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EXPERIMENTAL SYSTEM FOR CHARGING AND TESTING BATTERIES SPECIFIC TO MULTIROTOR DRONES

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ABSTRACT

The experimental stand created is made for charging, testing and monitoring the processes that take place at a drone, in a static and also dynamic manner. On this platform we have developed, created and tested various kinds of sensors, and charging methods, rechargeable batteries, multicopper drones, automatically without disconnecting or disassembling them from the drones they serve. Also, at this level we fitted a flat zone, that is polarized where the drone will land, in a controlled manner and after a preliminary testing of polarity and of tension level, the charging will begin, as its parameters will carefully monitored.

KEYWORDS: experimental stand, Li-Po battery, drones, increasing autonomy

1. Introduction

The drone as defined is a UAV device (Unmanned Aerial Vehicle) capable of flying, without being piloted by a person on board, it is automatic and is driven from a distance by a specialised operator, through a remote control. As was the case with the evolution of internet and then of mobile phones, drones have gone being exclusive for military purposes to the civil, where thanks to its remarkable advantages it quickly had a major impact on the industry. At first, due to large costs of owning but mostly maintaining one, they were small and had limited features. But since their limited applications did not raise any interest, and their autonomy was limited by costs, to a usage of only a few minutes, enough for scanning areas that were only visible to the operator, the production costs as well as costs for buying one are fair. As time passed, technological development had led to an increased efficiency and minimising of some hardware components, from the drone’s structure, and protocols and specific sensors have evolved, becoming more and more reliable. It was obvious that with this development that their price also continued to drop, so civil drones became more and more like professional drones ensuring a transport capacity sufficient for more and more complex operations. Moreover, the development of phones and tablets has increased the capacity of monitoring and control of such systems, through a remote control and an app that runs on tablets or smartphones and which does not use too many resources.

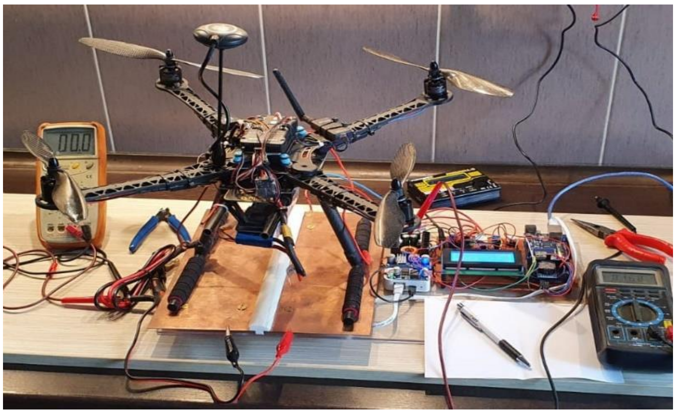

Fig. 1. *Image of the stand for testing and charging drones during calibration*

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With this in mind, technological limitations still exist, mostly concerning charging, because of the weak development of batteries. Finding an optimal battery is a constant concern of all factors present here. The goal is finding a balance between performance, flight time and battery charging capacity. Li-Ion and Li-Polymer batteries are most commonly used ones because of their large energy capacity and discharge capacity. In static mode this battery is well known and its charging and discharging capacities are relatively well known if a known charger is used for the specific voltage and power of that battery. The problems occur when the charging is automatic, autonomous, because in the case of an error the result will be a large flame or an explosion. There have been various attempts to make drone charging automatic, but none have as far as to completely automatise the whole process of charging, for this kind of batteries to become autonomous, this is what we all want. So, drones are captive to an operator that has to monitor the charging process, even if the drones have to be ordered from thousands of km away.

2. Automatic system for charging drone batteries

The presence of drones in industry has brought a lot of changes in many fields, mostly taking away the burden that existed before they were invented. Increasing the flight autonomy and automating the charging process would allow the drones to work autonomously, according to algorithms clearly implemented at their level, or be controlled from remote locations, without needing the presence of a human operator in the monitored location.

