POLYTECHNIC UNIVERSITY OF BUCHAREST
ELECTRICAL ENGINEERING DOCTORAL SCHOOL

DOCTORAL THESIS

- SUMMARY -

Cercetări privind extinderea regimurilor de zbor la vehiculele electrice fără pilot

Research on the extension of flight regimes to unmanned electric vehicles

Scientific Adviser:
Prof. PhD. Eng. Constantin GHIȚĂ

Doctoral student:
Eng. Vasile PLEȘCA

Bucharest, 2021

CONTENTS

1. INTRODUCTION

1.1 PURPOSE OF THE PHD THESIS

The drone by definition is a UAV (Unmanned Aerial Vehicle) type device capable of flying without being piloted by a person on board, autonomous or remotely controlled by a specialized operator, via a remote control.

Due to the rapid spread of drones in recent times, especially in the civilian field, since 2014 the governments of several countries are trying to develop legislation through which a precise classification of drones by categories to limit their uncontrolled access to prohibited areas or in which their presence could cause an accident by colliding with other aircraft, thus leading to loss of life. But as, in general, the presence of drones in the industry has brought significant changes in many areas, greatly facilitating the cumbersome approach used until their emergence, no matter how many limitations are imposed in the future, drones will continue to grow, eliminating, one by one, the limitations. legislative or technological [1].

The biggest problem with drones is their limited flight range, due to batteries, which have not been able to keep up with the development of other mobile technologies. Thus, one of the main purposes of this paper is to automate the loading process of multi-copter drones, without the need for operator intervention. Basically, this means increasing the flight autonomy by identifying the optimal solution for charging the batteries without having to change the batteries with a charged set, making and testing various charging systems, automatic with the transmission of electricity, by direct or wireless contact.

1.2 DRONE CLASSIFICATION - CRITERIA

The classification of drones is a very important stage which, in addition to highlighting the characteristics of various models, also differentiates drones from the point of view of legislative regulations.

➢ ***Classification of drones according to the area in which they will be used***

Due to the advantages that unmanned aerial vehicles bring in an ever-growing number of fields, drones specific to each environment have been developed, as follows:

- UAV - air vehicle without human personnel on board;
- USV - surface vehicle without human personnel on board;
- UUV - underwater vehicle without human personnel on board;
- UGV - land vehicle without human personnel on board;
- HAPS - high altitude satellites without human personnel on board.

Hybrid drones have been developed for various missions, which are able to operate in several work environments to achieve their objectives.

➢ ***Classification of drones from the point of view of aerodynamics***

From the point of view of flight aerodynamics but especially of the autonomy they are capable of, electric drones are divided into four main categories:

- fixed wing drone (airplane type), can fly easily in reconnaissance missions over very long distances (hundreds of kilometers) and at high altitudes.

- multi-copter drone. These are drones that operate over short distances with increased stability and can maintain a fixed position even at winds of 50 km / h.

- helicopter drone. This type of drone somewhat combines the main features of the two types of drones listed above.

- The balloon drone can carry a large enough number of sensors to monitor objectives and has the advantage of an almost unlimited range with an extremely high range due to the fact that on its fuselage can be mounted solar cells for recharging.

➢ ***Classification of drones from the point of view of the main field of use***

Concerning the field of use, drones can be divided into 6 main categories: drones for observation and reconnaissance, drones for transport, specialized drones for research and development, military drones with a secondary purpose, civilian-commercial drones.

➢ ***Classification of drones in terms of take-off mass (MTOW) associated with the risk of impact on the ground***

The classification of drones in terms of mass at take-off is very important especially in terms of legislation because it differentiates drones according to the expected kinetic energy in the event of an impact [2]. This energy also affects in-flight operability, including the safety of all maneuvers. Thus, they can be: micro / mini (<1kg), small (<13.5kg), normal (<4.3 tons), large (over 4.3 tons).

➢ ***Classification in terms of operational altitude associated with risk of air collision***

This classification of drones at altitude levels may decrease their risk of collision with other aircraft during flight, is divided as follows:

a) very low altitude, but the drone evolves in the visual field of the operator;

b) very low altitude, but the drone can occasionally evolve outside the field of view of the operator;

c) average altitude;

d) very high altitude.

➢ ***Classification in terms of aircraft autonomy***

This classification also has an impact on the application of legislative norms, the level of certification being a function of the autonomy of the aircraft, so of the level of navigation automation. Basically, these levels reflect the autonomy of the drone in decision making, the complexity of the mission and the environment in which it will evolve.

➢ ***Classification of drones from the point of view of the owner***

In terms of ownership, they can be public or state-owned when they are owned by government agencies, or they can be civil when they are exploited by private industry or civilians.

1.3 CURRENT STATE OF DRONE DEVELOPMENT

The vast field of unmanned aerial vehicles - UAVs or drone aircraft, as they are also known, has a spectacular development, with an impact on more and more civil and industrial activities. As with SMART mobile devices, they are incorporating more and more technological innovations, with the greatest prospects for use, both in the military and in the civilian field. If in the beginning the unmanned aircraft with fixed wing type on board were developed in the last years, the multi-engine UAV aircraft were developed quickly, which offer a series of advantages for entertainment but especially for the industrial environment. Their applications have a wide range of uses, such as audio-video surveillance, comparative recognition with database elements, GIS, monitoring and maintenance of strategic objectives, border patrol, crowd monitoring, radio relay, civil agriculture monitoring and industrial, meteorological research, environmental monitoring and surveillance, air traffic control, etc. There is a limitation in terms of electrical autonomy but solutions are being sought to extend this range. There are also limitations from a legislative point of view that reduce their possibilities of use, but through specific certifications and authorizations, these limits can also be eliminated or at least reduced. But despite all these limitations, drones are developing rapidly, this being possible both due to the technological development that led to the miniaturization of audio-video devices and sensors specific to the services they offer, which resulted in a beneficial and lower purchase price. Thus, the drone as a monitoring system has become something easy to purchase and use for many services that, in the past, were done endangering human lives. The main functions implemented on a drone use electromagnetic spectrum sensors, gamma ray sensors, biological sensors and chemical sensors, etc.

1.4 ACKNOWLEDGMENTS

As a sign of gratitude, I would like to thank all those who supported me in carrying out this work.

This paper was elaborated with the help of the Department of Material Machines and Electrical Drives of the Faculty of Electrical Engineering within the Polytechnic University of Bucharest.

I have the pleasure to give special thanks and a deep gratitude to the professor doctor engineer Constantin GHIŢĂ, the scientific leader of the paper, for the competent guidance and help brought throughout the realization of this doctoral thesis. At the same time, I also thank the Committee for guiding me for my doctoral activity, which included Prof. Dr. Eng. Tiberiu TUDORACHE, Mr. Assoc. Ion Daniel ILINA and Mr. Assoc. Vasile PETRE, for the help granted during the period of making the scientific reports related to the doctoral thesis and its final drafting.

I would also like to thank the Wing Computer Group SRL for supporting my scientific activity in the first part of the doctoral training and the Energy and EcoConcept for the second part of the doctoral training, to which I am deeply grateful for the support provided.

I would also like to thank the companies SC Solar Power and INCDE ICEMENERG for the space provided, so necessary for the intermediate and final tests.

Some of the results presented in the PhD thesis were obtained with the support of the Human Capital Operational Program, Priority Axis 6 - Education and skills within the project "Development of entrepreneurial skills of PhD and post-PhD students - key to career success" (A-Success) MySMIS code: 125125

Last but not least, I would like to thank my family for their permanent support and encouragement in order to complete this doctoral thesis.

2. USE OF DRONES IN VARIOUS FIELDS OF ACTIVITY

Drones as a concept are becoming more and more popular, and this is also due to the decrease in the final purchase price, but especially due to the accelerated advance of technologies at the level of a drone. Innovations in this field appear and are implemented in a record time, and the dimensions of the specific sensors for the missions that can be executed with the help of a drone decrease with the increase of their resolution. Missions that use drones as a support for sensors have become commonplace and services based on this technology are developing exponentially.

The presence of drones in the industry has brought significant changes in many areas, eliminating the approach used until their emergence. Below are some of the most important areas where drones have already changed for the better and how these trends will have a positive impact in the future.

➢ ***Military field***

Initially, drones were used only for military purposes to recognize targets and bomb strategic targets, being the most important innovation in the military field in recent years. Overall, the military has been, is and will be the best sponsor for many areas where innovation is present. In the case of drones, the advantages were obvious especially because their use saved the lives of soldiers and quickly provided important information in observation and espionage missions.

Another advantage of military drones is endurance, as drones can fly over 2,000 hours a year, compared to a war vehicle with people on board that can accumulate about 400 hours of operation in a year. In addition, in terms of combat equipment and features, the drone may be significantly superior to conventional fighter jets, as it provides additional space because it no longer requires the space occupied by the cockpit, the drone not having pilots. Thus, this space can be used for additional sensors or for additional loads. Also, due to the lack of personnel on board, drones no longer have limitations related to those imposed by the physical limitations of a human pilot and obviously the elimination of the risk generated by loss of life among pilots.

➢ ***The field of maintenance insurance for photovoltaic installations.***

Due to the interconnection of the cells at the level of the panels, of the panels in strings and of the strings to the inverter systems, during the operation of this equipment a series of defects can appear, some easy to see with the naked eye but others being difficult to identify, practically only when the defect has already generated major losses by spreading to other equipment or generating fires with a negative impact on the entire plant or its neighborhoods [3], [4].

Generally, in a photovoltaic installation, the defects have as a side effect, in the first phase, a local overheating. Thus, a scan with thermal imaging cameras, at the optimal angle and distance, generally detects 99% of defects. Due to the large size of photovoltaic plants and the large number of elements to be scanned, manual inspection is not efficient so aerial scanning is required while capturing images in the IR spectrum and visible. Defects are identified using specialized algorithms that take into account references previously recorded in databases such as dimensional, location and spectral references [5].

Heavy equipment equipped with a nacelle or manned aircraft is usually used for aerial scanning of such an installation. It is clear that using a machine between rows with fragile panels is not a practical solution, in addition the optimal scanning angles are difficult to achieve and especially difficult to maintain. The variant of using manned aircraft is an option, but it has several disadvantages: they are expensive and the captured images are made from a fairly large distance, within the range (30… 50) m, the distance that introduces errors in the analysis final by the fact that not all defects are highlighted. Drones have the ability to scan automatically or remotely, at predefined routes or at predefined angles, at much lower costs than the other variants [6], [7].

➢ ***The field of maintenance maintenance for wind turbines***

As in the case of photovoltaic systems, the drones used are equipped with infrared analysis and thermographic analysis sensors and high-resolution cameras, both for visual analysis and photography, and for thermal and infrared analysis. Detection of cracks and possible sediment deposits on the blades can unbalance the system and inevitably lead to damage to the entire production unit. Common defects that can occur are: structural cracks, delamination, degradation of the gel layer useful for maintaining minimal turbulence, peeling paint on the surface of the platform, the tower but especially on the blades, damage due to lightning strikes, damage to the lightning system, anomalies generated by manufacturing defects or generated by an incorrect assembly, etc. Also, in the case of wind farms as in the case of other industrial installations, it is recommended to plan aerial inspections that result in the prevention of such events, but also the extension of the operation of the entire system [8].

Normally, to identify deposits on wind turbine surfaces or structural defects are detected with ground binoculars or platforms, cranes, utility climbers, etc. are used, all of which pose risks to human personnel used for maintenance [9]. Using unmanned aircraft eliminates these risks and in addition the scanning distance, angle and resolution of image / video acquisition can be changed from the ground depending on the position of the sun or other factors in the location. The drone makes Ultra HD / 4K photo-video captures in the visible, infrared and thermographic imaging spectrum to detect anomalies in the turbine structure, which it stores locally and / or sends to the ground for further storage and analysis. With the help of this data, the ground system performs a geo-referential map indicating interactively, the intervention teams, the nature of the event, for an optimal intervention. Drones, being quite stable systems can operate in extreme conditions, with temperatures in the range of (-40 ... +60) ºC and wind up to 50 km / h.

➢ ***Monitoring the energy objectives of electricity transmission***

Overhead power line inspection (OHL) is usually done using helicopters or patrols using qualified personnel, but these methods have proven to be inefficient and expensive over time. Monitoring of high voltage networks, using unmanned flight equipment, is a major advantage over the classical methods used so far. The main features recommended by drones are: high maneuverability, ability to follow a flight plan, small drone size, high resolution scanning, low flight costs, human operator outside the risk area, large coverage area, allotted time maintenance that decreases exponentially etc. For optimal scanning, these inspections are generally done using two types of drones, one with a fixed wing that flies along the line, capturing raw data about the boundaries of the vegetation lane and possible structural problems, and the second type of drone. drone being the multi-engine drone that based on the raw data received from the first drone will perform a point scan where it signaled special events. Also, with this type of drone, preventive scans of the poles from a structural point of view or of the state of the electrical contacts can be made [10], [11].

Due to the high efficiency of drones in the inspection of overhead power lines, they are increasingly sought after, for these overhead inspections succeeding in successfully replacing the old expensive methods.

➢ ***3D measurements***

Drones are rapidly beginning to replace traditional land cadaster and topography methods. They have become so popular that many people in the field have given up the classic method of measuring the ground. Drones reduce working time, and the information captured by them is of excellent accuracy. Drones also eliminate human error involved in the process. Using the LIDAR laser scanning system, high-resolution maps can be made by remote sensing, atmospheric detection and other applications such as geographical, geomorphological, archaeological, topographic analysis and much more. The use of drones equipped with laser scanning systems is the ideal solution in the development segment that requires 3D captures of certain perimeters with high accuracy and accurate measurements of distances and angles. 3D models of industrial structures, buildings, dams and vegetation areas can be made. Through the autonomous flight system with points of interest, drones can perform flights autonomously, following the coordinates and automatically triggering photo capture.

➢ ***Agriculture***

Agriculture is an area where drones have already shown a positive impact, thanks to the many benefits that drones have already demonstrated. The problems facing agriculture are numerous and difficult to anticipate or control in a timely manner. Using a properly equipped drone system, information can be obtained quickly with the help of multispectral equipment, which easily identifies problem areas. In general, in agriculture, farmers have problems caused by drought, uneven irrigation, pests or specific diseases. All these problems can be solved simply with the help of drones and specific sensors placed on board, like multispectral cameras or high-resolution cameras. The data collected by these sensors are analyzed with the help of specialized software applications that can generate maps with the affected areas but also solutions to solve these anomalies. In addition, this data can be used directly in the positioning systems on agricultural machinery and thus the number of seeds, fertilizers, pesticides, etc., to be used to remedy the identified problems can be adjusted. Drones can also be useful for spraying fertilizers or crop protection products with high accuracy, being able to adjust the height and speed of spraying in real time depending on the direction and wind speed [12].

➢ ***Infrastructure thermography.***

Another area in which drones are being used more and more is the scanning of infrastructures in order to determine energy losses in the tire in particular. Following such a scan with specific sensors, many problems can be identified regardless of the phase in which they occurred. Thus, the performance problems due to all the construction phases can be identified: design, construction or appeared during the maintenance activities. Identifying and remedying these problems generally has an immediate effect in lowering the value of utility bills, eliminating risks to human health, but especially can prevent the occurrence of unwanted accidents [13], [14].

➢ ***Monitoring the forestry field.***

Another area where drones can be useful is the forestry area where they are used to study areas affected by legal or illegal deforestation or fires but also to plan tree planting. Drones can easily scan hard-to-reach areas, being equipped with the software and specialized sensors needed to create 3D maps of these areas.

