

BULLETIN OF THE TRANSILVANIA UNIVERSITY OF BRASOV • VOL.2 (51)-2009
SERIES I - ENGINEERING SCIENCES, ISSN 2065-2119 (Print), ISSN 2065-2127 (CD-ROM)

• **MECHANICAL ENGINEERING**

Velea, M.N., Lache, S.: *Investigation of the Compressive Behaviour of an Expanded Cellular*

BULLETIN OF THE TRANSILVANIA UNIVERSITY OF BRASOV • VOL.2 (51)-2009
SERIES I - ENGINEERING SCIENCES, ISSN 2065-2119 (Print), ISSN 2065-2127 (CD-ROM)

• **INDUSTRIAL ENGINEERING**

Alexandru, C.: *Functional Optimization of Windshield Wiper Mechanisms in MBS (Multi-Body System) Concept*.....
 Barbuceanu, F., Antonya, C.: *Eye Tracking Applications*
 Butuc, B., Moldoveanu, Gh.: *Computer Program for The Angles Describing the Sun's Apparent Movement in the Sky*.....
 Coste, L., Eftimie, E.: *Computer Program for Climatological Parameters Calculation and Radiation Simulation*
 Cozma, R.: *A Study of Global Friction Coefficient and the Starting Moment Variation for Radial Bearings*
 Daj, I.: *Calculus Modelling for Designing Ranging Drum Shearer Variants with Cutting Space*
 Duguleana, M.: *Learning Mobile Robots*
 Eftimie, E.: *Linke Turbidity Factor for Brasov Urban Area*

 Eftimie, N.: *Computer Program for the Cusum Chart*

 Hermenean, I.S., Visa, I., Diaconescu, D.V.: *On the Geometric Modelling of a Concentrating PV-Mirror System*
 Jaliu, C., Neagoe, M., Saulescu, R., Grosu, A.: *On a New Planetary Speed Increaser with Deformable Element used in R.E.S.*.....
 Mihail, L.A.: *Organisational Process Mapping for ISO/TS 16949:2009 Certification of Industrial Quality Management Systems*.....
 Vatasescu, M.M., Diaconescu, D.V., Visa, I.: *On the Simulation of a Mono-Actuator Bi-Axial Azimuth PV System*

BULLETIN OF THE TRANSILVANIA UNIVERSITY OF BRASOV • VOL.2 (51)-2009
SERIES I - ENGINEERING SCIENCES, ISSN 2065-2119 (Print), ISSN 2065-2127 (CD-ROM)

• **MATERIALS SCIENCE AND ENGINEERING**

Candea, V.N., Iordache, C.A., Dinu, M.O., Ploscariu, C.: *Thermal Cutting Equipment for Construction Materials with Thermal Lancing*
 Croitoru, C., Patachia, S.: *Molecularly Imprinted Poly(Vinyl Alcohol) for the Selective Absorption of Gallic Acid from Aqueous Solutions*
 Dumitrescu, L., Manciualea, I., Sauciuc, A., Zaha, C.: *Obtaining Biofertilizer by Composting Vegetable Waste, Sewage Sludge and Sawdust*
 Garcia Doreste, M.E., Gonzalez Martin, D., Tiorean, M.H., Mirza Rosca, J.C.: *Preliminary Studies for In Vivo Application of Surface Treated Ti6Al7Nb Prostheses*
 Geaman, V.: *Applications of Isostatic Processing Technology in the Field of Duralumin Alloys*
 Georgescu, B.: *An Overview of Welding on Cogged Surfaces*
 Lucaci, D., Duta, A.: *Comparative Adsorption of Copper on Oak, Poplar and Willow Sawdust*
 Markos, Z.: *Correlation between Microstructure and Properties of Siliconized Bronzes*
 Mateescu, G., Mateescu, A., Samoila, C., Ursutiu, D.: *Preliminary Experiments of the New Facility and Technology for Vacuum Drying and Thermal Polimerization of the Turbogenerators Stator Bars Insulation (INTEPOL)*
 Micu, D.A., Catana, D.: *Thermo-Mechanic Treatments Influence on Plastic Deformation Strength of High Speed Steel*
 Nath, G., Scorobetiu, L., Darolti, M., Stroe, M., Eftimie, C.: *Researches Regarding Reconditioning of Bimetal Materials*

