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Reduction in charging current of Super capacitor by series Parallel connection

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Abstract
High farad values of Ultra Capacitors (UC) are associated with very large current during charging. This paper proposes proper switching for re-configuration within ultra capacitor bank for reducing charging current. Proposed scheme is simulated using MATLAB Simulink and results were confirmed by mathematical calculation, which indicate that during charging process using similar re-configuration charging current can be reduced. Proposed work show that charging time can be reduced to 330 sec. from 480 sec. in constant current charging method & it is 31.35% faster. In constant voltage method charging time reduced to 96 sec. from 120 sec. & process is20% faster.

Keywords: Super capacitor, Charging , Energy exchange

Introduction

An electric double-layer capacitor (EDLC) has relatively very high energy density. It is also known as super-capacitor, super-condenser, pseudo-capacitor, electrochemical double layer capacitor, or ultra capacitor. Compared to normal capacitors of low farad value, the energy density of super capacitors is typically thousand times greater. In comparison with conventional batteries or fuel cells, EDLCs have a much higher pulse power density.

For efficient charging of super capacitors Li et al [1] have reported an application using feedforward boost converter, which eliminates the need to use voltage feedback or current feedback. H. Polbck [2] reported in 1999 that resonant converter-operation at high frequency, (typically 80 kHz), offers a cost effective solution to charging when super capacitor and battery work in coherence, for feeding high power to load. A low cost solution has been suggested by Chen and Lai [3], for designing a charger wherein switch-over takes place from constant current charging to constant voltage charging, by the microcontroller unit. Case of Large energy capacitor units rated at higher voltage has been dealt with by Jeong et al [4] who claim the charging scheme reported by them to be efficient. While dealing with a unit employing a super capacitor and a fuel cell, Kotsopoulos et al dealt with small stand alone system [5]. For electric vehicles, motor starting and regenerative braking involve high rates of discharging and charging. Chan Chau and Chan [6] suggested effective charging methods for super capacitors. For efficiency as well as for longer battery life, such hybrid system needs constant current charger and controlled isolation of battery during the process. This has been described by Kim et al [7].

Proposed Scheme

By using series / parallel combinations, charging times are reduced. Charging process become faster. This paper discusses the charging process of super capacitors at constant current and at constant voltage. As a typical case, a bank with four identical UC is dealt with. Although, the proposal can be readily extended to suitably cover different number of units in any other bank of capacitor. The comparison is to be done in two cases:

Charging process

The Charging process is possible in two different modes.

1. Constant Current Charging.
2. Constant Voltage Charging.

In each of these modes, it is found that if the network of capacitor to be charged is reconfigured as suggested in the proposed scheme, the total charging time can be reduced.

1.1 Constant current charging.

Analysis is done under following two methods in constant current charging.

1. Without Reconfiguration.
2. With Reconfiguration.

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1.1.1 Without Reconfiguration

Let single equivalent capacitor of 20 F or four identical capacitor of 5F is connected for charging on constant current source of 0.5 Amp 12V. Time required for increase in voltage from 0V to12 V will be T seconds.

$$Q = CV \tag{1}$$

$$V(t) = \frac{Q}{C} = \frac{1}{C}\int idt \tag{2}$$

$$12 = \frac{1}{20}\int_0^T 0.5dt \tag{3}$$

$$T = 480\,s \tag{4}$$

Time required to increase the voltage of 20 F capacitor from 0Vto 12V without reconfiguration will be 480 seconds with constant current source.

1.1.2 With reconfiguration

Reconfiguration of capacitors will be performed in three actions.

1. Action 1:- All the four uncharged capacitors will be in series up to capacitor voltage reaches to 12V.
2. Action 2:- All four partially charged capacitor from action 1 will be reconnected like, two capacitors will be in series and such two combinations will be in parallel and connected to source up to capacitor voltage reaches to 12V.
3. Action 3:-All partially charge capacitor from action 2 will be reconnected in parallel and charged through the source up to capacitor voltage reaches to 12V.

