Power control system for lightweight electric aircraft

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Abstract. This article describes the development and key features of the lightweight electric aircraft power system. The overview includes internals of main power control units and propulsion system rigging, hardware parts selection guide and fail-safe features in hardware and software of aircraft. The propulsion system includes lightweight solution utilizing brushless DC (BLDC) motor with a propeller as the main thrust generator, and a control system, which consists of insulated gate bipolar transistors (IGBT) 3-phase bridge and control system, as well as a special optical-insulated throttle controller. Main power control system automatically starts up aircraft modules and provides all the necessary information coming from the sensors. All of the key components in aircraft are connected through Controller Area Network (CAN) interface. To create a strong protection against surges and electric interference special cabling and interfacing aspects between several systems of lightweight aircraft are described. Part of the article provides a future extendibility, versatility and economical concepts.

1. Introduction

Electric aircrafts are emerging to the markets, and now it is time to figure out how it is possible to provide the sufficient level of safety, reliability and usability of their power control systems [1][9]. While developing the power and propulsion system for the lightweight aircraft, many decisions were taken into consideration. However, the most stable and sufficient solution was a control system with manual override features and a system with a zero-level manual control, coupled with a microcontroller unit with a large set of peripherals and features. Such systems can be modified according to a specific design, and even after many modifications, it has an overall manual control – which allows a pilot to have a control over every part of aircraft.

The main feature of the power control system is a protection of batteries, motor, inverter systems and an awareness of their state. Such features provide us with all necessary information for current state of aircraft as well as provide a simple control on the system contents. While the system permanently monitors the state of components, zero-level parts allow to bypass protection devices in emergency situations manually. Such features are needed because all electronics is prone to failure only by a matter of time, and a sufficient provision of redundant manual functions not only provides necessary features, but also allows to increase the uptime of the whole aircraft system. To fit the evolving requirements, the most recent component base was used as well as open-source projects with broad community. The choice in favor of open-source software and hardware was made to reduce the development time while maintaining the level of quality.

The developed system is suitable both for manned and unmanned electric aircrafts because safety decisions are relevant to unmanned crafts too.

2. Power control system overview

Power control system consists of several critical and informative units. The structural diagram of the system is presented on a figure 1.
While some parts of the system do the data acquisition, there is also a main device central control unit (CCU) which contains the microcontroller boards, contactors and relays for bootstrap and cooling system. All devices in the system are interconnected with an isolated Controller Area Network (CAN) bus using ISO1050 transceivers. The isolated bus was selected to detach from all-common ground concepts and to improve the electromagnetic compatibility of devices. After the “power on” process, which is initiated by a switch in a crew/pilot cabin, the CCU shorts two contactors for batteries, precharges the capacitors and then shorts the main power contactor. After that the electric power system is ready for use. Capacitor precharging is necessary to prevent sparking of contacts, which can lead, in the worst way, to inability to disconnect the power. The main part of central control unit is a microcontroller on printed circuit board (PCB), which is a modified and reworked version of the open source project FoxBMS [2][9]. It is worth to point out that main battery management system (BMS) features (balance, charge) [5] are not so important in this device, and it does another tasks – bootstrapping the system using a precharge relay system [10], monitoring and sending to the Controller Area Network (CAN) bus all the aircraft modules data. Microcontroller unit inside has a large capability to extend the power system functionality. To fit the described functions its firmware is heavily modified. The battery management microcontroller board is connected via an isolated relay system, and then, to contactors. It can disable redundant battery lines in a case of emergency. The algorithm watches the temperatures of batteries in several points and detaches the line if temperature is passing the upper limit. However, the control system requires aircraft user attention before making critical decisions, and there is a control panel used to inform a pilot about the status of components. 3d model of the central control unit is presented on figure 2.

**Figure 1.** Power control system schematic diagram
Figure 2. Central control unit 3d model.

The main difference between the developed CCU device and BMS is that BMS controls the state of the batteries, while CCU controls, displays and stores all the telemetry data from aircraft.

