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Improvement in Energy Transactions in Ultra Capacitor Banks by Series/Parallel Re-connection

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Abstract

In electrical circuit electrical Energy is the product of Voltage, Current, Time. Current decided by load. Source generally has drooping characteristics of voltage as in case of battery. Then only reconfiguration to increase the voltage for expediting the energy transfer. If Ultra capacitor is source of energy, due to large time constants are involved and Energy transactions become slower as a result. This paper proposes series parallel re-configuration within ultra capacitor bank for improvement in energy transfer. Proposed scheme is simulated using MATLAB Simulink and is confirmed by experimental verification which indicate time required to extract energy is 37% to 57 % Faster & up to 93 % Energy can be delivered for complete operation in typical cases of discharging.

Keywords: Super Capacitor, Energy Transfer

Introduction

An electric double-layer capacitor (EDLC) has relatively very high energy density. It is also known as super 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 feed forward 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 of super capacitor, discharging times are reduced. These processes become faster. Total discharging of super capacitor in minimum time is also dealt with. As a typical case, a bank with two 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:

- Without Reconfiguration
- With Reconfigurations

Discharging of Super Capacitor

In propose scheme, reconfiguration is dealt with series and parallel connections. Discharging of Super Capacitor is studied in above two cases. In case of no reconfiguration two fully charged capacitors of 7.5V 3.33F are connected with 10 Ohm resistance and time required for complete discharge and time required for voltage dropping up to 50% of load voltage is measured , as shown in Fig 1.

In case of reconfiguration, two fully charged capacitors of 7.5V, 3.33F are connected with 10 Ohm resistance up to the voltage dropping to 50% of load voltage. This is called as action 1. After this, parallel connection of Super capacitor will be reconfigured to have series combination, and connected to same load. This is called as action 2. Now the time required for complete discharge and time require for voltage dropping up to 50% of load voltage is measured, as shown in Fig 2(a) & 2(b).

These two different readings of time in both the cases are compared.

Without Reconfiguration

In case without reconfiguration two fully charged super capacitors of rating 7.5V 3.33F are connected to load. The variation of voltage across load is observed.

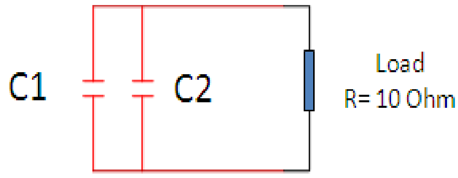

Figure 1(a): Without Reconfiguration

$$C_{eq} = 3.33\text{F} \times 2 = 6.66\text{F} \quad (1)$$

$$R_L = 10\Omega \quad (2)$$

$$V = 7.5\text{V} \quad (3)$$

$$\text{Energy Stored} = 0.5 \times 6.66 \times 7.5^2 = 187.6\text{J} \quad (4)$$

$$\text{Time Constant} = 6.66 \times 10 = 66.6\text{s} \quad (5)$$

Fig 1(b) shows the variation of output voltage versus time when two capacitors remain in parallel as in Fig 1(a) and no reconfiguration is exercised.

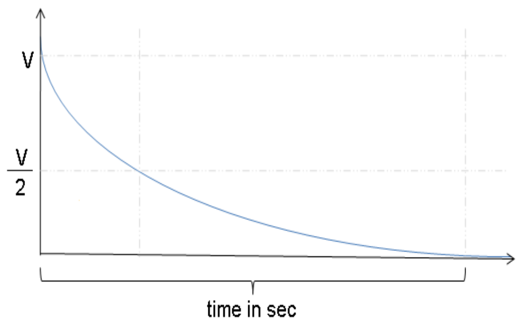

Figure 1(b): No re-configuration

With Reconfiguration

Let VL be the initial voltage across the load at the start of discharging period. Vuc represents the voltage across one unit of UC.