Action 1

Four uncharged capacitors are connected in series Ceq= (5F)/4=1.25F. Considering 0.5 amp constant current for charging. Time required for increasing voltage from 0V to 12V is to be calculated as follows. Initial voltage across the capacitor after second action

$$(V_i)=0V \tag{5}$$

$$12 = V_i + \frac{1}{1.25}\int_0^{T_1} 0.5dt \tag{6}$$

$$T_1 = 30\,s \tag{7}$$

Time required for increasing the voltage of series connected capacitor from 0V to 12V is 30 s.

Action 2

Two partially charged capacitors are connected in series and such two combinations are connected in parallel. Charging will start from V_i = 6V till the voltage reaches 12 V. Here, Ceq= 5 F. Consider 0.5 amp as the constant current for charging. Time required for increasing voltage from 6V to 12V is to be calculated as follows. Initial voltage across the capacitor after second action.

$$(V_i)=6V \tag{8}$$

$$12 = 6 + \frac{1}{5}\int_0^{T_2} 0.5dt \tag{9}$$

$$T_2 = 60\,s \tag{10}$$

Time required for increasing the voltage of series parallel connected capacitor from 6V to 12V is 60 s.

Action 3

Four partially charged capacitors are connected in parallel. Charging will start from V_i = 6V till the voltage reaches 12 V. Here Ceq= 20 F. Considering 0.5 amp constant current for charging. Time required for increasing voltage from 6V to 12V is to be calculated as follows.

Initial voltage across the capacitor after second action

$$(V_i)=6V \tag{11}$$

$$12 = 6 + \frac{1}{20}\int_0^{T3} 0.5dt \tag{12}$$

$$T_3 = 240\,s \tag{13}$$

Time required for increasing the voltage of parallel connected capacitor from 6V to 12V is 240 s. Total times required in all the three actions will be as follows.

$$T=T_1+T_2+T_3=30+60+240=330s. \tag{14}$$

3.1.3 Comparison of charging time in constant current charging method

Comparison of charging time in both the cases i.e. with and without reconfiguration in constant current charging method.

Time consumed in without reconfiguration = 480 s. from eq. (4)

Time consumed in with reconfiguration = 330 s. from eq. (14)

From above calculations, it is seen that time saving in percentage for charging with constant current source will be as follows.

$$[1-(330/480)]\times 100 = 31.35\%, \text{ faster.} \tag{15}$$

Charging of capacitor will be 31.35 % faster in case of constant current source method with series parallel reconfiguration.

1.2 Constant voltage charging

Analysis is done under following two methods in constant current charging.

1. Without Reconfiguration.
2. With Reconfiguration.

1.2.1 Without reconfiguration

Let single equivalent capacitor of 20 F or four identical capacitor of 5F is connected for charging on constant voltage source of 12V with current limiting resistance for a limit of 2 Amp per capacitor source should supply 8 Amp. Time required for increase in voltage from 0V to12 V will be as follows. The current limiting resistance will be R.

$$R = (12 - Vuc)/8 = 1.5\Omega \quad (16)$$

$$RC = 20 \times 1.5 = 30\,s \quad (17)$$

$$T = 4(RC) = 120\,s \quad (18)$$

Time required to increase the voltage of 20 F capacitor from 0Vto 12V without reconfiguration will be 120 seconds with constant voltage source.

1.2.2 With reconfiguration

Reconfiguration of capacitors will be performed in three actions same as performed in with reconfiguration in constant current source. But now source will constant voltage source.