Control and debug panel unit (CDPU) is made from an embedded computer Raspberry Pi, which is connected to a display and the Controller Area Network (CAN) transceiver or logger.

The flight data persists in the CAN network, and it is logged redundantly on a central control unit and on the Raspberry Pi flash card.

The power system is also connected to CAN and reports its state each 100 ms in order to provide voltage, current consumption and revolutions per minute (RPM) data.

CCU constantly monitors battery voltages and, in case of suspicious values, reports them to a pilot using the CAN messages, which are translated to the screen on the CDPU. Separate temperature measurement units report battery temperatures to the CAN network.

It’s needed to be said, in addition, that described system is implemented as a prototype and is tested on laboratory equipment.

3. Protection features

The main protection feature is using battery contactors and an automated system for their control. The power contactors should be used (e.g. Gigavac GV200 [3]). It is not permitted to increase current capacity using parallel connection of several contactors, because it can lead to excessive current in one of them, while they are closing. Power high voltage batteries have common ground with a low voltage supply, since they are used as a single power source.

Central control unit is extremely protected from any adverse factors to ensure its automated operation. All digital lines and contactor drives are decoupled from the microcontroller. Analog lines are protected with Zener diodes and other protective solutions such as using protective resistance for preventing surge over-current. Power supply is isolated from the plane electronics supply voltage and supports a very broad range of input voltages (+12 to +37V). Such voltage range is designed for compatibility with most of power sources on aircrafts.

To start the system and to override the operation of CCU the special control board was constructed, called manual override control panel. Its layout is presented on a fig.3.
To control the power plant the thrust lever controller (TLC) was developed. It is a separate device running a real-time operating system (RTOS) ChibiOS[4], and it has some features for fail-safe modes, such as arming fail-safe. Using RTOS is good for making flexible control system with many components. If a system is booting with a thrust lever high, arming fail-safe will not allow motor to start until the control system reboots with the correct lower position of thrust lever. Safety and protection features include redundant separate isolated power supply, optically isolated control signal transmitters and overall installation of protection diodes[8]. However, it might be useful to realize a completely redundant doubling of the thrust lever controller unit. TLC can be controlled from a control system shell on CDPU.

It is possible to calibrate the throttle curve, set up max, min and start point. There are auto-arming options on the TLC device. All such features provide flexibility of this unit, and thus it can be used in the high range of small aircrafts.

The brushless DC thrust motor (or motors) controller is protected using overall decoupling and uses low-impedance the Controller Area Network (CAN) bus and an optical wire, separate motor and logic power. Power stage drivers are decoupled using transformers so the logic and power parts are completely isolated in order to provide electromagnetic compatibility of the modules and the module concept itself. Such decoupling between power stage and logic power supply allows us to completely detach logic and power common grounds.

4. Zero-level control

Zero-level control is an aspect of control system that an airplane will survive and will continue its operation even after the only remaining units are inverter, motor and thrust lever. While the flight, aircraft is suspected to a set of adverse factors such as voltage surges or even a lightning strike. In this case, the described control system was designed to survive even after central control unit failure. The thrust lever in a pilot cabin is designed to receive analog potentiometer data and convert it to throttle setpoint signal, which type is Universal Asynchronous Receiver-Transmitter (UART), is transmitted through an optical wire, which can be a very long line, and it is completely protected from a surges and electromagnetic interference. It makes the system and thrust lever suitable for the wide range of electric aircrafts. If a failure of all units occurs except thrust lever, inverter and motor, the inverter and TLC remain to receive the low-voltage power and they continue to work. If a CCU failure occurs, the pilot can override its control system and connect the power to the inverter and TLC manually using a manual override control panel (MOCP). Thus, such concept allows a complex system to transform to a simpler in a case it is extremely needed.