➢ ***Inspection of bridges and various structures***

The introduction of drones in the field of inspections of various infrastructures has an increasingly favorable evolution because their use eliminates the risks for their operators or for the specialists who perform the inspections, in the classic way. In addition, they can make the inspection even from a distance and in a significantly shorter time in the case of a classic inspection where in most cases you need special vehicles, utility climbers, stairs, scaffolding, etc. [15].

Thus, using unmanned aerial vehicles of the multi-engine type, the inspection of bridges, chimneys, special structures can be done quickly and easily, having a number of advantages not to be neglected, some being given by the possibility of comparative scanning compared to previous scans. it is easy to detect any structural changes that have occurred between the two missions.

➢ ***Medical field - emergency medicine.***

The integration of drones in this field is recent, the drones are used for the beginning only over short distances for the transport of special packages that may contain sanitary materials. Frequently, drones can provide primary assistance until a human crew arrives at the scene of an event, carrying first aid kits and / or a mini defibrillator. But this mission is successful only if a viable person is present at the scene of the accident who can take over this equipment and on the basis of instructions received from the emergency service, which is at a distance to complete the first aid until the arrival of a specialized crew.

In addition, the usefulness of drones will be maximum in case of calamities or natural disasters when drones can transport drugs, food, etc. to isolated areas, increasing the chances of people assisted by such an emergency service [16], [17].

- ***The field of freight transport - delivery of orders / packages.***

In this field there is already competition between several competitors for the development of such activities using drones. So far, several solutions have been tested in several areas, including medical, an example being WALMART, which is experimenting with the delivery of food and COVID-19 tests during the pandemic using drones. Other companies that have tested this field are AMAZON, which has received favorable approval for parcel delivery activities using drones, developing the Amazon Prime service for the delivery of parcels with a mass of up to 5 kg. Another company in this field is Alphabet - Google Labs X, which has developed the "WING" delivery service that can transport packages of up to 1.5 kg over a distance of up to 10 km, a service that also applies to Europe.

- ***The field of entertainment***

The drones have had and still have a massive impact in everyday life due to the fact that all drones sold for the civil area have high resolution cameras. These cameras can easily record high-quality images or audio-video from hard-to-reach angles by a classic photographer. Thus, drones are starting to become a must-have gadget at any important event in a family's life and due to the compaction of the total dimensions, they are slowly starting to become commonplace during the holidays.

3. COMPONENT ELEMENTS OF AN ELECTRICALLY POWERED DRONE

From an aerodynamic point of view, multi-engine drones are unstable, but with the help of autopilot and aircraft-specific sensors, they can achieve perfect stability, even in improper flight conditions: wind speed up to 25 m / s, precipitation, extreme temperatures etc. Practically in these conditions the variations of parameters are extremely fast, exceeding the reaction speed of a human operator, so the control must be performed with the help of a microcontroller, which based on the information received from the sensors can ensure the stability of the drone automatically. A sketch of this system is shown in Figs. 3.1, [18], [19].

The entire assembly is a compromise between the total manufacturing price and the provision of minimum parameters that allow the fulfillment of safe flight missions, both for the transported goods but especially for the avoidance of human accidents.

Here are some examples of the main components of the drone, without going into too much detail.

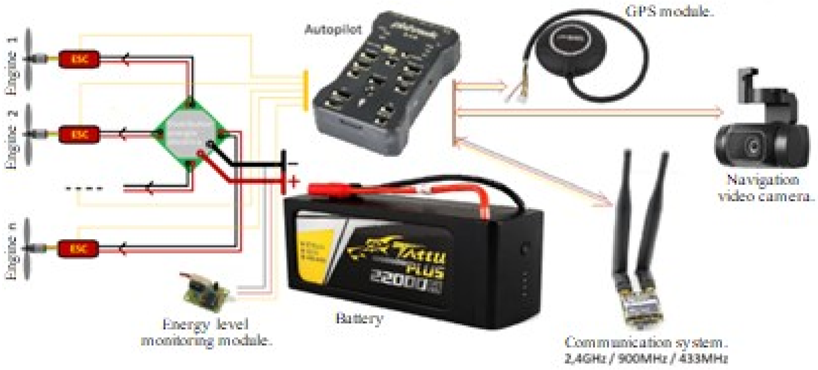


Fig. 3.1 *The minimal command scheme of a quadcopter type drone*

➢ ***Chassis and landing gear specific to multi-engine drones***

In general, the drone chassis is the main part that will serve as a support for all the other components that make up the drone. It is made of materials that are as light as possible but that can still absorb the shocks generated mainly by landings or takeoffs and that are not too rigid, there is a danger of introducing additional stresses in the structure of the drone. The most commonly used materials are aluminum and carbon fiber or combinations thereof. Plastic is also used, but only for limited elements or areas or for small, cheap drones used occasionally for hobbies, not for drones operating in the industrial, semi-professional or professional environment.

The optimal landing gear is selected according to the chassis used but especially the total mass of the fully equipped drone, including the payload carried by it.

➢ ***Navigation system - autopilot***

Autopilot is the drone's control system that makes the optimal decisions to ensure flight conditions and instant stability, according to an algorithm implemented in its microcontroller. As input data, it receives real-time information from the navigation sensors on board the drone and from the remote operator via the remote control. These sensors that make up the navigation system are:

- IMU - Inertial Measurement Unit - is an essential component of the navigation system of any drone. This is an electronic device, an inertial sensor that usually includes several components with the same structure, such as: gyroscope, accelerometer, magnetometer or compass. pressure sensor - returns the altitude value by accurately measuring air pressure at strict intervals.

- GPS - Global Positioning System - this is an indispensable sensor for the drone's navigation system, because it returns the position of the drone in space at a given time. In addition, this sensor helps to recover the drone when it loses communication with the operator, guiding the drone to an initially predetermined meeting point.

Another important sensor for the mission is the one that offers the autopilot information about the energy reserve on which it can still rely.

The remote controls used for drone control generally use proprietary protocols specific to its manufacturer, each offering a number of advantages but also disadvantages, offering longer or slower response times.

➢ ***Engine-propeller-electric driver assembly used in the construction of drones***

After the selection of the main part - the chassis, in relation to the total weight of the drone, it is very important to select an optimal engine-ESC-propeller tandem, which offers the traction and mobility of the drone in all possible flight conditions. Over time, for the propulsion of drones, from a constructive point of view, two types of engines with similar principles were used: brushed - brushed and brushless - brushless, schematically highlighted in Fig. 3.2.

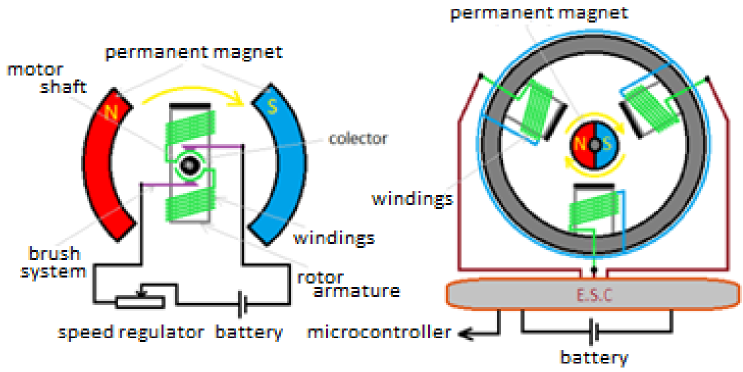


Fig. 3.2. *DC motors typical of the electric drone industry: brushed and brushless [20]*

In terms of efficiency, the brushless motor varies in the range (75… 80%), and the brushless motor varies in the range (85… 90%) [21]. In the case of classic brushless DC motors, the sequence of windings is done through a simple mechanism that includes an annular collector mounted jointly on the rotor shaft and a number of graphite brushes that directly transfer the necessary energy to electromagnets. But, although the brush motor is a simple one from a constructive point of view, which generally does not raise many problems, in the case of very sensitive electronics from a drone, the electrical contact between the collector and the brushes generates friction, noise, sparks and dissipates a lot of heat due to the electric arc that is created when switching between the respective sequences. Thus, electrical noises are generated in the electrical circuits, reverse parasitic pulses, distorting the power supply system. Other limitations also occur due to the heating of the windings, which limit the maximum engine speed, especially since they are concentrated towards the core of the engine, which makes cooling cumbersome.

Thus, in order to eliminate these limitations generated by the imperfect contact at the collector level, another constructive type of motor has been developed in which the sequence of phases is done electronically. For this, power transistors are used, positioned outside the motor and controlled via a microcontroller. Depending on the final destination of the drone, a multitude of constructive variants can be chosen. Thus, a small diameter and a higher stator means high speed of the motor-propeller assembly, with excellent maneuverability at low speeds, but a small torque. This limits the total mass that the drone can carry.

To control these motors, a specialized ESC type controller is used for each motor, or a compact one. When designing a drone, the ESC-engine-propeller assembly, which ensures the traction of a drone, must be able to provide a power reserve of at least 25% at any time during the mission, in order to compensate for any action generated on it by wind or other unforeseen situations [22].

➢ ***Choosing and sizing the batteries used to power electric drones***

Over time, several types of batteries have been used to power drones, with the greatest impact being those based on Lithium technology.

Depending on the useful mass and the autonomy necessary to fulfill the mission, the minimum capacity of the battery is dimensioned [23]. Thus, for the sizing and selection of the battery, the autonomy imposed by the respective mission parameters is initially taken into account, for ideal conditions. Thus, the main electrical parameters of the drone are taken into account, such as:

- P_{dec} - the electrical power required for the drone to detach from the ground [W];

- T - the ascending force necessary for the drone to take off [N];
- U_{bat} - nominal battery voltage [V];
- Q_{bat} - battery capacity [mAh];
- w_{drona} - the total weight of the drone without battery [N];
- w_{bat} - battery weight [N];
- t_{zbor} - flight time, minimum required / required autonomy [s];
- k_p - the reciprocity constant between the consumed power and the ascending force;
- k_b - constant energy density of the battery, given by the manufacturer.

Knowing the mathematical relations between these parameters, one can estimate the flight time for the ideal conditions:

- the electrical power required for the drone to detach from the ground:

$$P_{dec} = k_p \cdot T^{3/2} \quad (3.1)$$

- electric energy from E_{bat} battery:

$$E_{bat} = Q_{bat} \cdot U_{bat} \quad (3.2)$$

- total weight of the battery w_{bat}:

$$w_{bat} = E_{bat} \cdot k_b \quad (3.3)$$

The first condition for the drone to rise from the ground is that the force of the total weight of the system be equal to or less than the ascending force required for take-off:

$$T = w_{bat} + w_{drona} \quad (3.4)$$

The second condition for the drone to be able to move, to fly for a given time is that the electricity in the Ebat battery is at least equal to the product of the electrical power needed for the drone to detach from the ground and the time required to complete the desired mission:

$$E_{bat} = P_{dec} \cdot t_{zbor} \quad (3.5)$$

Thus, the estimated flight time for the drone is:

$$t_{zbor} = \frac{E_{bat}}{k_p \cdot \left(w_{drona} + (E_{bat} \cdot k_b)\right)^{3/2}} \quad (3.6)$$

➢ ***Technologies that underlie the most popular types of batteries***

Whether it is a mini battery with a capacity of max 100 mAh that powers a nano drone, or we are referring to packages of several cells that can reach up to 22,000 mAh or even more, used mainly on professional larger drones, in general the battery represents 20-30% of the price of the drone without including the transported sensors. This percentage does not seem to be important but the problem occurs when for various reasons during a mission, an error occurs in the supply circuit and thus the entire gear falls free resulting in most of the times material and sometimes even human damage. Thus, although the battery does not seem important, after such an incident we learn to put a high price on it.

In Fig. 3.3, the most common charging method for this type of battery is presented, where we can see that the charging profile of this method has an allure with constant current and constant voltage levels, divided into 3 distinct phases [24].

Phase I: Pre-charge. In this phase, the charging system tests the condition of the battery by monitoring the voltage and restores its passive layer which can be damaged due to incorrect storage. Thus, the battery is charged at a minimum current until the voltage rises above the minimum value imposed by the manufacturer on each cell. If the time given for this step exceeds 30 minutes, the battery is considered defective and the charging process is abandoned. In addition, if the ambient temperature is not in the range (0… 45) ºC, the start of this stage is delayed until the conditions are met. Negative temperatures favor the appearance of metallic lithium, which has as an effect, the accelerated degradation of the electrodes. Charging at temperatures above 50 degrees Celsius can lead to the battery inflating in the first phase, after which if the charging process continues, the battery may burn with a violent flame or even explode violently. If everything is in normal parameters, when the voltage exceeds the minimum voltage imposed on each cell, we move on to the next phase.

Phase II: Constant current charging. Practically in this phase the charging system will impose a constant current in the range (0.5… 1) C depending on the condition and age of the battery. This current is considered the safest for the charging process of these types of batteries, ensuring an optimal temperature level. This charging current can be increased but with strict temperature monitoring. If the temperature exceeds 50 degrees, the charging process is suspended for a predetermined period of time. This phase is considered complete when the voltage on each cell reaches the maximum voltage imposed by the battery manufacturer. This stage takes about 70% of the total time required for the charging process.

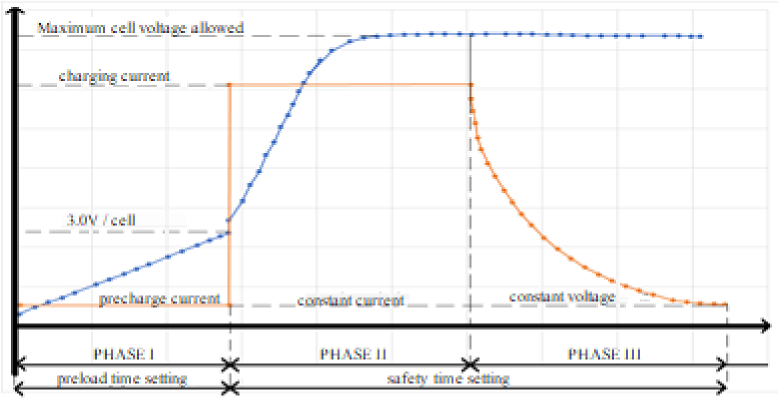


Fig. 3.3 *Charging profile with Lithium – Polymer batteries.*

Phase III: Constant voltage. In this phase the charging system will keep the voltage constant at the maximum value imposed, and the current will start to drop exponentially to a predetermined value, of (5… 10) % of the battery capacity, due to the internal resistance of the battery, which varies greatly in this stage. Depending on the quality and especially the age of the battery, the lower the internal resistance, the shorter the charging time. If a higher charging current is required and the charging time is shorter, but the battery life is significantly reduced, because the additional lithium is deposited on its anode, turning into lithium metal. It is very aggressive and extremely fast, reacting with the electrolyte, having as a direct effect the decrease of the battery life.

- ***Types of balancing systems for Li-Po battery***

Charging Lithium-Polymer batteries is a complex process that requires monitoring of critical parameters such as voltage on each cell, charging current but especially the battery temperature throughout the process. Thus, the charging system must be equipped with a special module for monitoring and balancing the cells [26].