From the energy analysis performed on several types of drones, the biggest consumer of a drone is the propulsion system, for example the engines that can be a minimum of 3 or maximum 8, with continuous operation, at speeds and variable energy consumption depending on the piloting style and the mission at hand. Another important consumer is the telemetry system, which transmits critical data on board the drone, such as: battery status, geographical position on X, Y and Z and videos, photos, specific to navigation, captured in real time by the video system located on the drone, etc., but which has a predictable consumption, within acceptable limits. Also, on the drone platform is the sensor system that can contain a series of mission-specific sensors and optionally a professional media capture system, in various spectra, visible and/or infrared, depending on the mission profile can be captured, with a consumption that can be estimated. Most of the time this system is placed on a gimbal support, which can be operated remotely. This is another energy consuming element, because it can be driven by 2 or 4 motors, and its consumption cannot be determined [1-3].

All these components have an impact on flight autonomy, being powered by one or two large capacity batteries, which can generally ensure a continuous flight with an average of 30 minutes. But in the case of a repetitive mission that may require flying over a high security zone or an objective with a large enough surface, such as photovoltaic power plants, even if the information captured from the sensors can be easily transmitted remotely, the limitations imposed by the batteries make the presence of specialized personnel at the location mandatory, in order to change the battery packs when they discharge.

Thus, in this paper I will present an automatic system for recharging a multi engine drone's batteries, without disconnecting them from the drone. To do this, I have created an experimental stand where I tested various conductive methods, that had as an object the charging of batteries in completely safe conditions with the possibility of controlling the whole system from distance.

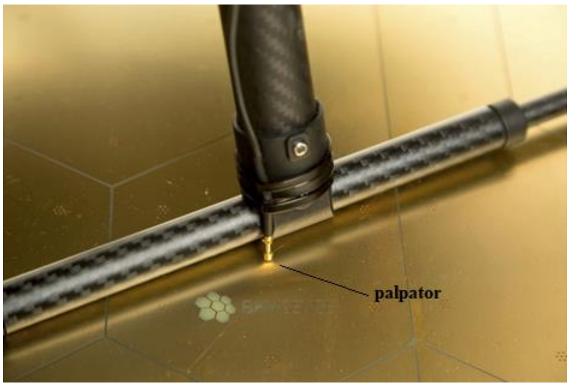

Fig. 2. *Showing the contact system between the padding of the drone and the probe* [3]

This being an experimental stand I have imposed certain limits of weight and electric parameters, thus it had all been thought after for drones with a maximum span of the landing gear of 600 x 250 mm with Li-Ion and Li-Po batteries with a maximum of 6 cells in series, that is about 6S - 22,2 V, 22000 mAh (Figure 1). The whole system is split into 2 main modules; the fixed base, which houses the main charging source, the system controller, the web server for monitoring/ local control or distant control and the only module placed on the drone that contains an BMS – Battery Management System [1, 4, 10] specially built for this autonomous charging source (Figure 3). Between the 2 modules there two clear links, a physical link that which is based on direct power contact between the BMS system placed on the

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drone and the charging area through some probes installed on the landing gear of the drone and a wireless link through which data collected from the BMS system are integrated in the implemented algorithm of the microprocessor placed on the fixed padding. The contact areas of the stand are made of a board with copper probes to ensure a perfect contact between the poles of the system; starting the charging process is done only once the drone has landed and firmly contacts the ground without generating disturbances because of the electric arc.

All monitoring and safety systems have been doubled according to recommendations of the IEEE 1625-2008 standard [4], practically eliminating the errors or problems caused by a fault at the sensors.

The components of the system are simple but work in tandem according to a well-developed algorithm that responds efficiently to the events that occur. According to the place where they are placed in the system, they are mostly mounted on the stand, only a small part is placed on the drone.

The ones located on the drone actually deal with the protection of the battery and the drone they serve. All the modules located here are miniature and chosen especially by the lowest possible weight, because through the system described here, I do not want to decrease its main characteristics: transport capacity and manoeuvrability of the drone. At the drone level, the most important parameter monitored by BMS is the battery temperature; the temperature reading is done with the DS1820 digital sensor, which has a measuring range between -55 °C ÷ +125 °C, enough to monitor lithium technology batteries and a resolution of up to 12 bits.