5. Cost of CCU with CDPU approach implementation

Central control unit allows pilots of an electric aircraft to feel safe while the flight, because they can inspect all the parameters and be sure that every unit is operating correctly. The estimated price for microcontroller circuit boards in the CCU are 1000 EUR, and the remaining automatics and CDPU cost approximately 500 EUR on the market, leading to an overall price of unit of approximately 3000
EUR, which may be compared in a price with a particular industrial BMS unit, which is described in reference [5].

6. Conclusion
Implementing a specific power control system may be useful in an electric aircraft in a case when it is necessary for the pilots to monitor all the status of components, e.g. some sort of scientific tasks. It is possible to bypass all the control system in a lightweight aircraft by using manual override controller only, but this approach leaves us without the necessary data for providing an advanced aircraft safety. The described power control system is worth implementing in some sort of an unordinary aircrafts using specific power sources [6][7].
Main results of this paper are the conceptual design of power control system, zero-level control, thrust lever controller implementation in a case of an electric aircraft, and safety decisions in the proposed concept.
The cost estimation of introducing such devices in an electric aircraft is provided.
All of devices provided are realized in a real-world scale as a prototypes and now they are under testing on a laboratory equipment.
The developed system and device have a potential for upgrading and improving and the primary goals are the on-air testing and further safety improvement.

7. References
[1] A. N. Varyukhin, V. S. Zakharchenko, A. V. Vlasov, M. V. Gordin and M. A. Ovdienko, “Roadmap for the Technological Development of Hybrid Electric and Full-Electric Propulsion Systems of Aircrafts,” 2019 International Conference on Electrotechnical Complexes and Systems (ICOECS), Ufa, Russia, 2019, pp. 1-7, doi: 10.1109/ICOECS46375.2019.8949910.
[2] FoxBMS Project and documentation – Fraunhofer IISB – URL: https://docs.foxbms.org/en/latest/ (Revised: 30.08.2020)
[3] Gigavac GV200 Datasheet – Gigavac – URL: http://www.gigavac.com/sites/default/files/catalog/spec_sheet/gv200.pdf (Revised 29.09.2020)
[4] ChibiOS Project - Giovanni Di Sirio – URL: http://www.chibios.org/dokuwiki/doku.php (Revised 30.08.2020)
[5] John Corman (2017) What is Battery Management System? – Nuvation Energy – URL: https://www.nuvationenergy.com/resources/article/what-battery-management-system
[6] A. V. Geliev, A. N. Varyukhin, V. S. Zakharchenko, I. O. Kiselev and D. I. Zhuravlev, "Conceptual Design of an Electric Propulsion System Based on Fuel Cells for an Ultralight Manned Aircraft," 2019 International Conference on Electrotechnical Complexes and Systems (ICOECS), Ufa, Russia, 2019, pp. 1-17, doi: 10.1109/ICOECS46375.2019.8949950.
[7] Zagumennov, Fedor & Merzlikin, V & Radaykin, Alexey. (2020). Densely-Packed Construction for Hybrid Power Control System for Unmanned Aerial Vehicles. IOP Conference Series: Earth and Environmental Science. 459. 022092. 10.1088/1755-1315/459/2/022092.
[8] Ao, Liangzhong. (2012). Thrust Lever Angle Signal Processing of an Aircraft Engine. 10.1109/ICCSEE.2012.445.
[9] Schwarz, Radu & Müsfik, Akdere & Waldhör, Stefan & Fühner, Tim & Wenger, Martin & Koffel, Stéphane & Lorentz, Vincent & Maerz, Martin. (2016). foxBMS – Free Open fleXible Battery Management System.
[10] Akdere, M. & Giegerich, Martin & Wenger, M. & Schwarz, R. & Koffel, S. & Fühner, Tim & Waldhor, S. & Wachtler, J. & Lorentz, Vincent & Maerz, Martin. (2016). Hardware and software framework for an open battery management system in safety-critical applications. 5507-5512. 10.1109/IECON.2016.7793001.