ELECTRONICS

UDC 621:314 (045)
DOI:10.18372/1990-5548.75.17559

D. A. Mykolaiets

ANALYSIS OF EXCHANGE POWER IN THE POWER SYSTEM OF AN UNMANNED AERIAL VEHICLE WITH A BLDC ENGINE

Scientific and Research Department, National Aviation University, Kyiv, Ukraine
E-mail: mykolaietsda@nau.edu.ua ORCID 0000-0002-9152-8593

Abstract**—***The purpose of this work is the analysis of the power supply system of unmanned aerial vehicle. One of the most important tasks of this system is to ensure the smallest possible losses in order to achieve greater endurance of the aircraft, which means – the ability to complete the mission. The presence of an inactive component of consumed power obviously reduces the efficiency of the entire unmanned aerial vehicle. Considering also that due to the influence of wind, speed changes and other factors, the power system spends a significant amount of time in the transition mode, the impact of this phenomenon becomes even more significant. Thus, the phenomenon of the occurrence of exchange power in the power supply system of an unmanned aerial vehicle is analyzed. One of the most common solutions for unmanned aerial vehicles is the use of a BLDC motor, which is a further development of DC motors and was created with the aim of improving their basic characteristics. This type of engine has gained its popularity due to numerous advantages: high reliability, efficiency, speed and others. The principles of control of the BLDC engine are given. The unmanned aerial vehicle power supply system, built on the basis of a buck converter and a bridge inverter, was analyzed. An equivalent circuit of the converter is built, taking into account the losses in the electric circuit. On its basis the relations for determining the value of exchange power in the power supply system are derived. With the help of these expressions, it is possible to determine the value of the exchange energy at an arbitrary time interval in the real power supply system of the aircraft. A model of the power supply system of an unmanned aerial vehicle with a BLDC engine was built in the Matlab Simulink software environment. A time diagram is obtained, on the basis of which it is possible to draw a conclusion about the content of exchange power in the converter circuit. To minimize this phenomenon, it is necessary to develop a compensation system or an intelligent control system.*

Index Terms—Exchange power; unmanned aerial vehicle; BLDC motor; power supply system; DC circuits.

I. INTRODUCTION

Unmanned aerial vehicles (UAVs) endurance has always been a bottleneck restricting the development of UAV technology. Insufficient endurance is one of the main defects of all current UAVs, which greatly limits the overall development potential of the UAV industry. During the flight, the speed of rotation of the engines is not constant, and its change depends not only on a change in flight speed or direction, but also on weather conditions, such as wind, since the stabilization system constantly aligns the drone. This leads to the fact that the power supply system of such a device is actually in transient mode for a significant part of the time. This, in turn, leads to the appearance of a significant content of the exchange energy component in the energy consumed from the battery, which, in turn, will increase losses, which means that it will reduce the range of the unmanned aerial vehicle.

The publications [1] – [4] presents the classification of UAVs and describes the structure of its typical power system. As a power source of such a system, a battery is usually used [4], [5], which is connected to a DC-DC converter, which in turn provides a constant value of the voltage at the input of the inverter.

Brushless DC motors [6], [7] are often used as the driving force for drones, and to power such motor, the system includes an inverter that controls the speed of rotation based on sensor data.

In publications [1], [8] – [10] it is described that there is a problem of exchange processes between the source and the load in electric vehicles powered by direct current. This phenomenon causes additional losses in power circuits of power supply systems.

Thus, the task of this paper is the analysis of the exchange power in the power system of a UAV with a BLDC engine.

ISSN 1990-5548 Electronics and Control Systems 2023. N 1(75): 73-77

II. CIRCUIT ANALYSIS AND CALCULATION

BLDC motor is similar to conventional DC motor in performance. Figure 1 shows a simplified circuit of power system with BLDC motor, it consists of a buck DC-DC converter, built on transistor VT7, choke L, diode D, capacitor C and a three-phase inverter, on VT1-VT6 transistors. The battery is modeled as a source of constant voltage E_β and its internal resistance r_β.

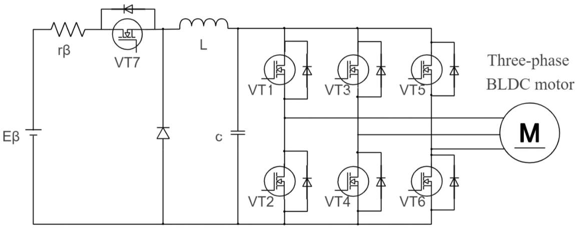

Fig. 1. Simplified circuit of power system and BLDC motor

The simplest control scheme of the BLDC motor is 120-degree commutation, in which the voltage is applied to the two corresponding phases, while pulse-width modulation is used to control the speed.