All parameters read at the drone are transmitted to the microcontroller on the base, via a LORA module (Figure 3), which together with the information collected from its sensors makes quick decisions to protect the battery and the drone by default, stopping charging or limiting the charging current, when the situation demands it.

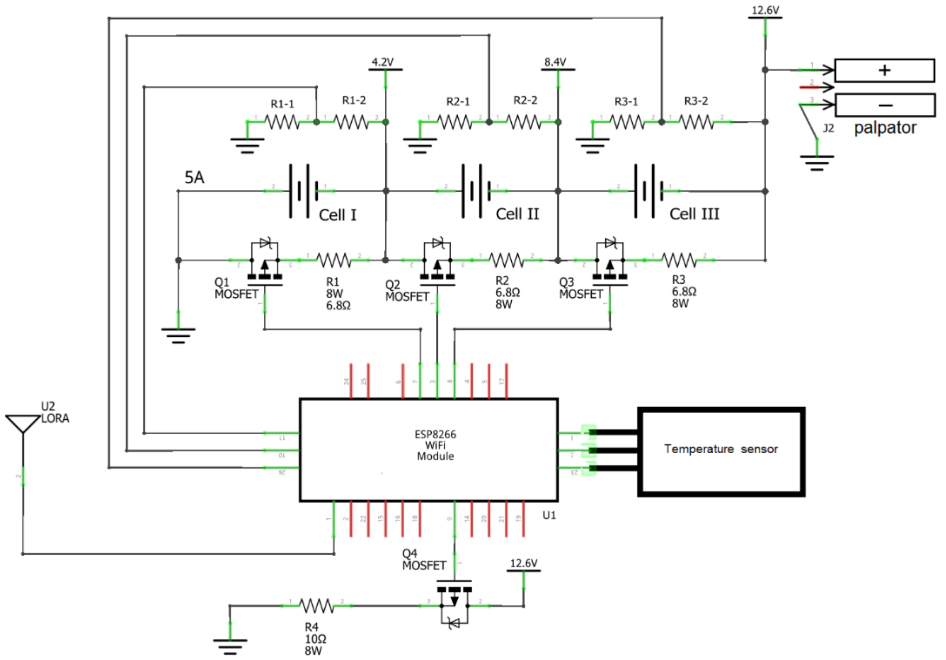

Fig. 3. *General scheme BMS - module located on the drone*

The Li-Po cells that make up these batteries are mini electrochemical systems. Depending on the requirements of the application they serve, to achieve the optimal voltage or capacity, they are interconnected in series or in parallel and are denoted by xSyP, where x is the number of cells in series, and y represents the number of cells in parallel [1, 4, 10]. But each cell has a unique self-discharge rate, a nominal capacity and especially a unique impedance, which varies over time, randomly, depending on several parameters. If the cells are connected in parallel these differences are not a problem during operation, because they will always find a way to balance their voltage level naturally. However, care must be taken that these voltage differences are not large enough to generate current shocks at connection, or rapid temperature rises, which would inevitably lead to the destruction of the cell package. Problems occur when cells are interconnected in series, because the cells are not ideal voltage sources, and the variations are quite large from cell to cell.

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The capacity of the battery [mAh] expresses the possible current generated by it in one hour, or half of this current for two hours, etc. until the battery reaches the minimum discharge threshold. Increasing the battery capacity can be done by connecting several cells in parallel [1].

Another quite important element is the "C rate" - the constant discharge of the battery together with the previous parameter provides information about the maximum amperage that can be safely discharged from the battery in a constant way, but also the recommended charging current.

Regarding the voltage at the battery terminals [V], for a LiPo battery, in general, three reference voltages are defined: the nominal voltage specified by the manufacturer, which is generally a multiple of 3.7 x no. of inserted cells, the maximum voltage per cell 4.2 V - the battery is fully charged when each cell reaches this value and the minimum discharge voltage 3.0 V per cell. Theoretically, the maximum voltage at the battery terminals divided by the total number of cells interconnected in series should not exceed 4.2 V per cell. But in practice, during the charging process, things are not like that, and when the voltage in the cells exceeds 4.2 V even by a few hundred millivolts, the cell temperature rises rapidly, destroying the battery [1].

