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Design and Implementation of On-board Hybrid Generator for Rotary Wing Drone

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Abstract*—Drone which power up with Lithium Polymer (LiPo) battery doesn't have long duration flight time. The average enterprise-class rotary wing drone that weighs more than 10kg has a flight duration of less than 20 minutes. By developing an on-board generator system, it is expected that flight time of enterprise-class drone increase significantly. This development has many challenges such as the output of generator must have a large amount of power, the system needs a battery as fail-backup system so the charging system must be developed. The weight of developed system is one of consideration whether this system can be used as an on-board system or not. This paper discuss how the process of power generation that used by propeller done and how charging system work with Lithium Polymer.

***Keywords*—hybrid, generator, rotary wing, charging-system.**

I. Introduction

The development of aerospace technology in the recent years is very rapid. The aerospace technology is developing both from the big scale and the small scale, on the small scale one of them is the rotary wing drone. In the last decade, people are already found a rotary wing drone is a common thing and many people use it in several activities such as photography, monitoring, mapping of an area, etc. The size of a rotary wing drone varies from as small as an adult fist until as big as fully-grown human adult. The rotary wing drone possess advantages compared to fixed-wing drone such as the ability to take off and land vertically, able to hover and create an agile maneuver. Those advantages make a rotary wing drone able to operate in small vicinity area with no special takeoff and landing area needed and also the rotary wing drone can perform precision inspection and able to maintain visual on single target in extended period. The rotary wing drone is very potential to be used in more sectors mainly inspection, and monitoring. But the obstacle come from the rotary wing drone power source.

Nowadays rotary wing drone are commonly powered with Lithium Polymer battery. The implementation of this battery technology has many considerations. Lithium Polymer battery has the highest power to weight ratio then the other battery technology and this battery also has high discharge and charge rate. But in general, the use of battery for drone facing real problem. The problem is short duration of flight time compared to the charging time needed to fully charge the battery. Development and improvement of the efficiency of motor and microcontroller power usage is growing, but these developments have not had a significant impact on the duration of drone's flight-time. Therefore, the rotary wing drone usage become limited due to its short duration of flight time especially in the long endurance mission.

Gasoline has a very high energy density at 12 kW h/Kg compared to li-ion battery which is around 160-230 W h/Kg [1]. Therefore, it is an appealing solution to use gasoline as the main fuel for the rotary wing drone in order to increase its flight time significantly. In harnessing the gasoline power, combustion engine is needed and the method to supply the generated power to the drone system is needed. If we use fuel propulsion system alone to the drone, it will increase the mechanical complexity of the drone. While, electric propulsion system is very simple without any mechanical complexity.

The idea of developing a hybrid on-board generator system is based on the energy density of gasoline which is much higher than current li-ion battery and to create a system that able to harness the large energy without mechanical complexity by creating hybrid system combining the fuel propulsion system and electric propulsion system. The system that developed should able to generate

1800Watt continuous power and the ratio of fuel consumption to flight time will be evaluated to assess the performance of the system. The output power is determined by the drone that will use the system which is the enterprise class drone with 20 kg of MTOW and 5 kg of payload.

II. Hybrid Generator Design

A. Block Diagram

In the system, combustion engine is the main power generator for the drone where the generated mechanical energy will be converted into electrical energy by a brushless DC motor and rectified before powering the drone propulsion system which is the brushless DC motor that will propel the propeller of the drone. The configuration of the system can be seen in the Fig. 1. Combustion engine act as the main power generator then, used to supply the propellers in order to fly the drone. Besides that, it is used for charge the LiPo battery through charging system. LiPo battery is used to start the combustion engine as an on-board starter by supplying current to brushless DC motor to rotate and create a rotation in the combustion engine piston so there will be a cycle inside the engine and the engine start running. Besides that, the battery supply power to the controller of the hybrid system to ensure that the controller will not be affected even if the combustion engine shut down in the middle of flight. This system is controlled by two controller, output controller and fly controller. The first one is used to control and ensure the power to drone is sufficient and safely transferred. The flight controller is used to control flight mechanism of the drone and to display it for user.