The flow of current through the power system of the inverter is presented in Figs 2 – 7 respectively.

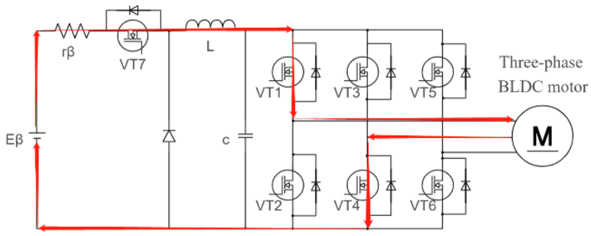

Fig. 2. VT1 and VT4 are turned on

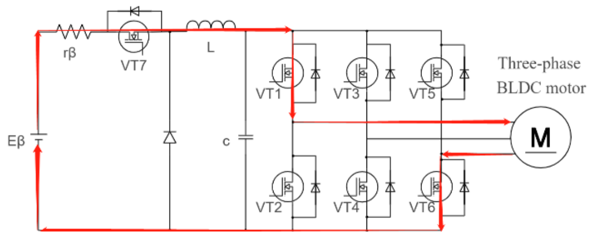

Fig. 3. VT1 and VT6 are turned on

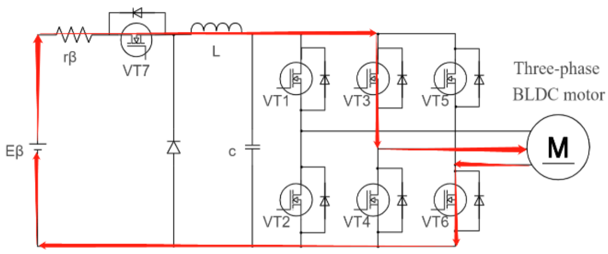

Fig. 4. VT3 and VT6 are turned on

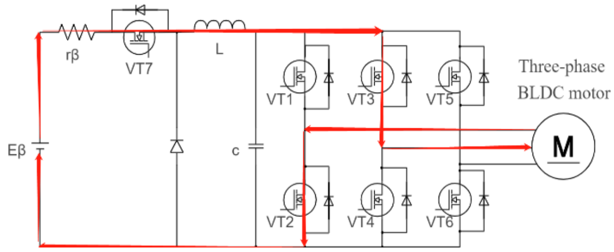

Fig. 5. VT3 and VT2 are turned on

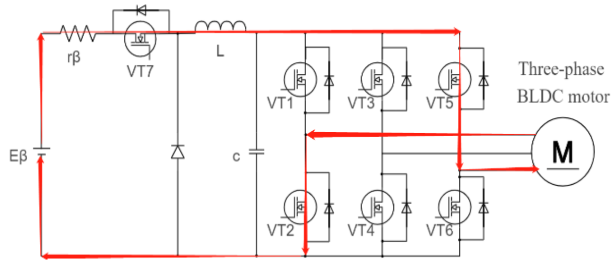

Fig. 6. VT5 and VT2 are turned on

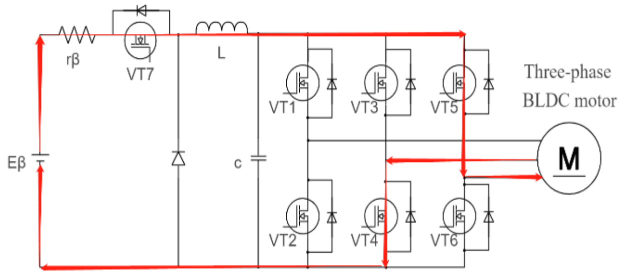

Fig. 7. VT5 and VT4 are turned on

Since the motor as a load is symmetrical, a single-phase equivalent scheme is chosen for further analysis, which will be similar for other phase combinations. In this case we consider VT1 and VT4 is turn on, other switches of inverter is off. In this scheme, phases *A* and *B* are replaced by resistors r_a and r_{a1}, chokes L_a and L_{a1}, reverse voltage sources $E_{a\alpha}$ and $E_{a\beta}$, respectively. The specified scheme is shown in Fig. 8.

