*Sindh Univ. Res. Jour. (Sci. Ser.) Vol. 48 **(4D)** 143-146 (2016)*

SINDH UNIVERSITY RESEARCH JOURNAL (SCIENCE SERIES)

Unequal Voltage Sharing Between Super Capacitors

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Received 28rd August 2016 and Revised 17th October 2016

Abstract: Newly developed super capacitor (SC), sometimes referred to as ultra capacitor have very high capacitance values compared with ordinary capacitors making them attractive for energy to rage applications. Due to the low voltage rating of a single cell it is necessary to connect a number of SC modules in a series to obtain a practical voltage rating required for power application. However when connected in series they lead to unequal voltage distributions during several cycles of charge-discharge and over voltage may appear on capacitors and therefore it is necessary to prevent this unbalance and hence to prevent individual capacitors from exceeding its rate voltage due to manufacturer's internal parameter tolerance. If preventative action is not taken the characteristics of the SC element subjected to a higher voltage could influence its lifespan, its characteristics may change with time and therefore the voltage equalization is necessary. This project has studied the problem of unequal voltages sharing in a series connection of SCs forcing the equal sharing of voltage between two and three SCs.

Keywords: Preliminary, Super capacitor

1. INTRODUCTION

Super capacitors (SCs) sometimes referred to as ultra capacitors electrochemical double layer capacitor shave very high capacitance values compared with ordinary capacitors making them attractive for energy storage applications. Although it is an electrochemical device there is not a chemical reaction involved in its energy storage mechanism. This mechanism is very much reversible, allowing the SCs to be charged and discharged many times (Uno and Toyota, 2008) (Technologies, 2009). SCs provide a higher power density than conventional batteries and a higher energy density than traditional capacitors (Frqckowiak and Beguin, 2010). The advantage of SCs are the extremely fast rates of charging and discharging speed, long lifespan, wide operation of temperature range, high efficiency, and they are environmentally friendly (Zhang et al., 2009). Due to the low voltage rating of a single cell it is necessary to connect a number of SC modules in a series to obtain a practical voltage rating required for power application. However when connected in series they do not share the voltage equally during charge and discharge. This may influence the lifetime of SC, its characteristics may change with time and therefore some form of voltage equalization is necessary. This project will be studied the problem of unequal voltage sharing a series connection of SCs using balancing resistor to forcing the equal sharing of voltage in a string of SCs. But this method is not used in high duty cycle applications because of high power dissipation in its resistance. This dissipations are reduced the efficiency of the module, depending on the value of the resistor. However there is complex method that is DC/DC converter which is more expansive and gives high quality result which is needed in some application. **(Fig-1)** a structure of SC.

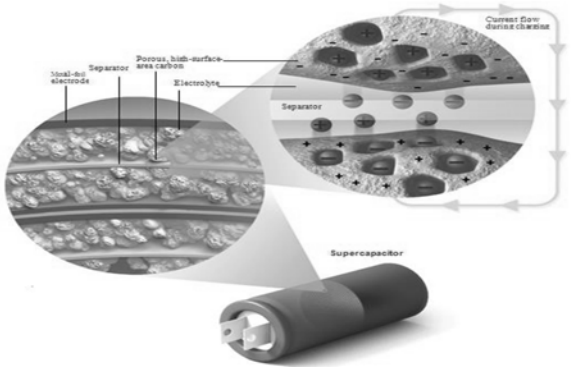


Fig1: Structure of Super capacitor (Zorpette, 2005)

2. METHOD

The SC shows non-ideal behavior, mainly as a consequence of the porous material used to shape the electrodes that causes the resistance and capacitance to be distributed with in a pore. A five element has good accuracy for most applications and accounts for frequencies up to10kHz. The transmission line model physically mimics the SC distribution and has good accuracy at high frequencies (GlavinandHurley, 2007).

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The equivalent circuit for the transmission line model of SC illustrated in (Fig-2).