In a first classification, the balancing modules are of two types: passive and active. In general, passive balancing consists in balancing the voltages for the two states: charged / discharged, so all cells reach the end of charging / discharging at the same charge level - SOC. This is done by connecting in parallel, on each cell, a power resistor selectively activated on the cells with higher voltage, practically dissipating the respective energy in heat. Active balancing redistributes energy from cells with a higher charge level using DC-DC capacitors or converters. A primary classification of active balancing systems can be:

• *Cell voltage balancing by charge redistribution*. This system has special circuits that are able to switch the excess energy from one cell to another cell that has a lower voltage. This way the energy accumulated in the battery is not lost, only redistributed. The difference between the previous method and this one occurs when balancing is done in the absence of a current source, this method accepting the balancing of the cells and when the charger is missing.

• *Energy transfer between cells*. This method uses capacitors to redistribute energy between cells. The system has a major disadvantage in that it takes a long time to test each cell, losing some of the energy stored in the capacitors. There is also a risk that due to the long time for monitoring and energy transfer, some cells will exceed the maximum voltage until they are scanned, there is a risk of self-destruction. However, there are more advanced systems that can group more cells so that the time problem can be partially solved, but energy loss still exists.

• *Inductive converter*. For energy transfer between cells, this system uses a power converter. Such a system is based on an algorithm that optimizes the entire balancing process giving it maximum speed and efficiency, compared to other systems, the energy transfer being done directly.

In conclusion, the ideal charger for a multi-cell battery clearly includes an active balancing type with cell-level temperature monitoring, charging current monitoring and the possibility of adjusting the voltage and charging current according to the cell temperature. But in general, due to the high costs, the most common option is a system with a passive balance, simple and cheap.

4. PRESENTATION OF THE SUPPORT DRONE DESIGNED AND CARRIED OUT AS PART OF THE WORK, AS A BASIS FOR TESTS.

In the tests performed in this paper, a quadcopter support drone was used, specially designed and built to test the developed loading system [27]. The initial parameters that formed the basis of its design are imposed by the useful mass that must transport it in stable flight conditions but also the chassis structure to allow the placement of sensors and modules in the key points of the systems that make it up. Thus, the configuration of the drone exemplified in Figs. 4.1, Quad Copter drone, with the following characteristics:

- S500 carbon fiber chassis, with a wheelbase of ϕ520 mm;
- fixed landing gear with a height of 250mm and an opening of 250x250mm;
- brushless motors with FPV 980rpm / volt;
- electronic control system - ESC, nominal 30A, BEC 5V / 2A;
- 32-bit Pixhawk autopilot;
- GPS module - NEO-M8N;
- 500mW / 433MHz telemetry system;
- 10 channel remote control;
- OSD mode and FPV camera;
- radio control 10 channels;
- Li-Po battery in 2S1P / 3S1P configuration.

The chassis of the support drone is a fairly common model, a high performance one for this class. The main body is made of carbon fiber, and the arms are made of ultra-durable polyamide-nylon reinforced with carbon fiber, a combination that gives it ideal strength and elasticity for such applications. It was selected because it is a type of modular chassis, allowing quick maintenance, being able to change damaged elements, which have suffered deformations, cracks, etc., in a short time and with minimal intervention, even during missions, due to threaded joints. In addition, it has integrated in the resistance structure and the energy distribution board used to energize the largest consumers of the drone: ESC - engines, battery system, etc.

The main elements and overall dimensions of the chassis are as follows:

• wheelbase: ϕ 520 mm;

• accepted range for the length of a propeller: 9 - 12 inches;

• mass: 420 g;

***Fig. 4.1**. Support drone specially designed for testing experimental modules*

The landing gear is a fixed one made of carbon fiber with an optimum hardness and elasticity to adsorb the shocks generated when landing and taking off the whole assembly. Constructively, it also consists of modules, which have the advantage that they can be interchanged extremely quickly, being composed of two elements that have the shape of the letter T. The two horizontal soles, which form the area of contact with the ground, are made of fiber pipe. carbon, with a diameter of 10 mm, length of 250 mm and are provided with non-slip sleeves to eliminate any slips that may occur on takeoff / landing. Also, for stability, its vertical elements form an angle of 70 degrees with the horizontal and are made of carbon fiber pipe with a diameter of 16 mm, with a length of 250 mm, joined by a threaded flange system.

A 30A ESC assembly was used for drone traction, with brushless motors that can reach a speed of 980 rpm / volt. The model used for engine speed control - Electronic Speed Control - ESC - is the HP Simonik 30A.

The engines used can provide excellent traction, for a total mass of at least 2kg, so 500 grams per unit, in conditions of optimal stability. Exceptionally, the drone can be loaded over this limit as well, but its maneuverability and stability gradually decrease.

The propellers used are within the dimensions imposed by the drone chassis, with a length of 10 inches and a mass of 11 g. In addition, they comply with the range generated by the design software. They are made of carbon fiber, covered with a protective layer of epoxy resin and are extremely impact resistant, balanced and elastic.

The autopilot used for flight control is PIXHAWK PX4 PIX, version 2.4.8, which is based on two 32-bit microcontrollers, one main and one in "hot" reserve.

In addition, this autopilot controls all additional elements of the navigation system, such as: buzzer, safety button, RGB LED, GPS + compass, etc.

The GPS used is a NEO-M8N model, compatible with this type of autopilot. It is very accurate, with a fast detection rate, including the compass needed to orient the drone.

From the point of view of telemetry, two specialized, independent systems were used to ensure a volume of information and an optimal control of the drone for any required civilian mission. Thus, for the remote control of the drone, it went on the frequency of 433MHz, with a power of 500 mW that offers a safe communication of up to 5 km, in the open field. Thus, the drone can be controlled from the remote control safely over a sufficiently large radius. Another telemetry system with which the drone was equipped is the one used for real-time video navigation. For the safety of the flight, but also of the drone, another frequency was used for the transmission of the captured images, of 5.8GHz.

5. EXPERIMENTS REGARDING THE EXTENSION OF FLIGHT REGIMES IN THE CASE OF ELECTRICALLY POWERED MULTI-MOTOR DRONES

The expansion of flight regimes, in the case of multi-engine drones, practically means the increase of flight autonomy, which can be done by several methods, but only two have a major impact on flight time. One solution may be to optimize instantaneous drone consumption by studying and comparing flight regimes during missions. Another solution would be to increase the autonomy of drones during missions by developing fixed loading systems located along its route. For this, polarized PADs for charging and a software for monitoring and / or commanding the automatic charging process are used, the method developed in this thesis.

5.1 EXTENSION OF FLIGHT AUTONOMY BY OPTIMIZING INSTANT CONSUMPTIONS AT THE LEVEL OF ELECTRICALLY POWERED MULTIMOTOR DRONES.

We cannot discuss the optimization of the charging process and especially its efficiency as long as we do not know the electrical phenomena that can occur during a mission performed with multi-motor drones and obviously the orders of magnitude of currents and voltages at the level of important consumers of a electrically powered drones [28].

To monitor and determine the energy consumption of the support drone, detailed in Chapter 4, a monitoring system was designed and placed on its chassis, in the main energy points represented by the power supply circuits of the largest consumers during a mission.

The components of the given acquisition system are chosen according to criteria specific to the aircraft: minimum energy consumption and a mass as small as possible. Taking into account these, the following were selected:

- Atmel Arduino MEGA 2560 development platform;
- current transducer LEM LA 55-P / SP1, 0 ÷ 100A, with high precision;
- SD Card mode, for saving local data;
- RTC DS3231 mode, clock mode, used for synchronizing stored data;
- voltage dividers, used for reading voltages in the microcontroller;
- serial communication mode: nRF24L01 (2.4GHz, PA + LNA) plus external antenna;
- ± 12Vdc symmetric switching source for power supply of current transducers;
- switching source, descending, for the general supply of the system;
- drone communication system - Arduino for measurement synchronization.

In this experiment at the level of the drone energization system, several main modules were defined, which combine hardware and software parts, in order to be able to easily determine the general consumption. Thus, in Fig. 5.1. the following modules are identified:

• *drone stability module* - composed of ESC type controllers - Electronic Speed Controller, varies the speed on the n engines that make up the propulsion / traction system of the drone, depending on the commands from the stability controller and the navigation module. The stability controller makes sure that the load of each engine is optimal, so that the drone is stable and does not fly chaotically, in the absence of specific commands.

• *drone navigation mode* - communicates with the operator through coded radio frequency channels, implementing the commands generated by it through the drone control console on the ground. Together with the previous module and the GPS sensor located on the drone at the highest level, it makes sure that the flight is smooth and at a fixed point.

• *data acquisition module* - consists of a series of sensors necessary for the determinations proposed in the project objective, a raw data storage module on SD Card of the acquired data and a raw data transmission module, to a central remote storage point, to the ground.

• *drone systems power supply mode*. Lithium Polymer batteries are used to power these systems, which have the ability to ensure a very high current for a short period of time, without being structurally damaged.

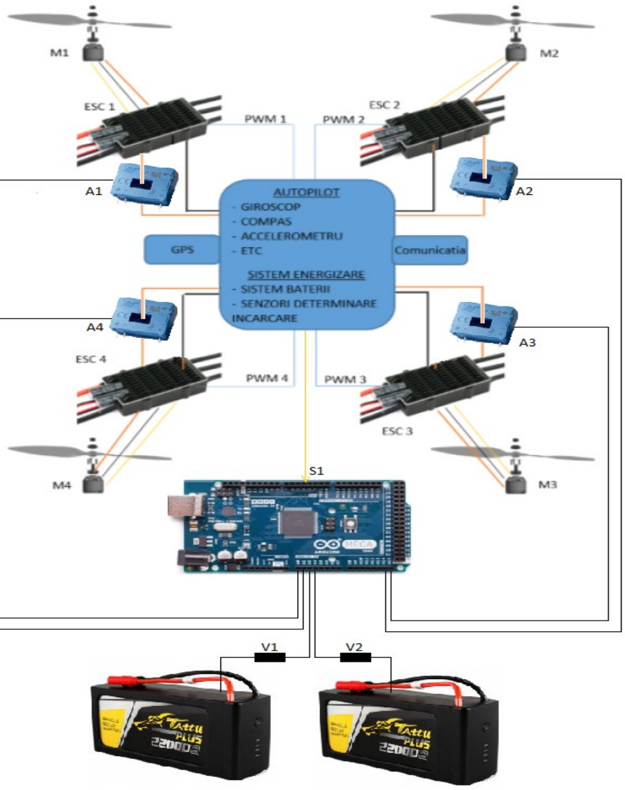


Fig. 5.1. Wiring diagram of the acquisition system on the battery consumers

The most dynamic parameters are those of the propeller - Motor - ESC tandem, so that on each motor the consumed current was measured, using the LEM LA 55-P / SP1 current transducers mounted on the ESC - battery circuit, more precisely at the output of the board. electric power distribution. To determine the power consumed in real time, we inevitably also need to measure the voltage at the battery terminals. Thus, 2 resistive voltage divider type voltage transducers were mounted on their terminals.

The other consumers on the drone: autopilot, GPS, communication system, etc. were neglected, estimating their constant consumption at an average of 6W like 5V / 1.2A.

All of these values were acquired and processed with the development board using analog inputs that have a resolution of 10 bits, sufficient for such somewhat slow variations. All purchased data was synchronized with locally recorded values on autopilot, which signals the acquisition system when the drone is energized.

➢ ***Results and conclusions of field tests***

The measurements were made in the area of Brasov, where a classic mapping mission was simulated. The average altitude of the drone during the mission was around 50 m above the ground and about 550 m above the level of the Black Sea. The duration of a mission was about 10 minutes, with a useful observation time of 6 minutes, making several passes to alternate several flight regimes.

During the flight the drone was controlled in several flight modes: short turns, aggressive, long turns, fast accelerations, slow accelerations, etc., at a constant altitude within acceptable limits. The route followed is highlighted in Figs. 5.4, and during the flight the meteorological conditions were good, the wind being gentle without major variations of speed and direction.

The main quantities purchased by the autopilot during the flight are shown in the following figures and represent the voltage level at the battery terminals. 5.2 and the level of the total current consumed by the battery Fig. 5.3.

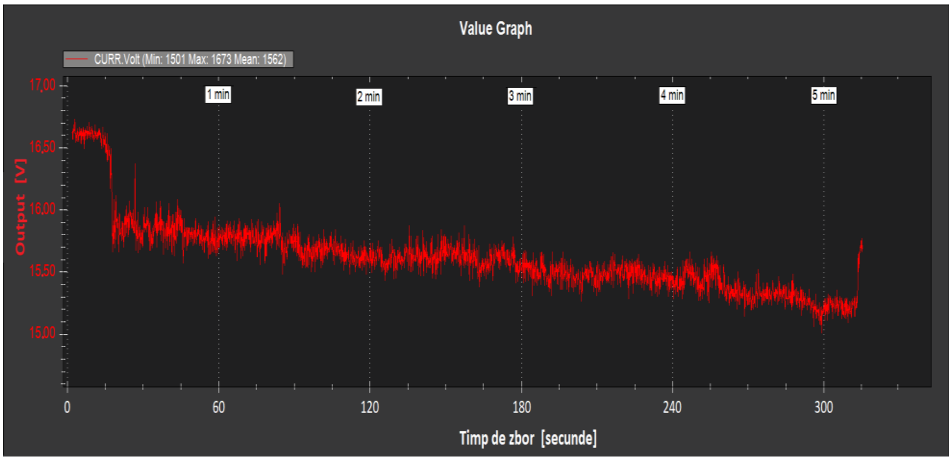


Fig. 5.2. *Voltage at battery terminals - AUTOPILOT values*

As can be seen, the voltage drops slightly during the execution of the mission, but it must be borne in mind that there is no additional consumer on the drone other than its electrical components that ensure its functionality and the system of acquisition and monitoring of operating data that can be neglected. problem, having an extremely low consumption compared to the general consumption.

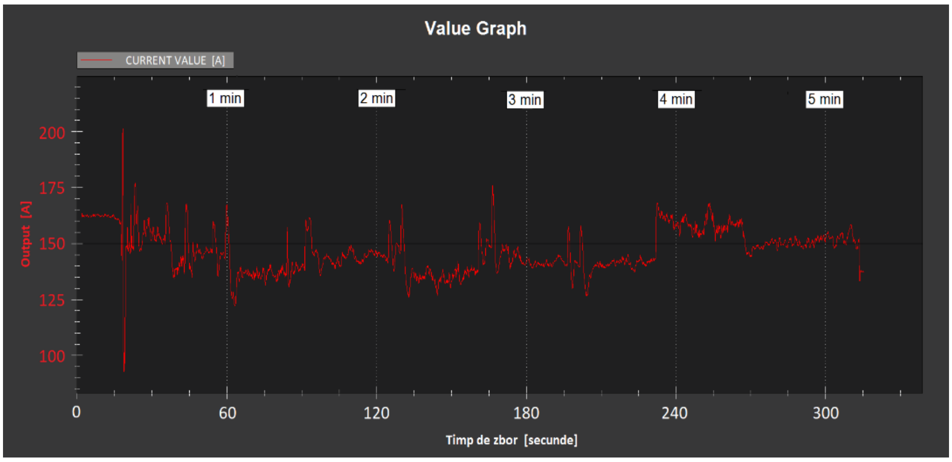


Fig. 5.3. *Total current extracted from the battery - AUTOPILOT values*

The most spectacular evolution is that of the electric current, which as seen in the following graph, coincides somewhat with the changes in altitude and direction of the drone (Fig. 5.4), which is natural as long as the largest and most important consumers of a drone. Multi copters are the engines that ensure the stability so necessary for a classic mission of observation or mapping of land surfaces where any deviation from the route can compromise the measurements made by introducing additional errors.