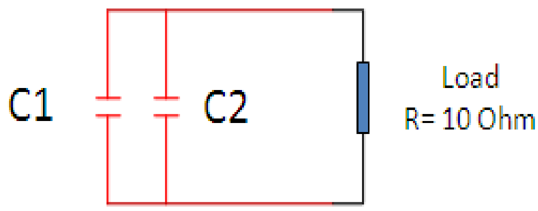

Figure 2 (a): Reconfiguration during Action 1

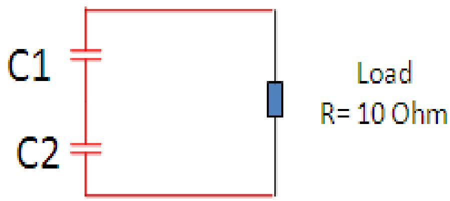

Figure 2(b): Reconfiguration during Action 2

Ultra capacitors are considered as fully charged and connected in parallel with load, up to the chosen voltage cutoff to 50% of VL. Now Super capacitor will start discharging through load resistance. When load voltage is becomes less than 50%, two capacitors are connected in series, then load voltage boosts up to 100% and then start, reducing exponentially. When the load-voltage reduces to 50% action should be stoped. Those two actions are graphically shown in Fig 2(c). In complete process, voltage is once boosted up to 100% by reconnection. It lies within 50% and 100% through the process. Thus by reconfiguration of the circuit, we extract the stored energy from UC in less time. This is substantiated by simulation and experimental verification.

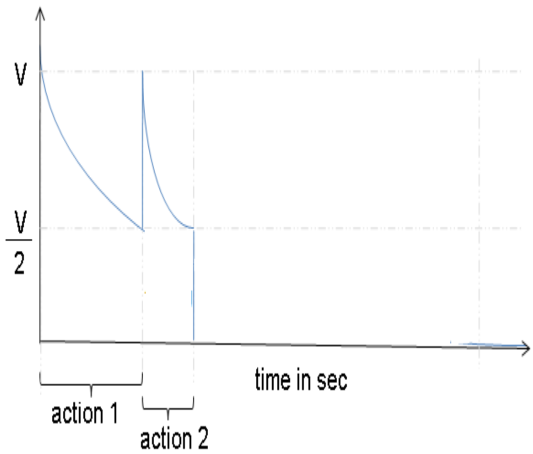

Figure 2 (c): Effect of re-configuration

Action 1: When two fully charged capacitors of 7.5V, 3.33F are connected in parallel to load voltage cutoff is chosen as 50% of load voltage.

Time required to decrease load voltage from 7.5V to 3.75V will be calculated as follows.

Initially voltage of UC will be 7.5 V and reduces up to 3.75V.

$$3.75=7.5(e^{-t/tc}) \quad (6)$$

$$RC = 6.66 \times 10 = 66.66\,s. \quad (7)$$

$$t_1 = (0.693 \times 66.66) = 46.15\,s \quad (8)$$

$$E = \int_0^{46.15} dw = \int_0^{46.15} pdw = 5.625 \int_0^{46.15} e^{(-2t/66.6)} dt = 140.46 J \quad (9)$$

140.46 joules will be consumed by load in 46.15s with parallel combination. up to load voltage cuttoff limit of 3.75V.

Energy Retained in super capacitor is calculated as follows

$0.5 \times 6.66 \times 7.5^2 = 46.85$ J (10)

Connections of two charged capacitors are similar to connections as shown in Fig 2(a).

Action 2: After action 1 voltage across super capacitor will be 50% i.e. 3.75V. When two capacitors of 3.33 F are connected in series

$$Ceq = 1.665\ F \quad (11)$$

$$R_L = 10\ \Omega \quad (12)$$

$$RC = 10 \times 1.665 = 16.6s. \quad (13)$$

Energy retained in capacitor after action 1will be calculated as follows.

$0.5 \times 1.665 \times 7.5^2 = 46.82$ J (14)

Action 2: can be performed in following two cases.

- Analysis of time required for 50% load voltage cutoff in both the cases mention in proposed scheme.
- Analysis of time required for 100% load voltage cutoff in both the cases mention in proposed scheme.

Analysis of time required for 50% load voltage cutoff in both the cases mention in proposed scheme

In action 2 time required for load voltage drooping from 7.5 to 3.75V is calculated as follows in.

$$t_2 = (0.693 \times 16.6) = 11.50\ sec. \quad (15)$$

Energy delivered to load from super capacitor in 11.50s

$$W = \int_0^{11.50} dw = \int_0^{11.50} pdw = 5.625 \int_0^{11.50} e^{(-2t/16.6)}\, dt = 35.0 J \quad (16)$$

Energy retained in super capacitor after action 2 will be as follows.