Action1

In action 1 four uncharged capacitors are connected in series equivalent capacitance (Ceq) = 5 F/ 4=1.25 F. Considering 2 amp charging current per capacitor. Time required for increasing voltage from 0V to 12V will be T_1 and current limiting resistance will be R. T_1 & R can be calculated as follows.

$$\text{Initial voltage across capacitor will be } (Vuc) = 0V$$

$$R = (12 - Vuc)/2 = 6\Omega \quad (19)$$

$$RC = 1.25 \times 6 = 7.5\,s \quad (20)$$

$$V(t) = 12[1 - e^{(-t/RC)}] \quad (21)$$

$$V(7.5) = 7.585V \quad (22)$$

$$V(15) = 10.376V \quad (23)$$

$$V(22.5) = 11.40V \quad (24)$$

$$V(30) = 11.78V \quad (25)$$

The total voltage across the series connected capacitor with time is graphically shown in Fig.1

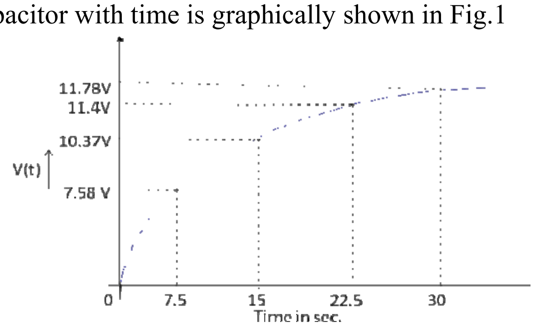

Figure. 1 Graph for variation of total voltage across the series connected capacitor with time during action 1

From Fig 1 better time for change over is identified as 15 sec. total voltage across the string is 10.37V. After this, change in voltage with respect to change in time will be very less. Percentage of total voltage build up across series connected capacitor is given below.

$$(10.37/12)\times 100 = 86.41\ \% \quad (26)$$

$$T_1 = 15\ s \quad (27)$$

$$\text{Voltage per capacitor} = (10.37/4) = 2.59V \quad (28)$$

When four capacitors of 5F are connected in series and charged through a constant voltage source. The total voltage across the string will be 10.37 at 15 seconds from eq. (21).

Action 2:

In action 2 two partially charged capacitors are connected in series, and such two branches are connected in parallel. Then equivalent capacitance (Ceq) = 5 F. Considering 2 amp charging current per capacitor, so source should supply 4 amp. Voltage per capacitor after first action will be (10.37/4)=2.59V and voltage across the branch the two series connected capacitor will be (2.59+2.59)=5.18V for action 2. Time required for increasing the voltage from 5.18V to 12V will be T_2 and. Current limiting resistance R. T_2 & R can be calculated as follows.

Initial voltage across two series connected capacitor after action 1

$$Vuc = 5.185V \quad (29)$$

$$R = (12 - 5.185)/4 = 1.7\Omega \quad (30)$$

$$RC = 5 \times 1.7 = 8.5\,s \quad (31)$$

$$\text{Voltage difference} = (12 - 5.185) = 6.815V \quad (32)$$

$$V(t) = 5.18 + 6.82[1 - e^{(-t/RC)}] \quad (33)$$

$$V(8.5) = 9.49V \quad (34)$$

$$V(17) = 11.07V \quad (35)$$

$$V(25.5) = 11.66V \quad (36)$$

$$V(30) = 11.80V \quad (37)$$

The total voltage across the series / parallel connected capacitor with time is graphically shown in Fig.2

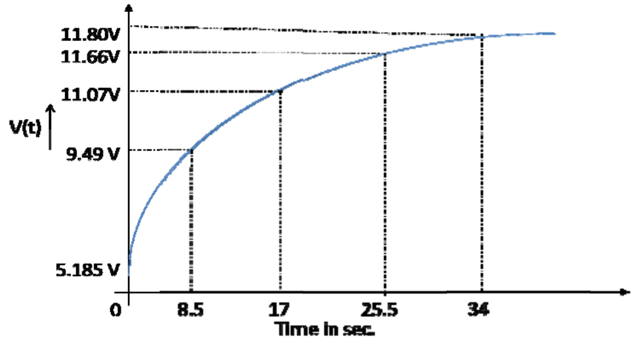

Figure. 2 Graph for variation of total voltage across the series/parallel connected capacitor with time during action 2

From Fig 2 better time for change over is identified as 25.5 sec. total voltage across the series/parallel connected capacitor is 11.66V. After this, change in voltage with respect to change in time will be very less. Percentage of total voltage build up across series connected capacitor is given below.

