Batteries Investigations of Small Unmanned Aircraft Vehicles

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Abstract

In this paper, will be shown and discussed the battery performance of small Unmanned Aircraft Vehicles (UAV) based on the full electric power supplying. The recent small-UAV using the hybrid power systems based on power electrochemical batteries to be energy efficient, have high power density thus reducing weight to achieve the maximum ranges. This paper shows that temperature effect decreasing the conversion efficiency up to 50 %. This could mean decrease in the power density and total capability of vehicular batteries. Therefore, use of UAV and range of application is affected by the variation in temperature. Paper gives brief outline of the investigation of batteries versus temperature effects. The batteries are compared and investigated using experimental method.

1 Introduction

The UAV systems are widely use as a vehicular system without pilot on board in many military or civilian applications. This paper are considered the technology of small UAVs, where weight is less than 50 kg. Traditionally, they are powered by combusting engine, where motor-driven system run at a variable speed and output efficiency is not so high; dynamic behaviour of these are lightly delayed; and power density of these units are lower in comparison with full-electric drive based on the electrochemical batteries. These units with combusting engine are significantly heavier and noisy; there are power damping with a high temperate loads. The reliability of these and their life expectancy depends on the operating temperatures. We can minimize these problems, at least in UAV, by using a electric concept based on the electrochemical batteries. Consequently, there is a trend in the vehicular systems to move from gas, diesel vehicles to hybrid or concept of full-electric drives based on the electrochemical batteries or fuel-cell.

A battery can deliver power and peak-power to the UAVs efficiently; nevertheless a optimum vehicle performance with a given battery can be obtained if the power system of UAV limits the life-reducing stresses.

The important issue of vehicular batteries of these UAV systems is that the load of batteries is extremely continuously high and pulsating, what can be seen in figure 1.

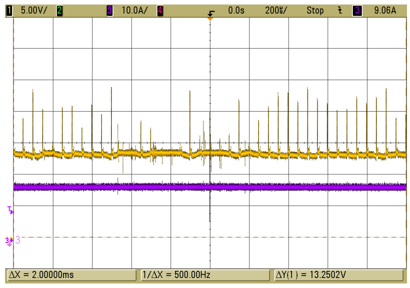

Figure 1: Behaviour of Battery with Power Electronic

Outputs of batteries are highly distorted, where high harmonics of high level produce extra losses reducing efficiency and increasing temperature stress of batteries.

2 Power Batteries

There are factually hundreds of types of batteries currently in use. All of them is based on the chemical electrolyte to conduct electrical current through the positive, negative ions betweens electrodes. The efficiency and power density of battery depending on the quality of chemical electrolyte, including all effects of temperature characteristics or characteristics of the changes of the internal resistances of electrolyte materials. The electrodes of these cells can be based on the different types of material, for example: a positive part is formed by using of nickel oxide or nickel hydroxide and minus-part is cadmium (Cd). Electrolyte of battery can be often based on potassium hydroxide (KOH). Technology of Lithium-Ion, where a plus-part is a lithium cobalt oxide ($LiCoO_2$) and minus-part is based on lithium with graphite, where electrolyte of these is, for example, Lithium hexafluorophosphate ($LiPF_6$) and organic nonpolar solvent. It is know and evident that species and quality of electrodes materials, electrolytes have effect on the maximum characteristics of the load-currents and losses of power batteries. In additionally, the output voltage of these power batteries is affected to be variable, for example, Ni-Cd make 1.2 V and Li-Ion produce approximately 3.6 V without a load applied to the cell. On the grounds of these, the power density of batteries or efficiency are variable accordingly output voltage and material of electrodes.

Even thought structure of the batteries are very similar of all producers of batteries, there is no assumption that characteristics of varies batteries from varies technologies are similar. One of the main characteristics of these varies behaviours are changes of battery-capacity versus current load. To draw a comparison between batteries can be applied method based on experimental test of the discharging batteries by means of the current 0.2·I for the duration 5 hours of discharging process. The example of the results of discharge-capacity versus value of current-load can be seen in figure (Fig. 2).

