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Super capacitor and its applications

Vishal V. Mehtre[1], Ankit Kumar Yadav[2], Sumit Mishra[3]

Assistant Professor, Department of Electrical Engineering, Bharati Vidyapeeth (Deemed to be University) College of Engineering, Pune, Maharashtra[1]

Student, Department of Electrical Engineering, Bahrain Vidyapeeth (Deemed to be University) College of Engineering, Pune, Maharashtra, India[2,3]

Abstract— Battery technologies are well established and widely used technology but they offer several disadvantages like weight, volume, large internal resistance, poor power density, poor transient response. On the other hand, due to advancement in the material and other technology, Super capacitor or Ultra capacitors or Electrostatic Double Layer Capacitor (EDLC) is a most promising energy storage device. They offer a greater transient response, power density, low weight, low volume and low internal resistance which make them suitable for several applications. This paper summarizes recent research and development in the field of super capacitor technology. This paper gives a brief insight into the design, characteristics and applications of the super capacitor.

Keywords: Super capacitor, capacitance, constant current, constant voltage, equivalent charge resistance, electrostatic double layer capacitance.

INTRODUCTION

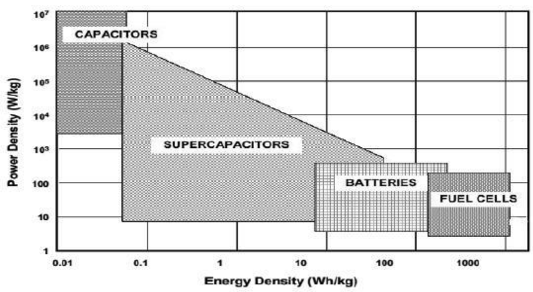
The discovery of the possibility of storing an electrical charge in surface arose from phenomena associated with rubbing of amber during the ancient times. In the mid eighteen century that was when the effect of such phenomena was understood during the period when physics of so-called ‘’static electricity’’ was being investigated and various ‘’electrical machines’’ were being developed.

In 1957 a group of General Electric Engineers were experimenting with devices using porous carbon electrode when they noticed electric double layer capacitor effect. Their observation at the time was that energy was store in the carbon pores and it showed an exceptionally high capacitance. Later in 1966, a group of researchers at Standard Oil of Ohio accidently rediscovered the effect while working on fuel cell designs.

2. CONSTRUCTION AND WORKING OF SUPER CAPACITOR

Conventional capacitors stores energy by moving electrons from one electrode to another. SC based on carbon materials has a higher surface area, where phenomena known as the electric double layer is used to store charges. For SC involving metal oxide or polymeric materials, pseudo-capacitance is the dominant charge storage mechanism. Though super capacitors and electrolytic capacitors are governed by the same capacitance equations, SC can achieve higher capacitance because of thinner dielectric and higher surface area of electrodes. This also allows for power density greater than battery and energy density greater than capacitors, as shown in Figure.1. Figure. 1 shows a ―Ragone plot‖, it shows the performance of various energy storage devices. SC occupies space between batteries and capacitors, this presents a unique advantage that makes them indispensable for applications which require high power delivered in a short time.

Figure 1. Ragone plot for different energy storage devices



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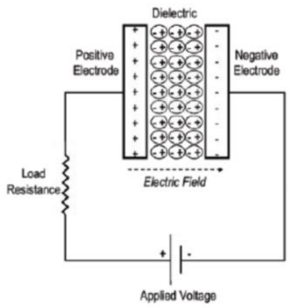

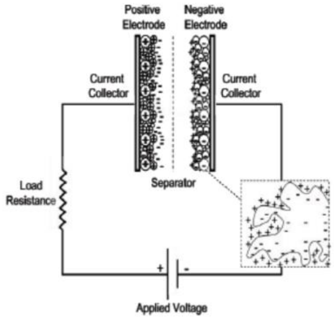

Figure 2. Schematic of a conventional **Figure 3.**Schematic of an electrochemical double-layer capacitor

SC uses a dielectric material to separate two carbon-based electrodes, which not only acts an insulator but also has electrical properties that affect the performance of SC. In SC there is no transfer of charges; instead, charges are stored electrostatically.

