UTILISATION OF ENERGY STORAGE SYSTEMS IN A PV ASSEMBLY

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REZUMAT. Lucrarea prezintă studii privind sistemele de stocare, de ultimă generaţie, a energiei, care ar putea fi utilizate pentru stocarea energiei din panourile fotovoltaice; și o comparație între acumulatori și supercapacitoare. Energia solară utilizată se modifică în cursul anului nu numai sezonier sau în ciclul zi-noapte, ci de la o zi la alta datorită condițiilor climatice diferite. În această situație există o nevoie clară de înțelegere și utilizare a sistemelor de stocare de ultimă generație, care ar putea permite utilizatorilor să economisească energie pentru un sistem autonom.

Cuvinte cheie: sistem de stocare a energiei, supercapacitoare, PV, acumulatori, baterii.

ABSTRACT. The paper presents investigations about the state-of-the-art energy storage systems, that could be used for storing energy from the PV panels, and a comparison between accumulators and supercapacitors. The used solar energy changes during the year not only seasonally or in the day-night cycle, but from one day to another due to the different climatic conditions. In this situation there is a clear need for understanding and using the state of the art storage systems that might allow the users, off the grid, to save energy for an autonomous system.

Keywords: energy storage system, supercapacitors, PV, accumulators, battery.

1. INTRODUCERE

Nowadays, the world's primary power source (approximately 70%) is obtained from the combustion of the fuels: carbon, petrol, rock gas, which are exhausting; their combustion produces big quantities of CO_2 and is constituted by the power obtained from the nuclear and hydro-electric power plants.

Considering the actual growing rate of the fuel's consumption, it is necessary to find new and cheaper power sources. At the same time, one can see the negative effects of using the classic fuel (nox emission, greenhouse effect). It is important to find and promote new technologies and applications regarding the utilization of unconventional power resources.

Photovoltaics (PV) represents one of the most interesting technical solutions for generating power, using renewable energy. In the photovoltaic process, the solar energy is transformed directly into electrical energy, without using any mechanical device.

The used solar energy changes during the year not only seasonally or in the day-night cycle, but from one day to another due to the different climatic conditions.

Similarly, the demand for electrical energy of consumers varies in time. To obtain equilibrium between the charge curve (consumer's demand) and the energy generated from the conversion of solar energy, the autonomous PV systems need units for energy storage. For these energetic systems, the prices for these units represent 30% from the costs of the system.

The matter of storing the energy has a multitude of solutions. Storing energy in an electric field placed in capacitors is a solution for short storing times. Battery storing is, however, the most popular method. The attempt is to combine supercapacitors and batteries for good optimization and to prolong the life of the batteries.

Energy storage technologies do not generate electricity but can deliver stored electricity to the electric grid or an end-user. They are used to improve power quality by correcting voltage sags, flicker, surges, and frequency imbalances.

The energy storage is a fundamental and critical aspect of any practical PV system, and involves the storage of excess PV-generated energy in a form suitable for use during periods when the solar input is insufficient to support load demands.

2. THE STATE-OF-THE-ART ENERGY STORAGE SYSTEM

2.1. Lead-acid battery

Traditionally, the lead-acid battery has been the technology of choice in PV-systems. This is primarily due to the comparative technical simplicity and the substantial capital cost advantage of the lead-acid battery over other possible energy storage technologies. However, the performance of the lead-acid battery compared to other components of contemporary PV-systems is varied, and on a life cycle basis, the lead-acid battery becomes a significant element of the total system costs. Experience with lead-acid battery storage systems varies with battery type and type of PV application, system sizing design and control scheme.

The lead-acid battery is the most widely used secondary battery and is still the technology of choice in most PV systems [1]. It involves the reversible electrochemistry between lead and lead oxide in sulphuric acid. Lead-acid battery technology is more than 100 years old, and in this context, it is “proven” technology. However, the energy storage capability of the lead-acid battery varies with battery design and use, and in all cases, the practical discharge capacity is at best only about 60%-70% of the theoretical capacity. None of the theoretical capacity is actually wasted, it is just unavailable due to a combination of polarization (voltage drop) factors which affect the degree of utilization of active material in the plates.

2.2. Flow battery

Flow batteries differ from conventional rechargeable batteries in one significant way: the power and energy rating of a flow battery are independent of each other. This is made possible by the separation of the electrolyte and the battery stack (or fuel cell stack). A flow battery stores and releases energy by means of a reversible electrochemical reaction between two electrolyte solutions.