Fig. 5.4 *Defining observation points for main drone electricity consumption systems*

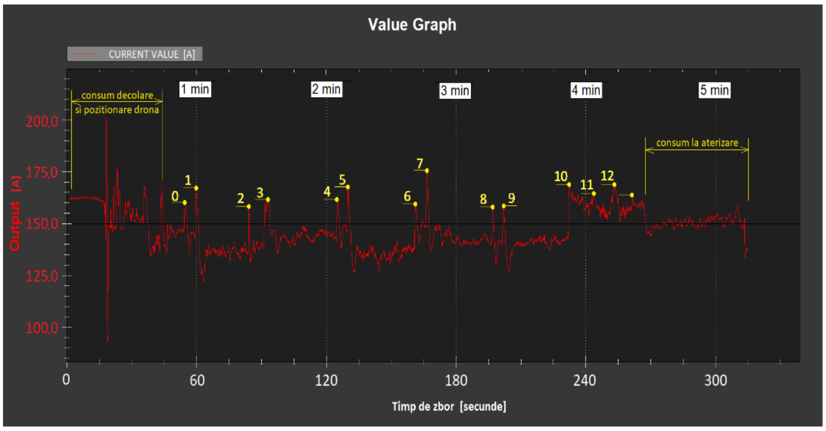


Fig. 5.5*. Maximums of current consumed in relation to the change of direction of travel*

The implemented system tries to increase the flight autonomy of multi copter drones by analyzing several flight regimes and by comparison to determine the most favorable flight behavior in terms of energy efficiency without affecting the accuracy of the mission to be performed. The values acquired with this system are partially exposed in the following graphs in which regions correlated with the various simulated regimes on the drone used were extracted.

Having all the parameters on the same graph, conclusions can be drawn much more easily, so that in the graph in Fig. 5.6 were displayed: the total current consumed by the drone system, measured on the battery terminals, the current consumed on each motor M1 ÷ M4 measured on the input terminals in the ESC for each engine and by difference was also displayed the total current consumed by Autopilot the consumption of the sensors connected to it, the consumption of the acquisition system and the consumption of the monitoring system located on the drone.

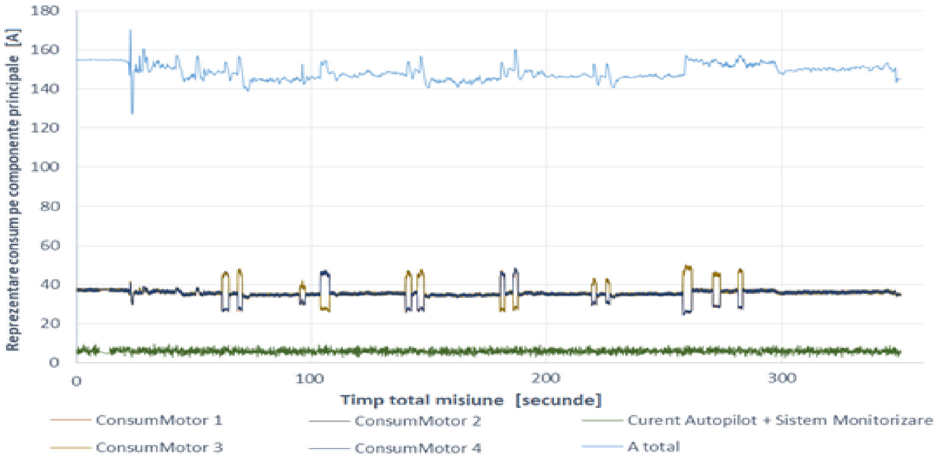


Fig. 5.6 *Real consumption of main consumers placed on the multi engine drone support.*

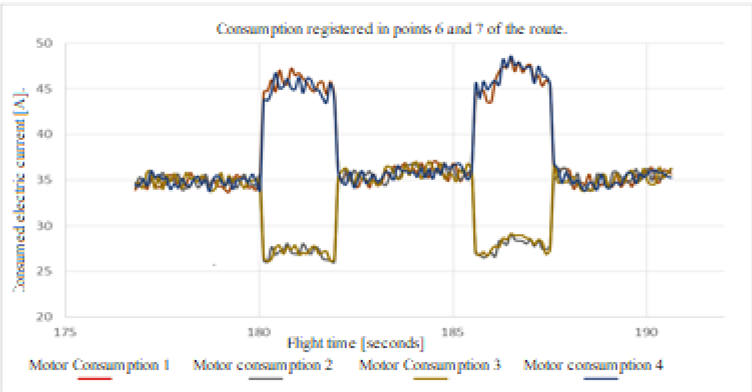


Fig. 5.7. *Actual consumption recorded in points 6 and 7 of the route characterized by precise flight with turns at right angles*

Thus, on the graph we can see the evolution of consumption on the drone's engines to change altitude and change direction, but more importantly you can see the difference between the flight regimes tested during the mission. Thus, in the previous graphs, the turns from points 8 and 9 were made on a wider contour without claiming right angles, as in Fig. 5.6 we can see that on these turns the consumption was at least 10% lower than in those with a right angle. For graphical exemplification by comparison the main peaks represented by turn changes were represented in two distinct figures: in Figs. 5.7, two right angle turns, represented by points 6 and 7 and in Figs. 5.8, two other turns represented by points 8, respectively 9.

Obviously, this economy only applies where the flight plan does not involve fixed point turns. Thus, for missions that do not have such a restriction, such turns can be pre-programmed in the flight plan, which in total bring quite significant current savings and which can extend the mission time by at least 10%. Thus, in the case of a mission involving many turns of this kind, the extra time can increase by as much as 30%, which is very important in this growing industry.

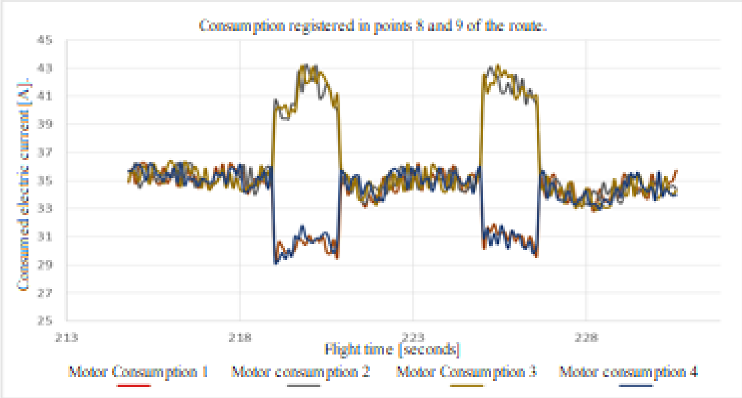


Fig. 5.8. *Actual consumption recorded in points 8 and 9 of the route characterized by precise flight but turns taken as wide as possible around the reference point*

Other energy savings can be made if the change of altitude is avoided very often because in these conditions the engines increase their speed and implicitly the consumption by 10 to 40%.

5.2 EXPERIMENTAL MODELS CONCERNING AUTOMATION OF CHARGING PROCESS OF DRONE BATTERIES ELECTRICALLY FUELD, WITHOUT DECOUPLING THEM

In this paper, several methods of automating the process of charging Li-Po batteries were studied, without disconnecting them from the support drone, having as main objective the increase of autonomy for each mission performed. Thus, several variants of charging PADs were studied and designed to automate the process, using direct charging with physical contact, but also wireless charging using induction coils.

These charging PADs can be mounted in the area of interest, and the drone will be "learned" to self-manage in terms of energy consumption by structuring the flight time with the possibility of self-charging with electricity by positioning independent on these loading PADs. Examples of preferred areas for the installation of these PADs are the roof of inverters in the case of photovoltaic parks, the roof of monitored buildings in the secure perimeter, the poles of power lines or the roof of monitored power stations, etc. [29].

The general scheme of principle is highlighted in Figs. 5.9 and is grouped into two distinct main modules with well-defined functions:

• module A - contains the elements mounted on the ground on the fixed loading pad;

• module B - contains the elements mounted on the drone.

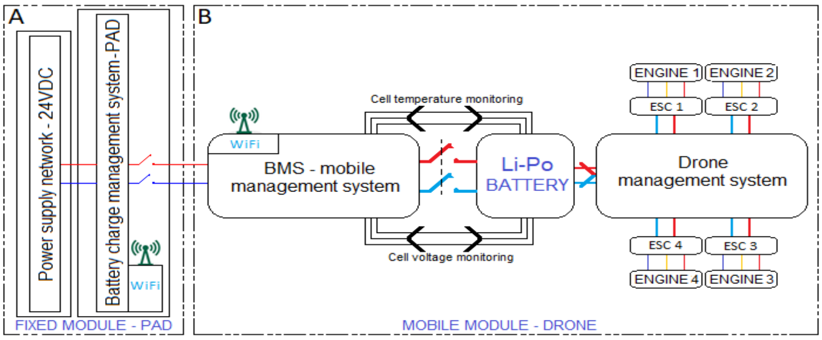


Fig. 5.9. *General scheme of drone loading system principle*

➢ ***Description of experimental stand with direct contact - laboratory testing.***

Being an experimental stand, for the laboratory, gauge limits were introduced, everything being limited to drones with a maximum landing gear opening of 600 mm. Other limitations are those related to the maximum voltage level, 3S1P, foe example a nominal voltage of 11.1 Vdc and a maximum of 12.6 Vdc. The whole system is based on a direct contact between the drone's electrical system and the loading area by means of probes installed on the drone's landing gear. The fixed contact areas of the stand are made of 2 mm thick copper sheet to ensure a perfect contact between the poles of the system. All monitoring systems, including protections, have been doubled according to the recommendations of the IEEE 1625-2008 standard, virtually eliminating the occurrence of an error or problem created by the failure of some sensors [30].

Broadly speaking, the stand developed in this section, tests the electrical parameters of the drone, sets the level and the charging current after which the charging process starts, constantly monitoring the whole process [31].

To select the best solution but also the safest method of charging these types of batteries, we studied the charging process managed by several specialized chargers on two batteries with different characteristics and capacities: one with two series cells - 2S1P, 7, 4Vdc, 5300mAh, 30C and one with three serial cells - 3S1P, 11.1Vdc, 10,000 mAh, 15C, both consisting of a single string in parallel.

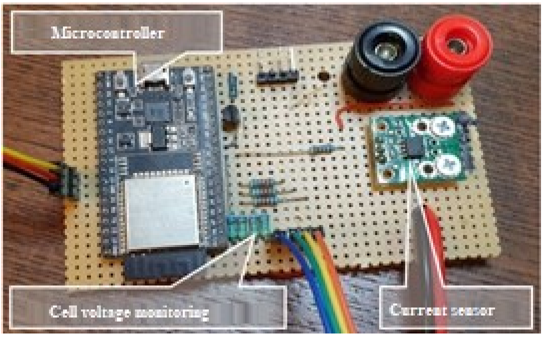


Fig. 5.10. *Experimental mode for monitoring battery / charger parameters during the charging / discharging process.*

Also, three different power chargers were selected for the tests: 50 W, 200 W and 300 W, respectively, among the most used in the field, for the two types of batteries selected. These chargers have also implemented specialized circuits for automatic battery management focused on the passive controlled balancing of the charge level on each cell. For this, an experimental module was developed - Fig. 5.10, which monitors all parameters at the battery level but also at the charger terminals, during the entire period of the charging / discharging process. A 32-bit microcontroller is used for data acquisition and monitoring [32], and an external reference voltage source - TL1431IZ produced by STMicroelectronics has been installed for the acquisition of analog signals with the best possible accuracy.

The monitored parameters are: the electrical voltage on each battery cell, the electrical voltage at the battery terminals, the charging / discharging current and the battery temperature.

• The voltage of the cells that make up the battery. Precision resistors with voltage resistors were used to read the voltages related to the cells that make up the battery.

Reading these voltages using a microcontroller that uses a 12-bit ADC for analog inputs has an advantage over other conventional solutions because the measurement range is divided into 212 discrete values, for example in 4096 samples, and the measurement is much more accurate, in this case.

• Electrical voltage at the battery terminals. This voltage coincides with the voltage previously measured, Ucell2 in the case of a 2-cell battery in series - 2S or coincides with the voltage Ucell3 in the case of a 3-cell battery - 3S. When the charger is connected to the battery, it will coincide with the value of the voltage at the charger terminals, which is generally about 10% higher than the maximum battery voltage - 13.5 Vdc for a 3S battery and 9.0 Vdc for a battery with a 2S configuration.

• Charge current measurement. To measure the charging current, it was decided to use a linear Hall effect current sensor, which can measure electrically isolated, which allows the sensor to be inserted anywhere along the current path. The ACHS-7121 sensor used is a bidirectional sensor with a measuring range covering the entire required ± 10A with high accuracy and reliability: typical total output error of ± 1.5% at room temperature with factory calibration, a voltage extremely stable output and almost zero magnetic hysteresis.

• Battery temperature. One of the most important parameters in the process of charging a battery is its temperature during the charging / discharging process. In the case of the BMS (Battery Management System) implemented on the drone, the temperature reading is done with the digital temperature sensor DS1820, which has a measuring range between (-55… + 125) ° C, enough to monitor lithium technology batteries and a resolution of up to 12 bits. In Fig. 5.11 are presented some images during the tests highlighting the 2 batteries used to energize the drone:

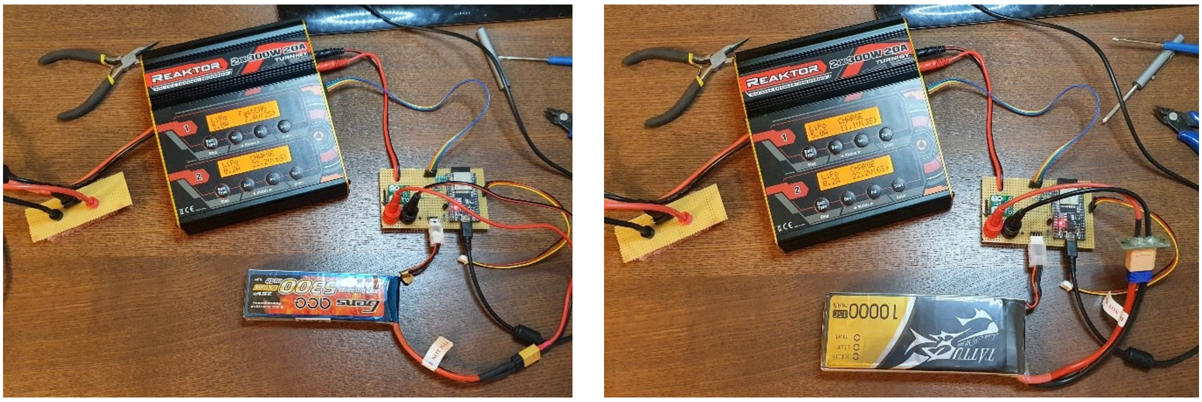


Fig. 5.11. *Images during the tests highlighting the monitoring system and the 2 batteries used.*

From the analysis of the preliminary data, results at the end of the tests performed, the architecture and the algorithm that is implemented on the experimental stand were designed. In Fig. 5.14 we can the image of the mobile module located on the drone which includes a specialized BMS. The algorithm developed using the results of this test, is based on the most common method of charging the Li-Po battery, using the constant current / constant voltage method and which practically follows the alignment of the charging curve in Fig. 3.3, previously exemplified in Chapter 3. This method has three main phases: preload, constant current charging and constant voltage charging.

