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4. ELECTRICAL AND ELECTRONICAL ENGINEERING

ENERGETICAL MONITORING OF THE STORAGE DEVICES BY USING SENSORS NETWORK PLACED INSIDE THE MOBILE SYSTEMS

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Abstract: *The goal of the paper is to identify the characteristics (voltage variation in time) and the comportment of the storage devices while they are exposed at extreme temperatures. The temperature variations simulated the impact of the AC system from a vehicle set at different temperatures (AC-heating, AC-cooling) on the storage devices.*

Key words*: super capacitor, battery, air conditioning, monitoring, mobile vehicle, sensors, energy storage, characteristics.*

1. INTRODUCTION

Nowadays, the protection of the environment became a major problem which affects our daily life. Because of this, the environment problem is taken in consideration by many groups of researchers. The finite resources of the energy, the pollution generated by our activities, inclusively by the transportation systems, became a major motor factor for many research programs having as goal to save and to make more efficient the usage of the energy [1].

The energy density level of the fossil fuels is very high, impossible, for the moment, to be reached by other solutions. The transitory regimes involve, in general, a loss of energy transformed in heat (e.g. the breaking process of the vehicles, the transient regime of all automatically processes govern by "climatronic" regulators or even the voltage regulator used for charging the batteries existing on vehicles. Starting to this idea it is essential to introduce on vehicle some rapid release storage elements able to store or to absorb very fast the transitory component of the power flow. More that, it will be an interest to study the dimensioning algorithms and also the topology and locality of these elements placed inside the vehicle. Another extremely important aspect is related to the energetic system response function of the environment temperature. For example, at low temperatures, some functions as starting the ICE (Internal Combustion Engine) or the heating process of the vehicle's habitat request a lot of energy consumed that can stress the classical batteries that endow actually the vehicles [2].

The experiments showed that only an integral view for the concept of modern vehicles can bring us a new level of energy efficiency that also means to take into account all the detailed characteristics of the elements involved in the energetic vehicle's sub-system [3].

The goal of the paper is to determine how storage devices placed in a vehicle can be influenced by the temperature and humidity fluctuations while they are exposed at extreme temperatures, thus simulating the real conditions that can appear inside of a vehicle environment in our daily life. Also, the charge/discharge characteristics of the storage devices have to be raised in order to be able to interpret them and to determine the optimally place of them inside the vehicle.

2. VEHICLE'S HVAC SYSTEM

Over the last years, with the trends of reducing costs and carrying weight, the interest in ensuring an optimal efficiency in a large sense (energy efficiency, comfort, dynamicity and performances - including reliability and availability) in vehicles has increased. Constructions of vehicles have developed from simplistic to modern cars, integrating the last hour technologies, organized on functional and aesthetic criteria, which ensure the passengers' comfort, ergonomics, safety and also high energy efficiency of the transportation systems [4].

The starting idea is the existence of two scenarios that could appear while the vehicle is functioning: hot versus cold habitat temperature that impose two reactions from the temperature regulator system (HVAC - Heating Ventilating and Air Conditioning) existing on vehicle: cooling and respectively heating the habitat. In both cases it is necessary to take in consideration two periods: (i) the transitory period that means the time to reach the set temperature and (ii) the period of stationary regime when the limits of temperature variation are very strictly controlled. Thinking about the power/energy sources able to provide these services it were identified the ICE and the batteries as primary sources of energy and the supercapacitors as rapid release and storage device.

The primary purpose of the AC system (Air Conditioning) is to assure the comfort of the passengers inside a vehicle and to permanently circulate a thermal treated air flow.

Thermal comfort is influenced by a combination of physical, physiological and psychological factors. ASHRAE standard 55 defines thermal comfort as "that state of mind which expresses satisfaction with the thermal environment" [5]. Models of thermal comfort that can be used to predict subjective comfort assessment have been developed. These models have been validated making human subject studies. The most notable figure of the thermal comfort analysis was P.O. Fanger, with his studies "Thermal Comfort" [6].

A vehicle represents a "moderate" thermal environment described by Fanger's equation (most widely used in automotive thermal comfort research). The environment of the vehicle is non-uniform and dynamic and most of the occupants will experience this comfort for more than one source simultaneously, like: external temperature, solar radiation, glazing (transmittance, reflectance and absorption).

