

DESIGN AND ANALYSIS HYBRID COMBINATION OF BATTERY AND SUPERCAPACITOR USING ORCAD/ PSPICE

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ABSTRACT:

Now a days, we have two options for storing of electrical energy i.e. battery and supercapacitor. But the major disadvantages of batteries are required more time for charging hence lot of research is going on the supercapacitor. Supercapacitors are charge quickly, have high energy density high power density and low cost. But the disadvantage is discharge quickly. The technical combination of battery and the super capacitor introduced a new device called hybrid-ultra capacitor. The paper focuses on parameters and formulae's required to design the hybrid supercapacitor.

Same time we focus on 1st time modeling of hybrid supercapacitor by using ORCAD/PSPICE software. For the higher order circuit MATLAB fail to shows the accurate results because leakage resistance is not consider in MATLAB so we used ORCAD/PSPICE.

KEYWORDS: self discharge, hybrid supercapacitor, activated carbon, ORCAD/PSPICE, electrolyte.

INTRODUCTION:

A significant worldwide increasing in the consumption of fossil fuels, resulting from the rapid growth of the global economy and producing two major associated issues. The first is the accelerating depletion/exhaustion of existing fossil fuel reserves and second are the affiliated environmental problems e.g., increasing greenhouses gas emissions and general air and water pollution. The need to develop and scale up sustainable, clean energy sources and their associated technologies is recognized worldwide as an urgent priority. Most renewable clean energy sources are highly dependent on the time of day and regional weather conditions. Development of related energy conversion and energy storage devices is therefore required in order to effectively harvest these intermittent energy sources. In the present technology, only three devices are used to store electrical energy i.e. battery, supercapacitor and fuel cell. The ES is also known as a supercapacitor or an ultracapacitor, has attracted considerable interest in both academia and industries area because it has some distinct

advantages such as higher power density induced by a fast charging/discharging rate (in seconds) and a long cycle life (4100000 cycles) when compared to batteries and fuel cells[1]. Depending on the charge storage mechanism, supercapacitors can be briefly classified as electrochemical double-layer capacitors (EDLCs), pseudo capacitors and hybrid-capacitors. Compared to both pseudo capacitors and pseudo capacitors, EDLCs constitute the majority of currently available commercial ESs, mainly due to their technical maturity [1].

I. PARAMETERS CONSIDERATION:

A. OPERATING TEMPERATURE RANGE:

The operating temperature range is the range over which the part will function, when electrified, within the limits given in the specification. It is the range of ambient temperatures for which the device has been design to operate. Higher formation voltages permit higher operating temperature but reduce its capacitance. The low-temperature limit is set largely by the cold resistance.

B. STORAGE TEMPERATURE RANGE:

The storage temperature range is the temperature range to which the part can be subjected unbiased, and retain conformance to specified electric limits. It is the range of ambient temperatures over which the hybrid ultra capacitor may be store without damage for short periods. For long period of storage keep hybrid ultra capacitor at the room temperature and in an atmosphere free of halogen gases like chlorine and fluorine that can corrode aluminium.

The hybrid supercapacitor storage temperature ranges are from -55 degree Celsius to the maximum limit of the operating temperature ranges.

C. RATED CAPACITANCE:

The rated capacitance of the hybrid supercapacitor is measured at 120 Hz frequency and 25 degree Celsius temperature range. The rated capacitance is also the capacitance marked on unit. LCR meter is used for the measurement of hybrid capacitor parameter.

D. CAPACITANCE TOLERANCE:

Capacitance tolerance means it is the maximum capacitance and minimum capacitance value that it allows for the safe working operating condition.

E. CAPACITANCE MEASUREMENT:

For Hybrid supercapacitors, capacitance is measured as the capacitance of equivalent series circuit at 25 degree Celsius in a measuring bridge supplied by a 120Hz source free of harmonics with maximum Ac signal voltage of 1V rms and no forward-bias voltage.

F. DISSIPATION FACTOR (DF):

Dissipation factor means it is the tangent loss angle measure by LCR meter and it is denoted as $(\tan\delta)$. Dissipation factor measured in percentage. It is also the ratio of the ESR to the capacitive reactance and is thus related to ESR by this equation:

$$DF = 2\pi fCR_s$$

Where,

f = test frequency in Hz.

C = Capacitance in micro farad.

Rs = equivalent series resistance in ohm.