Phase I. In the preload phase, the temperature of the ambient environment and the battery pack that was formed were first tested. If the temperature is not in the optimum temperature range (0… 45) C, the charging process is delayed. The beginning of the charging process at low temperatures favors the appearance of metallic lithium, which means the accentuated degradation of the electrodes that form a cell, and in case of a temperature above the upper limit it results in the accelerated degradation of the cell and implicitly of the battery. If the temperature of the cells is within the accepted limits, then the charging process begins, charging the battery at a rate of 10% of the nominal charging capacity, until the voltage reaches the threshold of 3.0 V on each cell. Basically, in this phase the integrity of the cells is tested, thus regenerating the passive layer, which is affected if the battery has been stored for a longer period of time. If the cell voltage does not reach the first voltage threshold within a maximum of 30 minutes, then the charging process ends with an error, because structurally or chemically the cells are compromised. If the voltage on each cell exceeds the 3.0 Vdc threshold then the charging process enters phase 2.

Phase II. In this phase, in the tests performed, the charging rate was set to 1C, the temperature remaining within acceptable limits for the test battery. The charging process remains set on these parameters until the voltage on each cell reaches the maximum prescribed by the battery manufacturer, which in this case is 4.2 V. And in this phase the evolution of the temperature is followed. If the temperature exceeds the maximum threshold, the charging process is suspended until the temperature drops below 45 Celsius. When the voltage reaches the prescribed value, it enters phase III. During this phase, the balancing system monitors the voltage of each cell, taking care that it does not exceed the required maximum.

Phase III. In this phase of the charging process the current begins to decrease exponentially at a predetermined minimum current and the voltage is adjusted to remain at the maximum reference values mentioned in phase II. The current decreases naturally due to the internal resistance of the battery up to a value of (5… 10) % of the charging current specified on the battery, when the implemented algorithm interrupts the charging process, considering the battery fully charged. For battery safety, this condition can be doubled by measuring the voltage on each battery cell. If all cells reach 4.2V, then the charging process is complete.

To test this theoretical algorithm, a prototype platform was built, and is exemplified in Fig. 5.12. Subsequently, based on the results obtained on it, a loading stand optimized from several points of view was built. Thus, all the facilities developed and tested on this pilot platform are detailed in the next paragraph, where it is presented directly on its improved version. The major difference between the two versions is that for this prototype the Arduino Mega 2560 microcontroller was used, which has a working frequency of 16 MHz, and in the optimized version a 32-bit miniature microcontroller was used, with clearly superior characteristics.

Another difference between the two variants is that for the protection of the battery in the charging process, in the initial variant a BMS system was used extracted from a low power charger, in which there was no possibility to be monitored or controlled from distance, and in the optimized version a special one was created, at the level of the drone, at which various functions were implemented for its monitoring and control.

Thus, to simplify the entire charging / discharging process performed with this optimized experimental stand, the whole process was divided into two distinct modules, one mounted on the drone battery, so, it is mobile, and another fixed near the two polarized landing areas, which controls the whole process. In the end, everything aims to reduce the final weight of the module installed on the drone and increase the autonomy of the missions by charging the drone's batteries in semi-automatic mode, without the need for a human operator to disconnect them from it.

The system components are simple but work in tandem according to a well-developed algorithm that responds efficiently to events that occur during the loading / unloading process [33]. According to the place where they are placed in the system, they are clearly divided into two distinct modules, one mounted at the stand, and the other placed on the drone, on the battery holder. For example, these components and their placement within the system are highlighted in Fig. 5.18 and Fig. 5.19. For the acquisition and monitoring of data and the control of the loading process, autonomously, for each module a 32-bit microcontroller was also used, as presented above. It weighs 10 grams, extremely small size and several communication interfaces: GPIO, 2xiI2C, Wi-Fi, Bluetooth, Bluetooth Low Energy, 2xI2S, 3xUART, USB micro, SDIO, 3xSPIO, the most important of which is the Wi-Fi interface, because this allows the exchange of data between the two modules, in a transparent regime, over a distance of at least 150 m. On these microcontrollers were implemented two software, based on the ESP_NOW protocol that allows an exchange of data between the two modules automatically, stable and at extremely good transmission speeds. In addition, on the fixed base microcontroller, a Web Server was implemented with which the user can take control of the entire process through a WEB interface.

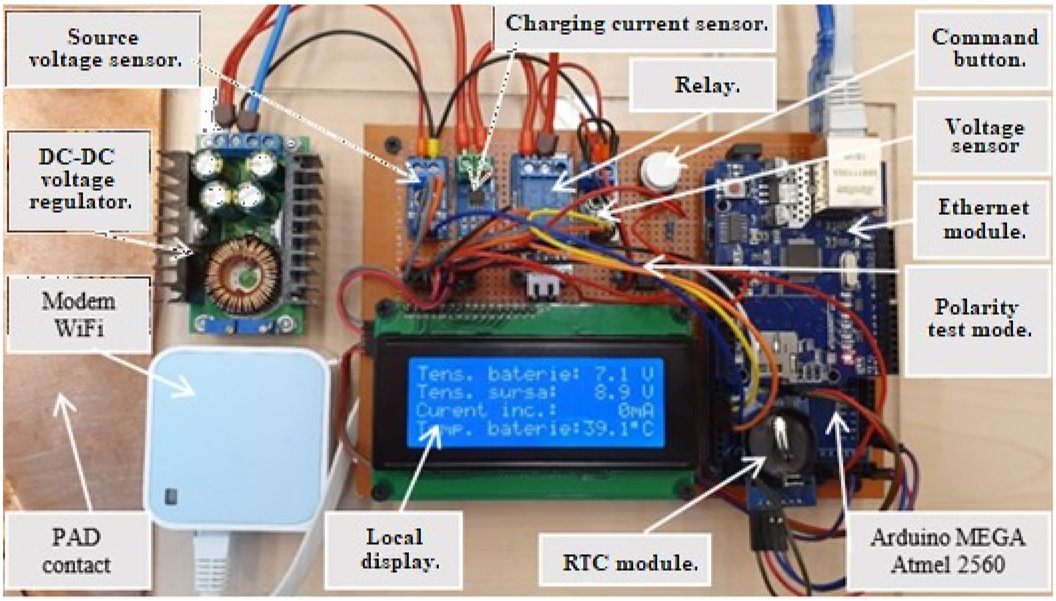


Fig. 5.12. *PAD monitoring and control module – prototype*

Through the HTML interface developed in this experimental model, the user can view and analyze in real time or offline the values of each sensor, displayed using sliders, which have the advantage of providing important information on the limits initially imposed by the user. The interface returns in real time, through an intuitive graph, the status of each value purchased: normal state - green slider, default state - orange slider and fault - red, and all errors are stored in the database and transmitted to the operator. If the user preset limits are exceeded, the microcontroller temporarily stops the charging / discharging process until the values return to normal or until the error is validated / reset by the operator, depending on the fault classification in the implemented algorithm.

A. Module located at the level of the drone - MOBILE MODE

The module located on the drone effectively deals with the protection and management of battery charging / discharging but also has the role of protection of the drone served. When designing this BMS, it was taken into account that it should be compact and as light as possible, because the introduced system does not want to decrease the main characteristics of the test drone: the transport capacity but especially the maneuverability of the drone. The final shape of this module is shown in Fig. 5.14.

The user has the possibility to start or stop the charging process whenever he wants, locally or remotely, regardless of the state of charge of the batteries. Another advantage is that it can decide whether to put the battery in standby mode - storage, in case of not using the drone for a longer period.

Thus, the parameters monitored at the drone level are:

- the electrical voltage on each cell in the battery structure.
- electrical voltage at the battery terminals;

- the electrical voltage of the charging source, connected to the module, by means of the probes;

- electric charging / discharging current on the main circuit;

- battery temperature;

• Electrical voltage at the battery cell terminals. Precision resistors with precision resistors were used to read the voltages related to the cells that make up the drone's battery.

All voltages are read relative to the GND (-) of the battery, so that:

- the voltage on cell 1 is:

$$U_{cell_1} = V_{cell_1} \cdot \frac{3{,}3 + calibrare}{4096} \quad [Vcc] \tag{5.1}$$

- the voltage on cell 2 is:

$$U_{cell_2} = \left(V_{cell_2} \cdot \frac{3{,}3 + calibrare}{4096}\right) - U_{cell_1} \quad [Vcc] \tag{5.2}$$

- the voltage on cell 3, in the case battery 2 being tested 3S1P, with 3 cells is:

$$U_{cell_3} = \left(V_{cell_3} \cdot \frac{3{,}3 + calibrare}{4096}\right) - U_{cell_2} \quad [Vcc] \tag{5.3}$$

where:

- U_{cell} is the cell voltage measured in volts;

- V_{cell} is the voltage acquired in discrete values;

- calibration - the calibration of the analog input used for the respective acquisition taking into account the standard voltage provided by the reference voltage source and the gross calibration performed by comparison with the voltage read on a precision multimeter.

- $4096 = 2^{12}$ represents the resolution of the ADC, for example the number of discrete values in the measurement range corresponding to the maximum voltage accepted on the respective input, which in this case is 3.3 Vcc.

• *Electrical voltage at the battery terminals.* This voltage coincides with the previously measured voltage U_{cell2} in the case of the 2 cell battery in series - 2S from which the voltage U_{cell1} is no longer subtracted or coincides with the voltage U_{cell3} from which U_{cell2} is no longer subtracted in the case of using a 3-cell battery - 3S. When the charger is connected to the battery, it will coincide with the value of the voltage at the charger terminals which is generally about 10% higher than the maximum battery voltage - 13.5 VDC for a 3S battery and 9 VDC for a battery with a 2S configuration.

• *Electrical voltage at the terminals of the charging source.* This voltage represents the voltage collected from the charging PAD using the two polarized probes, installed on the landing gear of the drone, highlighted in Fig. 5.13. For its acquisition, a voltage divider consisting of precision resistors is used, as well as for measuring voltages on cells. This is useful for setting a safe charge voltage level and is compared to the voltage at the battery terminals before starting the charging process.

• *Charging current measurement.* The ACHS-7121 sensor was used to measure this parameter, and its description and the measurement scheme used to acquire the charging / discharging current is the one described previously in the experimental module.

• *Battery temperature.* Also, for measuring the temperature, the sensor described in the experimental module mounted in a metal rod with UV protection and excessive humidity is used.

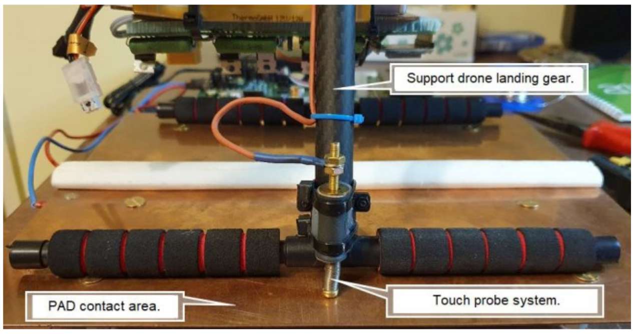


Fig. 5.13 *Scheme of direct contact system between PAD and the drone – experimental feeler*

Also with this sensor, the initial temperature of the battery pack is checked, before the start of any charging session. According to Lithium-Polymer battery manufacturers, if their temperature is below zero degrees Celsius, the charging process presents risks for the battery and its environment, there is a risk of destruction of the battery / batteries. Thus, the start of the charging process is postponed and the power supply of an electric heating element is ordered, which is initially mounted solidly on the battery.

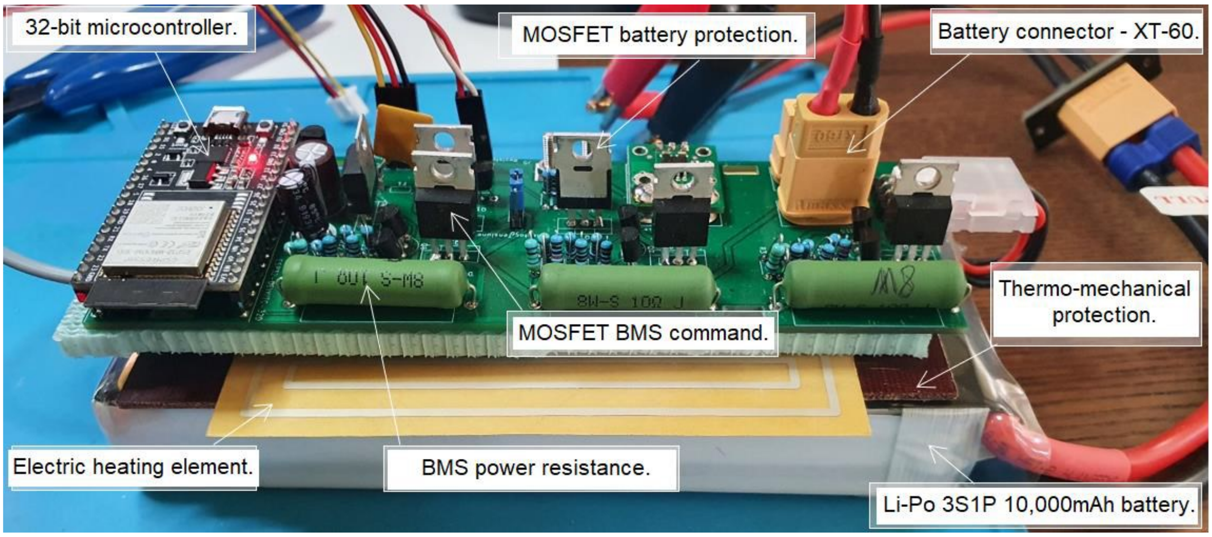


Fig. 5.14. *Compact battery module, BMS module and heating element*

All commands implemented in this module are given through the microcontroller according to an algorithm presented below and executed using power MOSFETs that have the advantage of a minimum mass compared to other types of control elements with the same characteristics: voltage and switched current.

Also, the BMS implemented at the level of the drone is a simple one and is based on a very precise monitoring of the voltages on the cells that form the battery [33]. When the difference between these voltages is greater than 50mV, on the cell / cells with higher voltage a power resistor is coupled in parallel, so the charging current on that cell decreases by slowing down the charging process strictly for them, allowing others to reach at the same charge level. If during the monitoring period the voltage of any cell increases above the maximum accepted threshold of 4.20 VDC / cell, the whole process is stopped, and the balancing of the cells will be completed on the next charging cycle. Fig. 5.15 exemplifies the control scheme for the BMS located on the module on the drone, at cell level, using a minimal interface between the microcontroller outputs and the MOSFETs used.

In the previous diagram, the +Vbat symbol represents the maximum voltage level related to the battery configuration used and is correlated by a jumper hardware selector as follows: 2S battery >7.4 VDC, 3S battery >11.1 VDC, reaching the maximum value of 8.4 VDC and 12.6 VDC, respectively, when the battery is 100% charged.