Protecting the battery by stopping the charging process when a cell reaches the maximum level of charging accepted (4.2 V) is not a solution because the charging would not be complete, and an incomplete charging will ruin the battery yield, which is based on a lower usage time given the minimum safety tension (3.0 V) of a cell at a given time and the maximum tension of a cell in the pack (4.2 V). From here comes the need of the maximum possible energy.

Currently, there are two major equilibrium classes: active and passive, that use various circuit topologies. The most used ones have a series of control algorithms, SoC based on history and tension, but both have the same objective: to monitor and balance the charge at each cell. That being said, developing a balance with more characteristics of control implemented would raise the yield and would prolong the life of a battery, but the cost of such a charger would be quite big. So, the producers of such chargers impose a passive equilibrium system.

Types of balancing systems used for Li-Po battery [1, 4, 10]

Cell voltage balancing through By-pass. This type of balancing module uses a simple voltage comparator that controls a power MOSFET mounted in parallel on each cell.

Cell voltage balancing by charge redistribution. Basically, the system tests each cell and through switching circuits transfers the excess energy to the weaker cells. This module is very expensive but it is very efficient and has the great advantage that it does not depend on the current generated by the charger, being able to perform cell balancing in any conditions.

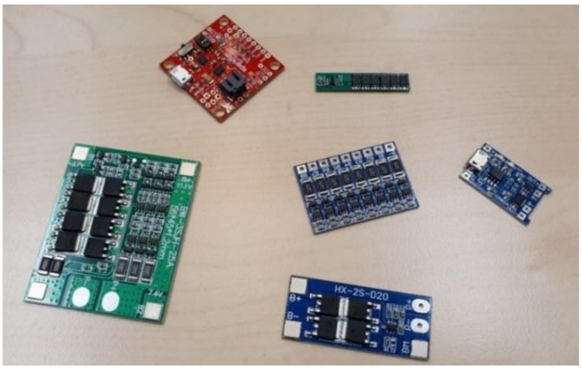

Fig. 4. *Various types of levelling Li-Po cells*

Energy transport between cells. This method also transfers energy to weaker cells but uses capacitors for this so the system is more affordable. Unlike the previous method, this one is very slow and has a fairly large size.

Inductive converter. This balancing system uses the concept of power converter in switching mode and performs balancing directly on each cell, independently of the others. But it has the disadvantage that it is very expensive and has a fairly large size and weight.

Analysing all these balancing methods and taking into account the limitations given by the weight of the BMS to be placed on the drone, and in solidarity with its battery, I have come to the conclusion that creating a minimally customized system is the only solution. In addition, the idea of integrating in the system a standard BMS module like the ones in the previous figure, after testing them I came to the conclusion that none of them offer the necessary specifications, and neither the required safety.

3. Description of the implemented algorithm

The algorithm implemented in this project requires the charging of Li-Polymer batteries using the most common charging method, which follows the alignment of the charging curve in Figure 5. This method has three main phases: preload, constant current charging and constant voltage charging [1, 4, 10].

Phase I. In the preload phase, first of all, the temperature of the environment and of the package of cells that form the battery are tested. If the temperature is not in the optimal temperature range: 0 ÷ 50° Celsius, the beginning of the charging process at low temperatures favours the appearance of metallic lithium which means the accentuated degradation of the electrodes that form the cell, and in case of a temperature above the upper limit results in 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, up to a voltage of 3.0 V on each cell.

Basically, in this phase the integrity of the cells is tested, thus the passive layer is regenerated, which would be affected if the battery had been stored for a longer period of time, and if the cell voltage does not reach the value of 3.0 V in a predetermined time (30 minutes), then the loading process ends with an error, because structurally or chemically the cells are compromised. If the voltage on each cell exceeds the 3.0 V threshold then the charging process enters phase 2.