There are four leading flow battery technologies: Polysulfide Bromide (PSB), Vanadium Redox (VRB), Zinc Bromine (ZnBr), and Hydrogen Bromine (H-Br) batteries.

2.3. Nickel-cadmium (NICD) and nickel-metal hydride (NIMH)

These batteries offer much better energy density than lead-acid batteries. NiCd batteries perform best when they are regularly and completely discharged and then recharged completely; otherwise, they display the memory effect, which limits their depth of discharge and usefulness. NiCd batteries can last for about 1,000 charge-discharge cycles and function well in extreme temperatures.

Many countries now impose strict disposal regulations on lead-acid and NiCd batteries. The heavy metals used in their manufacture can cause serious environmental pollution if not recycled or stored. Compliance with these regulations may add significantly to the cost of these batteries.

NiMH batteries lasts approximately 40% longer per charge than comparable Nickel-Cadmium batteries. They are lighter in weight and last up to 700 charge/discharge cycles.

2.4. Lithium ion batteries

Lithium ion batteries (Li ion) offer twice the energy per charge of NiMH and approximately 500 charge-discharge cycles. However, they cannot sustain high currents at temperatures below 0°C and are relatively expensive.

2.5. Lithium polymer

Lithium polymer batteries can be made in thin, flat or shape fitting forms and their biggest plus is that they won't leak corrosive electrolyte. They provide 500 charge-discharge cycles, but require smart chargers to monitor them closely. Lithium polymer batteries are not suitable for high-power applications, they are limited to the operating temperature range 0 - 65° and are relatively expensive.

2.6. Supercapacitors

A capacitor (figure 1) is a device used to store charge in an electrical circuit. It functions much like a battery, but charges and discharges much more efficiently (batteries, though, can store much more charge).

A basic capacitor is made up of two conductors separated by an insulator, or dielectric. The dielectric can be made of paper, plastic, mica, ceramic, glass, a vacuum or nearly any other nonconductive material.

Some capacitors are called electrolytics, meaning that their dielectric is made up of a thin layer of oxide formed on an aluminum or tantalum foil conductor.

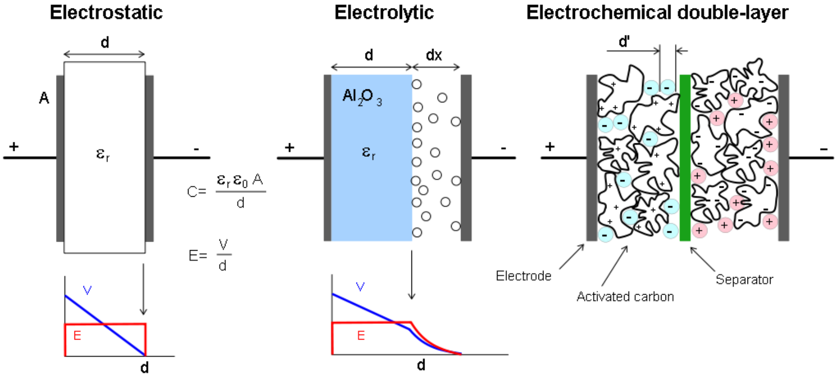
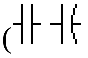
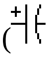


Fig.1. Comparison of construction diagrams of three capacitors. Left: "normal" capacitor, middle: electrolytic, right: super capacitor

There are 2 main types of capacitors:

- The non-polarized fixed capacitor () is a type of capacitor that has no implicit polarity -- it can be connected either way in a circuit. Ceramic, mica and some electrolytic capacitors are non-polarized. They are also called "bipolar" capacitors.

- The polarized fixed capacitor () is a type of capacitor ("polar") that has implicit polarity -- it can only be connected one way in a circuit. The positive lead is shown on the schematic (and often on the capacitor) with a little "+" symbol. The negative lead is generally not shown on the schematic, but may be marked on the capacitor with a bar or "-" symbol. Polarized capacitors are generally electrolytics.

The supercapacitor resembles a regular capacitor with the exception that it offers very high capacitance in a small package. Energy storage is by means of static charge rather than of an electro-chemical process that is inherent to the battery. Applying a voltage differential on the positive and negative plates charges the supercapacitor.