<i>Having as Basic Material VCRW85</i>	
Nicolae, A., Nicolae, M., Predescu, C., Calea, G.G., Berbecaru, A., Bors, I.: <i>Engineering Supply for Improving Knowledges Regarding Sustainable Development of the Environment (SDE)</i>	
Pascu, A., Iovanas, R., Petre, D., Roata, I.C.: <i>Industrial Application of High Power Diode Pumped Solid State Laser for Welding Technology</i>	
Patachia, S., Moise, G., Ozkul, M.H., Ekincioglu, O.: <i>Influence of the Self Crosslinkable Polymers on the Properties of the Macro Defect Free (MDF) Cements</i>	
Petre, D., Iovanas, R., Pascu, A.: <i>Studies on the Applicability of the High Velocity Thermal Spray Used In the Automotive Industry</i>	
Popovici, I., Isac, L., Duta, A.: <i>Electrical Conductivity in Copper Sulfides - Influence of the Deposition Parameters and Precursor's Concentration</i>	
Santana Jimenez, Y., Tejera Gil, M., Torrado Guerra, M., Baltes, L.S., Mirza Rosca, J.C.: <i>Interpretation of Open Circuit Potential of Two Titanium Alloys for A Long Time Immersion in Physiological Fluid</i>	
Sava, I.: <i>Compared Properties of Some Poly(Amide-Imide)s Obtained by Direct Polycondensation</i>	
Stroe, M., Scorobetiu, L., Dumitru, R., Nath, G.: <i>Considerations upon Displacing Dislocations in Steel MoCrNi15</i>	
Suteu, D., Bilba, D., Zaharia, C.: <i>HPAN Textile Fiber Wastes for Removal of Dyes from Industrial Textile Effluents</i>	
Varga, B., Fazakas, E., Varga, L.K.: <i>Preparation and Structural Characterization of Rapidly Solidified Al-Si Alloys</i>	
Zaharia, C., Suteu, D., Bilba, D.: <i>The Recovery of Streptomycin from Industrial Effluents</i>	

BULLETIN OF THE TRANSILVANIA UNIVERSITY OF BRASOV • VOL.2 (51)-2009

SERIES I - ENGINEERING SCIENCES, ISSN 2065-2119 (Print), ISSN 2065-2127 (CD-ROM)

• **ELECTRICAL ENGINEERING, ELECTRONICS AND AUTOMATICS**

Alexandru, M., Snae, G.D.M., Fiore, M.: <i>A New Method for Recalculating the Program Clock Reference in a Packet-Based Transmission Network</i>	
Carp, M.C., Puscas, A.M., Borza, P.N.: <i>Testing and Characterization of Aqueous Stacked Supercapacitors</i>	
Demeter, R., Campeanu, R.: <i>Microcontroller Based Ethernet Embedded Systems</i>	
Floroian, D., Moldoveanu, F., Suciu, C.: <i>Using Intelligent Agents for Medical Logistic System</i>	
Gaspar, Z., Toacse, Gh.: <i>VoIP Quality Assessment using the Student t-Test</i>	
Ion, C.P., Marinescu, C.: <i>Micro Hydro Power Plant with Induction Generator Supplying Single Phase Loads</i>	
Jipa, R.: <i>GALS-SA Test Extension</i>	
Lungoci, C., Oltean, I.D.: <i>About Supercapacitors Parameters Determination</i>	
Margineanu, I., Iu, L.M.: <i>The Automation of the Unloading or Recycling Process of the Fly Ash from the Silos in Cement Mills</i>	
Morariu, Gh., Miron, M., Mita, A.M., Stan, L.V.: <i>Some Aspects Regarding Low Intensity Microwave Electromagnetic Field Influence on Aqueous Solutions</i>	
Motoasca, S., Helerea, E., Oltean, I.D., Scutaru, G.: <i>Improved Evaluation of Losses in Soft Magnetic Materials</i>	
Musat, R., Helerea, E.: <i>New Solutions for Improving the Vehicle Heating System</i>	
Puiu, D., Suliman, C., Moldoveanu, F.: <i>The Decentralised Control of an Articulated Arm Robot</i>	
Rab, L.M., Munteanu, A.: <i>Considerations and Measurements Regarding a Didactic Portable Potentiostat</i>	
Scutaru, M., Ogrutan, P.: <i>High Frequency Signal Attenuation through Materials</i>	
Serban, I., Marinescu, C.: <i>Modeling of an Autonomous Microgrid for Frequency Stability Analysis</i>	
Stoica, M., Calangiu, G.A., Sisak, F.: <i>A Vision Method Proposed for Tracking Continuous Plane Curves</i>	
Toev, R., Scutaru, M., Iacobescu, T., Romanca, M.: <i>A Secure Architecture in Health Information Systems</i>	
Valadi, A. A., Alexandru, M.: <i>Comparison between AAC AND HE-AAC Models for Designing an Audio Codec</i>	