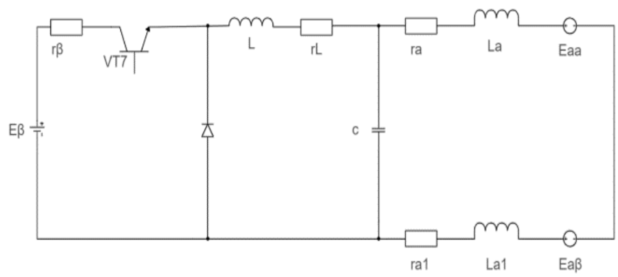

Fig. 8. Simplified equivalent circuit of power system

Since, as mentioned above, the load is symmetrical, it is assumed that $L_{a1} = L_a$ and $r_{a1} = r_a$. To determine the exchange power that will affect the battery, the corresponding equation is made:

$$E_{\beta} = r_{\beta} \cdot i_{\beta}(t) + L\frac{di_{\beta}(t)}{dt} + r_L \cdot ir(t) + r_a \cdot i_a(t)$$
$$+ L_a\frac{di_a(t)}{dt} + E_{a\alpha} - E_{a\beta} + L_a\frac{di_a(t)}{dt} + r_a \cdot i_a(t), \quad (1)$$

where $i_{\beta}(t)$ is the battery current; $i_r(t)$ is the choke current; $i_a(t)$ is the phase A current.

After performing the appropriate mathematical transformations, the current consumed from the battery is determined:

$$i_{\beta}(t) = \frac{E_{\beta} - (E_{a\alpha} - E_{a\beta})}{r_{\beta} + r_L} - \frac{E_{\beta} + 2i_a(0)\frac{r_{\beta}+r_L}{L}}{r_{\beta} + r_L} \cdot e^{-\frac{r_{\beta}+r_L}{L}t}$$
$$+ \frac{2r_a \cdot i_a(t)\frac{r_{\beta}+r_L}{L} - 2i_{\beta}(0)\frac{r_{\beta}+r_L}{L}}{r_{\beta} + r_L} \cdot e^{-\frac{r_{\beta}+r_L}{L}t} + \frac{2\left(\frac{r_{\beta}+r_L}{L}\right)^2 L \cdot i_a(t) + E_{a\alpha} - E_{a\beta}}{r_{\beta} + r_L} \cdot e^{-\frac{r_{\beta}+r_L}{L}t}. \quad (2)$$

Hence the value of exchange power in this system:

$$q(t) = E_{\beta}\Big(\frac{E_{\beta} - (E_{a\alpha} - E_{a\beta})}{r_{\beta} + r_L} - \frac{E_{\beta} - 2i_a(0)\frac{r_{\beta}+r_L}{L}}{r_{\beta} + r_L}$$
$$\cdot e^{-\frac{r_{\beta}+r_L}{L}t} + \frac{2r_a \cdot i_a(t)\frac{r_{\beta}+r_L}{L} - 2i_{\beta}(0)\frac{r_{\beta}+r_L}{L}}{r_{\beta} + r_L} \cdot e^{-\frac{r_{\beta}+r_L}{L}t}$$
$$+ \frac{2\left(\frac{r_{\beta}+r_L}{L}\right)^2 L \cdot i_a(t) + E_{a\alpha} - E_{a\beta}}{r_{\beta} + r_L} \cdot e^{-\frac{r_{\beta}+r_L}{L}t}\Big) - E_{\beta} I_{\beta}, \quad (3)$$

where I_{β} is the average value of the battery current.

Thus, from expression (3) it is possible to determine the amount of exchange energy for the required time interval.

III. SIMULATION

The Matlab Simulink toolkit was selected for modeling processes in the converter, the model scheme is presented in Fig. 9. The system is powered by a 50 V DC power supply, consist transistor VT7, inductor L, the capacitor C and diode D1 as the buck converter, three phase inverter is building on MOSFET transistor VT1-VT6, the BLDC motor is built on the L_a, L_{a1}, L_{a2}, $E_{\beta1}$, $E_{\beta2}$, $E_{\beta3}$, r_{a1}, r_{a2}, r_{a3}, Three-Phase V-I Measurement is used to measure voltages, currents and power of the inverter.

