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INACTIVE POWER COMPONENTS IN UAV POWER SYSTEM BASED ON DC-DC BOOST CONVERTER

This article analyzes the issue of inactive power components in DC power systems, with a particular focus on unmanned aerial vehicle (UAV) power networks. Analytical expressions were derived to determine the exchange power under various states of the power switch. A model based on the equivalent circuit of the converter–motor system was developed in MATLAB/Simulink. The simulation results demonstrate the presence of exchange power in a system utilizing a DC-DC boost converter, and the maximum values of this exchange power were determined. Finally, the study concludes that compensatory measures are necessary to minimize inactive power components.

Keywords: UAV, DC-DC boost converter, exchange power, inactive power components, Simulink, energy losses, DC motor.

The utilization of unmanned aerial vehicles (UAVs) offers several distinct advantages. Compared to traditional aircraft, they are low-cost and highly cost-effective. More importantly, UAVs eliminate the risk of flight personnel casualties, providing a significant edge when executing missions characterized by high risk, intensive labor costs, or operational complexity. Recent breakthroughs in UAV development have substantially enhanced their performance, continuously expanding their scope of application.

Publications [1]–[3] present classifications of UAVs and examples of their power systems. Generally, small UAVs use batteries as a power source, and less frequently fuel cells [4], [5]. An unmanned aerial system, illustrated in **Fig. 1**, is generally composed of three parts:

– the unmanned aerial vehicle;

– the ground control station, which can be autonomous or human-operated;

– the command and control system, which establishes communication and data links between the aircraft and the ground station.

In UAVs, the propulsion system is the component with the largest mass and dimensions. It enables aircraft motion through the mechanical power generated by the electric energy–propeller system, converting the stored energy into thrust. The onboard power source supplies energy to the DC bus through unidirectional and bidirectional converters to enable battery charging and discharging. These converters regulate the power flow and receive control signals from the power management system, which continuously collects data from onboard sensors.

Publications [6], [7] discuss the phenomenon of exchange power flow in DC networks, particularly in UAV power supply systems [8]. This phenomenon leads to additional energy losses in the parasitic resistances of

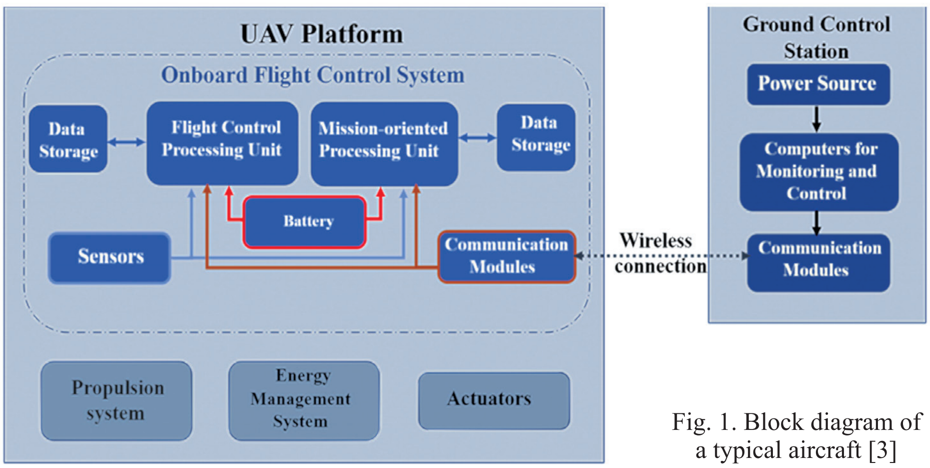

Fig. 1. Block diagram of a typical aircraft [3]

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power system components. Based on previous research [8], such losses amount to several percent of total power consumption, which consequently reduces UAV flight time. Since this topic contains significant gaps and has not been studied in depth, it is reasonable to investigate the flow of exchange power in UAV power supply systems based on a DC-DC boost converter.

The purpose of this study is to derive analytical expressions for analyzing exchange power in UAV power systems and to validate these expressions through simulation.

Circuit Analysis

When analyzing the phenomenon of exchange power in a UAV power system, it is first necessary to perform mathematical modeling of the system while accounting for parasitic parameters. To this end, let us consider the equivalent circuits of a converter loaded with a DC motor under various states of the power switch. Specifically, when the switch is closed, the equivalent circuit shown in **Fig. 2**, *a* is obtained.

