Electronic Speed Controllers: A Review

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*Abstract***— Drones have recently gained popularity as a function of its use in delivery, surveillance, photography, and military applications. In these applications, stability and a longer flight time for single charge are required. Because of its small size and great efficiency, BLDC motors are used in UAV applications. Controlling the speed of a BLDC motor requires the use of speed controllers. ESCs have grown in popularity as drones demand constant and rapid speed updates. The effectiveness of these speed controllers is critical since they influence flight duration and stability. This paper provides a comprehensive overview of electronic speed controllers (ESCs) employed in drone applications, as well as the various advanced control algorithms that can be employed to regulate them.**

Keywords— ESC, BLDC, FOC, Speed control, UAV, Drones.

I. INTRODUCTION

The efficiency and torque of the motor have led to significant growth of advancements in power electronics and the usage of permanent magnets in the motors, which has added to the benefit of the motor being lightweight. It has been employed in drone applications because of this advantage. ESCs (Electronic Speed Controllers) are used to control the motor's speed by converting the DC input voltage from the batteries to a three- phase trapezoidal wave for the motor. In the aspect of the use of unmanned aerial vehicles (UAVs). The speed of the motor is regulated by ESCs based on the user's throttle input. The speed of the motor is controlled by ESCs using a variety of control approaches. Field oriented control (FOC), also known as vector control, is one of the most effective techniques. This method involves modulating the current and voltage vectors to regulate the motor speed and torque. It uses the Clarke and Park transform to convert the sinusoidal current and voltage vectors of the motor to DQ axes. Since it is a sensorless control of the motor it reduces the weight of sensors adding on to less weight resulting in longer flight times.

II. LITERATURE REVIEW

Xin Xue[1] has proposed a thesis on three different algorithms (FOC, Sensor less, Sensored) for speed control of BLDC motor using 32-bit arm cortex microcontroller and compared the power quality based on different parameters like modulation period, Power supply voltage and clock frequency of microcontroller. From the outcomes of the experiment conducted the author came out with few results. The power quality of FOC is better compared to others at low-speed operations. At higher speed due to limitation in calculation of MCU, FOC has less power quality compared to other two. Shorter the modulation period better is the power quality. MCUs supply voltage and frequency does not affect the power quality, so lower voltage and CPU frequency to enhance the power efficiency and quality. This paper provides an overview to select different algorithm for different application.

Clayton R. Green, Robert A. McDonald[2] have proposed a methodology to test the efficiency of electronic speed controllers for BLDC motors. No complete(encompassing) model available as there are too many varying quantities. In order to model a better system each element (parameter) should be individually modelled and combined together. There are lot more advancements in battery technology. To validate the efficiency of ESC we require data, but there are only few data available on esc efficiency. The data available has more restrictions (the esc efficiency was taken from the overall efficiency by assuming a simple motor). The lack of data lead author into designing instrumentation capable of measuring input and output of esc so the efficiency can be calculated. Input power was calculated using current sensing resistor multiplied by its voltage. The output power was difficult to measure as it was 3-phase trapezoidal wave with a switching frequency of 8 to 32 KHz. It was measured using 2 voltmeters and ammeters. A current sense resistor was used along all three phases for balance. This model had many limitations. The sampling rate needed to be high enough to follow Nyquist frequency. The data acquisition system would only measure ± 10 volts. This imposed a limitation on input voltage.

Andrew Gong, Rens MacNeill, and Dries Verstraete[3] devised a method for assessing and testing the performance of a motor and electronic speed controller. The building of performance models for each component enables the ability to forecast the entire performance of the motor and ESCs under any operating conditions. The suggested approach uses a wide range of rotational speeds, torque values, and voltages as inputs to generate the performance map. Variations in input voltage cause changes in full throttle motor torque and rotational speeds, which are then used to compute motor efficiency (the ratio of electrical power at the input to mechanical power at the output). Faisal Amin, Erwan Bin Sulaiman, Wahyu Mulyo Utomo, Hassan Ali Soomro, Mahyuzie Jenal, and Rajesh Kumar devised a model based on electronic components instead of mathematical blocks, resulting in more realistic and accurate simulation results. They look at the PMSM's dc equivalent circuit, which is a good technique to implement FOC. The current, speed, and torque response for varied speed and torque are all acquired, and the study is extremely beneficial. The fact that speed is unaffected by rapid changes in load is an important conclusion.

