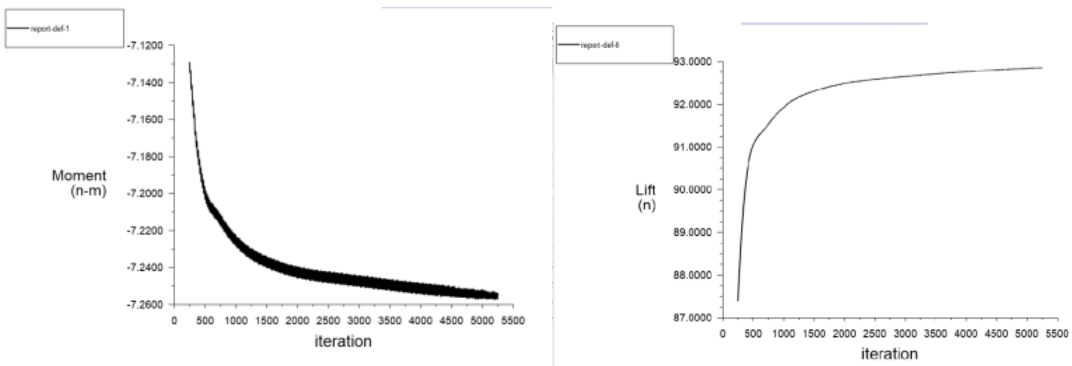

Figure 12: Rotor Simulation

Table 7: Blades Requirements and Verifications

Requirement	Verification
1. Provide a thrust of at least 5 kg.	1. a. Use the Ansys Fluent simulation software to conduct aerodynamic simulations on the rotor model and obtain approximate thrust data. b. Use a force sensor to measure the thrust of the rotor at 3500 rpm.
2. At 3500 revolutions per minute (rpm), it has sufficient structural strength to withstand the centrifugal force.	2. a. Use Ansys to conduct a static structural analysis of the rotor model b. Compare the simulation results with the results of the breaking tensile test.
3. Have high aerodynamic efficiency.	3. a. Post - process the flow field simulation results in Ansys to obtain the aerodynamic efficiency of the propeller.

	b. Conduct physical experiments to obtain the working efficiency of the rotor.

2.5.2 Propeller blade clamp

In order to make the propeller more suitable for manufacturing by the vacuum-assisted resin infusion technique, we designed only a single rotor blade when making the mold. After manufacturing two rotor blades, we used a propeller clamp to connect them. The propeller clamp is made of aluminum alloy material.

Table 8: Propeller blade clamp Requirements and Verifications

Requirement	Verification
1. have sufficient structural strength	1. verified through actual experimental tests

2.6 Tolerance Analysis

This tolerance analysis focuses on evaluating the influence of component tolerances on the overall performance of the drone power system. It encompasses all key components such as the rotor, motor (including its electromagnetic core, housing, and bearing), and the motor control system (comprising the control device, PCB board, and hall sensor), along with their connections. For the rotor, manufactured via the hot carbon fiber press technique, dimensional tolerances like a ±0.5 mm variation in blade diameter can affect thrust and power consumption; a larger diameter may boost thrust but also increase drag, while a smaller one could reduce thrust. Fiber alignment tolerances of ±1° can weaken the rotor's mechanical properties, leading to more vibration and reduced ability to endure aerodynamic forces, thus affecting drone stability.

In the motor's electromagnetic core, the 18 - slot Si - steel stator and 22 - pole N52 NdFeB magnets with AWG 23 copper windings in a 3 - phase configuration have tolerances. The diameter of the core having a tolerance of ±0.2 mm might alter the magnetic field distribution, which could impact the motor's torque and efficiency. If the diameter is too large or small, it may cause magnetic flux leakage or reduced magnetic coupling, respectively. The number of windings turns could have a tolerance of ±1 turn per phase, which would change the resistance and inductance of the windings. This, in turn, can affect the current flowing through the windings, potentially leading to a 5 - 10% change in motor efficiency and torque output.

The aluminum finned housing and 6205 angular contact bearing of the motor also have tolerances. The housing's thickness tolerance of ±0.1 mm can impact its heat - dissipating ability; a thinner housing may not effectively dissipate heat, causing the motor temperature to rise above the 80°C limit, while a thicker one may add unnecessary weight. The bearing's inner and outer diameter tolerances of ±0.01 mm can affect the smoothness of rotation. If the tolerances are not within the specified range, it may lead to increased friction, higher wear, and a reduction in the maximum rotational speed, which could limit the motor's performance.

For the motor control system, the PCB board's component placement tolerances are significant. Resistors and capacitors on the PCB may have a tolerance of ±5% in their values. This can affect the control signals sent to the motor, potentially causing inaccuracies in the motor's RPM control. The connection between the control device and the PCB, as well as the connection with the hall sensor, has a tolerance in terms of electrical conductivity. A resistance increase of ±0.1 Ω in these connections can lead to signal attenuation, resulting in a delay or error in the feedback loop for motor speed control.

In summary, component tolerances in the drone power system can have a significant impact on its performance. By carefully controlling these tolerances during the manufacturing process and selecting components with appropriate precision, we can ensure that the power system meets its design requirements for thrust generation, motor efficiency, rotational speed, and electrical performance, and functions reliably in various operating conditions.