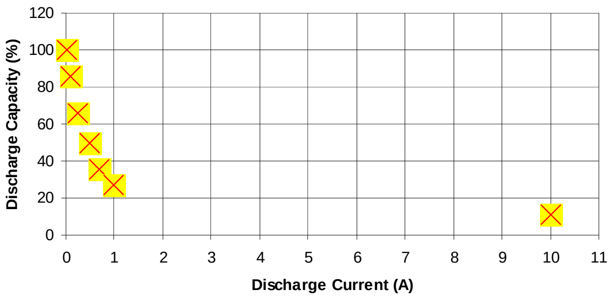

Figure 2: Discharge Capacity versus Discharge Current (experimental results)

The example of the results of discharge-capacity versus pulse-current loading can be seen in figure (Fig. 3), where there are an apparent effects of these discharging processes into discharge-capacity of power battery.

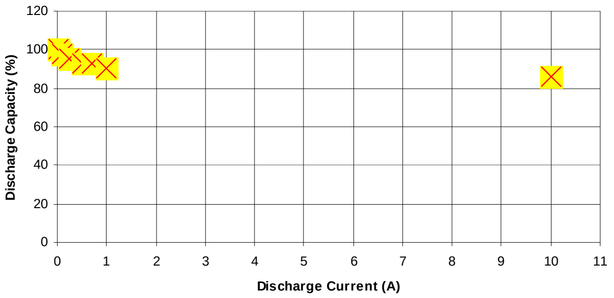

Figure 3: Discharge Capacity versus Discharge Pulse-Current (experimental results)

3 Experimental Investigations of Power Batteries vs Discharge Current

Nickel-Cadmium has been developed to a high degree of efficiency and dependability. This technology of batteries is out of date; Nickel-Cadmium cells are replays with a modern batteries, nevertheless, these are fit for vehicles, namely aircraft applications on the grounds of a good reliability. There are resistant to number of discharge cycles under controllable loading. These batteries are still used now in aircraft systems for several reasons: it lower operating costs, and reduce the need electronics to manage. It is a relatively high-value of charge or discharge currents can be obtained.

The disadvantage of these is low voltage per cell. Voltage is lower then 1 V per battery-cell for process of battery discharging. That is reason why this concept has low value of power density of UAV power source.

The experimental test of results of Nickel-Cadmium battery for battery-pack (8x 1.2 V) are shown in figure (Fig. 4). It can be seen that discharge-currents reduce battery capability from 100 % (point A) to 40 % (point B), consequently, the results of discharge-capacity change (ΔC) is 60 % for the process of the investigation effects of the current load 1 A and 2 A.

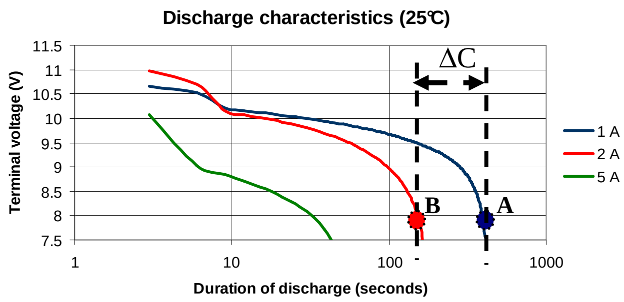

Figure 4: Capacity-change of Nickel-Cadmium Battery versus Current Loud (experimental results)

Lithium-Ion batteries are suitable technology for vehicular systems. They are energy efficient and their power density is a very good. Lithium-Ion batteries are capable to reach the highest capacity of power source. The investigations of parameters energy density and their comparing are shown in figure (Fig. 5). It can be seen, Lithium-Ion batteries have 3x higher parameter of energy density then technology of Nickel-Cadmium.