G. EQUIVALENT SERIES RESISTANCE:

ESR is the sum of all types of resistances including intrinsic resistance of the electrode material and electrolyte solution, mass transfer resistance of the ions, and contact resistance between the current collector and the electrode.

H. CYCLE-LIFE:

Cycle-life, a necessary indicator of the stability of the ES, is also one of the important parameters for measuring the overall ES performance. General test procedures for stability analysis involve the electrode undergoing charge and discharge cycling in a certain electrolyte to compare the initial and final capacitance. For example, EDLCs using carbon electrodes generally have a very high cycling stability.²⁴ However, when pseudo capacitive reactions are introduced, the cyclic stability is generally reduced due to the non-ideal electrochemical reversibility resulting from the interactions between the electrolyte ions and the electrode materials. Actually, the cycle-life of the ES depends on many factors such as the cell type, electrode material, electrolyte, charging/discharging rate and operating voltage and temperature, all of which will be discussed below.

I. SELF-DISCHARGE RATE:

Another issue concerning the ES performance is self discharge rates, which are related to potential losses of a charged electrode over a period of storage time.^{27,28}

During the self-discharge process, current leakage leads to a decrease of the cell voltage, which in turn may limit the use of ESs for some applications requiring a fixed amount of energy retention for a relatively long time. Several mechanisms have been identified to explain the potential change during the self discharge process.²² As will be discussed more completely later, the ES self-discharge rate and its mechanism are dependent on the type of electrolyte, its impurities and residual gases.

J. THERMAL STABILITY:

Most potential applications for ESs occurs in the temperature range of 30 to 70 degree Celsius, therefore expanding the current working temperature range of ESs can further widen the scope of applications. For example, most electronics related to space avionics applications are required to operate at temperatures as low as 55 degree Celsius. Fuel cell vehicles, on the other hand, may require a high working temperature for ESs. The application of working temperature can affect several properties of ESs such as the energy and power densities, rate performance, ESR, cycle life and self-discharge rate. In particular, the temperature-dependent performance of ESs is strongly dependent on the nature of the electrolyte such as the concentration and the type of conducting salt, and the specific properties of the solvent (e.g., freezing point, boiling point and viscosity). This subject will be discussed in greater detail for specific electrolytes throughout this review.

In summary, based on the above comments, it can be seen that the primary characteristics of ESs are strongly dependent on the specific electrolytes employed. The following sections provide a focused overview of recent developments concerning many different kinds of electrolytes and their associated ESs, used in a wide variety of applications.

III. DESIGN HYBRID SUPERCAPACITOR:

ELECTROLYTE:

1. ACIDIC ELECTROLYTE:

To increase the energy densities of the aqueous Hybrid supercapacitors, some efforts have been devoted to developing hybrid supercapacitors to make their cell voltage wider. When a symmetric ES with the same type of electrode materials as both the electrodes in aqueous electrolytes (e.g., H₂SO₄ or KOH), the maximum cell voltage is limited by the gas evolution reactions [1]. However, if an ES with asymmetric configurations (the anode materials are different from those of the cathode) is used, the resultant ESs could have a wider working potential window even in aqueous electrolytes [2]. The combination of two different electrodes in an ES can work complementarily in separate potential windows, leading to

a higher operating voltage in aqueous electrolytes. For example, the high over potential for H₂ evolution at a carbon-based negative electrode and O₂ evolution at a battery-like (e.g., PbO₂) or pseudocapacitive electrode (e.g., RuO₂) could give an ES a working voltage window of aqueous electrolytes beyond the thermodynamic limit of water[2]. To date, several types of asymmetric ESs, such as carbon//PbO₂, carbon//RuO₂, carbon//ECPs and carbon with different mass or properties in each electrode, have been tested in strong acid electrolytes, and demonstrated the feasibility for application.

It may be noted here that, there are other types of acid electrolytes that may be used for ESs, including perchloric acid, hexafluorosilicic acid and tetrafluoroboric acid. However, few of them have been studied for the application in ESs due to a concern for safety. In addition, the self-discharge in the concentrated electrolytes, especially in the presence of contamination (e.g., metal ions) and oxygen is also a concern[3][4].