BULLETIN OF THE TRANSILVANIA UNIVERSITY OF BRASOV • VOL.2 (51)-2009

SERIES I - ENGINEERING SCIENCES, ISSN 2065-2119 (Print), ISSN 2065-2127 (CD-ROM)

• **CIVIL ENGINEERING**

Alqatamin, A., Talposi, A.: <i>The Action of Short Columns at Reinforced Concrete Building Constructions</i>	
Boian, I., Moldovan, M.: <i>Energy Efficient Operation of the Open Loop Heat Pump Systems</i>	
Mantulescu, M., Tuns, I.: <i>A Geological Study's Premises for Resizing the Geothermal Exchange Field within the Transilvania University PRO DD Research Institute</i>	
Tuns, I., Mantulescu, M., Tamas, F.: <i>Analysis on the Degradation State of the Site of Certain Residential Buildings</i>	

BULLETIN OF THE TRANSILVANIA UNIVERSITY OF BRASOV • VOL.2 (51)-2009
SERIES I - ENGINEERING SCIENCES, ISSN 2065-2119 (Print), ISSN 2065-2127 (CD-ROM)

• **CONFERENCES 2009**

Tierean, M.H., Stefanescu, D.M.: *The 6th Edition of International Conference on Materials Science & Engineering, BRAMAT*

2009
 Alexandru, H.V., Rudolph, P., Dumitru, A., Cizmas, C.B.: *International Summer School on Fundamentals and Basic Methods of Crystal Growth*

Alexandru, H.V., Rudolph, P., Cizmas, C.B.: *Romanian Conference on Advanced Materials, ROCAM 2009*
 Visa, I., Ceccarelli, M., Corves, B., Jaliu, C.: *The 10th IFTOMM International Symposium on Science of Mechanisms and*

Machines
 Chiru, A., Vlase, S., Niitsu, Y.: *The 3rd International Conference Computational Mechanics and Virtual Engineering, COMEC*

2009
 Chivu, C., Rio-Belver, R.M., Kechagias, J.: *Economic Engineering and Manufacturing Systems*
 Bacanu, Gh., Feidt, M., Bozzini, F.: *The 17th International Attended National Conference on Thermodynamics (CNT-17)*.....

Authors

Index

TESTING AND CHARACTERIZATION OF AQUEOUS STACKED SUPERCAPACITORS

M.C. CARP¹ A.M. PUȘCAȘ¹ P.N. BORZA¹

Abstract: Supercapacitors are promising storage energy devices which have a wide range of potential applications. The present paper describes the measurement and determination process of the electric series resistance for a supercapacitor ECONO 14 V/40 F. The impedance spectroscopy method was used in order to determine how the electric series resistance of the supercapacitor is influenced by the frequency, current and voltage variation. Also, a model of a supercapacitor is analysed and its simulated values are compared with the measured values.

Key words: supercapacitor, electric series resistance, impedance spectroscopy.

1. Introduction

Supercapacitors have rapidly found their way in a wide range of applications, from static to dynamic.

In all the domains where energy is converted from electrical to mechanical or chemical, the rapid release storage devices have a crucial role by assuring the necessary amount of power [1].

In many applications, either capacitance or electric series resistance (ESR) is more critical. For example, applications like power and memory backup require increased capacitance in order to provide properly run-time. Also, assuring low ESR is mandatory to decrease drop voltage for pulse power applications. Thus, the main factors that reduce the life time of the supercapacitors are the variation of the capacitance and ESR with voltage. To improve the quality of the supercapacitors first it has to be decided which of the processes affects more the comportment of the supercapacitor: decreasing capacitance or increasing ESR.

As storage devices, the goal of the supercapacitors is to fill the gap between batteries and capacitors [5]. Thus, a system composed by a battery and a supercapacitor not only provides high energy density but it also assures high power density.

A supercapacitor can not be easily characterised because of its complexity. Thus, the goal of the paper is to develop a standard and reproducible method able to measure the variation of the electric series resistance with frequency and voltage.