Inside the vehicle it exist two major factors that dramatically affect the vehicle's environment: HVAC system and windows [7]. The HVAC systems were developed especially to increase the passengers' comfort.

In Fig. 1 is presented a typical HVAC system with interior air flow repartition tubes.

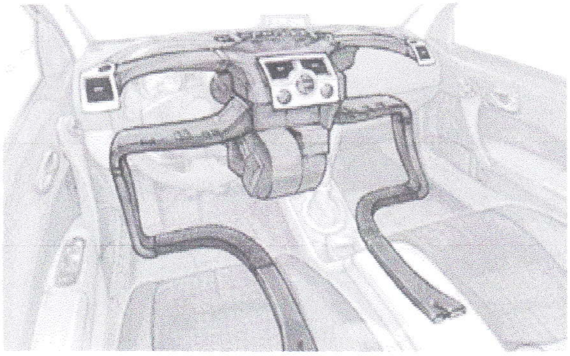

Fig. 1 Air flow repartition inside the vehicle

The optimal comfort rate can be obtained only with automatically air conditioning systems. At the automatic HVAC system, the passenger sets the desired temperature and the system's role is to maintain it constantly by using temperature and humidity sensors placed in key points inside the vehicle. In order to maintain the temperature and humidity in a strictly range, the energy and fuel consumption are increased. The storage devices characteristics were made by simulating a vehicle environment having an automatic HVAC system.

A big interest in the hybrid vehicles research is focused on determining the optimally place of the energetically storage devices inside the vehicles. In order to assume that, studies about voltage variation with temperature in time were made, these temperature variations simulating the AC impact on the storage devices' characteristics.

As a case study, it can be considered an AC system, a 14V/40F supercapacitor and a 12V/77Ah battery as devices under test.

The studies made by ADEME for summer conditions showed that the fuel consumption of a vehicle is increased with 25-35% when using the AC system in towns and with 10-20% when the AC system is used outside the town. As an average, ADEME affirms that the fuel consumption is annually increased with 5% [8].

The energy provided by the supercapacitor reaches 3920 Ws and its extraction factor is 50% [9]. That means the supercapacitor can assure 1960 Ws. The battery has high energy density, but only 15% of its energy can be delivered to the system (138.6 Wh).

The AC systems have to work properly in extreme situations. For example, in summer, while the vehicle is stationing at high temperatures, the attracted solar energy can reach 1000W/m^2 and thus, the interior temperature can easily reach 60-65°C. In such situations, the AC system has to provide in a short time high cooling energy (e.g. 10kW). Having 1960 Ws, 5 supercapacitors connected in parallel can provide this cooling energy in 1 second. Instead of connecting in parallel 5 supercapacitors, a battery and a supercapacitor connected together are preferred because the damaging current spike it appears only at the starting AC switch on process. At switching on, the AC system will be supplied from the supercapacitor thus assuring the load smoothing and the rest of the necessary energy will be provided by the battery.

In Fig. 2 is presented the flow diagram that can be used for the AC switching on process. Firstly, the supercapacitor is charged from the battery until its voltage (V_{SC}) reaches the set threshold voltage (V_{Th}). The supercapacitor's charging process is made in a specified period of time. After the system reached time out ($T_{Time\ out}$) it starts the supply process for the AC from the supercapacitor. When the voltage from the supercapacitor reaches the second set threshold (V_{Th2}), the supplying process is switched on the battery and both of the devices are charged from the alternator.

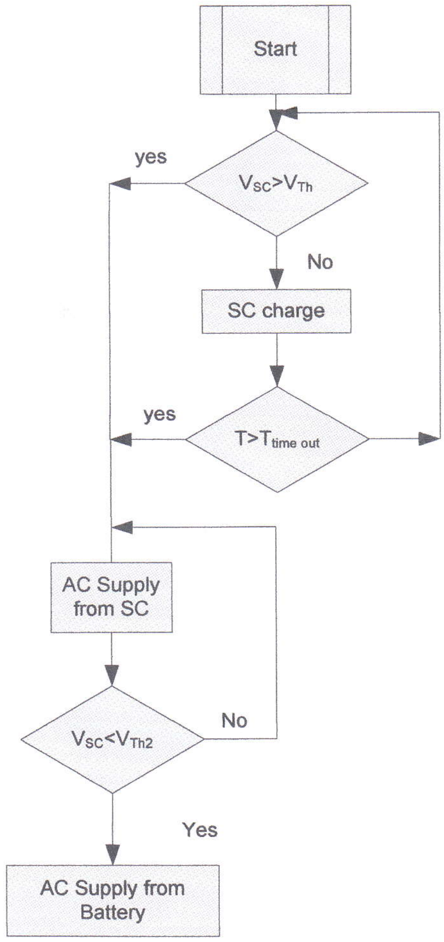

Fig. 2 Flow diagram for AC switching on

3. DEVICES' DESCRIPTION

The landscape of the storage devices is complex and actually incomplete known.