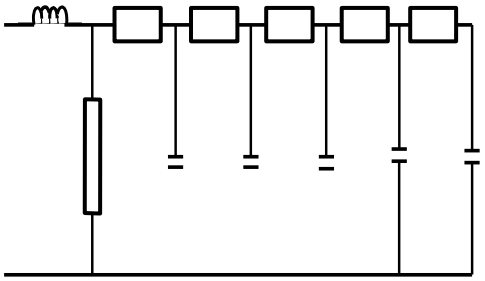


Fig 2: Transmission line model of super capacitor

A transmission line in each pore is resulted in a capacitance treatment. In this model, it forms a distributed super capacitor and a distributed electrolyte resistance that extends in to the depth of the pore (Kotz and Carlen, 2000). Fig.3 shows electrode representation as five elements transmission line.

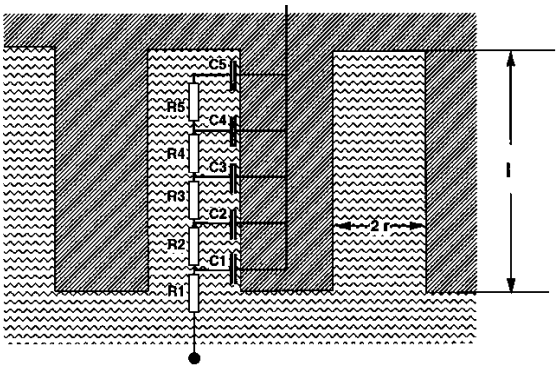


Fig3: Five element transmission line

The resistance of the bulk material is taken to be much smaller than the electrolyte resistance and at high frequencies the capacitors behave as small impedance elements. The current primarily flows along R_1 and C_1 in to the electrode material and almost no current flows deep in to the pore. At high frequencies the resistance and the double layer capacitance are both decreased (Glavin and Hurley, 2007).

The classical equivalent model is commonly used in simple systems where the frequency is not critical. The other models are applied to analyze more complicated applications. **(Table-1)** represents a comparison between these models. It was shown that there are three super capacitors models and each model has its own characteristics which explained the super capacitor behavior. The three branch models and the transmission line model are very complicated; hence the simple equivalent model is chosen to be used in this project because it is easily and not complicated as the others.

Table-1: Comparison of Three Super capacitors Models

Classical Equivalent Model	Three branch model	Transmission line model
Advantages		
Simple to apply. Use for discharging circuits.	Simple to measure three different times constant. Can be use in several application need high frequency.	Can be applied in high level of frequency.
Disadvantages		
Not for high level of applications. The Error ratio is a little bit high.	Complex with many parameters. Not use to predict the behaviour of a capacitor after some hours or days.	It cannot see the influence of a large current. Very complex.

3. RESULTS AND DISCUSSIONS

Due to the low voltage rating of a single cell it is necessary to connect a number of super capacitor modules in a series to obtain a practical voltage rating required for power application. However when connected in series they lead to unequal voltage distributions during ever al cycles of charge- discharge and over voltage may appear on capacitors and therefore it is necessary to prevent this unbalance and hence to prevent individual capacitors from exceeding its rate voltage (Technologies, 2009) (Yasser,2006). If preventative action is not taken the characteristics of the super capacitor element subjected to a higher voltage could influence its lifespan, its characteristics may change with time (aging effect) (Rizoug et al.,2004). Basically there are a number of reasons for the unbalance of voltage in a series string of super capacitor, one of which is the spreader of internal parameters of super capacitors such as the capacitance, equivalent series resistance (ESR) and self-charge rate (Yasser, 2006). Generally speaking, there are different methods of voltage balancing with varying cost, which are used indifferent applications. The voltage balancing methods are: passive balancing and active balancing (Zhangetal.,2009).

1) Manufacturing dispersion of the parameters of supercapacitors

Dispersion of parameters of super capacitors produced by the same manufacturer can reach ±25%fortheESRand±20% for the capacitance. A study was conducted on four super capacitors manufacturing by Maxwell rated at 2600 F and 2.5V. The tolerances were ESR (3%) and on capacitance (5%). Fig.4 shows these manufacturing dispersions of super capacitor parameters tolerances (Yasser, 2006).