2. Supercapacitors

Supercapacitors are rapid release energy storage devices which provide high power density and can be rapidly charged or discharged. Compared with the batteries or other chemical or electrical power supplies, supercapacitors have unique features consisting in a very high efficiency of bidirectional power transfer and a very high cyclability - two-three order higher than batteries. Also, supercapacitors are less affected than batteries by the deep discharge

¹ Dept. of Electronics & Computers, Transilvania University of Braşov.

processes, by temperature (the operating range is $-40\text{ }^{\circ}\text{C}$ to $+70\text{ }^{\circ}\text{C}$) and they work well in harsh conditions. These devices are based on the latest developments in the electrical storage devices and nanotechnology fields, especially related to the huge surfaces obtained on materials like activated carbon, MnO_2 and others [2].

If usual capacitors are composed from a conductive material and a separator, the supercapacitor crosses into the technology of the battery, being made from electrodes (activated carbons, metal oxide, polymers) and electrolyte (aqueous or organic). The electric double layer supercapacitor (EDLC) can be easily developed, has reduced manufacturing costs and is frequently used in many applications nowadays. The internal structure of an EDLC is shown in Figure 1.

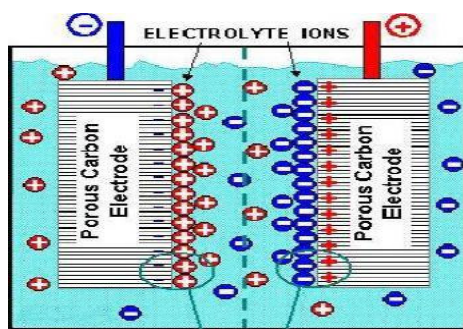


Fig. 1. EDLC internal charge separation process [9]

Function of the type of the electrolyte, the decomposition voltage can have values between 1.2 V (aqueous electrolyte) and 2.7 V (organic electrolyte), or even more. This value of the voltage limits the energy density that can be stored on supercapacitors. Other important features are: (i) the specific surface of the activated carbon have values between $2000\text{--}3800\text{ m}^2/\text{g}$ of material; (ii) the specific capacitance have values between 100 and more than 200 F/g; (iii) price/farad is around 0.025 till 0.1 \$/F; (iv) the specific

power density has values between $2\text{--}4\text{ kW/kg}$; (v) and the specific density have values between $2\text{--}3\text{ Wh/kg}$.

Batteries can provide high power only if the cycling duty is reduced. Instead, supercapacitors are commercially available to extend the life time of the battery in the electronic equipments [8].

The electrolyte of the *aqueous supercapacitors* can be KOH or H_2SO_4 solutions. The ions of these solutions have high mobility and can penetrate relatively easily and fast the huge surface of armatures thus assuring a low electric series resistance and a high power density. Also, these kinds of supercapacitors have low decomposition voltage that involves low energy density. For *organic electrolytes*, the mobility of the charge is lower and depends on the temperature. The temperatures below zero Celsius degree have a bigger impact on the parameters of the supercapacitors increasing the value of the ESR and reducing the values of the power density. But, supercapacitors have relatively high decomposition voltage that involves high energy density.

Even if the elementary cells are composed by two devices connected in series (double layer capacitors), the connectivity between these elementary cells became, for practical reasons, the most important. Thus, in order to assure higher operating voltages, the supercapacitors are connected in series and to decrease the value of the electric series resistance they are connected in parallel. For the elementary cells, the chemical and technological aspects are dominant and they are designed to obtain good performances and adequate voltage for different applications. For these reasons, using a proper electrical model of the supercapacitors is essential to obtain similitude between simulation and experiments. The comportment of the supercapacitor will be analysed by identifying its parameters using the spectroscopy impedance method and volt-ampere methods.

EDLC is consisting of two capacitances and an ESR connected in series and dependent on voltage and temperature. In

parallel with these are connected other two elements: the parasitic capacitance (C_p) and the self discharge resistance (R_{sd}).

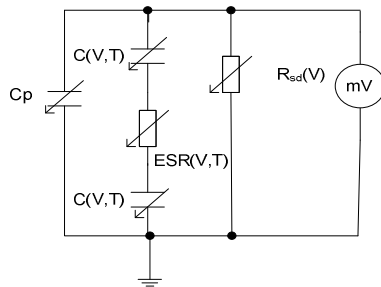


Fig. 4. Basic model of a supercapacitor

This model was completed with values for each component using two different correlated methods: (i) static: volt-ampere method that determines the $C(V,T)$ capacitance and $R_{sd}(V)$ (ii) impedance spectroscopy method that determines C_p and ESR. Another test was performed in order to measure the self discharge resistance of the same device. The variation is illustrated in Figure 5.