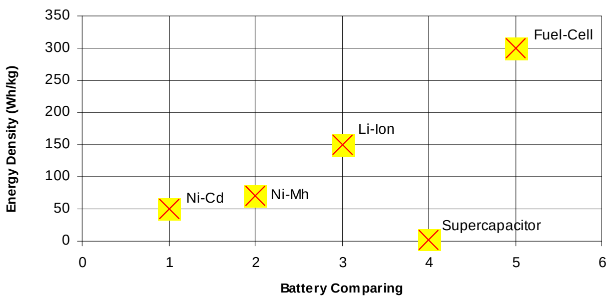

Figure 5: Battery Comparing versus Energy Density

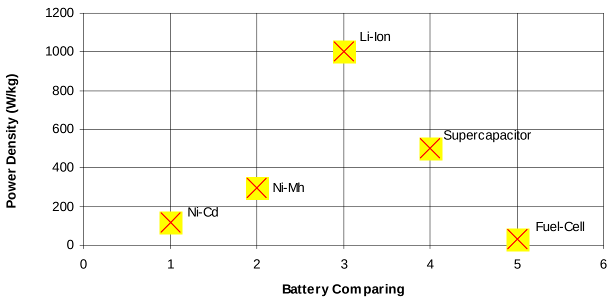

Figure 6: Battery Comparing versus Power Density

As mentioned above, the cell-voltage is higher, around 3,7 V per cell, in comparison with for example Ni-Cd, what is useful to improve value of power density of these power batteries of UAV systems, see figure (Fig. 6).

Results of investigations of Lithium-Ion batteries are demonstrate in figure (Fig. 7) for pack of batteries (4x 3.7 V). It can be seen that current 2 A reduces battery capability from 100 % (point *A* of current 1 A) to 53 % (point *B*). The results of experimental verification of changing capacity (ΔC) is 47 % what is a slightly better results then result of figure (Fig. 4).

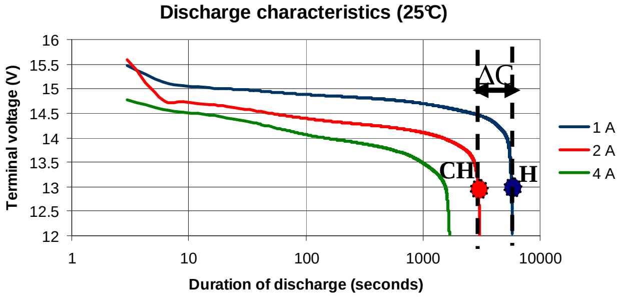

Figure 7: Capacity-change of Lithium-Ion Battery versus Value of Current Loading (experimental results)

The focus of recent research has been upon Hydrogen Fuel-Cell technology. A major advantage of using these Fuel-Cells for vehicles system is their energy density (Wh/kg). Energy density is higher than, for example, Lithium-Ion batteries, see figure (Fig. 5). Additionally, next benefits of Fuel-Cells are a cleaner technology enabling alternative fuels, such as methanol, hydrogen, etc. However, the power density is fairly low in comparison with electrochemical batteries, see figure (Fig. 6).

Many types of Fuel-Cell are currently being researched. Alkaline Fuel-Cells can achieve efficiency higher than 60%, but on the other hand, the life-time is usually lower then 2000 hours. The main disadvantage of these alkaline Fuel-cell is a lower power density in comparison, for example, with the Fuel-cell based on the polymer electrolyte membrane (PEM). Therefore, vehicular systems of UAV are based on the PEM technology, where output efficiency is approximately lower then 50%.

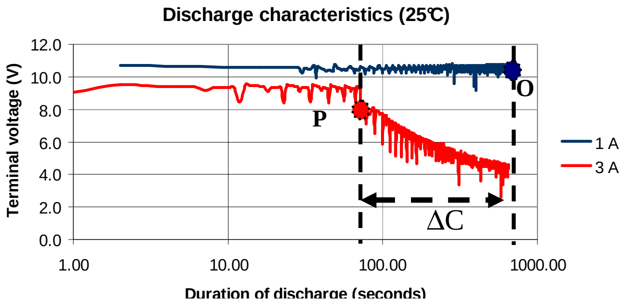

Figure 8: Fuel-Cell Investigation versus Value of Current Loading (experimental results)

Results of investigations of Fuel-cell of power (30 W) and tank of hydrogen for 10 l, is shown in figure (Fig. 8). It can be seen that current 3 A reduces capability from 100 % (point *O* of current 1 A) to 13 % (point *P*). The results of these investigations confirm that properties of power density of character from the figure (Fig. 6).