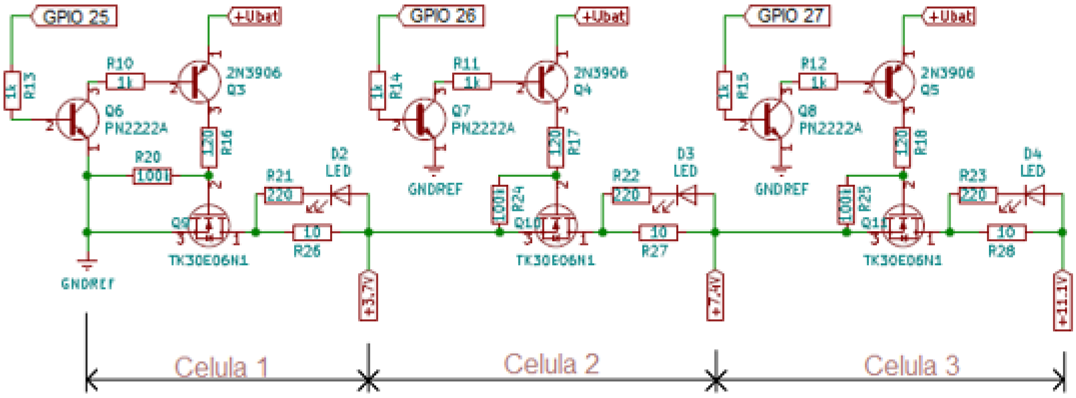


Fig. 5.15. *Passive battery cell balancing control module – BMS*

All these parameters are transmitted to the microcontroller on the fixed PAD, which together with the information collected from its sensors, quickly makes decisions for the protection of the battery but also the drone by default, stopping charging when the situation requires it.

B. The module located at the level of the fixed base - FIXED MODULE

It is located on the ground, on the charging base and has the task of providing the voltage and electricity required for the entire charging process, while doubling the monitoring and protections related to the charging process. Also included in its configuration are the PADs used as a base for landing the drone but also as an electrically polarized active area for electricity transfer to the BMS installed on the drone. The PADs are made of 2 mm thick copper sheet with a high purity of over 99.9% in order to ensure the tightest possible contact between the probes mounted on the landing gear and the fixed base. The probes are also made of copper and the connection between them and the module placed on the battery is made with a multi-wire conductor with silicone insulation. The final shape of this module is shown in Fig. 5.16.

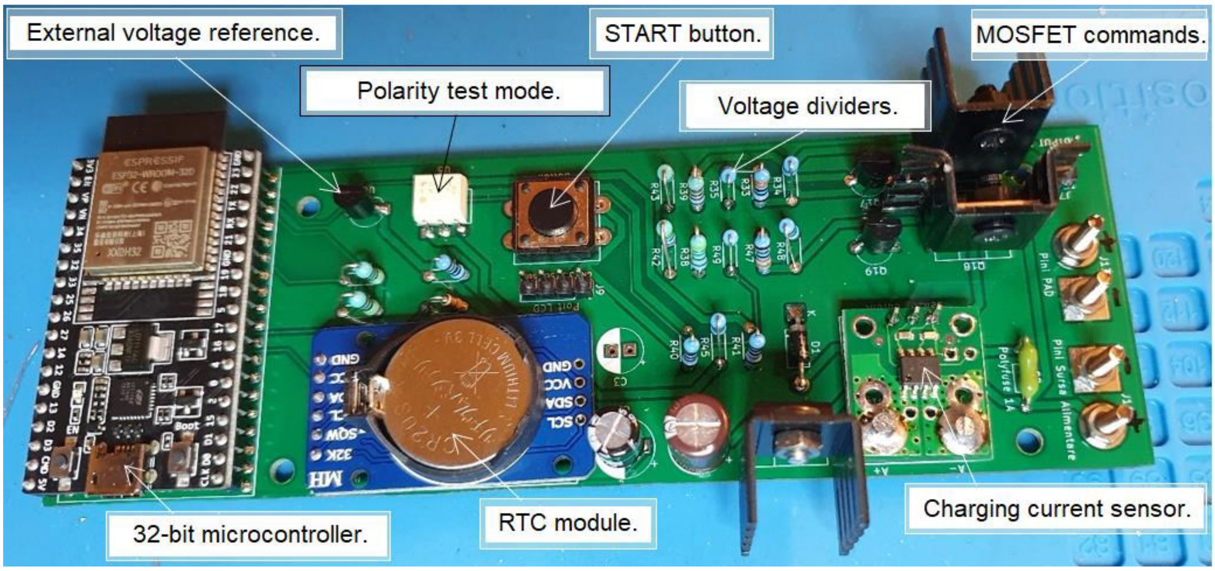


Fig. 5.16. *PAD monitoring and control module*

The parameters monitored at the PAD level are:

- the electrical voltage at the battery terminals collected by means of contacts formed by the two probes and the polarized PADs;

- the electrical voltage of the source used for the charging process;

- electric charging / discharging current on the main circuit.

• *Electrical voltage at the battery terminals.* This voltage is taken over by the contacts formed by the two probes mounted jointly with the landing gear and the polarized fixed PADs, using the same voltage divider scheme, used in the case of the experimental module and the analog input GPIO35.

• *Charging current measurement.* This parameter is also measured according to the description made in the test module described in the previous subpoint, using the same type of sensor and the analog input GPIO27.

Other equipment in the test scheme at the PAD level are:

• *Circuit for sensing the current* direction between the PAD system and the drone battery Fig. 5.17. This module is very important because reversing the current at the terminals of a Li-Po battery causes it to self-destruct. This simple circuit provides the microcontroller with information about the position of the drone on the charging pad by identifying the direction of the current flowing through the optocoupler.

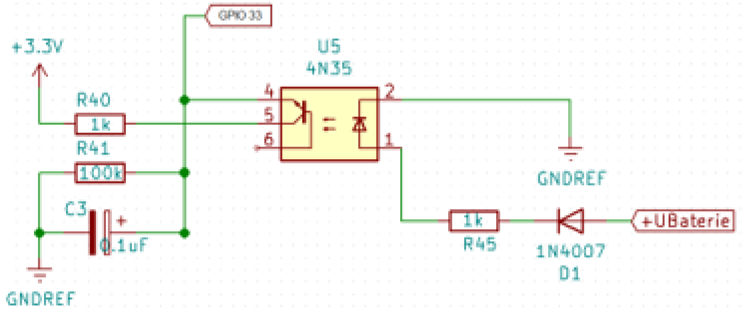


Fig. 5.17 *Battery polarity testing circuit connected to the charging PAD*

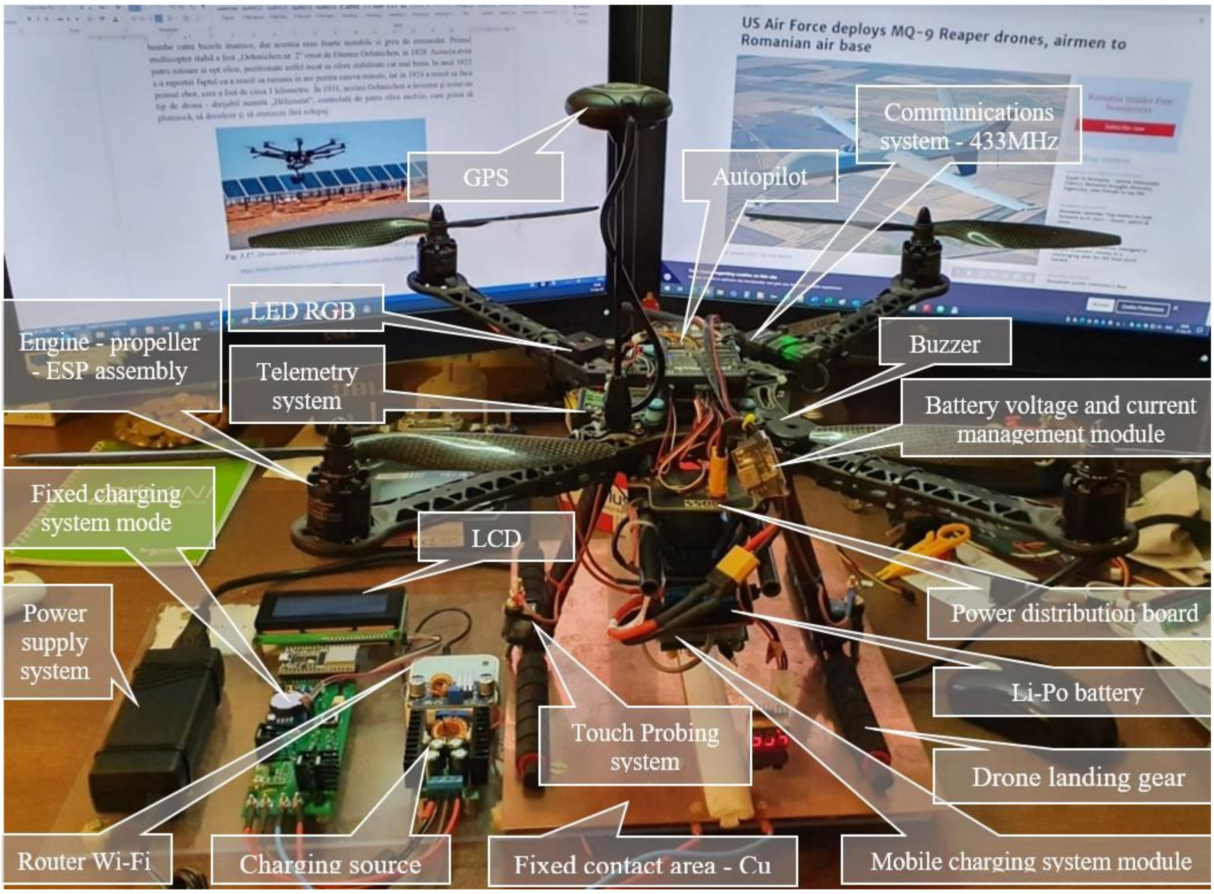


Fig. 5.18 *Drone assembly + charging system during tests – I*

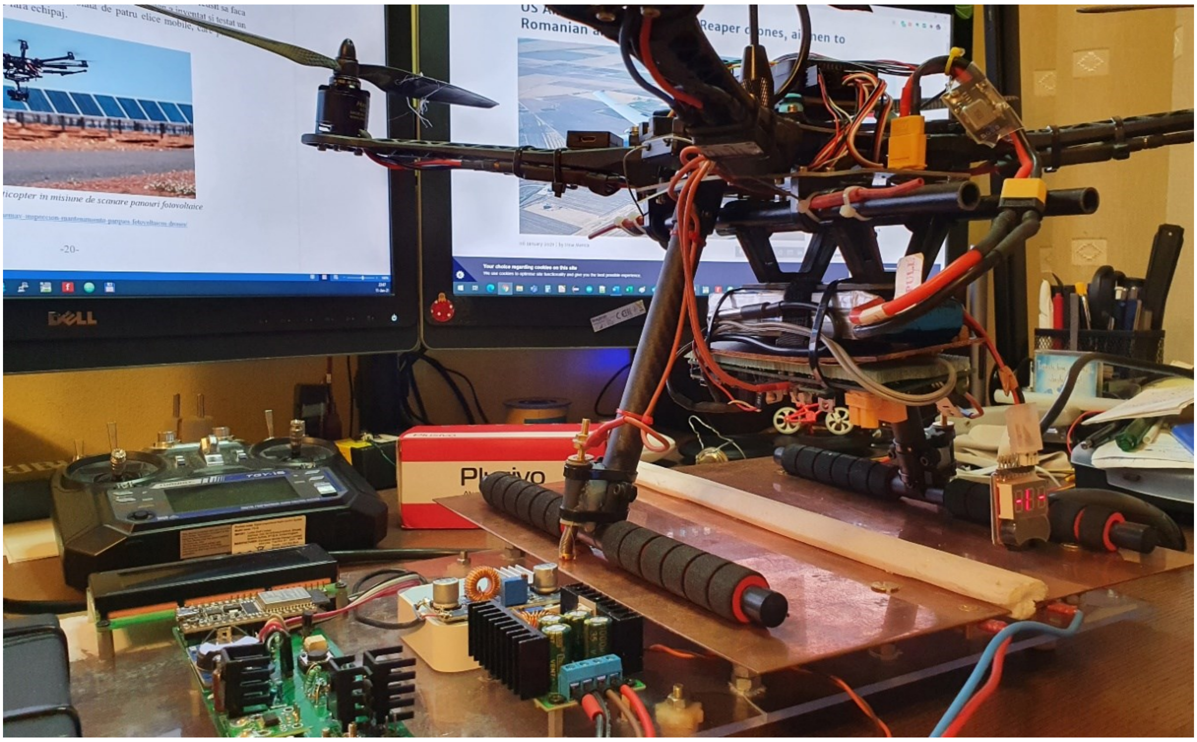


Fig. 5.19. Drone assembly + charging system during tests.

➢ ***Description of user interface, developed for monitoring and control of the charging system, locally or remotely.***

The user interface runs on the microcontroller of the fixed module located on the ground, where a web server has been implemented, to which a maximum of 7 distinct users can connect simultaneously.

The interface consists of two main screens, the first screen in which the interface starts is exemplified in Fig. 5.20 and represents the area where the user can see the status of the system and all its parameters, grouped according to the basic functions they have within the system.

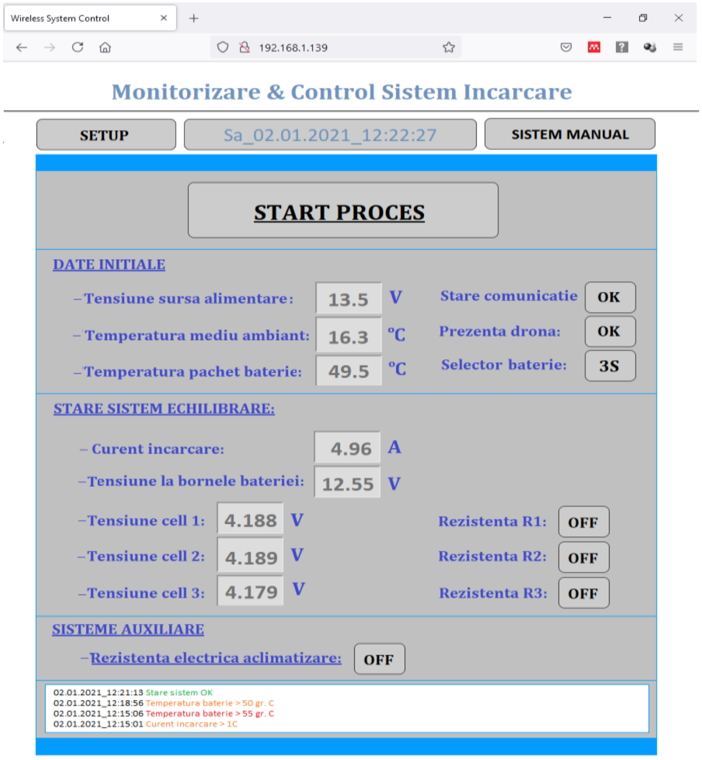


Fig. 5.20. User interface for charging process – main screen

Thus, the following can be monitored: power supply voltage, ambient temperature, battery pack temperature, charging current, voltage at battery terminals, voltage at cell terminals, communication status between the two modules, electrical resistance status used for battery preheating, condition cell balancing system, battery polarity status, drone presence at the charging PAD, battery type and configuration.

Fig. 5.21. *Balancing system status - signaling resistance status balancing cell 2*

Each value is easily visible in a well-defined contour, the background of which is colored according to its state: light gray if the value is in an acceptable range, orange, if the value is close to a fault threshold - Fig. 5.22 and red if the value exceeds this predetermined threshold - Fig. 5.23. In this case the loading process is interrupted and the "START PROCES" button is deactivated to avoid initiating any command. Also, the status and color of this button is changed depending on the status of the system parameters. If the system is turned on, the color of the button is green, and the message "SYSTEM ON - 120" appears on the button, where the numeric value represents the elapsed time from the beginning of the charging process, in seconds. If one of the parameters enters the default zone, this button will be colored orange, and the message on the button will be maintained depending on the system status: "SISTEM ON - 1980" or "START PROCES". If any of the initial conditions are not met, the loading process is reset and the button is colored red with the message "PROCESS ERROR".