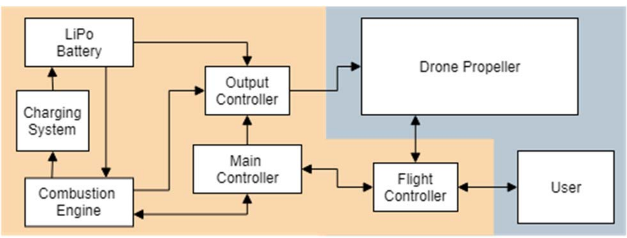

Fig. 1. Hybrid Generator Block Diagram

The combustion engine that being used in the system is a two stroke engine model Zenoah G320RC. The engine is choosen because it can provide up to 2400 Watt of power. Besides that, this engine can produce rpm output to 13000 which can generate more stable and greater power. [3]

B. Operation State

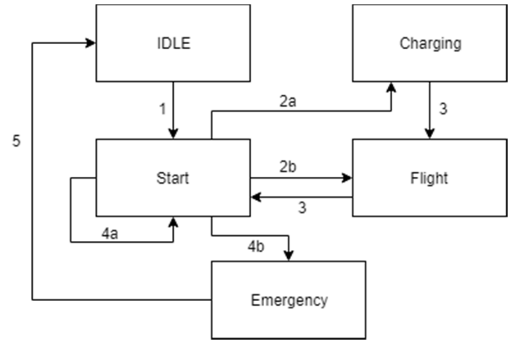

Fig. 2. Hybrid Generator State Diagram

The diagram above shows how hybrid generator system works. There are five states in system operation. First, idle state, where system is in idle condition and ready to receive commands from user. System will start to work when it is switched on. There are two condition in starting state. First (2a), if system sense the battery level is lower than threshold voltage, system will charge battery first before flying the drone. The second (2b), system will fly immediately after system is switched on.

While drone is flying, user must monitor the operation through the user interface anytime. When the engine failed to transfer enough power to the drone, system will back to starting state in order to produce sufficient power to drone. But, if the failure condition happened three times in a row while drone is flying, system's state will be switched to emergency, either returning to home or landing at current location.

C. Output System Calculation

The drone that will use in this system will have no-payload weight without fuel about 15 Kg and the MTOW is 20 Kg. From there, the power needed for the system can be calculated. The calculation is made with assumption that the drone is hexacopter, with every rotor using T-motor U10II KV100, and using T-motor G30*10.5CF as the propeller. Below is the calculation that is used to determine the power that the hybrid generator should able to supply.

$$Thrust = \frac{MTOW}{number\ of\ rotor} = \frac{20\ Kg}{6} = 3.333\ Kg$$

Based on the brushless DC motor specification, the input power needed to the motor to generate the thrust is 277.8 Watt at 3.3369 Kg [2].

$$Power = number\ of\ rotor\ x\ input\ power$$

$$Power = 6\ x\ 277.8\ W = 1666.8\ W$$

Therefore, the power that the hybrid system should able to supply is 1666.8 W but as a safety margin the system should able to supply continuous power at 1800 W with maximum power at 2000 W.

D. *Components*

The combustion engine used to realize this system is Zenoah G320RC. The engine is a two-stroke engine that capable to supply up to 2400 W [3]. The generator that convert the mechanical energy into electrical energy is using brushless DC Sunnysky 210 KV because the system is operating at 12S therefore the BLDC need to rotate at around 10000 rpm which is match with the combustion engine specification. The maximum power that the BLDC can deliver is stated at 3000 W [4]. Thus, the components that being used is technically able to deliver a continuous power at 1800 W, as the specification of system output.

III. IMPLEMENTATION AND EXPERIMENTATION

A. *Output System*

The system output is tested in several loads which will result in different power usage between each load. The load that will be used is 4 Ω, 2 Ω, and 1.33 Ω. The power supposed to be obtained by each load is in the table below.

TABLE I. TESTING SCHEME FOR HYBRID SYSTEM

Load (Ω)	Voltage (V)	Power (W)	Current (A)
4 Ω	50 V (12s)	625 W	12.5 A
2 Ω	50 V (12s)	1250 W	25 A
1.33Ω	50 V (12s)	1875 W	37.5 A

In the testing procedure, dummy load is used as the load. The specification of the dummy load is 4 Ω 1000 W and by paralleling it with the same dummy load the desired load can be formed. Here is the picture of the dummy load used in the experiment.