All figures above (Fig. 4, 7 and 8) show that the current-value of discharging has an effect on results of changing of battery-capacity. It is also evident from these that the output voltages of batteries are, additionally, affected by means of value of discharge-current. The main resin why the batteries are affected is that internal resistance is variable and step-up. Consequently, output voltage and efficiency of battery are variable also. Therefore, the real battery capacity is dependent on the battery's internal resistance, which greatly varies with temperature or the value of discharge current. In addition, reliability of the battery of capacity is reduced by over-current loading, where high level of current destroys the battery's internal resistance.

4 Experimental Investigations of Power Batteries vs Temperature

Several approaches can be applied to investigate behavior of batteries versus temperature effect. The experimental approach to test batteries is more complicated due to requisite for many tests to establish proof of battery behaviors. On the other hand, these approaches of the experimental investigations could be more reliable in compare with modeling method of the investigations. More than hundreds tests we did it through system on automatic-test based on the GPIB standards. The test set-up of control software, where VEE Pro (graphical language environment) was applied, is shown in figure (Fig. 9).

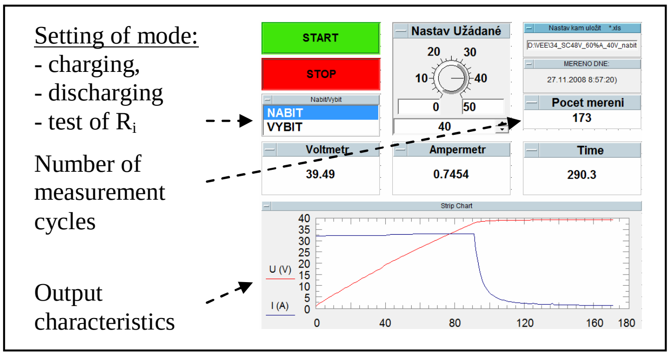

Figure 9: Test-system of Battery Investigations vs Temperature

The test-battery is loaded by means of temperature stress between -60°C to +80°C. Loading of the battery is made it by using of the electronic load (6063B). The program control of experimental set-up has process of using: charging mode, discharging mode and investigation of internal battery resistance.

The results of temperature investigations of Ni-Cd battery versus temperature effects can be found and obvious comparing results of figures (Fig. 7 and 10). These results of the temperature investigations were obtained experimentally at the temperatures +25°C and +10°C.

The next temperature investigation for -10°C was irresponsible due to battery behaviors.

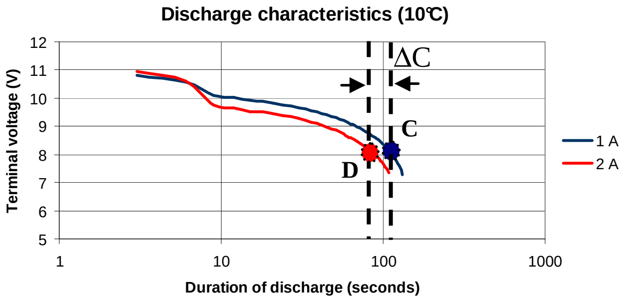

Figure 10: Capacity Investigation of Nickel-Cadmium Battery versus Temperature Stress (experimental results)

It can be seen that behavior of batteries under temperature stress is also variable. If the results are comparing, it can be seen that the change of battery capacity was change from 100% to 30% for 1 A current load and from 40% to 25% 2 A current load during temperature change from the +25°C to +10°C. The results for temperature stress -10°C was acceptable only for load current up to 1 A. Higher current loading of the batteries (Ni-Cd) was poorly reliable to present the output behavior. These effects of the temperature and load stress make changes of the internal structure of the electrochemical material. That is reason why the value of the internal resistance of battery can be interesting to describe running conditions of battery.