2. ALKALINE ELECTROLYTE:

According to the literature, to improve energy density, a series of alkaline electrolyte-based asymmetric ESs with wide potential windows have been developed. Generally, for those asymmetric ESs, the positive electrodes are different from the negative electrode. The positive electrode is a battery-type one (e.g., Ni(OH)₂) or pseudocapacitive one (e.g., RuO₂) where charge is stored through faradic reactions, and the negative electrode is a carbon-based one where charge is primarily stored by the EDL. The operating cell voltages of these asymmetric ESs were reported to be effectively increased in the KOH electrolyte, e.g., 1.7 V for carbon//Ni(OH)₂, 1.4–1.6 V for carbon//Co(OH)₂, carbon//Co₃O₄, and carbon//Co₉S₈, 1.6 V for carbon//NiSS₂, and 1.4 V for carbon//RuO₂-TiO₂. Because of the larger operating voltage window and the usage of a high capacity faradic-type electrode, most of these ESs could deliver higher energy densities ranging from 20 to 40 W h / kg, with some even as high as 140 W h/kg, which was comparable to rechargeable lithium-ion batteries. However, due to the usage of faradic-type electrodes, the cycling stabilities of these asymmetric ESs are normally much lower than those of the EDLCs. For example, it was reported that there were more than a 10% loss in the specific capacitance of some asymmetric ESs after a certain number of cycles (1000–5000). Besides, these asymmetric ESs usually suffer from a slower charging–discharging process when compared to the EDLCs and their few-second response.

3. NEUTRAL ELECTROLYTE:

Neutral electrolytes have also been extensively applied for asymmetric ESs, allowing for a larger operative

voltage and thus a higher energy density. As identified, most pseudocapacitive materials (e.g., MnO₂) have high specific capacitances, although their potential windows are limited, this restricts the cell voltage and thus the energy density of symmetrical ESs if using these materials. For MnO₂-based symmetrical ESs, the cell voltage is about 1 V in most cases. By replacing the negative electrode with other different electrode materials (e.g., activated carbons), which have a complementary potential window to that of MnO₂, the cell voltage can be significantly increased through extending to a more negative voltage.

Compared with the previously mentioned asymmetric ESs using a battery-type positive electrode (e.g., AC//PbO₂ and AC//Ni(OH)₂) in the strong acidic or alkaline electrolyte, asymmetric AC//MnO₂ ESs in neutral electrolytes have a great advantage of a long cycle life due to the pseudocapacitive behavior of MnO₂. Since neutral electrolytes were used in the early work on asymmetric AC//MnO₂ ESs reported by Hong et al. and Brousse et al., considerable efforts have been made to focus on the development of neutral electrolyte-based asymmetric ESs[5].

To date, various types of negative and positive electrode materials have been explored for asymmetric ESs using neutral aqueous electrolytes (mostly sulfate salt-based electrolytes). This asymmetric ESs could reach an operative cell voltage range of 1.8–2.0 V, which is higher than those reported for the asymmetric ECs with strong acidic or alkaline electrolytes. Because of the increased cell voltage, most of the reported energy densities could be achieved to high values above 20Wh/kg and some reported values could even be as high as 50 W h/kg. Excitingly, some of these reported energy density values can be comparable to or higher than those of the organic electrolyte based EDLCs. Therefore, if other issues (e.g., cycle life and rate performance) could be further improved, these asymmetric ESs with neutral electrolytes should be very promising alternatives for commercial organic electrolyte-based EDLCs.

Recently, it was reported that a very high cell voltage of about 4 V could be seen in neutral electrolytes such as Li₂SO₄ and LiCl by using a battery-type Li negative electrode coupled with an appropriate positive electrode material (e.g. AC and MnO₂). Since the metallic Li electrode could not work directly in contact with an aqueous electrolyte, a water-stable multilayered Li negative electrode (a protected Li electrode) might be used. To conclude, using neutral aqueous electrolytes in ESs can not only solve the corrosion issues but also provide a cost effective and environmentally friendly way to increase the operating voltage and thereby the energy density. However, more improvement in the ES performance with

neutral electrolytes is still needed to further increase the energy density and cycle-life.

4. ORGANIC ELECTROLYTES:

In order to further increase the energy density, asymmetric ESs with organic electrolytes have also drawn considerable attention. Since the early studies on the asymmetric ESs with the organic electrolytes by Amatucci et al., a number of organic electrolyte based asymmetric ESs, such as graphite//AC (electrolyte: 1.5 M TEMABF₄/PC), carbon//TiO₂ (1 M LiPF₆/EC-DMC), carbon// V2O₅ (1 M LiTFSI/ACN), carbon//Li₄Ti₅O₁₂ (1 M LiPF₆/ EC-EMC),¹⁹³ and carbon//ECP (1 M TEABF₄/PC), have been developed. Due to the much wider operative cell voltages (generally 3–4 V) obtained in the organic electrolyte, these asymmetric ESs can deliver energy densities (usually above 30 W h/kg) much higher than those reported for aqueous-based asymmetric ESs, although the formers have lower specific capacitances compared to the letters.