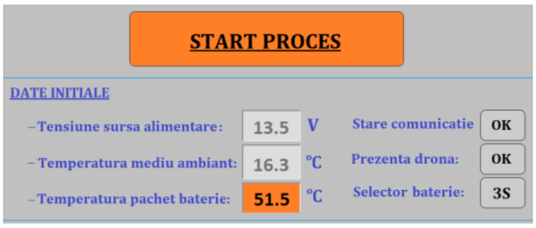


Fig. 5.22. *Upload process signaling user interface*

Also in this screen, at the bottom of it, are displayed the last four events that occurred during the process, the rest being stored in the network or local database, in text format, on the SD card.

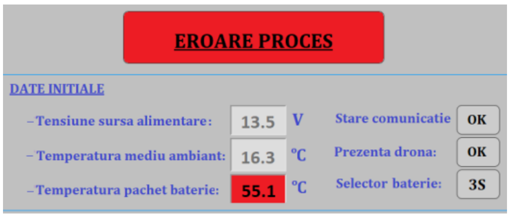


Fig. 5.23. *Charging process user interface - fault signaling*

Clicking on the "SETUP" button enters the second screen of the interface, Fig. 5.24, where the user can set four automatic start times of the charging system by selecting the desired days and the hour and minute at which it will test the battery status and keep it ready to start missions at any time.

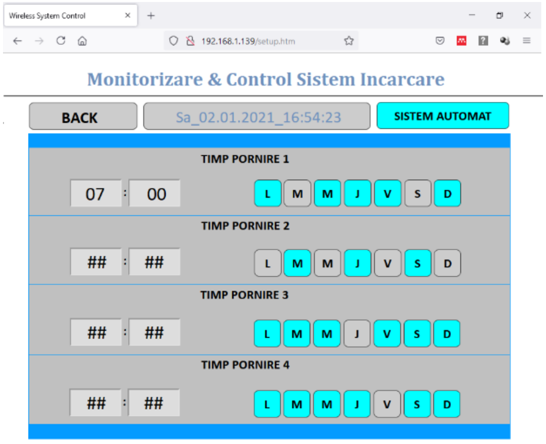


Fig. 5.24. *Charging process user interface - secondary screen*

By ensuring an internet connection, the user can monitor the system and control the whole process, from anywhere he can access an internet connection, thanks to the protections integrated in it.

5.3 EXPERIMENTAL STAND FOR TESTING - CHARGING / DISCHARGING A LARGE-SCALE BATTERY.

For testing the experimental stand in real conditions, several modifications were made to the fixed PAD - Fig. 5.25, because in real field conditions, the support must withstand an impact with the equipped drone, which can have a total mass of up to 25 kilograms, a mass not to be neglected. Thus, the entire assembly was transferred to a structure made of a hard plastic material called polyamide, which is distinguished by its special characteristics: hard structure with good resistance to long use in aggressive environments, a good thermal insulator and especially electrical, essential quality in this case [34].

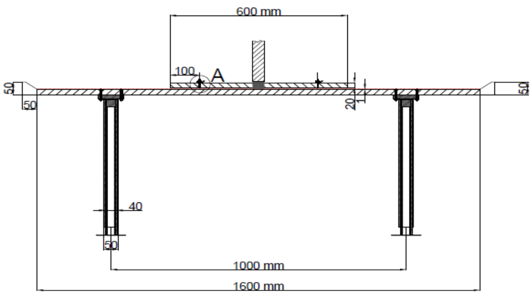


Fig. 5.25. *PAD construction sketch loading with direct contact - side view.*

A copper plate with a thickness of 2 mm was mounted on the polyamide support plate, which represents the landing surface but also the polarized poles of the system, necessary in the loading process - Fig. 5.26.

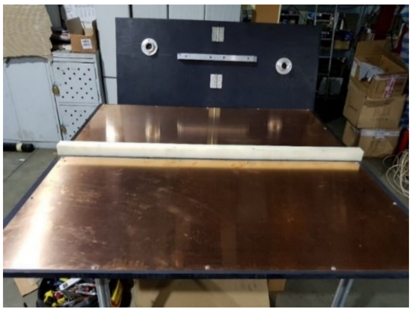


Fig. 5.26. *PAD support charging with direct contact, with highlighting of the active surface.*

6. RESEARCH ON THE WIRELESS TRANSFER OF ENERGY REQUIRED BY THE CHARGING PROCESS.

In order to reduce the errors that can be caused by the direct contact system between the fixed PAD and the landing gear using spring probes, the work also performed tests for wireless energy transfer using specialized kits.

Four methods of wireless transmission of electrical power between two well-defined points in the immediate vicinity, described below, have been identified.

➢ *Capacitive coupling.* The wireless transmission of the electric power is done by the capacitive coupling of two electrodes, positioned in two relatively parallel planes, as in Fig. 6.1.

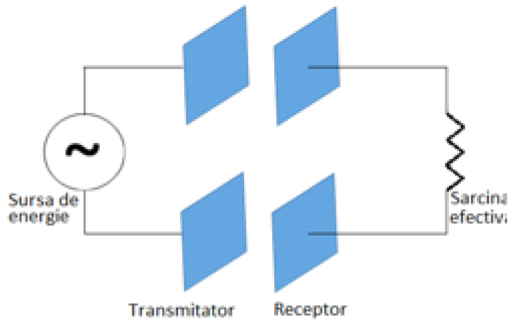


Fig. 6.1. *The principle of wireless transmission of electricity - Capacitive method*

As seen in Figs. 6.1, the wireless transmission of electricity using the capacitive coupling method takes place through the electric field (displacement current) using two identical sections having each capacitance C. One of the main advantages of using the electrostatic transfer method over the inductive method is that the placement the device to be charged on the basis of charging is more advantageous.

➢ *Electromagnetic induction.* The wireless transmission of electrical power is done by the current induced by a magnetic field between two coils at a sufficient distance for the losses to be acceptable (Fig. 6.2).

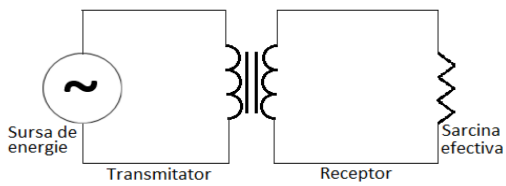


Fig. 6.2. *Wireless transmission of electricity by inductive method.*

As seen in Figs. 6.2 wireless transmission of electricity using the inductive coupling method takes place via the magnetic field, the most conclusive example being the similarity with current or voltage electrical transformers, with the exception that non-contact open core energy transfer applications are preferred here or complete lack of core. Instead of a core made of a ferromagnetic material, such as for use in a transformer, our device uses an "air core". Similar to a transformer, these devices use one coil for transmission and another for reception and only operate on alternating current. In short, the variation of the magnetic field from one coil induces a current in another coil near it.

➢ *Magnetic resonance imaging.* The wireless transmission of electric power is done using the phenomenon of magnetic resonance which is based on the whole principle of electromagnetic induction. The condition for which magnetic resonance imaging performed is that the two coils and the field generated in their vicinity oscillate at the same frequency. If the two coils are not resonant, the energy transfer is not performed. The advantage of this method is that in combination with the inductive coupling method it can reduce electricity losses by incorrectly positioning the two coils.

➢ *Radio waves*. The wireless transmission of electrical power is done through radio waves that are transmitted and received with the help of special antennas. Generally, microwaves generated by terrestrial transmitters and received by rectifier antennas are used to convert this signal into electric current. This method is suitable for wireless transmission of electricity, punctually, over long distances, even going so far as to wirelessly power spacecraft directly from Earth.

6.1 RESEARCH ON WIRELESS POWER TRANSFER TO INCREASE THE AUTONOMY OF ELECTRICALLY POWERED DRONES

In order to reduce the errors caused by the direct contact system between the fixed PAD and the landing gear, specialized putties for the wireless transfer of electricity were tested during the work. The kit used is composed of two distinct coils, transmitter and receiver, respectively, each with a transmission conditioning and synchronization module (Fig. 6.3).

To test these modules, the transmitter coil was connected to a stabilized voltage source of 12 Vcc, and the current was kept constant at 1A. The receiver coil is connected to a consumer with a supply voltage of 5 Vdc and a maximum electrical power of 10W.

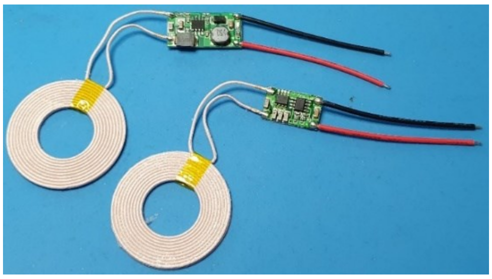


Fig. 6.3. *Wireless power transient module kit - 5 V, 2 A maximum*

In the circuit thus formed, the relative position of the two coils was changed in a controlled way, starting with the placement of the perfectly parallel coils and increasing the distance between them, in vertical plane, from mm to mm, keeping the parallelism of the two coils constant. The evolution of the electrical parameters in the system was followed with an emphasis on the transmitted electrical power, and the obtained measurements are represented in Fig. 6.4.

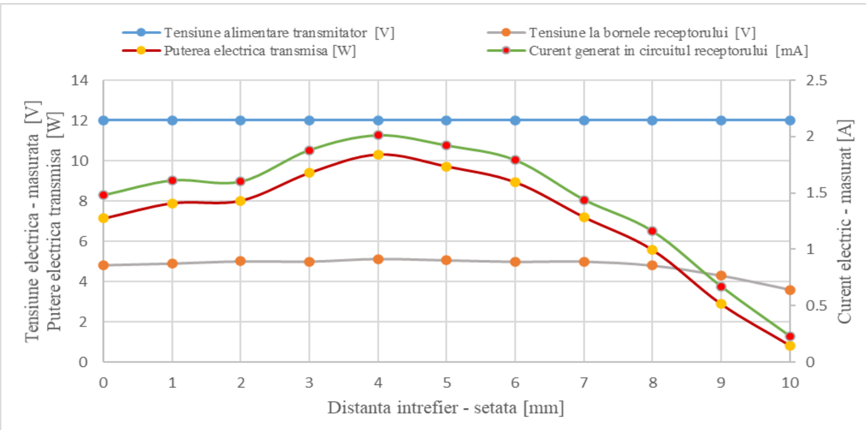


Fig. 6.4. *Graphic evolution of the tests performed on the wireless electricity transmission kit by varying the air gap between the two coils in the vertical plane*

The second stage of the tests was the relative movement of the coils in the horizontal plane starting from the perfect overlap of the coils and their placement at a fixed distance of 4 mm. As in the previous case, the 1 mm step was kept, and the results can be seen in Fig. 6.5.

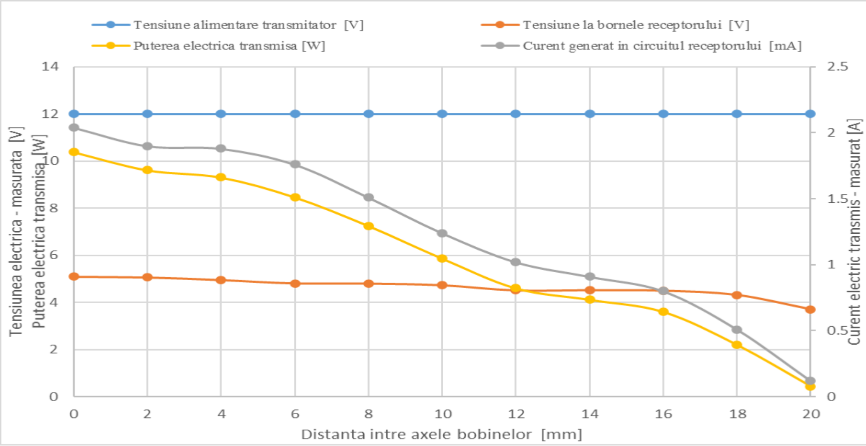


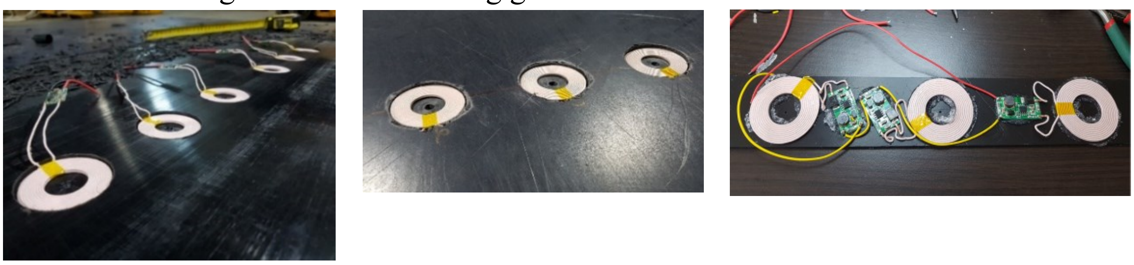
Fig. 6.5. *Graphic evolution of the tests performed on the wireless power transmission kit by moving the coils horizontally*

As can be seen from the two graphs, Fig. 6.4 and Fig. 6.5, the relative position of the two coils that form the putty, transmitter and receiver, is a vital one for the energy transfer efficiency. A deviation of a few mm vertically and one of more than 1 cm horizontally causes the process of electricity transmission to be limited or even interrupted.

6.2 TESTING SYSTEM FOR CHARGING / DISCHARGING LI-PO BATTERY, USING WIRELESS TRANSMISSION OF ELECTRICITY.

To remove the probes from the scheme of the experimental stand, for the wireless transmission of electricity were used the putties presented in the previous paragraph. They are based on the wireless transmission of electricity, through the effect of electromagnetic induction, using ready-tuned coils with a very good efficiency. In this kit, the optimum transmission distance is in the range (3… 6) mm, in the vertical plane, and in order to have an optimal efficiency the coils must be aligned very precisely.

The electromagnetic energy emitted by these putties can easily penetrate through non-ferromagnetic materials, so it was decided to keep the support from the stand developed in the previous chapter, for which polyamide was used as the base material. The transmitter coils were embedded in these plates, as can be seen in Figs. 6.6, arranged at equal distances and in identical numbers for each leg of the drone landing gear.



a) Transmitter coils plugged into the fixed PAD

b) Receiver coils plugged into the drone landing gear

Fig. 6.6. *Arrangement of the transmitter coils on the charging system.*

Using these putties, the alignment of the drone on the fixed support is no longer critical, and by arranging the transmitter coils on the support plate it was ensured that the receiver coils are permanently aligned with at least 6 transmitter coils thus ensuring the power required for the loading process. The receiving coils were placed on the soles of the two legs of the drone's landing gear, strictly respecting the location and distances from the transmitting coils [34].

7. ORIGINAL CONCLUSIONS AND RESULTS

➢ ***General conclusions***

In this paper, drones in general have been analyzed, with an emphasis on the analysis of several possibilities to increase the autonomy of their missions. The main developments in this field were presented and several possibilities to increase the autonomy of missions performed by multi-engine drones, without modifying too much from a structural point of view the platforms on which these drones are built. The experimental verifications performed on the support drone, validated a good part of the theoretical results that were the basis of the initial idea and that were tested in this paper.