Meghana N Gujjar and Pradeep Kumar[4] have proposed a MATLAB or Simulink-based comparative performance analysis of foc using spwm and svpwm. We can deduct from the simulation results that the model that uses the SVPWM technique has enhanced system performance, draws less current for motor operation, has a smooth speed response and reduced torque ripple, and is also better at utilizing bus voltage. This paper gives an overview of space vector pulse width modulation and how it differs from sinusoidal pulse width modulation in terms of field-oriented control implementation.

Kristen N Mogensen[5] focuses on the consideration of electronic speed control used in drones and provided a clear picture of the steps to be followed for motor selection. The design considerations in this paper are particularly limited for the brushless motors used in medium-sized drones. The ESC consists of a power section, a current sensor, a microcontroller and a communication interface for the flight controller. The motor selection is mainly decided keeping the motors control algorithm in mind and is selected as trapezoidal or FOC. The author has also done a comparison of the Pulse Width Modulation methods. Suitable graphs have been drawn to convert from optimal PWM to sinusoidal phase voltage and optimal PWM to form trapezoidal commutation generation in trapezoidal control. The flight ability of the drone also depends on the type of algorithm used. The desired value of frequency of pulse width modulation ranges from 30kHz to 60 kHz. This is important as the performance of ESC mainly depends on this and had to be ensured whether the chosen values of frequencies are correct. The efficiency of the open loop system may be low compared to the closed loop system because in the open loop system the control signal is taken and it is assumed that the captured signal may be correct but the signal may not be. So, the current more than the desired value is taken to run the motor. In the case of a closed-loop control system, the system is capable of deciding the motor is functioning correctly or not. In a closed-loop control system, the measured values of current and voltages are taken so that they can be considered as feedback signals.

Jalu A. Prakosa, Dmitry V. Samokhvalov, Gabino R. V. Ponce, Fuad Sh. Al-Mahturi[6] have proposed a result analysis for brushless DC motor speed regulation in quadcopters. Because the frequency of switching current is exactly related to speed, they employed a six-step commutation technique to control the motor's speed. We can deduct from the findings that the relationship between motor speed and duty cycle varies from linear to proportional, with faster speed implying a bigger duty cycle. Due to the microcontroller's time constant, the PWM duty cycle is not linear to motor speed. Increased PWM Duty Cycle can enhance motor speed; nonetheless, the authors believe that faster microcontrollers and advanced optical sensors are required to improve speed control.

Bum-Su Jun, Yoon-Sang Kook, Joon-Sung Park and Chung- Yuen Won [8]have developed a model in electronic speed control (ESC) for drone application. They have used sensorless speed control by slide mode observer technique to command the speed of the motor. They have simulated and experimentally tested a PMSM motor from the output obtained for both the test it can be deduced that there was no deviation from simulated value and experimental value. They have used a NTC inside a motor to measure the exact temperature. The author furthermore states that the efficiency and stability of the drone can be improved by enhancing the electronic speed controller with failure function which will measure the temperature of the stator in real time. This paper gives an overview of testing the motor and its outcomes with respect to efficiency of motor and ESC.

Joseph P John,Dr S Suresh Kumar and Jaya B[9] focuses on different aspects of Space Vector-based FOC. They give a detailed explanation of space vector pulse width modulation. The paper mainly deals with the controlling of the motor in two quadrature axis is dq axis. In a field-oriented control technique, the motor is mainly controlled in the direct quadrature axis. Space vector Modulated Pulse is also generated along with this for driving the brushless DC motor which helps in improving the efficiency and improving the performance of the system. This paper mainly focuses on the advantages of bldc Motors over brushed DC Motors. In field- oriented control the currents and the voltages are within the dq system of the motor which means that the current should be remodeled from the 3-phase stationary reference frame to the 2-axis rotating dq frames. In the similar way the voltages are transformed from the 2 axis dq reference frame to the 3- phase reference frame. The stator windings are moved from the stator's stationary frame to the rotor 's revolving frame.