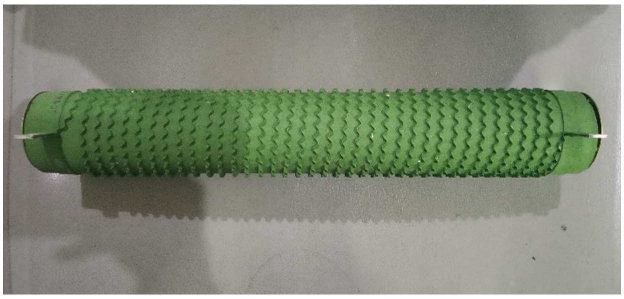

Fig. 3. Dummy Load

Experiment results are displayed in GUI as shown below.

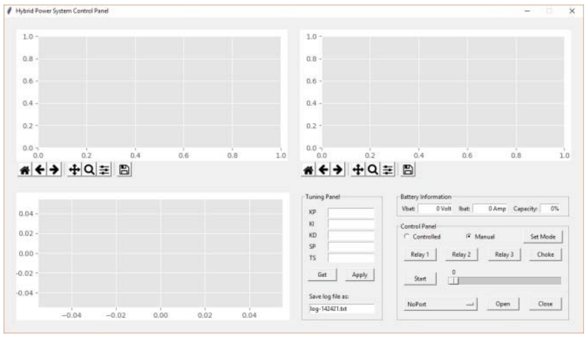

Fig. 4. GUI Display

GUI consist of three graphics display, first (upper left) is to display output voltage, where y-axis indicates voltage in Volt unit (V); second (bottom left) is for throttle position, where y-axis indicates throttle position percentage (%); and third (upper right) for output current, where y-axis indicates current in Ampere (A). All x-axis, in graphics display, indicates the operation or testing time in seconds (s).

The first experiment is done at 4 Ω and the experiment result shown in the picture below.

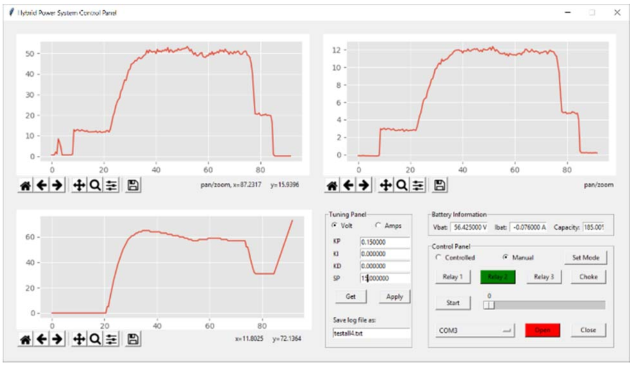

Fig. 5. Experiment Result for 600 Watt Output

The result of the experiment at this operating point is shown by the graphical user interface that is used to monitor the hybrid system.

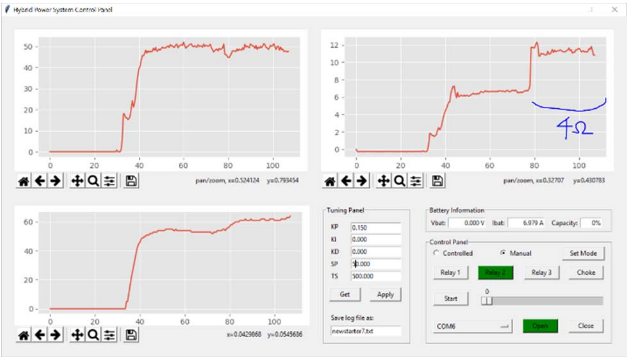

Fig. 6. Experiment Result for Switching Load

From the result of the experiment, the controller able to perform well and it is shown by the system able to maintain the operating voltage at 50 V.

B. *Operating Duration vs. Fuel Needed*

In this system design, Zenoah G320RC engine, that has 519 g/kWh of fuel consumption [5], is chosen. If the fuel density is 0.7 g/cm3 then the of fuel tank volume and operation duration can be obtained as the table below.