The results of test for -10°C for 1 A current is shown in figure (Fig. 11), where capacity of battery was a bit improve from point *C* (30 %) to point *E* (38 %), what is a bit strange and untypical behavior of battery under temperature stress, on the other hand, these behavior is repetitive during test check.

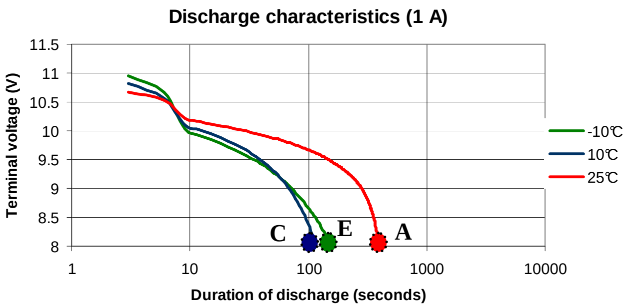

Figure 11: Capacity Investigation of Nickel-Cadmium Battery versus Temperature Stress (experimental results)

Nickel-Metal technology is comparable to Nickel-Cadmium, where cadmium is replied by means of metal-hydride due to environmental issues. On the other hand, these kinds of batteries can be characterized by means of higher value of internal resistance, therefore the discharging efficiency and capacity are lower in comparison with batteries of Nickel-Cadmium, what can be seen in figure (Fig. 12). The capacity varies with the temperature from point *F* (100 %) to point *G* (22 %), where drop of capacity versus temperature stress is higher then previous case of Ni-Cd power battery technology, compare figures (Fig. 11 and 12.).

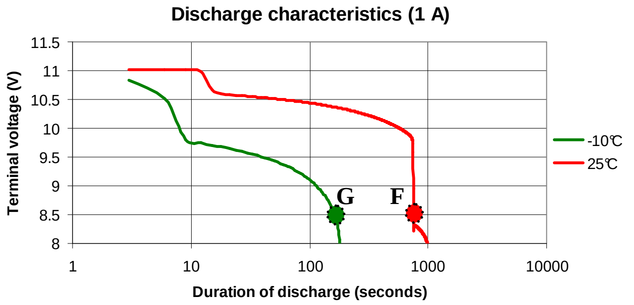

Figure 12: Capacity Investigation of Nickel-Metal Hydrid Battery versus Temperature Stress (experimental results)

Lithium-Ion batteries could be suitable technology for vehicular electric-drive systems due to parameters of the energy and power density, see figures again (Fig. 5 and 6). The results of experimental investigation of Li-Ion batteries versus temperature stress are shown in figures (Fig. 13, 14, 7).

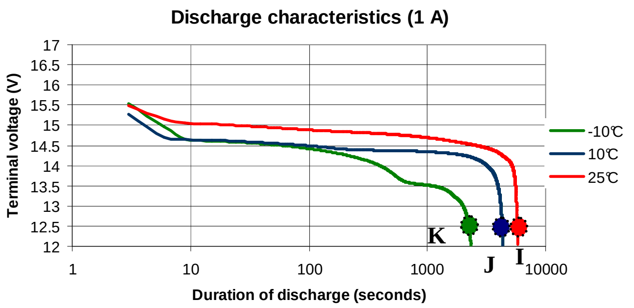

Figure 13: Capacity Investigation of Lithium-Ion Battery versus Temperature Stress under 1A (experimental results)

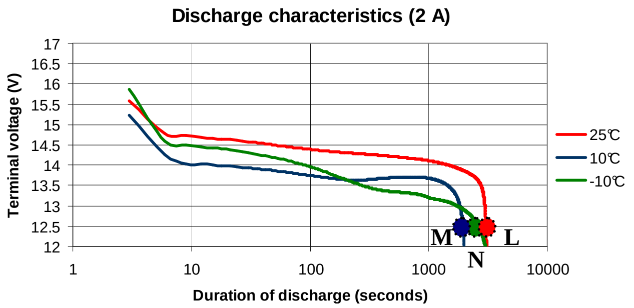

Figure 14: Capacity Investigation of Lithium-Ion Battery versus Temperature Stress under 2 A