3. TAXONOMY

Super capacitors can be classified into 3 classes: EDLC, Pseudo-capacitors and Hybrid capacitors. Based on charge storage techniques, they can be further classified as Faradaic, Non-Faradaic and combination of both. In the Faradaic process, charges are transferred between electrode and electrolyte. In Non- Faradaic process by means of physical process charges are distributed on the

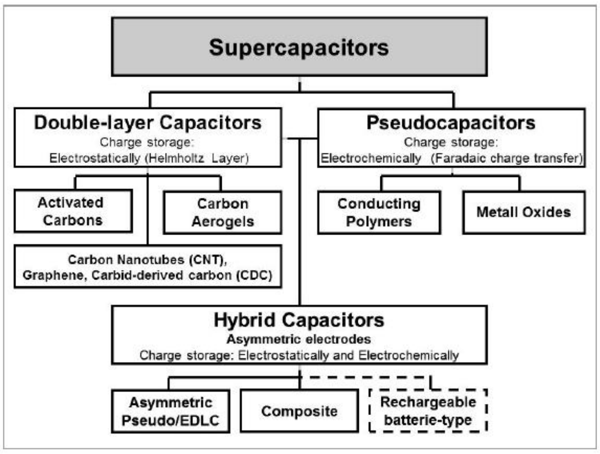

Figure 4. Taxonomy of super capacitors

4. QUANTITATIVE MODELING OF SUPER CAPACITORS

For better understanding the working principles of SC, several models are proposed. Quantitative modeling helps to predict the performance characteristics, which in turn helps to reduce time and cost of fabrication and physical experimentation. Physical characteristics cannot be completely and precisely explained with one single model, so there are different models proposed. Properly characterizing SC has recently become important because of their enormous potential as energy storage devices. Electrical models can be used to describe SC behavior in terms of voltage, temperature and frequency.
Some of the basic models are.

1. Electrical double layer model
2. Porous electrode model
3. Equivalent Circuit Model
4. Intelligent Model

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5. CHARGING AND DISCHARGING

General SC charging and discharging cycle begins with a constant current (CC) mode followed by constant voltage (CV) mode or with a CC mode followed by constant power mode followed by CV mode. Otherwise just a CV mode.
Based on SC charging and discharging at constant current, Equivalent Series Resistance (ESR) and capacitance measuring methods are devised for DC characterization Initially, SC is charged at Constant Current (CC) till it reaches a small voltage, then it is connected to a fixed voltage DC source. Then SC is discharged at CC, until voltage drop is seen at the beginning of the discharge cycle. Charging time can be increased by changing some of the parameters. Figure. 6 show the profile of the discharging process. SC voltage comprises of capacitive and resistive component. Voltage due to charge and discharge is represented by the capacitive component. Voltage change due to internal resistance is given by the resistive component and internal resistance is given by ESR .SC charge redistribution leads to voltage drop or boost in a relatively short term compared to self-discharge. Effects of super capacitor self-discharge for low power applications and high power application have been investigated using different models.