Among these asymmetric ESs, Li-ion capacitors (LICs) have attracted particular attention [6]. Typical LICs combine a Li-ion battery-type negative electrode and an EDLC type positive electrode (e.g., AC) with an Li-containing organic electrolyte such as LiPF₆, LiClO₄, and mixtures of two or more solvents (e.g., EC-DMC). There are two types of negative electrodes, i.e., carbon-based (mostly graphite) and lithium titanate (Li₄Ti₅O₁₂) electrodes. LICs using a single solvent are very rare. In some cases, additives are used in the electrolytes. Actually, the compositions of the reported electrolytes for LICs are almost the same as those for LIBs, which have already been reviewed elsewhere. Even extensive studies have been focused on the development of electrode materials; the effect of electrolytes on LIC performance has received relatively limited attention. Unlike the ACN-based EDLCs whose performance was reported to be relatively insensitive to temperatures between 30 and 4 degree C, the LIC performance (e.g., energy and power densities) with carbonate-based electrolytes was found to degrade severely at low temperature especially below 0 °C[6]. Besides the poor low temperature performance, the LICs also suffer from a relatively low rate capability arising from the battery type negative electrode. Further effort on both LIC electrode materials and electrolytes is necessary to solve this temperature limitation.

ELECTRODES MATERIAL:

1. CARBON MATERIALS:

Carbon materials in their various forms are the most used electrode materials in the fabrication of supercapacitors. Reasons are due to its (i) high surface area (ii) low cost (iii) availability (iv) established electrode

production technologies. The storage mechanism used by carbon materials is electrochemical double layer formed at the interface between the electrode and electrolyte. Hence, the capacitance mainly relies on the surface area accessible to electrolyte ions. Important factors which influence electrochemical performance are specific surface area, pore shape and structure, pore size distribution, surface functionality and electrical conductivity. Having a high specific surface area in the case of carbon materials, results in a high capability for charge accumulation at the interface of electrode and electrolyte.

2. ACTIVATED CARBON (AC):

The most widely used electrode material is AC and that is due to its large surface area, good electrical properties and moderate cost. AC can be produced by either physical or chemical activation from various types of carbonaceous materials (e.g. wood, coal nutshell etc.). The physical activation involves the treatment of carbon precursors at a high temperature (700-1200 C) in the presence of oxidizing gases like steam, CO₂ and air. In the case of chemical activation, it is carried out at a lower temperature (400-700 C) using activating agents such as sodium hydroxide, potassium hydroxide, zinc chloride and phosphoric acid.

3. CARBON NANOTUBES (CNT):

A great deal of attention is been given to CNT as supercapacitor electrode material due to its unique pore structure, good mechanical and thermal stability and superior electrical properties. Carbon nanotubes are produced via catalytic decomposition of some hydrocarbons and by carefully manipulating different parameters, it becomes possible to generate nano structures in various conformations and also control their crystalline structure. Carbon nanotube unlike other carbon based electrodes, have mesopores that are interconnected, this allows for a continuous charge distribution that utilizes almost all of the accessible surface area. CNTs have a lower ESR than activated carbon because the electrolyte ions can diffuse into the mesoporous network.

4. GRAPHENE:

Graphene has enjoyed significant recent attention. Graphene a one atom thick layer 2D structure has emerged as a unique carbon material that has potential for energy storage device applications because of its superb characteristics of high electrical conductivity, chemical stability, and large surface area. Recently, it was proposed that graphene can be used as a material for supercapacitor applications, because when graphene is used as supercapacitor electrode material it doesn't depend on the distribution of pores at solid state, as compared to other

carbon materials such as activated carbon, carbon nanotubes etc.