TABLE II. DURATION CALCULATION OF ZENOAH G320RC

Volume (cc)	Output (kW)	Duration (Hours)
3000	1.8	2.25
3000	2	2.02
3000	2.2	1.84
3000	2.4	1.69
3500	1.8	2.62
3500	2	2.36
3500	2.2	2.15
3500	2.4	1.97

Duration of the operation (T) is calculated by this equation.

$$T = \frac{Volume \times Density}{Fuel\ Consumtion \times Power}$$

C. *Filtering Generator Output*

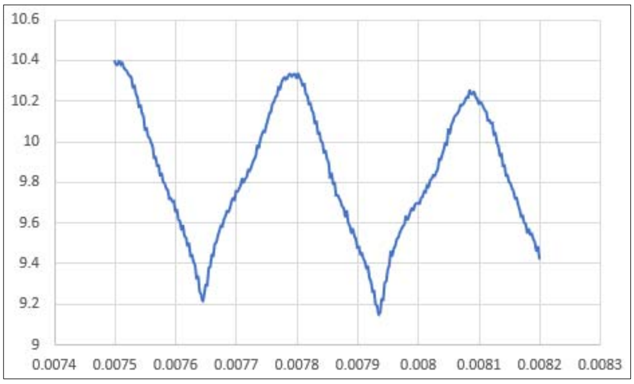

Fig. 7. Generator Output Voltage

From the experiment results, the output of generator has voltage ripple with characteristics has frequency of 3.5kHz - 4kHz and 7 Volt of amplitude. Ripple frequency measured when throttle 0%. When higher engine's rpm is used, the amplitude of voltage ripple will go higher too. For 50 Volt of output, ripple voltage reaches 7 Volt. Based on that characteristic, protection system is needed to ensure charging process safely done. Protection system used in this design is low pass filter. Filter was designed using basic RLC circuit with 170 Hz of cut-off frequency and 3 Ampere of maximum current.

D. *Constant Current for Battery Charging*

LiPo battery charging method used in this system is CC-CV (Constant Current-Constant Voltage) that controlled fully by the main microcontroller. Constant current method in this system is limited to 2 Ampere. This number was got from power calculation that used for charging. With 2 Ampere of constant current, system must use 100 Watt of power. On the other side, if higher charge rate is used, components in low pass filter will be more complex.

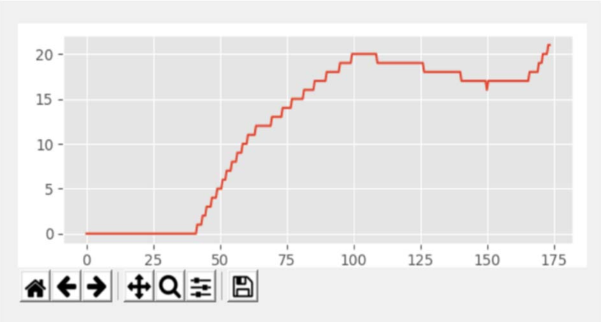

Fig. 8. Controlled Throttle Position (Axis-y : Throttle Percentage (%) ; Axis-x : time (s))

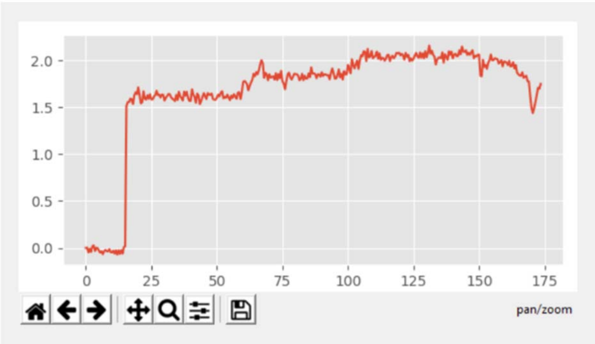

Fig. 9. Output Current (Axis-y : Output Current (Ampere) ; Axis-x : time (s))

Constant current control tested by using constant load and by controlling voltage input that transferred to the load. Figure 8 shows that measured current while using 8 Ohm dummy load can be controlled well by 2 Ampere constant current method. This result is obtained by controlling the throttle position.

IV. Conclusion

In developing on-board generator system, designed control system can generate expected result. For power output, testing is done in the first step which is operation in output power of 625 Watt. In this step, testing focus is to observe operation of control system and battery charging mechanism. As the result, this system can manage and handle impulsive change of the load and adjusted as shown in Fig 5. On the other side, ripple produced in output voltage with frequency of 3.5 kHz – 4 kHz and amplitude of 7 Volt. This problem can be solved by using a filter with cut off frequency of 170 Hz and resulting a stable output. However, the voltage readings get disturbed because the capacitor used in the filter require discharge rate for a few seconds. By solving this problem, testing can be continued to the next stage.

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