The main parameters that influence the life time of a supercapacitor are the capacitance function of voltage and temperature $C(V,T)$ and the ESR(V,T) which also varies with voltage and temperature.

ESR is an important parameter that depends on multiple factors like: the electrolyte resistance, the electrode materials resistance (including the interface between the activated carbon layer and the collector electrodes). While the characteristics of the supercapacitors are deteriorating, the value of the ESR increases and thus the value of the capacitance decreases.

ESR is also composed from two basic conduction processes: electronic and ionic. The electronic influence is due to the ohmic resistance in the conductor and in the carbon particles and the ionic influence is due to the ions mobility from the electrolyte and the dimension of the carbon

activated porous [6].

Because the impedance measured at the terminals of the supercapacitor is also dependent on voltage and frequency variation, *impedance spectroscopy* method was used to determine the impedance and ESR parameter of a 14 V/40 F ECOND supercapacitor.

Generally, ESR has values in tens-hundreds of $m\Omega$ and its values increase with voltage and decrease with frequency. In a lot of applications it is possible to appear over voltages on the supercapacitors. In such cases, we do not find in literature data about their comportment. Thus, we decided to test which is the variation of the *self discharge process* of the device when it is charged with 15% more than its nominal voltage. The influence of the ESR value it can be observed at the very beginning of the self discharge process, in the first seconds, when the drop voltage has increased values.

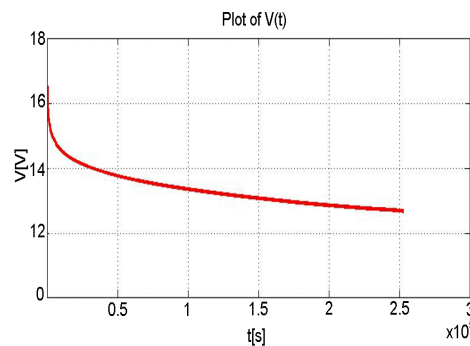


Fig. 5. Self discharge process

As it can be seen in Figure 5, at the excess voltage period, the self discharge resistance is lower than in the case of the supercapacitor charged in the nominal range.

Supercapacitors have two mainly limitation: ESR and high capacitance loss.

Parameters like voltage, current, temperature, capacitance $C(V,T)$, parasitic capacitance (C_p) and ESR influence the life

time of the supercapacitors. While the supercapacitors are deteriorating, the ESR is increasing thus decreasing the capacitance [4].

5. Impedance Spectroscopy

Impedance spectroscopy method is one of the most important analytical and electrochemical techniques used to identify the values of the parameters of the supercapacitors and to analyze them [3].

Real applications have elements that can not permit to analyse a circuit from the resistance point of view. Thus, the impedance concept represents a method to generally approximate the parameters of a circuit. Impedance represents the ability of a circuit to support the electrical current flow and it is measured when applying a small AC signal (1 V, 10 A) to the input of the circuit and varying the frequency. The current and voltage are measured at the circuit's output [7].

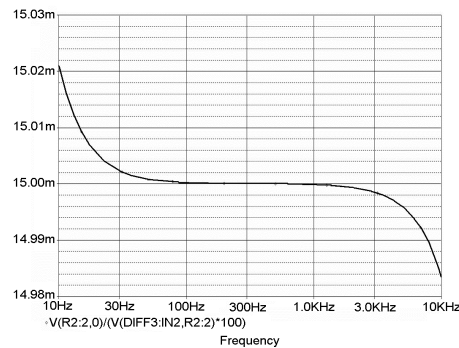


Fig. 6. *ESR variation function of frequency - simulation*

The range of the considered frequency was chosen thus to minimize the influence of the imaginary part of the impedance (represented by the capacitive and inductive reactance). Thus, the basic model illustrated in Figure 4 was simulated and the results are shown in Figure 6.

As it can be observed in Figure 6, the

first part of the simulation (10 Hz - 30 Hz) represents influence of the capacitive reactance, the second part (30 Hz - 1 kHz) represents the ESR variation and the third part of the simulation (1 kHz - 10 kHz) represents the influence of the ESR parasite capacitance.

Because of the ESR parasite capacitance, the values of the electric series resistance decreases with frequency. The experimental results are presented in Figure 7.