Among all carbon materials used as electrode materials electrochemical double layer capacitors, newly developed graphene has higher specific surface area (SSA) around 2630m²/g . If the entire SSA is fully utilized graphene is capable of achieving a capacitance of up to 550 F/g . Another benefit of using graphene as electrode material is that both major surfaces of graphene sheet are exterior and are readily accessible by electrolyte. There are many different methods currently being researched for the production of different types of graphene such as chemical vapors deposition, micromechanical exfoliation, arch discharge method, unzipping of CNTs, epitaxial growth, electrochemical and chemical methods and intercalation methods in graphite.

ANALYSIS USING ORCAD/PSPICE:

Hybrid ultra-capacitors are the integration of super capacitor and battery technologies. For performance improvement of a hybrid ultra-capacitor based system, accurate modeling is one of the requirements. Hybrid ultra-capacitors or hybrid capacitor (HUC) is modeled and then simulated from fundamental circuit of Supercapacitors with focus on leakage resistance parameter variation.

1. ELECTRICAL REQUIVALENT CIRCUIT:

Electrical equivalent circuit of the super capacitor can be designed in time domain, and frequency domain. Here time domain approach is considered, electrical circuit parameters are extracted based on the voltage and current characteristics gained from simulation in PSPICE environment.

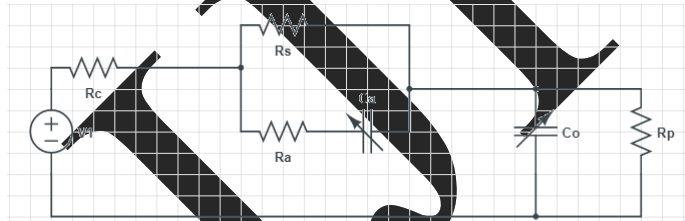


Fig1. Electrical equivalent circuit of hybrid ultracapacitor

Corresponds to the internal series resistance, followed by the parallel combination of, with series and. This combination represent lithium ion doped layer porosity equivalence, whose value goes on Increasing with decrease of frequency. This branch represents electrical equivalence of Lithium ion batteries for parameters represent the leakage effect of the same. Parallel combination of R with C represent supercapacitor effect, where capacitance is chosen and as voltage controlled device, as a super capacitor is nonlinear which can be

studied in depth from electrochemical impedance spectroscopy.

Supercapacitor fundamental circuit as shown in figure 2 is equally applicable to hybrid capacitor, when temperature sensitivity reach within range of - 40 degree Celsius To 55 degree Celsius.

2. PSPICE BASED FUNDAMENTAL ELECTRICAL DOUBLE LAYER CAPACITOR/HYBRID CAPACITOR CIRCUIT:

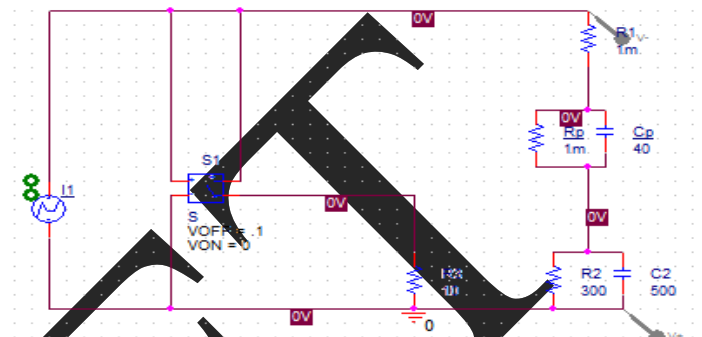


Fig 2. Hybrid model in ORCAD/PSPICE.

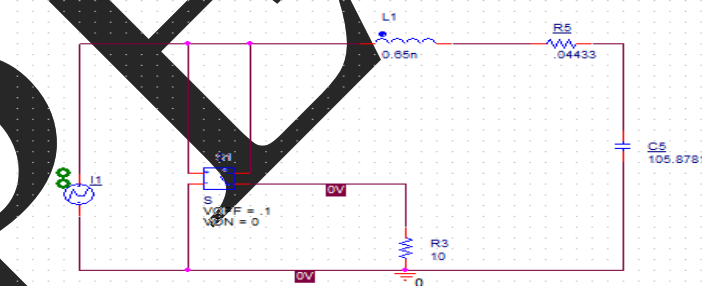
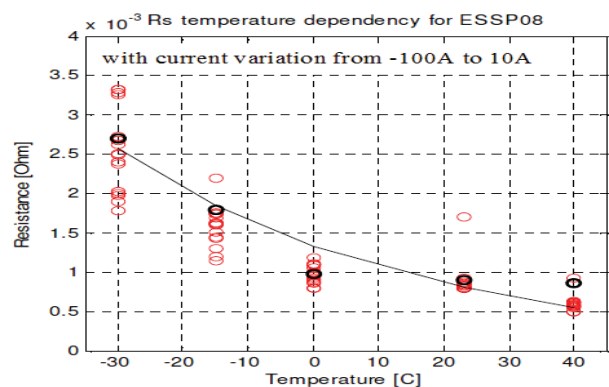