Whereas a regular capacitor consists of conductive foils and a dry separator, the supercapacitor crosses into battery technology by using special electrodes and some electrolyte. There are three types of electrode materials suitable for the supercapacitor. These are: high surface area activated carbons, metal oxide and conducting polymers.

The electrolyte may be aqueous or organic. The aqueous variety offers low internal resistance but limits the voltage to one volt. In contrast, the organic electrolyte allows 2.5 volts of charge, but the internal resistance is higher.

To operate at higher voltages, supercapacitors are connected in series. On a string of more than three capacitors, voltage balancing is required to prevent any cell from reaching over-voltage.

The amount of energy a capacitor can hold is measured in microfarads or µF. (1µF = 0.000,001 farad). While small capacitors are rated in nanofarads (1000 times smaller than 1µF) and pico-farads (1 million times smaller than 1µF), supercapacitors come in farads.

The gravimetric energy density of the supercapacitor is 1 to 10Wh/kg. This energy density is high in comparison to a regular capacitor but reflects only one-tenth that of the nickel-metal-hydride battery. Whereas the electro-chemical battery delivers a fairly steady voltage in the usable energy spectrum, the voltage of the supercapacitor is linear and drops evenly from full voltage to zero volts. Because of this, the supercapacitor is unable to deliver the full charge.

In terms of charging method, the supercapacitor resembles the lead-acid battery. Full charge occurs when a set voltage limit is reached. Unlike the electrochemical battery, the supercapacitor does not require a full-charge detection circuit. Supercapacitors take as much energy as needed. When full, they stop accepting charge. There is no danger of overcharge or 'memory'.

The supercapacitor can be recharged and discharged virtually an unlimited number of times. Unlike the electrochemical battery, there is very little wear and tear induced by cycling and age does not affect the supercapacitor much. In normal use, a supercapacitor deteriorates to about 80 percent after 10 years.

The self-discharge of the supercapacitor is substantially higher than that of the electro-chemical battery. Supercapacitors with an organic electrolyte are affected the most. In 30 to 40 days, the capacity decreases from full charge to 50 percent. In comparison, a nickel-based battery discharges about 10 percent during that time. [2]

In a conventional capacitor, energy is stored by the removal of charge carriers, typically electrons, from one metal plate and depositing them on another. This charge separation creates a potential between the two plates, which can be harnessed in an external circuit. The total energy stored in this fashion is a combination of the number of charges stored and the potential between the plates. The former is essentially a function of size and the material properties of the plates, while the latter is limited by the dielectric breakdown between the plates. Various materials can be inserted between the plates to allow higher voltages to be stored, leading to higher energy densities for any given size.

In contrast with traditional capacitors, super capacitors do not have a conventional dielectric, as such. They are based on a structure that contains an electrical double layer. In a double layer, the effective thickness of the "dielectric" is exceedingly thin – on the order of nanometers – and that, combined with the very large surface area, is responsible for their extraordinarily high capacitances in practical sizes.

In general, supercapacitors improve storage density through the use of a nanoporous material, typically activated charcoal, in place of the conventional insulating barrier. Activated charcoal is not the "perfect" material for this application. Free electrons are actually (in effect) quite large, often larger than the holes left in the charcoal, which are too small to accept them, limiting the storage. Recent research in supercapacitors has generally focused on improved materials that offer even higher usable surface areas. Experimental devices replace the charcoal with carbon nanotubes, which have similar charge storage capability as charcoal (which is almost pure carbon) but are mechanically arranged in a much more regular pattern that exposes a much greater suitable surface area. Other teams are experimenting with custom materials made of activated polypyrrole, and even nanotube-impregnated papers. A completely different approach is being pioneered by EEStor, who claim to have developed a dramatically improved insulator based on barium titanate that improves the permissivity of the insulator by several orders of magnitude, improving energy density (Figure 3) not through electron capacity but via much higher potentials. EEStor claims that their capacitors can operate at extremely high voltages, on the order of several thousand volts. [6]

2.7. Electrical- energy- storage unit (EESU) cell

An electrical-energy-storage unit (EESU) (Figure 2) has as a basis material a high-permittivity composition-modified barium titanate ceramic powder. This powder is double coated with the first coating being aluminium oxide and the second coating calcium magnesium aluminosilicate glass.