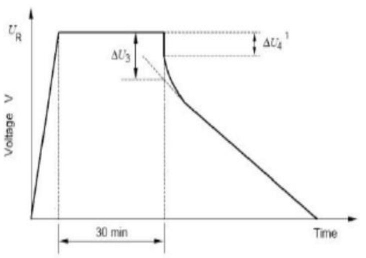

Figure 5. Charging and discharging at constant current

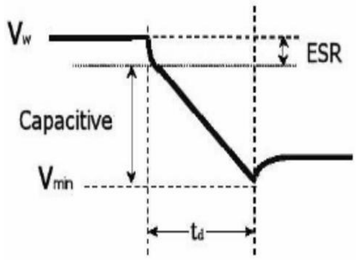

Figure 6. Profile of super capacitor a discharging

6. LIFETIME ANALYSIS

Compared to other charge storage devices, SC has a much longer lifetime. With Non-Faradaic process, there is no chemical associated as there is no transfer of charge between electrolyte and electrode, which means it can last longer than capacitors and batteries which uses chemicals to store charges. The SC with polymer electrodes have a lesser lifetime as liquid electrolytes evaporate overtime, which is a function of temperature and voltage applied. Temperature and voltage plays a vital role on a lifetime of SC. In designing energy storage system an accurate aging model plays a critical role. In order to estimate the balance charge left in the device, precise calculation of instantaneous SC energy has to be done. In a certain scenario, SC is subjected to rapid charging/discharging cycles with constant power characteristics that is, when current increases voltage decreases and vice-versa. Increase in current cause's voltage drops and these losses escalate especially when cells are connected in series, due to high ESR. ESR and equivalent capacitance (EC) values changes with the device age. Generally, manufacturers provide ESR and EC values with 20% tolerance, complicating the energy balance estimation

7. SELECTION OF SUPER CAPACITOR

To replace the batteries in the system, choosing the correct values and ratings of super capacitors is very important. Also, it is important to relate capacitance and energy in terms of watts per hour. Battery charging and discharging time is calculated based on the ampere-hour rating, an equation relating ampere-hour and capacitance is given below.

Ah = [(Vmin+ Amax) / 2] * [F / 3600]
Here, Ah = Ampere hour
F = Farad
Vminand Vmaxare terminating voltage levels

Table 1. Battery equivalent capacitance rating

Sl. No.	Battery rating (mAh)	Equivalent capacitance (Farad)
1	1000	782
2	1250	978
3	1500	1173
4	1800	1408
5	2100	1643

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8. COMPARATIVE ANALYSIS OF SUPER CAPACITOR AND OTHER STORAGE DEVICES

Compared to the battery or electrolytic capacitors, SC has higher energy density and higher power density together with smaller volume and weight. SC has a long life cycle compared to batteries, up to 500000 times. It can be said that battery and SC are complementary because batteries are limited in the power levels they can support but have high energy to weight ratio, whereas SC can support various power levels but has lower energy to weight ratio. Modern applications are high power rated; this has led to the manufacturing of batteries with high power which in turn requires sacrificing energy density and life cycle. Similarly with the capacitors, as they now suffer from low energy density and higher self-discharge. Compared to individual SC and battery, hybrid energy storage systems can achieve better energy and power performances. There have been several hybrid models proposed which show superiority over battery-only systems. Battery-super capacitor, fuel cell-super capacitor hybrid models are some examples.

Storage device characteristics	Super capacitor	Capacitor	Battery
Charging time	1 – 30 s	$10^{-3} < t < 10^{-6}$S	1 < t < 5 h
Discharging time	1 – 30 s	$10^{-3} < t < 10^{-6}$S	T > 0.3 h
Energy density (Wh/kg)	1–10	< 0.1	10 – 100
Life time (Cycle number)	10^6	10^6	1000
Power density (W/kg)	10,000	> 1,000,000	< 1000
Charge / discharge efficiency	0.85– 0.98	> 0.95	0.7 – 0.85

Table 2. Comparison between super capacitor, electrolytic capacitor and battery performance

9. ADVANTAGES AND FUTURE SCOPES

Batteries are dangerous when mistreated; overheating may cause batteries to explode. SC does not overheat because of low internal resistance. The lifecycle of batteries are low, comparatively, SC has a lifetime of virtual infinity. This makes these devices useful where it is subjected to frequent charging and discharging cycles [4]. Shorting terminals of fully charged SC will cause it to discharge quickly, which may result in electrical arching, which might damage the device.

Some of the features of super capacitors are
i) Low ESR.
ii) Low leakage current.
iii) Higher life cycle.
iv) A wide range of operating temperature.
v) Higher useable capacity.

Some of the fields where super capacitors can be used are:

1. in transmission lines.
2 SC UPS: For critical loads which need ride-through of few second, SC system without any batteries are useful
3. Hybrid SC-Battery UPS: SC and battery can complement each other in their short-coming which would reduce battery cycling, in turn, increasing battery life
4. System frequency and stability control.