$(11.66/12)\times100=97.16\ \%$ (38)

$T_2 = 25.5$ s (39)

Voltage per capacitor = (11.66/2) =5.83V (40)

When two partially charged capacitors of 5F are connected in series and two such branches are in parallel. This series / parallel combination is charged through a constant voltage source. The total voltage across the string will be 11.66 after 25.5 s from eq. (33).

Action 3

In action 3 four partially charge capacitors are connected in parallel. Now, equivalent capacitance (Ceq) =20F. Considering 2 amp charging current per capacitor, so source should supply 8 amp. Voltage per capacitor after second action will be (11.66/2) =5.83V and voltage across the parallel connected four capacitors for action 3 will be 5.83V. Time required for increasing the voltage from 5.83V to 12V will be T_3 and. Current limiting resistance R. T_3 & R can be calculated as follows. Initial voltage across capacitor after action 2 (Vuc) = 5.83V. (41)

$$R = (12 - 5.83)/8 = 0.771\Omega \quad (42)$$

$$RC = 20 \times 0.717 = 15.42\,s \quad (43)$$

Voltage difference = (12 - 5.83) = 6.17V (44)

$$V(t) = 5.83 + 6.17[1 - e^{(-t/RC)}] \quad (45)$$

$$V(16) = 9.51V \quad (46)$$

$$V(32) = 10.92V \quad (47)$$

$$V(48) = 11.42V \quad (48)$$

$$V(64) = 11.62V \quad (49)$$

The total voltage across the parallel connected capacitor with time is graphically shown in Fig.3

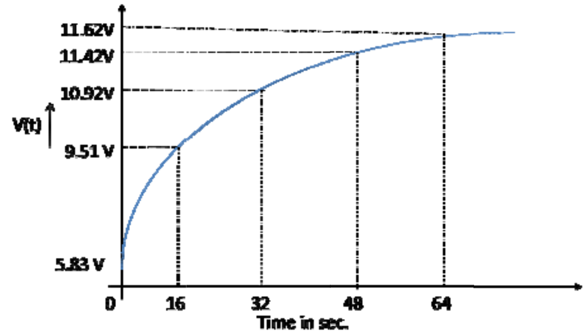

Figure. 3 Graph for variation of total voltage across the connected capacitor with time during action 3

From Fig 3 better time for change over is identified as 48 sec. total voltage across the parallel connected capacitor is 11.62V. After this, change in voltage with respect to change in time will be very less. Percentage of total voltage build up across series connected capacitor is given below.

$(11.62/12)\times100=96.83\%$ (50)

$T_3 = 64$ s (51)

When four partially charged capacitors of 5F are parallel this parallel combination is charged through a constant voltage source. The total voltage across the capacitor will be 11.62 after 64 seconds from eq. (45).

From eq. (21), eq. (33), eq. (45)

Total time required in all three actions will be as follows.

$T=T_1+T_2+T_3=15+17+64=96$s. (51)

Variation of voltage per capacitor is graphically shown in Fig. 4

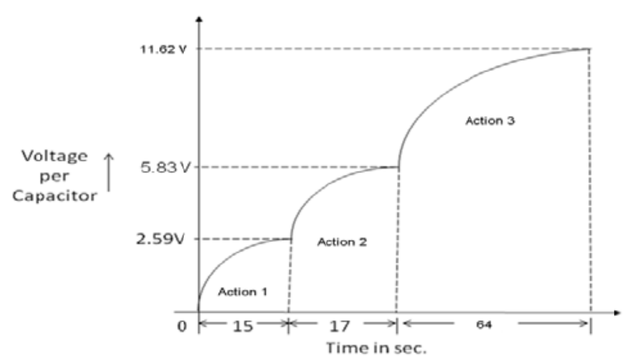

Figure. 4 Voltage per capacitor in with reconfiguration

1.2.3Comparison of charging time in constant voltage charging method

Comparison of charging time of capacitor in both the cases i.e. with and without reconfiguration in constant voltage charging method. Time consumed in without reconfiguration = 120 s. from eq. (18)

Time consumed in with reconfiguration = 96 s. from eq. (51). From above calculations, it is seen that time saving in percentage for charging with constant voltage source will be as follows.