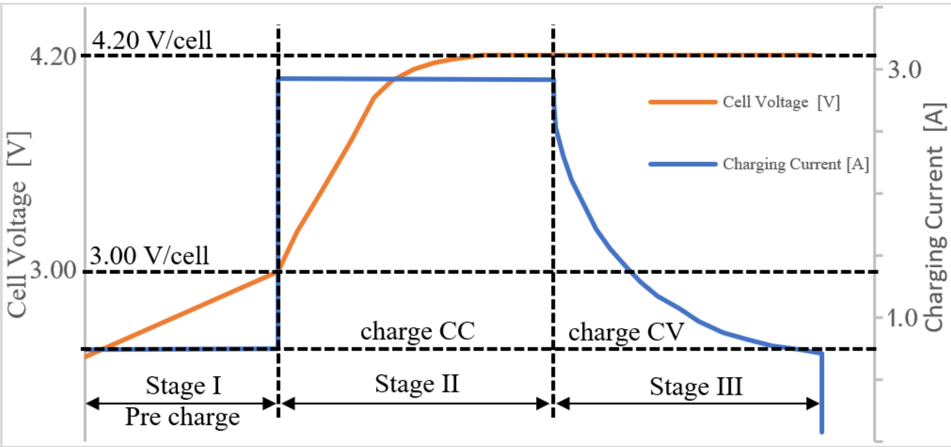

Fig. 5. *LiPo battery charge profile, using the constant current / constant voltage model*

Phase II. In this phase the level of the charging current is kept at a constant, limited from 0.5 C to 1 C, to avoid heating the battery and ruining the cells. For these tests I have kept the charging rate to 1 C, the temperature remaining within the acceptable limits for the test charger. The charging process remains set on these parameters till the tension on each cell reaches the maximum noted on the battery: 4.2 V. Even at this phase the temperature is monitored. If the temperature passes the maximum threshold the charging process is suspended till temperature drops below 45 degrees. When the tension reaches the noted value, we enter phase III.

Phase III. In this phase of the charging process the current begins to drop to a prescribed value and the tension is the to a reference maximum value set in phase II. Lowering the current is done naturally because of the internal resistance of the battery to a value of between 5-10% from the charging current specified on the battery.

As a percentage phase II is about 70% of the total charging time, and phase III is the remaining 30%. Generally speaking, the lower the internal resistance of the battery, the lower the charging time is also, and setting a charging current that is greater makes passing through the two phases quicker. But increasing current for charging over the specified limit makes the lifetime of the battery drop a lot because metallic Lithium appears which sets on the anode. This is an aggressive metal that easily reacts to the electrolyte leading to lithium loss, which in turn leads to a reduction of battery life.

The implemented system here notes when the battery has charged to 100%, by monitoring the charging current, that ultimately drops slowly till it reaches the value of C/20.This value is associated with finishing the charging process, but for safety reasons it can be doubled by measuring tension on each cell of the battery. If all cells have a tension of 4.2 V, then the charging process is done.

Furthermore, as I stated above, during the entire charging process, the battery temperature is continuously monitored, and if it goes over the safety interval the charging process is suspended by the microcontroller. If the charging time is not a critical one then, in order to eliminate the effects that could appear on the battery structure, it is possible to set the charging process to be a slower one, but not longer than 3 to 5 hours, depending on the parameters of the battery, but especially the age and condition of the battery.

Another function implemented in the developed charging stand algorithm is to detect the discharge rate of Li-Po batteries. This is a rather important

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initial parameter, being imposed by their manufacturer depending on the application it serves, and can vary quite a lot. For this they use thicker or thinner active materials depending on the desired application, the thin layers have a higher loading rate but the energy density is lower. But the discharge rate decreases a lot when the temperature drops below 0 C, but also with the accumulation of a significant number of charging cycles.