Batteries and supercapacitors are electrochemical energy systems carefully designed and fabricated which offer together high power and energy density.

Batteries are combinations of one or more electrochemical galvanic cells which store, with high energy density, chemical energy in contrast with supercapacitors which are electrochemical capacitors that assure high power density.

The supercapacitor technology became an open topic nowadays and is receiving considerable research interest in both academia and industry, due to the wide range of its potential applications, like high power density and high peak power requirements. Supercapacitors are used in order to increase the system's performance, safety, availability, efficiency and fiability. Also, supercapacitors assure backup power for mobile applications, cut pulse current noises, enhance load balancing when used in parallel with a battery, reduce battery's size, extend battery's life cycle by covering the power pulses, minimize space requirements and can be rapidly recharged from any energy sources.

Supercapacitors don't intend to replace batteries; their aim is to fill the gap between capacitors and batteries. Thus, a combination of both devices (batteries and supercapacitors), as presented in Fig. 3, where batteries are designed to offer the steady state energy and super capacitors to supply or to absorb the transitory energy transferred in case of the vehicles applications, is preferred [10].

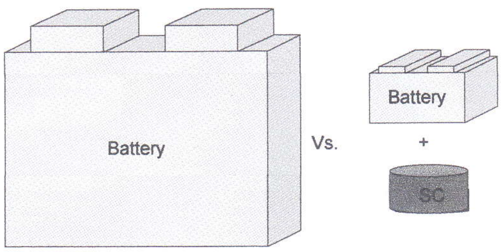

Fig. 3 SC reduces battery's size [9]

Nanotechnology improved the supercapacitors' characteristics, their parameters, their life cycle and power density, made them ultra small, very scalable and their performance scales with size and weight.

Devices' life cycle is defined as the number of complete charge-discharge cycles. For batteries, as high energy density devices, the deepness of the discharge is better to be limited at maximum 15-20% of their capacity in order to prevent the unattended fails [11]. Other influence factors of the battery's life time are: (i) the active materials used for electrodes, (ii) physical factors such as: temperature, humidity and pressure, (iii) electrical factors such as: over and under voltage, current variation in time (peak current).

Regarding the life time, if a battery has between 500 and 1200 life-cycles, then a super capacitor virtually has unlimited life cycle – can be cycled millions of time. Having complementary performance seems to be suitable to use for high reliable transportation applications [12].

In Fig. 4 is presented a comparative view between supercapacitors' and batteries' energy/power densities [9].

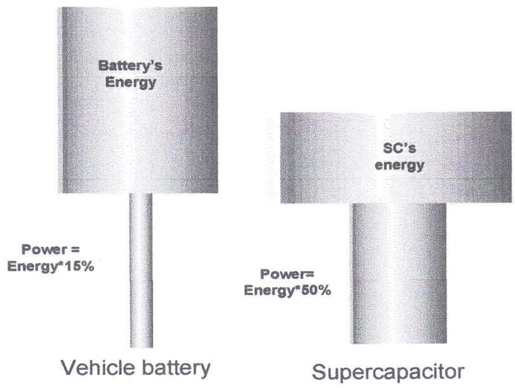

Fig. 4 Energy/Power densities for SC and battery

Supercapacitors have the largest area on the ragone diagram (Fig. 5), they have high cycling stability, rapid charging and discharging times and temperature stability, as it also can be seen from the experiments. By contrast, batteries have high energy density but they have limited number of cycling, the charging and discharging processes are not stable with temperature, as it can also be seen from experiments.