Lithium-Ion batteries are more energy efficient in comparison with previous kind of batteries, as can be seen below discussion. Batteries are also affected by temperature stress and a high value of discharging current. The results of experimental verifications of capacity changes are:

from 100 % (+25°C; 1 A), point *H*, to 53 % (+25°C; 2 A), point C*H* of figure (Fig. 5).

The effects of temperature investigations are:

to 74 % (+10°C; 1 A), point *J;*

to 40 % (-10°C; 1 A), point *K;*

to 34 % (+10°C; 2 A), point *M;*

to 47 % (-10°C; 2 A), point N.

The results of test for -10°C and 2 A current loading represent again very strange battery behaviors, where temperature under zero Celsius helps to improve capacity of battery.

The results of tests to the hydrogen fuel-cell (PEM) versus temperature variations are shown in figures (Fig. 15 and 8).

As can be seen, the internal resistance of a PEM varies also with temperature and value of current loading. In additionally, behavior of PEM dependents also on numerous factors including operating conditions such as pressure or quantity of hydrogen in the storage units.

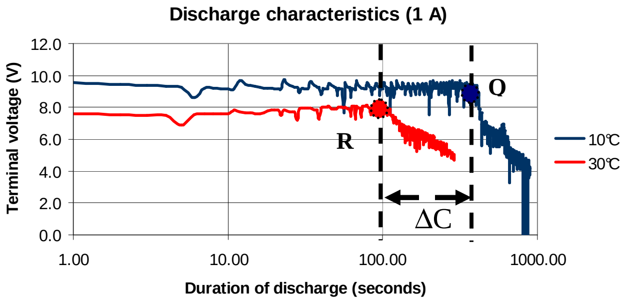

Figure 15: Capacity Investigation of Fuel Cell versus Temperature Stress under 1 A (experimental results)

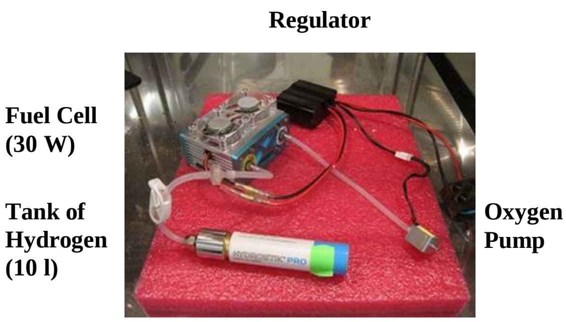

Figure 14: Capacity-change of Lithium-Ion Battery versus Temperature Stress under 2 A (experimental results)

5 Conclusions of Batteries Investigation

Battery investigation of experimental test can be summarized into figures (Fig. 15 – 17), where effects of current and temperature can be shown as a drop of battery-capacity.

Nickel-Cadmium concept of UAV can create a good solution for using of power-buffer of small-UAV. Nevertheless, these technology of batteries are heavy, bulky and energy density is not a good enough in comparison with Lithium-Ion concept, see figure (Fig. 5 and 6).

Nickel-Metal Hydride battery are less efficient in compare with Nickel-Cadmium batteries, see figure (Fig. 18). The drop of capacity is a slightly higher in comparison with Nickel-Cadmium batteries, see figure (Fig. 16 and 17). They have a high self-discharging and temperature effects is a higher, figure (Fig. 17).