Andrew Gong and Dries Verstraete[10] has done the experiments for testing of Electronic Speed Controllers for UAVs (Unmanned Aerial Vehicles). The performance data of the electronic speed controllers are insufficient. After testing is done, models are derived to know the efficiency and the working of controllers in different circumstances. An empirical model based on some of the physical losses that occur is described in the paper to allow prediction and simulation of the performance of ESCs. ESC efficiency maps were drawn in order to analyze the working under different operating conditions. they help in modeling the performance of the controllers for various input voltages and for different values of output power. An overview is done based on the testing done, as well as outputs describing the input voltage effect, input current and power output from the efficiency of ESCs. In this paper, a reduced-order for ESC efficiency is introduced to allow for more accurate modeling and predictability of ESCs efficiency.

Aidan McCoy[11] has developed a comparative performance analysis to test different startup and control strategies to drive the brushless DC motors. Due to their numerous advantages, brushless DC motors have become a frequent component of electronic applications in our era. Every motor in a drone application need more than just power; each one also requires its own ESC. The ESC is in charge of receiving a signal indicating what speed/torque the motor should operate at. The current flow to the motor is then controlled to maintain it spinning while staying within these limits. There are a variety of control strategies available, each with its own set of disadvantages and benefits. Dynamic starter strategies, as well as six-step and field-oriented motor control systems, are the focus of this work. Permanent magnets are used on the rotors of BLDC motors, and MOSFETs control the electromagnetic windings to align the magnetic field. A commutation is a breakdown of this sequence into six different possible outcomes. One pole with + Vcc, one with -Vcc, and one off are required for each commutation. This allows for the development of a magnetic field that pulls the motor in one direction. This study is on motor control for drones, with a focus on systems that employ PWM for power and speed communication. PWM solves the problem of transferring a continuous stream of the percentage of available voltage to use to operate the motor. PWMs with a very high frequency can very precisely capture this data. The accuracy required while maintaining the data flow constantly updating is retained by keeping it digital until the very last step, because drone motors constantly change speeds to suit inputs and changing situations, this is critical. According to the theory used in this work, the 6 step BLDC motor control, the motor rotates and the magnets travelling across the coils produce a voltage that can be measured. Fixed startup, as previously mentioned, is easier to implement because it just repeats a startup script until the motor delivers readable feedback, Dynamic startup, on the other hand, allows for a more controlled and speedier startup with fewer resets. Field oriented control provides the most control once the motor has started rotating. A combination of planned startup scripts and field-oriented control is the optimum control technique for drone applications, since it combines complexity with more control.

Young Tae Shin and Ying-Khai Teh [12] have concentrated mainly on power consumption statistics of drones, since drones in the present era have been manned with high resolution cameras, gps sensors and various other applications. The addition of these applications on the drone have not only helped the drone's field of work range, but has also increased the power consumption of the drone. This has become a challenge to reduce the power consumption by checking and optimizing the battery of the drone with various new methods. This research focuses on power electronics design difficulties, with a particular emphasis on the drone's most power-hungry electronic module, the electronic speed controller (ESC). Silicon-based Insulated Gate Bipolar Transistor (Si-IGBT), a new wide-bandgap semiconductor device, is being developed using cutting-edge Silicon-based Insulated Gate Bipolar Transistor technology (Si-IGBT). On the 3-phase motor driver, models of silicon carbide (SiC) and gallium nitride (GaN) power transistors, power loss, and flight time estimation are computed and compared. The power transistors that implement the ESC switches are a crucial component that leads to power loss. In this research, multiple power transistor technologies (Si-IGBT, SiC, and GaN) will be examined with the purpose of optimising flight time. The voltage step-down is performed by dividing the voltage from the main Lipo to 5V using a variable resistor divider. Excess voltage (power) is converted into heat when voltage division is done with resistive elements. An overheated BEC causes thermal shutdown, resulting in devastating implications for the drone. The built-in charge pump supports the high-side FET, while the built-in linear regulator supports the low-side FET, which, like the system linear BEC scenario, has low power efficiency.When possible, the low side FET should be powered by a switching voltage regulator to improve power efficiency even more. When a power FET is turned on, it becomes a resistive element with a resistance value known as RON.