5. Micro grid and micro-generation: SC can be used as an energy storage device in a micro source system connected to micro grid

6. SCs are suited as an energy storage system for hardening sensitive equipment against voltage sag.

7. in a wind turbine system: SC can provide a simple, highly reliable solution.

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8. In telecommunication, to achieve highly reliable operation, usually, they are supported by ―hot standby system‖ like battery backup, parallel type UPS and redundant DC-DC converter. There is some power consumption in the standby unit. It becomes a serious problem because power saving is an important issue. So they require a cold standby device like diesel generator set, fuel cell etc. But their response time is large. The solution is to use SC which operates in a shorter time as soon as an interrupt occurs in a system.

9. Cold starting of the diesel-fueled engine, diesel-fueled engines are more difficult to start at a temperature up to -40°C. Lead acid batteries are used in engine cranking. At low-temperature resistance offered by a battery is high which affect the high current discharge of a battery which
Is necessary in the situation. Again, battery ages, the internal resistance further increases and current discharge capability further reduces. SC bank can be used with battery to supply necessary cranking current to cranking motor.

10. Hybrid electric vehicle use battery alone system to drive the vehicle through inverter and motor. If along with battery which is rich in energy density, SC which is rich in power density is used together, the transient requirement i.e., a pulse of current during acceleration is supplied by SC and during deceleration or breaking the energy will be returned back to the SC. An appreciable amount of energy used during acceleration will be regained.

10. CONCLUSION

In this paper, some of the characteristics of the super capacitors have been discussed which will be helpful to select super capacitor and design energy storage system using it. With high power density, short charging time, large discharging time, long life and environmentally friendly properties super capacitor may be chosen as an alternative for battery or other energy storage devices.

REFERENCES

[1] Chukwuka C, Folly K. A, ―Batteries and Super-capacitors‖, IEEE PES Power Africa, pp. 1 – 6, 2012.
[2] A. Armutlulu, J. K. Kim, M. Kim, S. A. Bidstrup Allen, M. G. Allen, ―Nickel-oxide-based super capacitors with high aspect ratio concentric cylindrical electrodes‖, Transducers &Eurosensors, pp. 1480 – 1483, 2013.
[3] C. D. Lokhande, D. P. Dubal, Oh-Shim Joo, ―Metal oxide thin film based supercapacitors‖, Current applied physics, Vol.11, pp. 255 - 270, 2011.
[4] J.Manikandan, R.MohanaPriya, S.Pavithra, D.Sarathkumar, ―Rapid Smart Phone Charging Using SuperCapacitor‖, International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 4, pp. 2175 - 2180, 2015.
[5] IonuţCiocan, CristianFărcaş, AlinGrama, Adrian Tulbure, ―An Improved Method for the Electrical Parameters Identification of a Simplified PspiceSupercapacitor Model‖, IEEE SIITME, pp. 171 - 174, 2016
[6] R. Kotz, M. Carlen, ―Principles and applications of electrochemical capacitors‖, ElectrochimicaActa, Vol. 45, pp. 2483 - 2498, 2000.
[7] Marin S. Halper, James C. Ellenbogen, ―Supercapacitors: A Brief Overview‖, 2006.
[8] Z. Li, C. Jie, ―An impedance-based approach to predict the state-of-charge for carbon-based super capacitors‖, Microelectronic Engineering, Vol. 85, pp. 1549 - 1554, 2000

BIOGRAPHIES

Mr. Vishal Mehtre has completed his Master in Electrical Engineering (Power Systems) from Bharati Vidyapeeth (Deemed to be University) College of Assistant Professor in department of Electrical Engineering. He has industrial experience about 2 years in Suzlon Power Infrastructure Pvt. Ltd. as Engineer in Power Evacuation department and has an teaching experience of more than 5 years. His area of interest is Renewable sources of energy specially Wind and solar with its analysis, optimization and power quality