The paper addresses a modern field of civil and industrial UAVs and the optimization of the lithium-polymer battery recharging process. Lately, drones have become increasingly important in many fields, which until recently were accessible only to specialists, at extremely high costs. There are limitations in their development, their autonomy depending on the total mass at takeoff but especially on the energy system, the quality of the batteries, which failed to keep up with the accelerated development of mobile equipment in general. An autonomous, automatic or semi-automatic multi-engine drone battery recharging system can greatly expand the areas in which they can operate. Also, the elimination of the human operator that was supposed to be present on site, in order to replace the batteries with some preloaded ones, can improve and automate most missions that have as a scenario objective monitoring or predictive maintenance services, remotely supervised by a human operator.

The idea of creating an automatic charging system consisting of two synchronized modules, one mobile containing a specialized BMS, mounted on the drone and another fixed located at the level of the charging PAD, located in a fixed point on the ground, helps to increasing the autonomy of the missions ensuring the energetic autonomy of the drone by automating the loading process, located on the drone route.

Chapter 1 of the paper presents an introduction to the issue of the doctoral thesis. The history of drones, the current stage of their development, a complete classification of drones from several points of view are briefly presented: the field of use, the effective mass of the drone, the autonomy of operation, from a military point of view and others. It also highlights the main legislative texts that govern this area. Thanks are given to those who helped the author of the paper in the theoretical and experimental studies undertaken.

Chapter 2 presents a comprehensive analysis of the areas in which these drones excel and highlights the advantages and disadvantages of their use in these areas. Particular attention is paid to the field of maintenance for various industrial equipment such as photovoltaic installations, wind turbines, power transmission lines and telecommunications poles. Other objectives achieved in this chapter refer to the monitoring of military and civilian objectives, drone applications in the medical field, transport and entertainment.

Chapter 3 presents the main components of a multi-engine drone system and the main sensors frequently used in their missions. Here the emphasis was on the main consumers of a drone that can directly influence their level of autonomy: the propeller-engine-ESC assembly and the navigation system. The main features of the batteries that power the drones and the sensors and transducers that help to understand the safe loading / unloading process have also been reviewed.

Chapter 4 presents the main parameters of the support drone, specially designed and made for testing the modules developed in this paper. Virtually all its systems are monitored and communicate with the fixed charging base to optimize the charging process, and the batteries that power this drone are the target of this research.

Chapter 5 contains most of the original contributions made in this paper. The measurements made in the area of Brașov, where a mapping operation was simulated, are presented. The instantaneous values of the voltage and of the absorbed current are recorded, both for the case of the normal movement of the drone and for the cases in which its direction of movement changes suddenly. Two distinct methods by which flight autonomy can be increased were examined, but it is also demonstrated how flight times can be increased without having to disconnect the batteries from the support drone. Thus, an experimental loading system consisting of two electronic modules is presented that supervises and controls the entire loading process without affecting in any way the mission performed by the support drone. The transmission of energy to the batteries located on the drone is done, by direct contact, by means of probes mounted on the landing gear of the drone.

Chapter 6 analyzes some elements of wireless transmission of electricity used to charge batteries located on the drone, but also an experimental stand for testing these processes.

Chapter 7 presents the main conclusions regarding the chapters presented in the thesis, then lists some of the most important original contributions made by research conducted in the paper, and at the end of this chapter the main directions for further development of research presented in the paper are presented.

- ***Original contributions***

The paper deals with a constantly expanding topic of interest, the drones are in an accelerated development, due to the multiple advantages they bring in many areas, to the end user, at lower and lower costs and risks. Increasing the autonomy of missions specific to multi-engine drones greatly increases their development horizon, the direct benefits being immediate. In general, it has already been shown that using drones for dangerous areas and areas eliminates the risks that may arise when using a conventional solution.

The main original contributions of the doctoral thesis are the following:

• Presentation in a compact way of the history of drones with emphasis on the current stage of development of unmanned aircraft on board and systematization of the main features according to the current legislation in the field;

• Presentation of the main areas in which drones already excel, depending on the impact they bring to daily life;

• Presentation of design hypotheses for multi-engine drones and systematization of the main useful information for design, development and use of multi-engine drones.

• Design and practical implementation of a multi-engine drone used as a test base for research on the expansion of flight regimes.

• Development of experimental modules for evaluating the consumption of a multi-engine drone and optimizing the energy management system, which immediately results in increased flight autonomy.

• Design and construction of an autonomous charging stand, multi-engine drones, to increase the autonomy of missions. Thus, two miniature modules were created that take information during the charging process and generate clear commands, depending on an algorithm implemented in their microcontrollers. Basically, the transmission of energy to the battery module is done in two distinct ways: one with direct contact, very firmly using probes and another based on a wireless solution, using specialized putties.

• Increase flight safety by increasing flight regime.

• Development of specialized software for the use of the drone in different situations, for optimizing the energy consumption of the drone, for ensuring a safe operation of its various elements, for achieving an optimal working regime both in terms of travel routes and protections to be ensured in the normal operation of the drone.

➢ ***Perspectives for further development***

• Completing the technical solution of the autonomously developed charging system, with innovative positioning solutions with increased precision and extending the range for the protection of the battery and implicitly of the aircraft on the entire mission;

• Increasing the wireless transmission distance of electrical energy by testing several wireless energy transmission solutions, using the knowledge gained from the practical realization of the drone used for experiments in the work.

• Extending the solution developed in this paper to another field in full development: that of electric cars. Charging the batteries of the electric car autonomously, transparently, without human intervention, is desired by any user.

8. BIBLIOGRAPHY

[1] **PLEŞCA, V.**, Liliana DELCEA, and C. GHIŢĂ, "*Vehicule electrice aeriene fãrã pilot – drone*", in SIMPOZIONUL DE MAŞINI ELECTRICE SME'17, vol. 2017, Link acces: https://portal.issn.org/resource/ISSN/1843-5912.

[2] VALAVANIS, K. P., G. J. VACHTSEVANOS, D. FELIX, and J. EVANS, "*Handbook of Unmanned Aerial Vehicles*", Dordrecht: Springer Netherlands, 2015, ISBN 978-90-481-9706-4, ISBN 978-90-481-9707-1 (eBook)ISBN 978-90-481-9708-8, DOI 10.1007/978-90-481-9707-1.

[3] **PLEŞCA, V.** and Mihaela PLEŞCA, "*Cadrul legislativ românesc privind utilizarea SRE, comparativ cu cel din ţările cu realizări majore privind promovarea SRE*", in TEHNOLOGIILE ENERGIEI-producerea, transportul şi distribuţia energiei electrice şi termice, Ed. ICEMENERG Bucuresti, Oct. 2008.

[4] MIREA, A., **V. PLEŞCA**, Alina DUMITRESCU, Victoria Ardelean, and Mihaela PLESCA, "*Estimation of the necessary electricity and sizing of an autonomous photovoltaic system*", EEA - Electrotehnică, Electronică Automatică, vol. 60, no. 2, 2012.

[5] OLTEANU, G., **V. PLEŞCA** şi alţii, "*Energia în era post-petrol*", Bucuresti: Editura ICEMENERG, 2010.

[6] **PLEŞCA, V.**, "A*utomation of the predictive maintenance process of photovoltaic installations using multimotor drones*", EMERG - Energy, Environment, Efficiency, Resources, Globalization, vol. 6, no. 2, pp. 51–61, 2020, DOI: 10.37410/EMERG.2020.2.04.

[7] **PLEŞCA, V.** and C. Purece, "*Predictive maintenance of photovoltaic plants using multirotor drones with automatic recharging system of Li-Po batteries*", E3S Web Conf., vol. 180, p. 02007, Jul. 2020, DOI: 10.1051/e3sconf/202018002007.

[8] DUMITRESCU, Alina., **V. PLEŞCA**, A. MIREA, Mihaela PLEŞCA, and Victoria ARDELEAN, "*Development and integration of off-shore wind turbines into power systems*", ISSN: 2392-828X, EEA - Electrotehnică, Electronică, Automatică, vol. 60, no. 2, pp. 56-64.5, 2012, [Online]. Available: http://www.eea-journal.ro/ro/d/5/p/EEA60_2_9.

[9] PLEŞCA, Mihaela, **V. PLEŞCA**, Alina Dumitrescu, Victoria Ardelean, and A. Mirea, "*Wind energy - great potential, modest achievements*", EEA - Electrotehnică, Electronică, Automatică, vol. 60, no. 2, 2012.

[10] LUQUE-VEGA, L. F., B. CASTILLO-TOLEDO, A. LOUKIANOV, and L. E. GONZALEZ-JIMENEZ, "*Power line inspection via an unmanned aerial system based on the quadrotor helicopter*", in MELECON 2014 - 2014 17th IEEE Mediterranean Electrotechnical Conference, Apr. 2014, pp. 393–397, DOI: 10.1109/MELCON.2014.6820566.

[11] DĂESCU, I., F. CRĂCIUN, **V. PLEŞCA**, and F. SIMEN, "*ENERGOFIX - metodă şi echipament pentru determinarea calităţii energiei electrice*", Revista tehnologiile energiei - producerea, transportul şi distribuţia energiei electrice şi termice, Ed. ICEMENERG, Bucuresti, Mai 2005.

[12] G. GHISE, "*Dronele care „tratează" bolile plantelor*", in Revista Ferma, web page accesat la 02.06.2020, link accesare: https://www.revista-ferma.ro/articole/agricultura-viitorului/dronele-care-trateaza-bolile-plantelor.

[13] TERMOVIZIUNE/TERMOGRAFIE, "*Termoviziune cladiri*", web page accesat la 20.08.2019, link accesare: http://vvp.ro/ro/servicii/termografie-cladiri.

[14] ZECAPH.COM, "*Identificare a puntilor termice si a pierderilor de caldura prin termografie in constructii – ZECAPH*", web page accesat la 20.12.2019, link accesare: https://zecaph.com/termografie-in-constructii/identificare-a-puntilor-termice-si-a-pierderilor-de-caldura-prin-termografie-in-constructii/.

[15] HALLERMANN, N. and G. MORGENTHAL, "*Visual inspection strategies for large bridges using Unmanned Aerial Vehicles (UAV)*", in Bridge Maintenance, Safety, Management and Life Extension - Proceedings of the 7th International Conference of Bridge Maintenance, Safety and Management, IABMAS 2014, pp. 661–667, DOI: 10.1201/b17063-96.

[16] M. GEORGESCU, "*Premieră medicală: rinichi pentru transplant, transportat cu drona*", web page accesat la 20.06.2019, link accesare: https://mindcraftstories.ro/tehnologie/premiera-medicala-rinichi-pentru-transplant-transportat-cu-drona/.

[17] BIZIDAY, "*SUA. Organe umane pentru transplant, livrate cu drone, în două zboruri de testare efectuate în deșertul Nevada*.", www.biziday.ro, 2020.

[18] BERSHADSKY, D., S. HAVILAND, and E. N. JOHNSON, "*Electric Multirotor UAV Propulsion System Sizing for Performance Prediction and Design Optimization*", Jan. 2016, AIAA 2016-0581, Session: Design Processes and Tools, DOI: 10.2514/6.2016-0581.

[19] MOHAMED, M. K., S. PATRA, and A. LANZON, "*Designing Electric Propulsion Systems for UAVs*", in Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), vol. 6856 LNAI, Springer, Berlin, Heidelberg, 2011, pp. 388–389.

[20] Q. DEVICES, "*Commutating Encoder*", web page accesat la 20.07.2018, link accesare: https://www.quantumdev.com/brushless-motors-vs-brush-motors-whats-the-difference/.

[21] Dirjish, M., "*What's The Difference Between Brush DC And Brushless DC Motors?*", web page accesat la 27.05.2017, link accesre: https://www.electronicdesign.com/technologies/electromechanical/article/21796048/whats-the-difference-between-brush-dc-and-brushless-dc-motors.

[22] ALEX TECH, "*How to choose the right motor for your multicopter drone - Guides*", web page - accesat la 20.05.2018, link accesare: https://www.dronetrest.com/t/how-to-choose-the-right-motor-for-your-multicopter-drone/568.

[23] dr. ing. M. RUBA, *"Sisteme de stocare a energiei în VE și VEH", Curs 7, Universitatea Tehnică din Cluj-Napoca,accesat la 01.11.2020, link accesare:* https://ems.utcluj.ro/mircea-ruba/teaching/is/Curs%207.pdf

[24] AMANOR-BOADU, J. M. and A. GUISEPPI-ELIE, "*Improved Performance of Li-ion Polymer Batteries Through Improved Pulse Charging Algorithm*", Applied Sciences, vol. 10, no. 3, p. 895, Jan. 2020, DOI: 10.3390/app10030895.

[25] BARSUKOV, Y. and J. QIAN, "*Battery Power Management for Portable Devices*", Publisher: Artech House, 2013, ISBN-10: 9781608074914, ISBN-13: 978-1608074914;

[26] A. FLORESCU, "*Despre baterii*", web page accesat la 20.01.2019, link accesare: https://www.radioamator.ro/articole/view.php?id=178.

[27] DAMIEN, "*The basics of drones - A Definitive Guide For Newbies*", web page accesat la 15.05.2018, link accesare: http://beginnerflyer.com/. http://beginnerflyer.com/how-to-fly-a-drone-like-a-pro/.

[28] BALS, J., Y. JI, M. R. KUHN and C. SCHALLER, "*Model Based Design and Integration of More Electric Aircraft Systems Using Modelica*", More Electric Aircraft Forum, Barcelona, no. June 2016, pp. 1–12, 2009, accesat la 20.11.2018, link accesare: https://www.researchgate.net/profile/Christian-Schallert/publication/225004732_Model_Based_Design_and_Integration_of_More_Electric_Aircraft_Systems_Using_Modelica/links/5625ea7408aeabddac91d6cf/Model-Based-Design-and-Integration-of-More-Electric-Aircraft-Systems-Using-Modelica.pdf

[29] AYRES, "*Jacksonville Bridge Inspections - Structural Inspection - Ayres*", web page accesat la 20.04.2019, link accesare: https://www.ayresassociates.com/project/jacksonville-bridge-inspections/.

[30] WEIEEE, "*IEEE Standard 1394*", IEEE STD. 1394-2008, Oct. 2008, DOI: 10.1109/IEEESTD.2008.4659233.

[31] **PLEŞCA, V.** and C. GHIŢĂ, "*Research on improving the autonomy of missions executed by unmanned aerial vehicles – UAV*", in SIMPOZIONUL DE MAŞINI ELECTRICE SME'20, 2020, vol. 2020.

[32] **PLEȘCA, V.** and Sanda-Victorine PAȚURCĂ, "Experimental System for Charging and Testing Batteries Specific to Multirotor Drones", Ann. "Dunarea Jos" Univiversitatea Galaţi. Fascicle IX, Metall. Mater. Sci., vol. 43, no. 4, pp. 5–12, Dec. 2020, DOI: 10.35219/mms.2020.4.01.

[33] **PLEŞCA, V.**, GHIŢĂ, O. M. and others, "*Experiments on Extending the Flight Regimes of Electrically Powered Multi-engine Drones Using Automatic Loading Systems*", published in: IEEE - 12th International Symposium on Advanced Topics in Electrical Engineering (ATEE), 2021, DOI: 10.1109/ATEE52255.2021.9425251.

[34] COSTEA, Ilona Moise and **V. PLEȘCA**, "*Automatic battery charging system for electric powered drones*", in 2018 IEEE 24th International Symposium for Design and Technology in Electronic Packaging (SIITME), Oct. 2018, pp. 377–381, DOI: 10.1109/SIITME.2018.8599208.