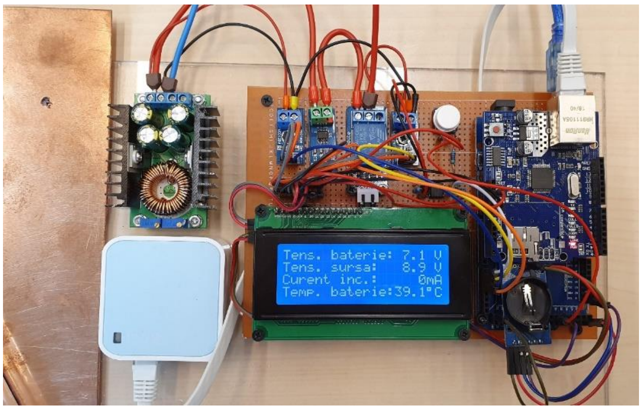

***Fig. 6.** The monitoring and command module at the base level*

The necessary function for preparing these batteries for safe storage has also been implemented, for longer periods when the drone is no longer used. Storing Li-Ion batteries for a longer period of time is done by bringing the voltage of each cell to a safety value of 3.7 V, otherwise high voltages will lead to corrosion of electrolytes, which destroy the battery over time. This value of 3.7 V per cell is a minimum accepted because a voltage lower than this can lead to the dissolution of protective layer and also to its irreparable damage. This type of battery, unlike NiCd and NiMH batteries, has an almost imperceptible self-discharge process, so it does not require additional charging/discharging cycles during storage. But storing these batteries at high temperatures can lead to accidents or fires, and storing them at low temperatures increases the shelf life.

4. Security elements implemented in the algorithm

During the charging process but especially during the operating process Li-Polymer batteries can be easily subjected to stress, so the protections that can act externally on the charging process are: overvoltage, overcharging, overcurrent, overtemperature, short to terminal or at the cell.

Overvoltage applied to the terminals of a battery - may occur during the charging process if the main source of the charger has failed. This has the immediate effect of overheating the cells in a very short time, and the result is damage to the cells and in some cases their explosion with fire. To eliminate this event during the charging process, the voltage on each cell and at the base level, on the contact areas, is measured. If the voltage exceeds the imposed limits, the microcontroller commands to stop the charging process, with event recording in the database and will block the process until this defect is reset by a human operator. The same can happen in case of accidental polarity inversion. Thus, when the drone lands on the loading pad, the correctness of the polarity is tested and if the drone has settled properly and the contact is firm, the loading process is started with the observance of all the imposed limits. If the drone did not respect the position drawn for landing then a signal is issued to the drone system and / or to the operator in charge of it, to resume the correct landing process. To determine the polarity at the charging pad, the circuit in the Figure 7 was used, which in case of incorrect polarity will generate a voltage of 5 V at the input of the microcontroller, in which case it will not allow the charging process to begin.

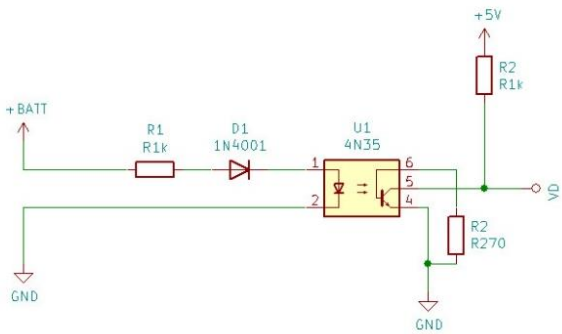

***Fig. 7.** Polarity circuit test*

The charging current and the correct polarity are measured during the whole charging process, and in case the drone is disconnected from the source or the

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polarity of the current changes, the whole process of testing and charging starts from the beginning.

Battery overcharge - This parameter can be determined thanks to the communication modules of LORA type that have a coverage of kilometres. Thus, during flight, the module placed on the drone will send to base information about tension on each cell and temperature of the battery. By analysing the character of the curve of discharging the operator can identify if the choice of drone battery was done correctly or it has structural problems. Generally, a super discharge has an immediate effect over the battery and reduces its life more than it writes it does because at low voltages the copper current collectors of the battery are dissolved. If measures to remedy this are taken quick turning back to normal parameters is done during the charging process when the copper sets on the respective electrodes.