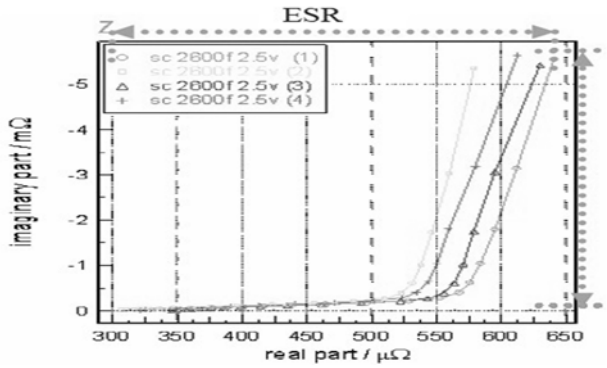


Fig4: Parameters of manufacture tolerance

The dispersion of individual cells self-discharge rate can influence the cells voltage distribution specially in low duty-cycle applications. **(Fig-5)** shows that the four a fore said super capacitor components did not have the same self- discharge rate, as a consequence a difference in the cells voltage have appeared (Yasser, 2006).

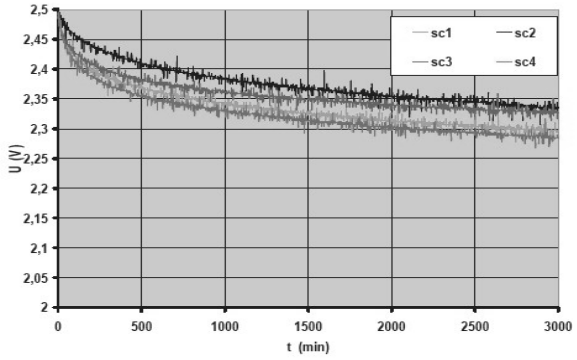


Fig 5: Super capacitor self-charge

2) Temperature influence

The ambient temperature has an effect on the behavior of super capacitor; the increase of ambient temperature causes very large decrease in equivalentseries resistance ESR, a slight increase in capacitance as depicted in Fig.6 and decrease in the self- discharge rate in super capacitor (Yasser, 2006).

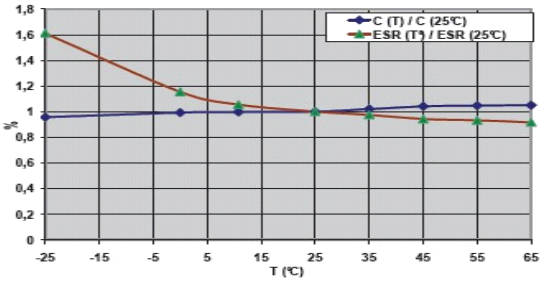


Fig 6:` Variation of super capacitor parameters with temperature Charging SC cells without balancing circuit.

Case1: Modeling without leakage current

The circuit was simulated without a leakage resistor as shown in **(Fig-7)**, the super capacitors will be charged according to their individual capacitive value. Due to the capacitance tolerance, the cells have variation in capacitance -10/+20%, and therefore, the individual cell voltages will vary depending on capacitance. The cell with higher capacitance will be charged to lower voltages, and the cells with smaller capacitance will be charged to higher voltages as shown in **(Fig-7)**. According to the results obtained from the simulation, V_{sc1}=2.857V and V_{sc2}=2.143V.