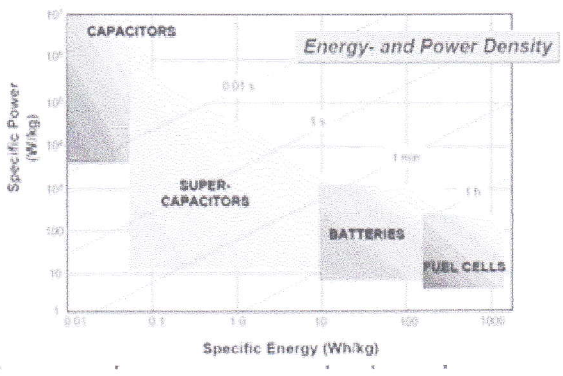

Fig. 5 Ragone diagram [13]

For batteries, their features such as nominal capacity, state of charge (SoC), state of health (SoH) and also the span life need more precision in definition. The type of the active cycle applied on batteries, the deepness of the discharge processes and the temperature have a crucial influence on their life time.

The development of the widespread applications of the supercapacitor technology will only be possible when appropriate high-voltage supercapacitor solutions will be developed to fulfill requirements such as voltage level, maximum current requested by transportation applications, cost, reliability, operating temperature range and environmental concerns [14].

4. MEASURING METHODS AND TEST BENCH IMPLEMENTATION

At present, there are implemented multiple methods for devices health monitoring like:

(i) discharge test - it is made off line and it is time consuming;

(ii) measurement of the electrolyte's physical properties;

(iii) open circuit voltage - it requires long rest period before making the measurements;

(iv) internal resistance - it can be made at very small time interval (<10ms);

(v) alternative current impedance spectroscopy - it is non-destructive.

Unfortunately, these methods are not designed for continuously monitoring and, in this case, long periods of charging and discharging are missed while the devices' health can be degraded.

A model for a supercapacitor with two components (first order conduction and second order conduction) is presented in Fig. 6.

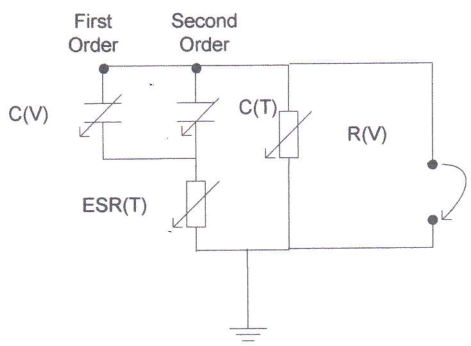

Fig. 6 Supercapacitor basic model

Supercapacitors' and batteries' charge/ discharge rate and thermal comfort depend on temperature and humidity. In order to simulate the impact of the air conditioning system (AC) from a vehicle on the storage devices, temperature was varied, the storage devices' characteristics were obtained and thus it was determined how quickly the storage device will lose its energy at different temperatures and constant load. To measure these characteristics, a test bench that can measure online the important parameters was implemented. Having a 2A load, the devices' voltage is monitored at different temperatures. The characteristic voltage/time is obtained on line by using a Fluke 1998B scope meter, a HP 34401A multimeter, a laptop and a data acquisition system (DAQ). All the data are stored in the scope meter's memory and also, are simultaneously transmitted via Bluetooth to the laptop. The stored data are processed in Matlab tool.

For supercapacitors it is necessary to analyze and measure their voltage characteristics function of temperature variation, the type of the active cycle, the electrode materials and the electrolyte in order to optimally integrate them into composed storage systems placed in vehicles.

In order to correctly characterize a storage device it is necessary to include at least the following topics: voltage variation, energy density, power density, inner resistance, temperature range of operation, geometry of the elementary cells, type of package, aging, and environmental effects (relating to operation and end- of-life disposal).

To achieve this goal, we developed first a test bench system used to determine the characteristics of the supercapacitors/batteries and to raise their voltage characteristics.

The developed test bench presented in Fig. 7 consists of a 12V Rombat Pilot Diesel Hybrid battery, 77Ah, a 14V/40F ECOND LTD PSCAP supercapacitor, a heating Carbolite camera, type PF120 (200) and a cooling Derby camera, DK 9620 Alestrup, type F26LT, voltage and current sensors (placed on the storage devices), temperature and humidity sensors (placed inside the heating/cooling camera) and a ATMega128 microcontroller based acquisition system, all of these submissived to the interior environment variations (simulating the AC-heating, AC-cooling).