Consequently, the expression describing this circuit is

$$E_a = R_a i_a(t) + L\frac{\mathrm{d}i_a(t)}{\mathrm{d}t} + R_{L1} i_a(t) + R_s i_s(t) + L_s \frac{\mathrm{d}i_s(t)}{\mathrm{d}t}, \quad (1)$$

where $i_a(t)$ and $i_s(t)$ are the currents of the accumulator and the motor stator, respectively.

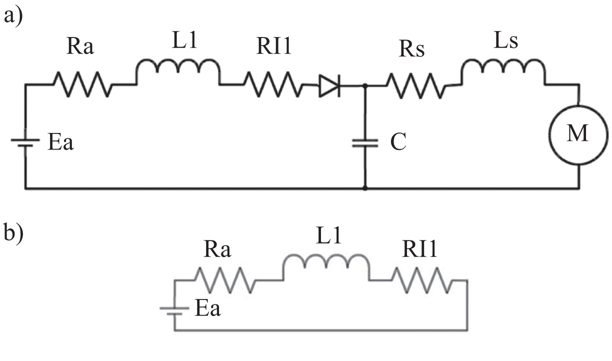

Fig. 2. Equivalent circuits when the switch is off (*a*) and when is on (*b*)

Following mathematical transformations, the exchange power is determined as follows:

$$q(t) = \left(E_a \frac{E_a - Es}{R_a + R_L} - E_a \frac{E_a L_1 + i_a(0)(R_a + R_L)}{(r_a + r_L)L_1} - \right.$$
$$- \frac{(R_a + R_L)R_s i_s(t) + \dfrac{(R_a + R_L)^2}{L_1} L_s I_s(t)}{(r_a + r_L)L_1} -$$
$$\left. - \frac{(r_a + r_L)\cdot i_s(0) - E_s L_1}{(r_a + r_L)L_1} \right) \exp\left(-\frac{r_a + r_L}{L_1} t \right) - E_a I_a, \quad (2)$$

where I_a and E_a are the constant values of the battery current and voltage, respectively;
$i_a(0)$ and $i_s(0)$ are the initial current values after the corresponding change in the switch state.

When the switch is in the open position, the equivalent circuit shown in Fig. 2, *b* is obtained.

In this case, the exchange power is determined by the following expression:

$$q(t) = E_a \frac{i_a(0)\dfrac{R_a + R_L}{L_1} - E_a}{R_a + R_L} \exp\left(-\frac{R_a + R_L}{L_1} t \right) - E_a I_a. \quad (3)$$

Thus, from the above expressions, given the known circuit parameters and initial conditions, it is possible to determine the exchange energy in the system over specified time intervals.

Simulation Results

The electrical circuit shown in **Fig. 3** was modeled in MATLAB/Simulink based on the equivalent circuits in Figs. 2 and 3. The battery voltage is 12 V, the DC motor voltage is set to 24 V, the converter operating frequency is 1 kHz, and the motor power is approximately 170 W. The power consumption time-domain diagrams are presented in **Fig. 4**.

As can be seen, even at the stage of analyzing the power consumed from the battery, there are time intervals during which the power takes negative values,