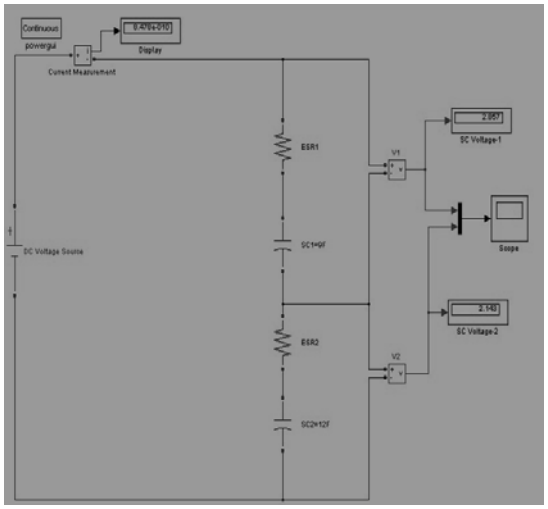


Fig7: Modelling without leakage current of two SCs

Fig-8 shows the output response of above said modeling.

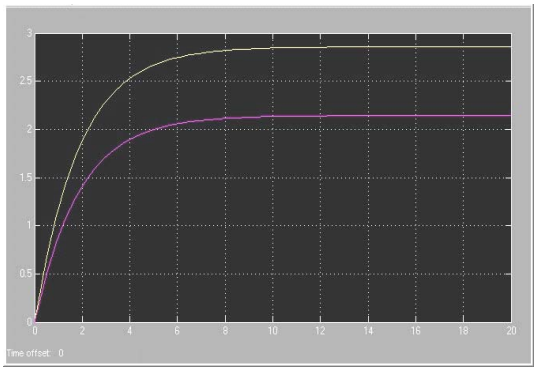


Fig-8: Output response of modeling without leakage current two SCs

Case2: Modeling with leakage current

When the circuit was simulated with internal parallel resistor (leakage current) as illustrated in **(Fig-9)**, the voltage distribution in the string is less than in Case1 because of the leakage resistor. The capacitor voltages, 2.857V of SC_1 and 2.143V of SC_2 were arrived at by

using the results from Case1 because if the voltages had started from zero, they same function of capacitance would have resulted but considerably more time would have been consumed EPR is calculated by following equation:

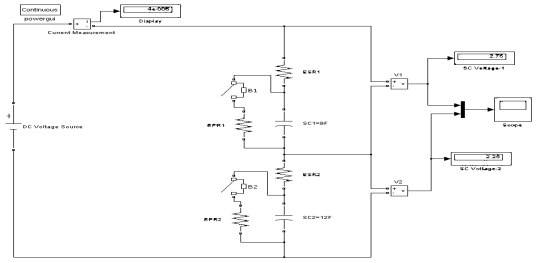


Fig-9: Modeling with leakage resistor of the two SCs

The simulation has showed the voltage differences between the two super capacitors, consequently SC_1=2.75V and SC_2=2.25V, as illustrated in **(Fig-10)**, SC_1 has exceeded the surge voltage of 2.7V as given by the super capacitor manufacturer.

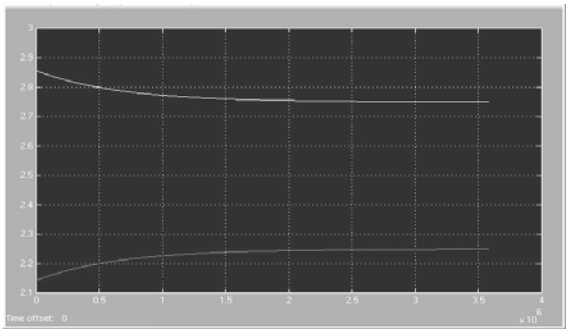


Fig10: Output response of modeling with leakage resistor of the two SCs

4. CONCLUSION

The empirical information and the theory of super capacitors have been presented in this paper together with the result when charging two SC without any balancing method a simple equivalent circuit module has been used with different values of balancing resistors. The circuit simulated without a leakage resistor show the super capacitors will be charged according to their individual capacitive value.

Due to the capacitance tolerance, the cell shave variation in capacitance-10/+20%, and therefore, the individual cell voltages will vary depending on capacitance. The cell with higher capacitance will be charged to lower voltages, and the cells with smaller capacitance will be charged to higher voltages. Circuit simulated with internal parallel resistor (leakage current) show less voltage distribution in the string compare to Case1 because of the leakage resistor.

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