[1-(96/120)]×100 = 20%, faster. (52)

Charging of capacitor will be 20 % faster in case of constant voltage source method with series parallel reconfiguration.

1.3 Simulation results of charging action using MATLAB

The circuit parameters used for simulation in MATLAB / Simulink environment is given below. Simulation work is done only in constant voltage method. This is explaining below. Configuration parameter for simulation is Solver is ode25tb, Variable stapes, Non adaptive algorithm. Simulation is done for constant voltage source method. Voltage Source of 12 V, Capacitor is of 5F, Ideal switches, static range block are the components of simulation. The Simulation model and its output response when reconfiguration of circuit is not done are shown in fig. 5 Fig. 6 shows the response of simulation of without reconfiguration during charging. Fig. 7 shows the simulation of with reconfiguration during charging. Fig. 8 Response of simulation of with reconfiguration during charging

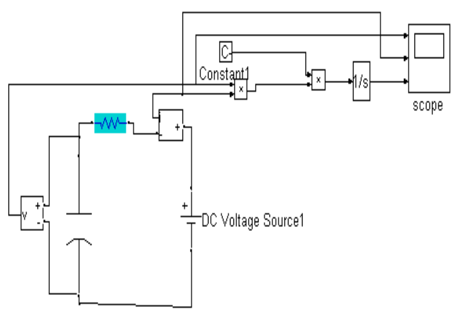

Figure. 5 Simulation diagram without reconfiguration during charging

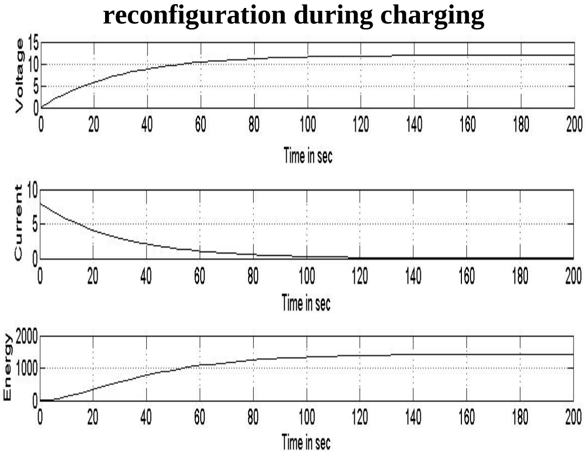

Figure. 6 Response of simulation of without reconfiguration during charging

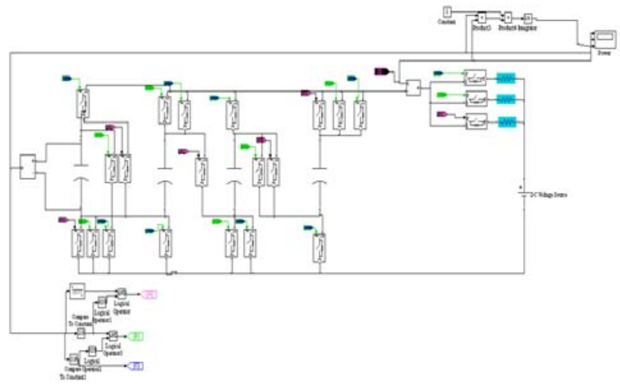

Figure. 7 Simulation of with reconfiguration during charging

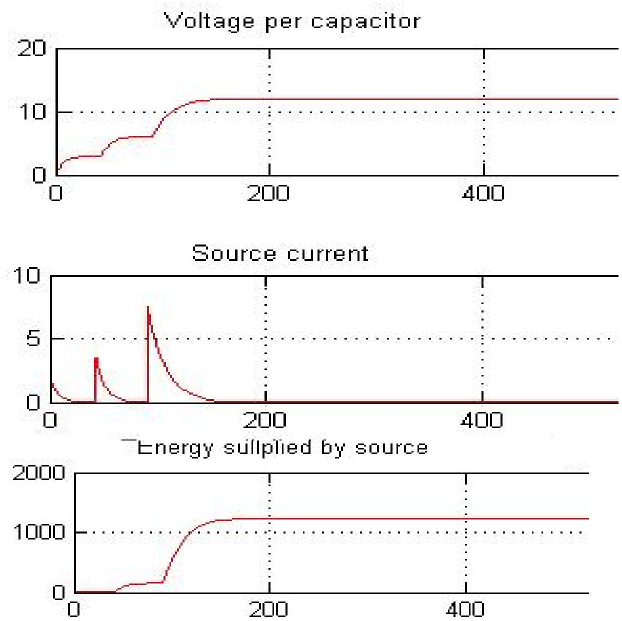

Figure. 8 Response of simulation of with reconfiguration during charging

6. Conclusions

Series / parallel reconnections lead to faster processes during exchange of energy in case of capacitor banks. The proposed scheme also helps to reduce the rating of charging circuit. It deserves attention for applying to industrial system. In industrial applications for ride-through applications in drives, and applications as short duration UPS, super capacitor banks are used. It is necessary work on prototypes', to conclude the quantitative advantages of the proposed scheme, when implemented for real life strategic applications.