Overcurrent during discharge - the occurrence of overcurrent during discharge of the drone battery on mission may be due to a defect caused by a consumer or even a failure of a cell in the battery component. In general, the battery can withstand an occasional overcurrent but only for a very short time, 10 seconds and within acceptable limits, which in most batteries is twice the rated capacity. When such an event occurs, the battery temperature begins to rise rapidly, so the operator will be warned to make an emergency landing or if the drone flies autonomously it will return to the charging pad, where it will pass into a state of waiting evaluation from a human operator. If the drone does not land in a short time, the battery will overheat, and when its temperature exceeds a critical value of 600 °C there is a chance of almost 100% that the battery will be destroyed in most cases and it will catch fire.

Overcurrent during charging - during the charging process the current is monitored using a specialized current transducer, so if an overcurrent occurs, the entire system goes into safe mode. In general, the charging current is in the range of 0.7-1 C for ordinary batteries but can obviously be much higher for high power batteries, specially designed for such mode. Obviously, if no action is taken quickly, the immediate effect is to increase the temperature and in the second phase to cover the anode with a Lithium metal powder. This phenomenon electrically disconnects the respective area, and the battery becomes more and more inefficient. If the process continues, the Lithium metal powder reacts with the electrolyte and the temperature in the cell reaches several thousand degrees, resulting in the destruction of the battery. This phenomenon can also occur when charging the batteries at temperatures below zero degrees Celsius, so to avoid it the stand was fitted with a heating element that brings the battery to an acceptable temperature level in compliance with JEITA specifications.

Overvoltage at cell level - supplying the battery with the voltage specified by the manufacturer during the charging process does not eliminate the occurrence of overvoltage in the cells that make it up. This can occur if the cells initially have a different SOC loading level and obviously if the cells have a different self-discharge rate. Within the stand this situation was avoided by the BMS created, monitoring each cell and by means of the microcontroller and the MOSFET, decisions are made to isolate the cell or to reduce the charging current applied to the respective cell, putting in parallel with the resistance power.

Short circuit at the cell or battery level - this type of fault occurs at the cell level and is the most common, but unfortunately conventional chargers do not provide protection at the cell level for this parameter. At the moment, even manufacturers that comply with international standards, specific to these types of batteries, have not developed cell-level protections, focusing on the protection of the entire cell package. The charging system presented here offers this protection on each cell, by isolating them in case of a defect.

In the end we have reached a stable version that includes several types of sensors. The stand tests the electrical parameters of the drone, compares the voltage level and the charging current initially set and if everything is in order, the charging process starts. The whole process is recorded in a database, and all the data can be viewed in an almost instantaneous time in a web page, from where various settings and commands can be executed to the execution elements of the system.

5. Conclusions

Automating the battery charging process, without disconnecting them from the drone, opens new horizons for an autonomous usage regime of drone systems. Thus, these applications that involve the repetitive scanning of some objectives or elements found in areas that are hard to access, can be done autonomously by implementing superior algorithms at the drone and the navigation system. Such applications can be: Perimeters that need continuous security, scanning and defect detection at the level of photovoltaic panels, agricultural crops, etc.

Creating a personalized BMS with complex functions and managed through complex algorithms that run on a microprocessor, increase the duration of functioning of a battery, but mostly accidents that can occur because of fire or explosion of such a battery can be avoided; they mostly lead to the collapse of the whole system of sensors including the drone support. Besides the fact that such a drone equipped with sensors has a very large cost, where losses can be in the order of thousands of euros, the uncontrolled collapse can generate human and material accidents where it crashes.

During the tests carried out on this stand, a series of characteristics of consumption have been determined at the level of the entire drone. Also, several battery configurations have been tested: 1S1P, 2S1P, 3S1P, 3S2P, etc.

Because of the limited weight but mostly because of the electrical parameters: tension and maximum charging current, that can be set at a given moment, the possibility of testing is extremely limited. In a future test this will be tested and created for electrical solar panels, with a centralized configuration of inverters. Thus, for field tests the generous sizes of the flat roof of these inverters will be used for placing the charging stand.

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