Dávid Rau, Jozef Rodina, Lukáš Palkovič and Peter Hubinský[13] have developed a model to optimise the propulsion system of micro aerial vehicles (MAVs) in order to obtain longer flying endurance. An MAV is made up of a propeller BLDC (brushless DC) motor, motor controller, and battery (often Lithium based chemistry). The main goal of this study is to improve the motor control component. The synthesis of a BLDC controller employing a field-oriented control approach is proposed in this paper, which offers increased performance in the propulsion system's dynamical response, lower power consumption, and overall higher efficiency. Because it is significantly more efficient, the FOC technique was chosen. This research presents a Using MATLAB SimPowerSystems, create a FOC controller for BLDC motors. The motor operating mode is determined by using zero or positive values of the output torque given to the model. The back emf output must be set to a trapezoidal output in order to build a nonlinear model that matches the real BLDC motor. FOC control has a better dynamics behaviour pattern when the needed speed values are followed, which is practically identical to FOC control speed values. Torque is not as stable as with FOC control during operation, but it is contained. The hardware format is the second factor that contributes to reduced efficacy. When compared to FOC control, it is a multiple of the number of transistors flipping. The goal of this research was to develop a sensor-free vector FOC BLDC motor. The Park and Clark transformations were used to apply the current and speed loops to the control. They were able to uncover viable options for predicting the rotor's position and speed after obtaining a MATLAB simulation model and evaluating it for the essential attributes.

V.M. Bida, D. V. Samokhvalov and F. S. Al-Mahturi,[15] this paper provides an overview of vector control techniques for permanent magnet synchronous motors and the existing classification of such techniques. Table2.1 gives a comparative data regarding few of the control techniques (DTC, DTC with SVM, VVC and NTC) used for the control of the motor and shows how the FOC technique has better advantage with respect to the ripple at high speeds compared to other techniques. This study contains a unified classification of vector control strategies that incorporates numerous vector control concepts and speed control approaches. Basic qualitative properties characterize the approaches outlined in the classification. A comparative examination of the methodologies is used to make recommendations for those real-world applications. This classification is simple and can be expanded upon. This paper describes some vector control methods and their existing classifications, as well as proposing a more extended method classification. All DTC techniques are quite suitable for application in the traction and transport drive system, according to the analysis undertaken. VVC and PBC technologies are suitable for traction drives, as well as industrial and technical equipment that does not require great positioning accuracy. For precise tracking, targeting, and drive adjustment, direct FOC approaches with non-traditional speed control (FLC, SMC, MPC) and NTC are optimal. Simultaneously, NTC technology ensures the maximum level of system robustness and independence from rapid changes in engine parameters and disturbances.

Table 1: Comparison of different control techniques

SL.NO	METHOD	Advantages	Drawbacks wrtFOC
1	DTC	Do not require inverter circuit with PWM	Cannot be usedfor high sped applications dueto ripple.
2	DTC withSVM	Certain reduction in theripple compared to DTC	Cannot be used for high sped applications due to ripple
3	VVC	Do not require the position of the motor Only the flux component is regulated	High ripple and torque overshoot Cannot be used in high precision drive systems
4	NTC	Used for high precision control Uses Lyapunov function	Less robust compared to FOC and changes to external disturbances.

Abbreviations

PWM- Pulse Width Modulation, DTC- Direct Torque control, VVC- Voltage Vector Control, NTC- Non-Linear Torque Control.

III. CONCLUSION

ESCs are very important to control the speed of the motor. Thispaper gives a detailed review on different motor control technologies available in the market and an overview on their efficiency considering different parameters. based on the application for which the motor is used we can choose the bestcontrol algorithm from the various option available.

This paper also gives a comparison table between different vector control techniques and justifies why FOC is a better algorithm for precisive application based on the ripple and other factors.

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