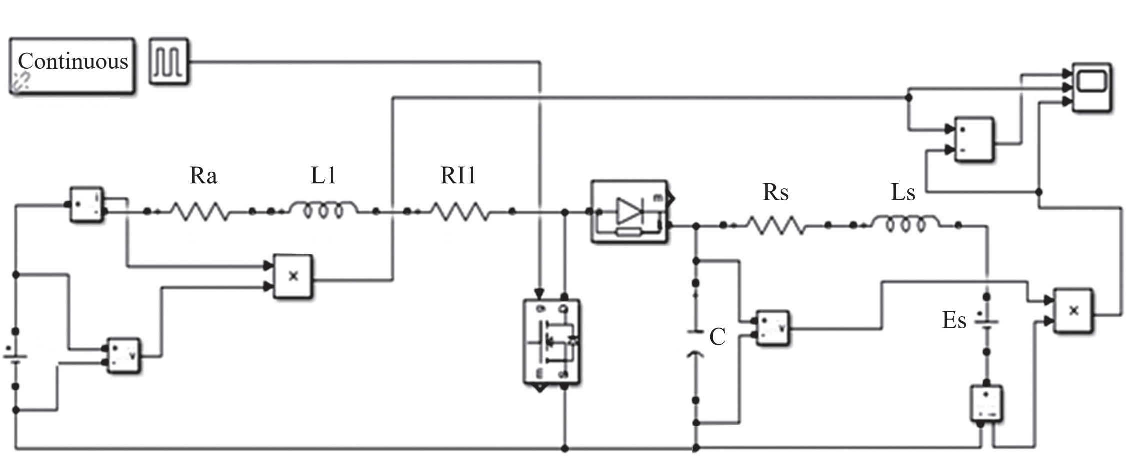

Fig. 3. Simulation model

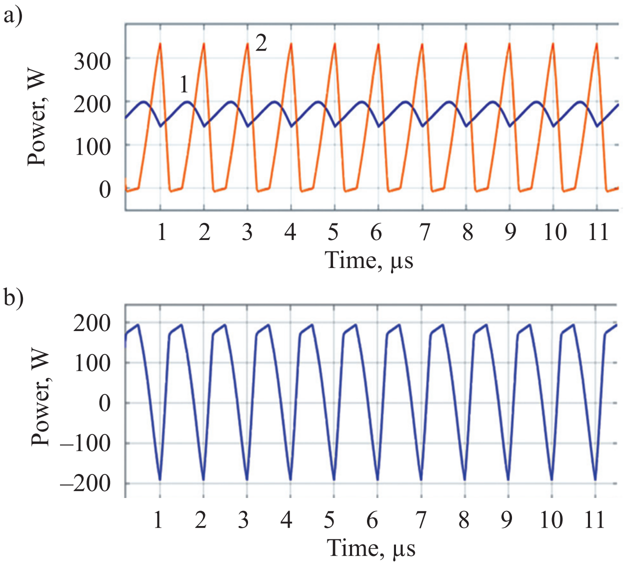

Fig. 4. Simulation results:
a — power consumed from the battery (*1*) and power consumed by the motor (*2*); *b* — difference between the power consumed from the battery and that consumed by the motor

indicating the presence of inactive power components. The maximum value of this power is 9.1 W. This results in a portion of the power being dissipated in the internal resistance of the battery. However, when considering the difference between the power consumed from the battery and that consumed by the motor (Fig. 4, *b*), it becomes evident that a significant portion of the power does not flow directly from the source to the load but instead circulates between the reactive components of the circuit. In this case, the maximum value of this power is 189.1 W. Thus, the simulation confirms the presence of exchange processes in the power system. It should be noted that increasing the parameters of the reactive components in the circuit leads to a higher value of the inactive power component.

Conclusions

Thus, the phenomenon of exchange power flow in the UAV power supply system based on a DC boost converter has been analyzed. The presented analysis results clearly demonstrate the presence of exchange power in the system. As a result of the simulation, maximum exchange power values of 9.1 W and 189.1 W were obtained in accordance with the evaluation methodology. Such energy exchange processes inevitably lead to additional energy losses and, consequently, to a reduction in the UAV's flight time. To mitigate the impact of this phenomenon, it is necessary to develop compensatory links or control strategies.

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НЕАКТИВНІ КОМПОНЕНТИ ПОТУЖНОСТІ В СИСТЕМІ ЖИВЛЕННЯ БПЛА НА ОСНОВІ ПІДВИЩУВАЛЬНОГО ПЕРЕТВОРЮВАЧА ПОСТІЙНОГО СТРУМУ

Роботу присвячено аналізу обмінної потужності в системі живлення безпілотного літального апарату. Присутність цієї компоненти повної потужності саме по собі вже призводить до збільшення втрат в колі перетворювача навіть при роботі в усталеному режимі, а у випадку безпілотного літального апарату цей фактор має ще більший вплив, оскільки під час польоту присутні різноманітні зовнішні чинники, такі як вітер, дощ тощо. У разі використання широко вживаної мультикоптерної схеми система керування налаштовується так, щоб постійно вирівнювати апарат відносно горизонту. Також під час польоту часто необхідно маневрувати, і тоді частота обертів двигуна теж змінюється. Все це призводить до того, що здебільшого силова система фактично перебуває у перехідному режимі, що неодмінно збільшує частку обмінної потужності.

Проаналізовано проблему наявності неактивних компонентів потужності в системах живлення постійного струму, зокрема, безпілотних літальних апаратів. Виведено аналітичні співвідношення, що визначають обмінну потужність при відповідних станах силового ключа. У середовищі MATLAB/Simulink побудовано модель, яка відповідає схемі заміщення системи «перетворювач – двигун». Результати моделювання наочно демонструють наявність обмінної потужності в системі живлення на основі підвищувального перетворювача постійного струму. Зроблено висновок про необхідність застосування компенсаційних заходів для мінімізації неактивних компонентів потужності.

Ключові слова: БПЛА, підвищувальний перетворювач постійного струму, обмінна потужність, неактивні компоненти живлення, Simulink, втрати енергії, двигун постійного струму.