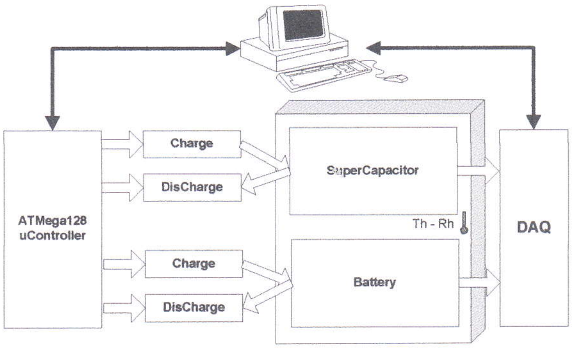

Fig. 7 Test bench implementation

In Fig. 8 it is presented in detail the test bench implementation. The test bench is composed by a switch for selecting the charge/discharge process and a switch for selecting the device under test (battery and supercapacitor). The control commands are given by using an ATMega128 microcontroller.

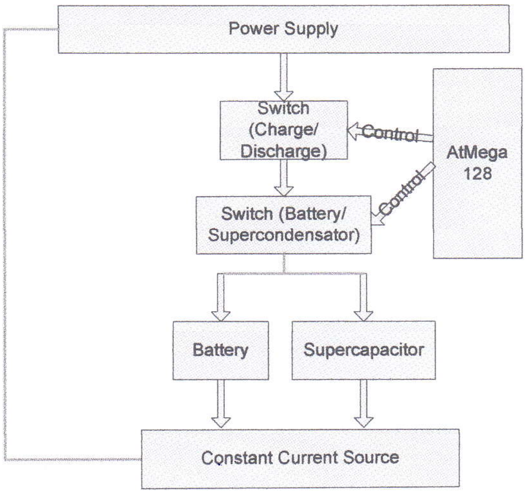

Fig. 8 Detailed test bench implementation

5. Experiments and results

In order to optimally integrate the storage devices in a system, experimental data were accumulated and the results were interpreted.

While at batteries the capacitance variation with temperature is pronunced, at supercapacitors, the capacitance variation with temperature is reduced also having a reduced ESR (Electrical Series Resistance).

The chemical reactions of the batteries are dependent with temperature and thus, the battery's performance is deteriorating while exposing it at extreme temperatures. In the supercapacitor case, because there are not complicated reactions while normal functioning, its performance remains approximately the same in a wide range of temperature (–40^0 C;+70^{0}C), as it is ilustrated in the experimental graphics (Fig. 10 a, b and Fig. 12 a, b).

To acquire the experimental data it was used the test bench described above.

The Relative Humidity (RH) and Dew Point variation function of temperature measured by the help of the SHT11xx sensor were:

Table 1 Experimental data

Temperature [^{o}C]	Humidity [%]	Dew Point [%]
-40	9.5	-58.08
-25	10.74	-47.06
0	25	2.9
20	35	4.1
60	8.78	15.93

The experimental results for the supercapacitor are presented in Fig. 10 (a, b).

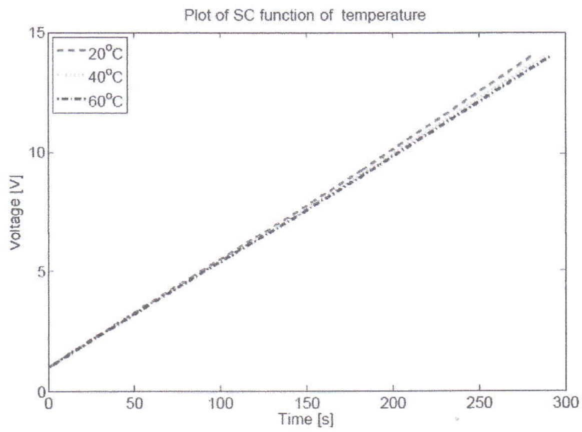

Fig. 9 a Supercapacitor's voltage variation function of temperature variation having 2A constant load