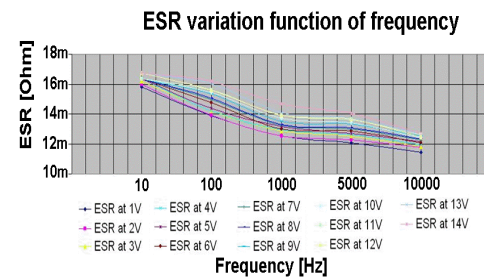


Fig. 7. *ESR variation function of frequency - experimental results*

As it can be seen in Figure 7, the variation of the parameters of the supercapacitors with frequency is approximately similar with the simulated model. Thus, the basic model illustrated in Figure 4 was validated by the experimental results shown in Figure 8.

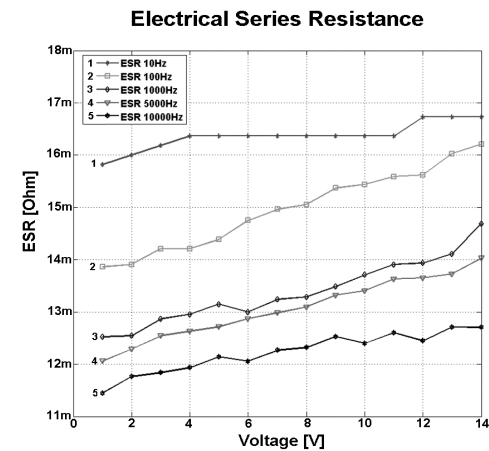


Fig. 8. *ESR variation function of frequency and voltage - experimental results*

As it can be seen in Figure 8, the ESR is dependent on voltage and frequency. Its values are decreasing while increasing the frequency and are increasing while increasing the voltage.

6. Conclusions

As promising storage energy devices, the landscape of the supercapacitors is complex, actually incomplete known and under research because of their power delivery capabilities [4]. Also, their parameters are very important while developing specific power applications.

As it is presented in the present paper, the electrical impedance and implicitly the electric series resistance of the ECOND 14 V/40 F supercapacitor is dependent on frequency and voltage variation, electrical impedance increasing with voltage and decreasing with frequency.

Because of the considered frequency and voltage range, the distributed values of the supercapacitor were easily determined, the ESR having its measured value in range of $m\Omega$.

Thus, as it can be observed from the experiments, because of the reduced ESR value (under $20 m\Omega$) and their high performances the supercapacitors are properly to be used especially in transitory applications.

Acknowledgements

The present paper is a part of the national research project "TRANS-SUPERCAP" currently under development at Transilvania University of Braşov.

References

1. Borza, P.N., Carp, M., et al.: *Supercapacitors and Their Applications on Vehicles*. In: IJEET - International Journal Engineering in Transportation **4** (2009) No. 2, p. 27-34.
2. Chen, J.H., Li, W.Z.: *Electrochemistry of Carbon Nanotubes and Their Potential Application in Supercapacitors*. In: Proceedings of the 197th Meeting of Electrochemical Society, Toronto, Canada, May 14-18, 2000, p. 62-67.
3. Orazem, M.E., Tribollet, B.: *Electrochemical Impedance Spectroscopy*. ECS - The Electrochemical Society, Pennington, Wiley, 2008.
4. Puşcaş, A.M., Muşat, R., et al.: *Energetical Monitoring of the Storage Devices by Using Sensors Network Placed Inside the Mobile Systems*. In: AFASES - The International Session of XIth Scientific papers, Scientific Research and Education in Airforce, Braşov, Romania, 20-22 May 2009, p. 745-752.
5. Taberna, P.L., Simon, P.: *The Role of the Interfaces on Supercapacitor Performances*. In: ESSCAP'06, Lausanne, 2006, p. 112-119.
6. Zubieta, L., Bonert, R., et al.: *Considerations in the Design of Energy Storage Systems Using Double-Layers Capacitors*. In: IPEC Tokyo 2000.
7. *** *Basics of Electrochemical Impedance Spectroscopy. Application Note*, Gamry Instruments. Available at: <http://gamry.com>. Accessed: 16-01-2009.
8. *** *Using Supercapacitors for Energy Storage*. Available at: <http://www.discoversolaerenergy.com/storage/supercaps.htm>. Accessed: 22-02-2009.
9. <http://www.itpower.co.uk/investire/pdfs/capacitors.pdf>.