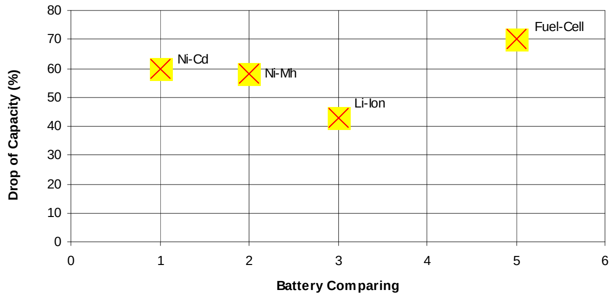

Figure 15: Battery Comparing versus Change of Current from 1A to 2A

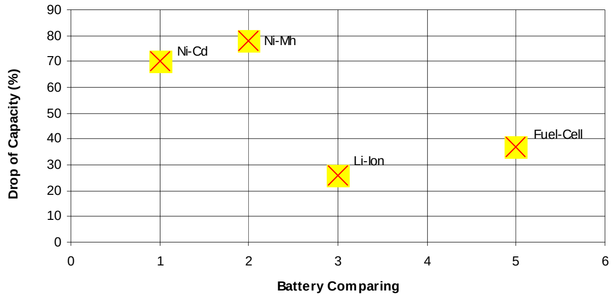

Figure 16: Battery Comparing versus Change of Temperature from +25°C to +10°C by 1 A Discharge Current

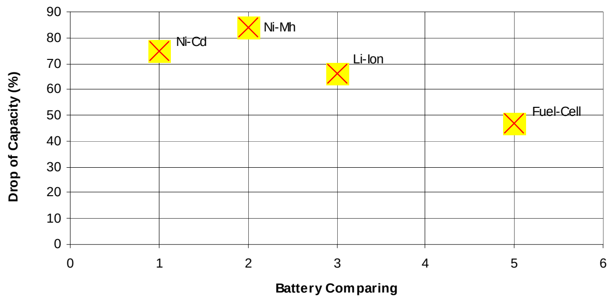

Figure 17: Battery Comparing versus Change of Temperature from +25°C to +10°C by 2 A Discharge Current

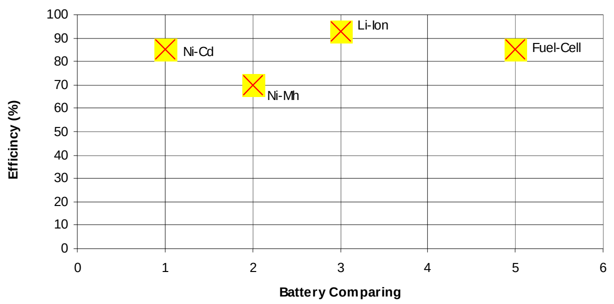

Figure 18: Battery Comparing versus Efficiency

Lithium-Ion batteries are good at parameters of energy density due to a higher voltage per cell to help to achieve considerable weight reduction for the whole systems of UAV. In this context, it is of interest to mention cell life-time behavior. If these batteries cell are discharged down to 2.5 V, then the operating time of the cell can be approximately 500 cycles. If the discharge process is stopped around 3 V per cell, then more than 1500 cycles can be achieved. However, these operating battery cycle properties are affected and reduced by the temperature of the operating environment and by over-currents loading also, see figure (Fig. 17).

Fuel-Cell technology is able to efficiently cover requirement of the parameters of energy density in comparison with electrochemical batteries. On the other hand, Fuel-Cell cannot be used as a fully replacement of the electrochemical batteries due to parameters of power density, figure (Fig. 6). A mix-concept of Fuel-Cell and electrochemical batteries can be helpful to improve parameters of power density; as well as set up a power-buffer of UAV to cover pulsating loads efficiently.

6 Conclusions

This paper discusses the performance of electrochemical batteries and fuel-cell; and shows experimental verifications based on temperate tests of vehicle battery capability. The concept of power buffer of UAV with Lithium-ion batteries are suitable for UAV system due to effieciency and energy and power density in comparing with Nickel-Cadmium, Nickel-Metal Hydride or Fuel-Cell technology concept of power buffer.

A comprehensive investigation of Lithium-Ion battery stability versus temperature and versus high-load currents proved the efficiency of Lithium-ion batteries as they are the most efficient energy storage currently available for new vehicular systems.

Acknowledgements

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