7. References

[1] Li Cheng-Chou, "A Stand Alone Super Capacitor Charging System Using A Feed Forward Boost Converter," Proceedings of 2011 International

Conference on System Science and Engineering, Macau, China, 8-10 June 2011 ICSSE 2011 p.p. 65-69.

[2] Helen Pollock, “High efficiency, high frequency power supplies for capacitor and battery charging,” published by the IEE, Savoy Place, London WCPR OBL,IEE 1999, p.p. 9/1-9/10

[3] Bo-Yuan Chen, Yen-Shin Lai, “New Digital-Controlled Technique for Battery Charger With Constant Current and Voltage Control Without Current Feedback,” IEEE transactions on industrial electronics, March 2012,vol,59.3,p.p. 1545-1553.

[4] In-Wha Jeong , long-Soo Kim, Gennadi I. Guse. and Geun-Hie Rim, “Design of 35kJ/s 25kV Capacitor Charging Power Supply for Pulsed Power Systems,” IEEE Conference of the IEEE Industrial Electronics Society Busan, Korea, November 2 - 6,2004,Vol 3, p.p. 2860-2863.

[5] Marco S. W. Chan , K. T. Chau , and C. C. Chan, “Effective Charging Method for Ultra capacitors” Journal of Asian Electric vehicles, Volume 3, Number 2, December 2005,Vol 3, Number 2, p.p. 771-776.

[6] Donghwa Shin, Younghyun, Kim, Jaeam Seo, and Naehyuck Chang, “Battery-Super capacitor Hybrid System for High-Rate Pulsed Load Applications”, EDAA, 14-18 march 2011, p.p. 1-4.

[7] A. Kotsopoulos, J.L. Duarte, and M.A.M. Hendlix, “A Converter to Interface Ultra-Capacitor Energy Storage to a Fuel Cell System”, Dept of Electrical Engineering, Technical University of Eindhoven. The Netherlands , IEEE,4-7 may,2004,Vol 2, p.p.827-832.

[8] P.R. Sawarkar, S.G. Tarnekar , S.B. Bodkhe ,“ Improvement in Energy Transactions in Ultra Capacitor Banks by Series/Parallel Re-connection”, International Journal of Electrical Engineering, ISSN 0974-2158 Volume 5, Number 5 (2012), pp. 641-652