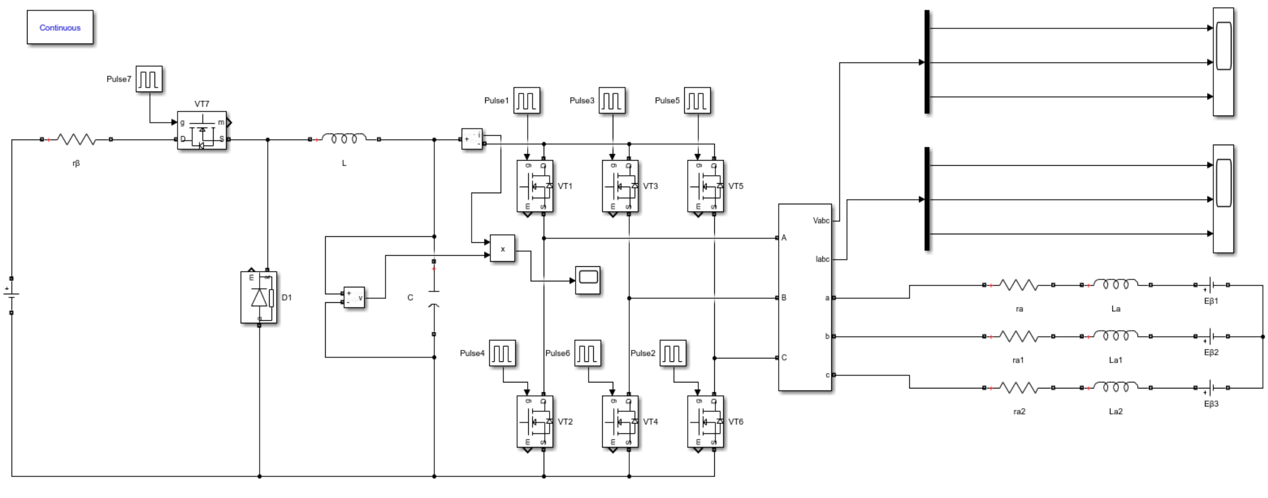

Fig. 9. Simulation of power system

From the time diagram of consumed power, presented in Fig. 10, it can be seen that its direction changes at the corresponding time intervals. In this way, the presence of the content of exchange power in the power system, which works on the BLDC engine, is confirmed.

Accordingly, the value of the inactive component of the consumed power may vary and depends on the power system parameters.

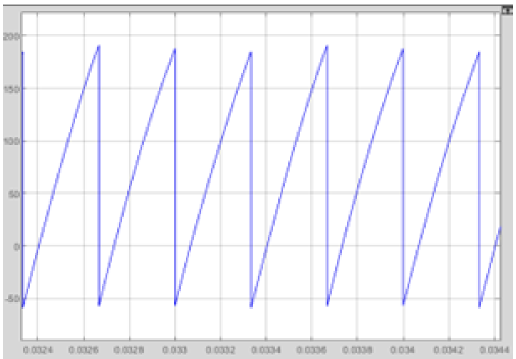

Fig. 10. Time diagram of consumed power

IV. CONCLUSIONS

The conducted analysis clearly illustrates the problem of the availability of exchangeable energy in the power system of an unmanned aerial vehicle with a BLDS engine, which ultimately leads to a reduction in flight duration. To reduce this effect, there is obviously a need to develop compensating circuits or algorithms for intelligent control of converters.

REFERENCES

[1] D. A. Mykolaiets, "Analysis of Exchange Power in the Power System of Drone", *Mikrosyst., Elektron. ta Akust.*, vol. 27, no. 1, pp. 252748–1, Apr. 2022. https://doi.org/10.20535/2523-4455.mea.252748.

[2] N. Darwin, A. Ahmad, and W. A. A. Wan Mohd Akib, "The Potential of Low Altitude Aerial Data for Large Scale Mapping", *Jurnal Teknologi*, vol. 70, no. 5, Sep. 2014. https://doi.org/10.11113/jt.v70.3523.

[3] M. R. Szabolcsi, "Beyond Training Minimums – A New Concept of the UAV Operator Training Program," *International conference KNOWLEDGE-BASED ORGANIZATION*, vol. 22, no. 3, pp. 560–566, Jun. 2016. https://doi.org/10.1515/kbo-2016-0096.

[4] M. N. Boukoberine, Z. Zhou, and M. Benbouzid, "A critical review on unmanned aerial vehicles power supply and energy management: Solutions, strategies, and prospects," *Applied Energy*, vol. 255, p. 113823, Dec. 2019. https://doi.org/10.1016/j.apenergy.2019.113823.

[5] M. Kim, S. Lee, and S. Bae, "Decentralized Power Management for Electrical Power Systems in More Electric Aircrafts," *Electronics*, vol. 7, no. 9, p. 187, Sep. 2018. https://doi.org/10.3390/electronics7090187.

[6] S. Nijandan, G. Gokulakrishnan, R. Nagendra Prasad, S. Mahendran, and P. S. B. Kirubakaran, "Autonomous Onboard Power Generation System in Uavs for Long Range," *International Journal of Engineering Research & Technology (IJERT)*, vol. 04, no. 02, Jan. 2015. https://doi.org/10.17577/IJERTV4IS020576.