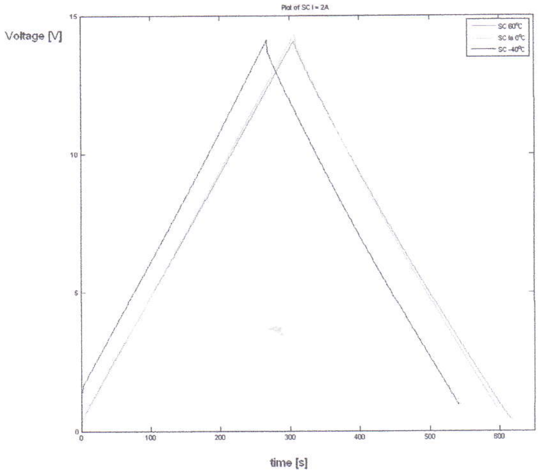

Fig. 10 b Supercapacitor's voltage variation function of temperature variation having 2A constant load

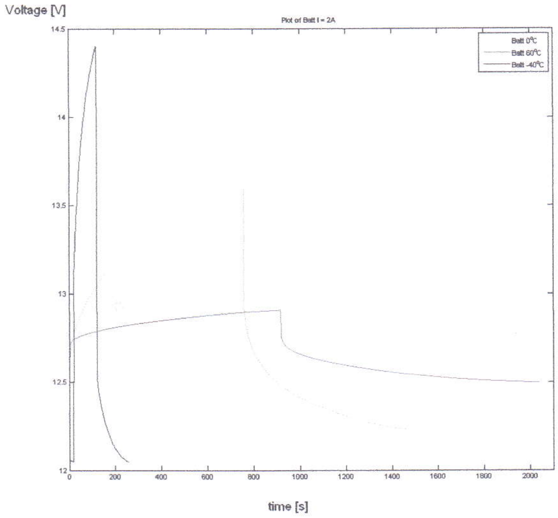

Fig. 12 b Battery's voltage variation function of temperature variation having 2A constant load

The supercapacitor's parameters dependent on temperature are ESR and the second order capacity conduction.

As it can be seen in Fig. 10 (a, b), the comportment of the supercapacitor it is not considerably influenced by the temperature and humidity variation, the charging and discharging time having approximately the same value at -40°C and at 60 °C.

Because the implemented test bench had a 2A active constant load connected in series with the supercapacitor's loses resistance, the variation of the ESR and of the second order capacity conduction function of temperature are insignificant compared with the first order capacity's conduction variation with voltage.

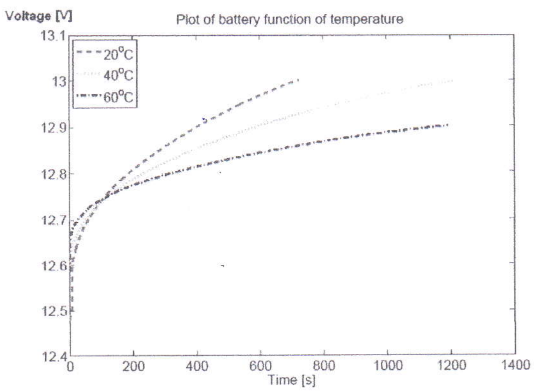

Fig. 11 a Battery's voltage variation function of temperature variation having 2A constant load

It can be seen in Fig. 12 (a, b) that batteries have a considerably dependency with temperature variations.

Thus, in the batteries case, as higher is the temperature, as slower are the charging and discharging process and as lower is the temperature as faster are the charging and also the discharging process.

As it can be seen in Fig. 12 (a, b), at low temperatures the charging process (from 12.2V to 14.4V) and discharging process (from 14.4V to 12.2V) are made in less than 350 seconds. Because there is not enough time to complete the battery's chemical reactions its state of charge is affected and its life time is considerably reduced. For example, at low temperatures, some functions as starting the ICE or starting the heating process of the vehicle's habitat stress the battery because of the huge amount of requested energy which can be provided only for a small period of time.

For this reason, supercapacitors used in combination with batteries can bring a new level of energy efficiency and, concomitantly, can improve the battery's life time.

6. CONCLUSIONS

As it was presented in the present paper, the thermal treated air flow influences both the thermal comfort of the passengers in a vehicle environment and the voltage characteristics of the storage devices (battery and supercapacitor). Also, the actual storage device's (battery) comportment proved to be affected by a rapid variation between extreme temperatures.

The experiments showed that the comportment of a supercapacitor is considerably stable with temperature and humidity variation in a wide range of temperature (-40°C; 60°C) in contrast to a battery, which proved to be not stable at all in the same range of operating temperature. For this reason, a supercapacitor used in combination with a battery not only improves the battery's life time but it also offers a good stability with a wide range of temperature and humidity.

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