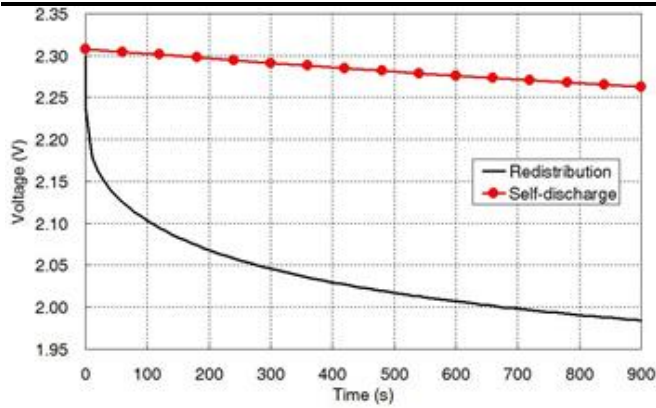
Fig 3. Hybrid supercapacitor without inductance

3. RESULTS:

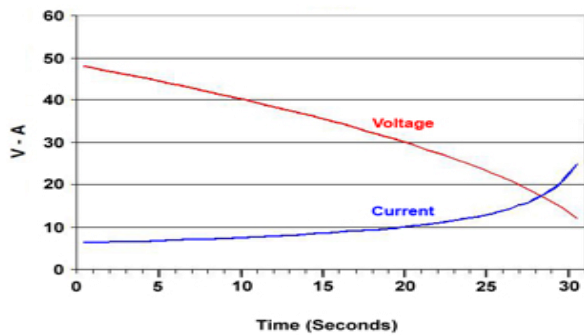
PSPICE simulation model is simulated with voltage controlled switch model as shown in figure 2, through dynamic piecewise linear current pulse generator or current source.

As voltage reaches maximum, it discharges through 10 Ohm resistance. Simulation results of fundamental circuit for parametric Sweep of leakage resistance is observed in figure 5 and can be concluded as any leakage resistance value higher than 10 milliohm, show same dynamic response.

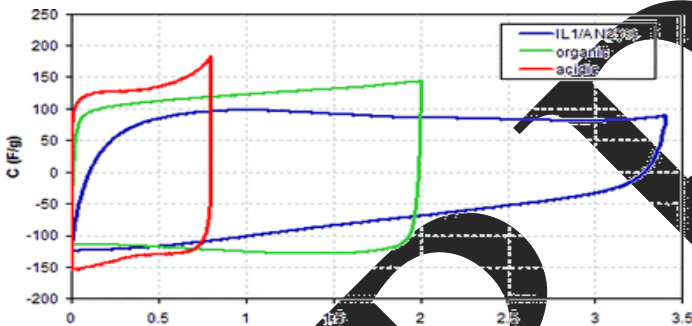




Discharge profile



Time (Seconds)



4. CONCLUSION:

1. IN CASE OF TECHNOLOGY:

In this paper we conclude that Hybrid supercapacitor is the new technology used for storing of electrical energy. We discuss that, battery required more time for the charging but by using the technical combination of batteries and the supercapacitors reduce charging time, increase power density and energy density also. More research is going on renewable energy sources, we can produce large energy but due to lack of technology, we can't store in much more amounts. So, hybrid technology is the best option in future for storing of renewable electrical energy.

2. IN CASE OF ANALYSIS:

Fundamental equivalent circuit model of the hybrid capacitor using leakage resistance is an improvement over super capacitor model. Modeling of Hybrid supercapacitor has been done for the first time using 5th order and further reduced to 2nd order equivalent circuit in ORCAD/PSPICE. The proposed model for hybrid capacitor appears to be more realistic has self leakage aspect has been address. It is proposed to further improve hybrid capacitor model, for reduce leakage effect similar to supercapacitor model, and effect of nonlinearities of voltage and temperature will be included in next designs. Validation of the same has to be tired, with the help of electrochemical impedance spectroscopy (EIS) in frequency domain.

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