[7] O. Solomon and P. Famouri, "Dynamic Performance of a Permanent Magnet Brushless DC Motor for UAV Electric Propulsion System – Part I", in *IECON 2006 - 32nd Annual Conference on IEEE Industrial Electronics*, Paris, France, 2006, pp. 1400–1405. https://doi.org/10.1109/IECON.2006.347808.

[8] N. A. Kostin and O. H. Sheikina, "The signs of availability of exchange power in electric traction circuits of the direct current system", *STP*, no. 42, pp. 98–102, Dec. 2012. URL: http://stp.diit.edu.ua/article/view/9295, https://doi.org/10.15802/stp2012/9295.

[9] Kostyn N. A.; Sablyn O. Y., "Reaktyvnaia moshchnost v systemakh эlektrycheskoho transporta postoiannoho toka," *Visnyk Pryazovskoho derzhavnoho tekhnichnoho universytetu : zb. nauk. prats,* vol. 2, no. 15, pp. 75-80, 2005. URL: http://eir.pstu.edu/handle/123456789/1220.

[10] Y. A. Yatsenko, V. E. Tonkal, A. V. Novoseltsev, S. P. Denisyuk, V. Y. Zhuykov, and V. T. Strelkov, *Balans energiy v elektricheskih tsepyah*. Kyiv: Nauk. dumka, 1992

Received December 11, 2022

Dmytro Mykolaiets. ORCID 0000-0002-9152-8593. Candidate of Science (Engineering). Associate Professor.
Scientific and research department, National Aviation University, Kyiv, Ukraine.
Education: National Technical University of Ukraine "Kyiv Polytechnic Institute", Kyiv, Ukraine, (2011).
Research area: reactive power compensation, geometric approach for the analysis of semiconductor converters, the control systems for power supplies for electronic equipment.
Publications: more than 30.
E-mail: mykolaietsda@nau.edu.ua

Д. А. Миколаєць. Аналіз обмінної потужності в системі живлення безпілотного літального апарату з BLDC двигуном

Метою даної роботи є аналіз системи електроживлення безпілотного літального апарату. Одне з найважливіших завдань цієї системи – забезпечити якомога менші втрати, для досягнення більшої витривалості літака, а значить – здатності виконати місію. Наявність неактивної складової споживаної потужності явно знижує ефективність всього безпілотного літального апарату. Враховуючи також, що через вплив вітру, зміни швидкості та інших факторів енергосистема проводить значну кількість часу в перехідному режимі, вплив цього явища стає ще більш значним. Таким чином, проаналізовано явище виникнення обмінної потужності в системі живлення безпілотного літального апарату. Одним із найпоширеніших рішень для безпілотного літального апарату є використання двигуна BLDC, який є подальшим розвитком двигунів постійного струму і створений з метою покращення їх основних характеристик. Цей тип двигуна отримав свою популярність завдяки численним перевагам: високим надійності, коефіцієнта корисної дії, швидкості та іншим. Наведено принципи керування двигуном BLDC. Проаналізовано систему живлення безпілотного літального апарату, побудовану на основі понижувального перетворювача та мостового інвертора. Побудована еквівалентна схема перетворювача з урахуванням втрат в електричному колі. На її основі виведено співвідношення для визначення величини обмінної потужності в системі електропостачання. За допомогою цих виразів можна визначити величину обмінної енергії на довільному інтервалі часу в реальній системі живлення літака. У програмному середовищі Matlab Simulink побудовано модель системи електроживлення безпілотного літального апарату з BLDC двигуном. Отримано часову діаграму, на підставі якої можна зробити висновок про вміст обмінної потужності в схемі перетворювача. Щоб мінімізувати це явище, необхідною є розробка системи компенсації або інтелектуальної системи керування.

Ключові слова: обмінна потужність; безпілотний літальний апарат; BLDC двигун; система живлення; кола постійного струму.

Дмитро Анатолійович Миколаєць. ORCID 0000-0002-9152-8593**.** Кандидат технічних наук. Доцент.
Науково-дослідна частина, Національний авіаційний університет, Київ, Україна.
Освіта: Національний технічний університет України «Київський політехнічний інститут», Київ, Україна, (2011).
Напрям наукової діяльності: компенсація реактивної потужності, геометричний підхід для аналізу напівпровідникових перетворювачів, системи керування для джерел живлення електронної апаратури.
Кількість публікацій: понад 30.
E-mail: mykolaietsda@nau.edu.ua