3. Cost and Schedule

3.1 Cost Analysis

Table 9: Components Cost

Part#	Name	Description	Manufacturer	Quantity	Cost

1	BOM	All components for motor control board	Etc.	1	$60
2	Housing and bearing Customization	Including the rotor, magnets, bearing, shaft and so on	Tianyi Model online shop	/	$20
3	Stator customization	Including Stator and copper wire purchase, Stator winding fee	Tianyi Model online shop	/	$25
4	Carbon fiber prepreg	High - strength carbon fiber prepreg	DaXing shop	/	$50
5	Photocurable printing materials	Light - curable printing resin	DaXing shop	/	$40
6	Vacuum bag	Vacuum - sealing bag, to reshape the carbon fiber	DaXing shop	10	$2
7	Breathable fabric	Air - permeable fabric	Laboratory	/	$2
8	Total	/	/	/	$199

3.2 Schedule

Table 10: Detailed Schedule Table

Week	Task	Responsibility
	Schematic of motor design	Zhuoyang
	Rotor design and simulation	Bingye

Before	Stator and rotor design	Yuyang
	Rotor manufacture	Zikang
4/14	**Design Document Due**	**All**
	Board build.	Zhuoyang
	Test ultimate stress of rotor prototype	Bingye
	E-magnetic simulation	Yuyang
	Prototype build	Zikang
4/21	Board testing	Zhuoyang
	Test new prototypes	Bingye
	Housing and bearing design	Yuyang
	Prototype improve	Zikang
4/28	Board testing	Zhuoyang
	Try to improve rotor manufacturing process	Bingye
	Thermal simulation	Yuyang
	Prototype test	Zikang
5/5	Board testing complete.	Zhuoyang
	Finish rotor manufacturing	Bingye
	Motor components customization and production. Assemble all the components.	Yuyang
	Test done	Zikang
5/12	Fully control the motor	Zhuoyang
	Combine rotor part with motor	Bingye, Zikang
	Combine motor, propeller and the control board together and do mock test	Yuyang
	Mock Demo	**All**
	Ready	Zhuoyang

5/19	Get rotor subsystem ready	Bingye,Zikang
	Get motor ready	Yuyang
5/26	Algorithm optimization aiming at comprehensive safety.	Zhuoyang
	Test on stability of the rotor and improve it	Bingye, Zikang
	Start the draft of final report and debugging.	Yuyang
5/27	**Final Demo & Final Report**	**All**

4. Discussion of Ethics and Safety

4.1 High Voltage Safety

The drone power system employs high voltage to enhance efficiency, but it also introduces significant hazards such as electric shock, arc flash, and component failure due to excessive heat. To mitigate these risks, it is imperative to ensure proper insulation and maintain adequate physical separation of all high-voltage components. Overcurrent and overvoltage protection devices—such as fuses, circuit breakers, or electronic protection circuits—should be incorporated into the design. Additionally, emergency shutoff mechanisms must be installed to rapidly disconnect the high voltage during fault conditions, thus safeguarding both personnel and equipment [3].

4.2 Rotor Safety

Rotor blades endure substantial mechanical stresses during operation and can be subject to catastrophic failure under extreme conditions such as collisions, material fatigue, or manufacturing defects. To address these concerns, rotors should be constructed from high-strength, fatigue-resistant materials, and robust design practices—including structural reinforcement and redundancy—must be applied to minimize the risk of breakage. Regular inspection and maintenance are vital to detect early signs of degradation, ensuring that any potential failure does not lead to loss of control or collateral damage.

4.3 Motor Safety

Motors operating under high loads or experiencing mechanical shock may suffer internal component failures or, in the worst-case scenario, complete disintegration. To prevent such outcomes, redundant motor designs should be considered, ensuring that the failure of one motor does not compromise the overall system functionality. Effective thermal management systems, such as heat sinks or active cooling techniques, are necessary to keep motors within their safe operating temperatures. Real-time fault detection and monitoring using sensors for current, temperature, and vibration should be implemented to trigger protective actions, such as controlled shutdowns or power cutoffs, upon detecting abnormal behavior.

4.4 Integrated Safety Measures

For enhanced overall safety, electrical and mechanical isolation must be enforced. High-voltage circuits should be isolated [4], and critical mechanical components (like rotors and motors) must be adequately shielded to contain debris in the event of failure. Continuous monitoring of current and voltage through feedback circuits is essential; these signals are fed back to the onboard microcontroller, allowing for closed-loop control and timely execution of emergency protocols. The integration of these measures enables the system to dynamically respond to potentially hazardous conditions.

4.5 Training and Maintenance

Ensuring the safe operation of the drone power system also relies on comprehensive training for all personnel involved. Operators must be well-versed in high-voltage safety practices, emergency response procedures, and standard operational protocols. In addition, a rigorous maintenance schedule is critical. Regular inspections should be performed on all high-voltage components, rotor assemblies, and motors to confirm that safety measures are intact and functioning properly. This proactive approach to maintenance and training is fundamental to preventing accidents and ensuring long-term system reliability.

References

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