The components of the EESU are manufactured with the use of classical ceramic fabrication techniques which include screen printing alternating multilayers of nickel electrodes and high-permittivity composition-modified barium titanate powder, sintering to a closed-pore porous body, followed by hot-isostatic pressing to a void-free body. The components are configured into a multilayer array with the use of a solder-bump technique as the enabling technology so as to provide a parallel configuration of components that has the capability to store electrical energy in the range of 52 kWh.

Fig. 2. EESU cell.

These units achieve a level of capacitance claimed to be much higher than what is currently available in the market. The claimed energy density is 1.0 MJ/kg (existing commercial super capacitors) typically have an energy density of around 0.01 MJ/kg, while lithiumion batteries have an energy density of around 0.54- 0.72 MJ/kg. [4]

However, standard household wiring is not capable of delivering the power required for this, so charging times this short would probably require purpose-built high capacity dispensing stations. Overnight charging at home should still be practical, as is using a second EESU for the home which could be charged overnight using cheap, off-peak electricity to then charge the EEStor unit in the car in 5-10 minutes on demand.

Based on the claims, presented in this paper, a five-minute charge should be enough to give the capacitor sufficient energy to drive a small car on a distance of 300 miles (the equivalent of 480 km).

2.8. Nanocomposite paper

Nanocomposite paper is a hybrid energy storage device that combines characteristics of batteries and supercapacitors.

This energy storage device is based on two basic, inexpensive materials: carbon nanotubes and cellulose. Electrolyte, an ionic liquid, provides the third component. Engineered together, they form nanocomposite paper. It is as thin and flexible as a piece of paper—it can be twisted, folded, rolled and cut to fit any space without losing any of its energy. The paper battery can also be stacked to boost the total power output.

To create this paper, the cellulose is first dissolved in the ionic liquid and then infiltrated with aligned carbon nanotubes which form the uniform film. Then it is solidified on dry ice, soaked in ethanol to remove the ionic liquid and dried in a vacuum, which leads to the final product: Nanocomposite paper. The ionic liquid contains no water, which means there is nothing in the batteries to freeze or evaporate, therefore its ability to function in temperatures up to 300 degrees Fahrenheit and down to 100 below zero [7].

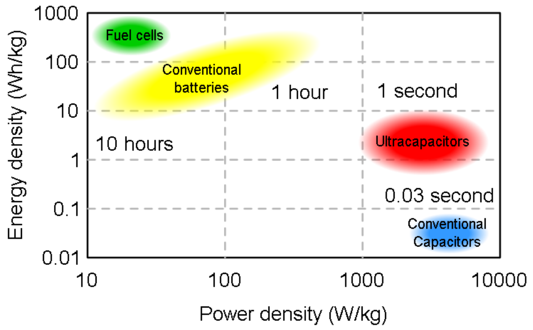


Fig.3. *Ragone plot showing energy density vs. power density for various energy-storage devices*

The supercapacitors operate with electrolytes including aqueous solvents, room temperature ionic liquids, and bioelectrolytes and over record temperature ranges.

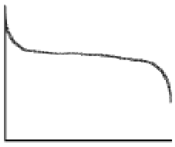
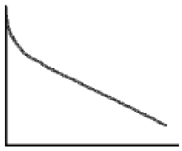
The cellulose is porous with randomly distributed pores of 50 ± 5 nm [5]. The nanocomposite paper, which can be typically a few tens of microns thick, contains multiwall nanotubes (MWNTs).

Two of the nanocomposite units bonded back-to-back make a single supercapacitor device. The thin lightweight (≈15-mg/cm^2) design of the device results from avoiding the use of a separate electrolyte and spacer, generally used in conventional supercapacitors.

3. CONCLUSION AS A COMPARISON

Is presented in table 1.

Tab.1. Comparison between accumulators and supercapacitors [3]

	Accumulators	Supercapacitors
Energy Storage Method	Faradic reactions Mass transfer between the electrodes	Mostly electrostatic interactions Ionic charge accumulation at the active material/electrolyte interface
Discharge curve		
Cycle life	Depending on cycling profile Impact of the active material degradation and parasitic phenomena such as electrolyte degradation	>>1000000 Impact of parasitic phenomena such as electrolyte degradation
Energy level	60 Wh/kg 140 Wh/kg	1-10 Wh/kg
Power level	0.4-0.8 kW/kg 0.3-1.5 kW/kg	1-6 kW/kg

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