$0.5 \times 1.665 \times 3.5^2 = 11.70$J (17)

Total time taken by both the actions up to the voltage fall of 50% is T50% and calculated as follows.
From Eq.8. & Eq. 15

$$T50\% = 46.15+11.5=57.65 \text{ s.} \quad (18)$$

Total Energy delivered in both the actions in 57.65s is as follows.
From Eq.9 & Eq. 16.

$$140.46+35=175.46 \text{ J} \quad (19)$$

Analysis of time required for 100% load voltage cutoff in both the cases mention in proposed scheme

Time required for voltage drooping of 7.5to0V is calculated as follows in action 2.

$$t_2 = (4 \times 16.6) = 66.4 \text{ s.} \quad (20)$$

Energy delivered to load from super capacitor in 66.4s

$$W = \int_0^{66.4} dw = \int_0^{66.4} pdw = 5.625 \int_0^{66.4} e^{(-2t/16.6)} dt = 46.67 J \quad (21)$$

Energy retained in super capacitor will be as follows.

$$= 0.5 \times 1.665 \times 0^2 = 0 \text{ J} \quad (22)$$

Connections of two charged capacitors in action 2 is similar to connections shown in Fig 2(b)

Total time taken by both the actions up to the voltage fall of 100% is T100% and calculated as follow.
From Eq.9 & Eq.20.

$$T100\% = 46.15+66.4=112.55 \text{ sec} \quad (23)$$

Total Energy delivered in both the actions in 112.5s is as follows.
From Eq.9 & Eq. 21

$$140.46+46.67= 187.13J \quad (24)$$

Comparison of Result

Comparison of time consumed in following cases is studied.

- Analysis of time required for 50% load voltage cutoff in both the cases mention in proposed scheme.
- Analysis of time required for 100% load voltage cutoff in both the cases mention in proposed scheme.

Time consumed in 50% voltage dropping under with and without reconfiguration .

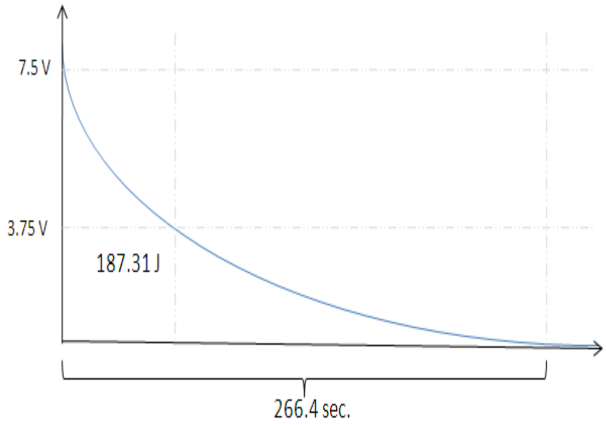

Figure 3 (a): Response of Load voltage without reconfiguration with amount of energy delivered to load

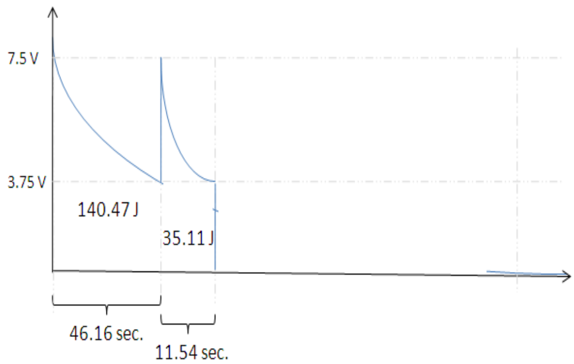

Figure 3 (b): Response of Load voltage in with reconfiguration and amount of energy delivered to load in both the actions.

Energy delivered to load with reconfiguration is as follows.
175.58 J in 57.7 sec. as shown in Fig. 3(b) (25)

Time required for without configuration for same the amount of energy deliver to load is as follows.
175.58= 0.5×6.66×(7.52-VL2)
VL= 1.876V

Time required to reduce the capacitor voltage from 7.5 V to 1.876 V will be
1.876=7.5e (-t/66.6)

T=92.24 sec.

Energy delivered by without reconfiguration is 175.58J in 92.24 sec. (26)

Time saving due to proposed scheme is as follows.
(1-(57.7/92.24))×100= 37.44 % Faster (27)

From Eq. 8, Eq. 18, Eq. 9, Eq. 19
A) In with reconfiguration for 57.7 seconds load voltage will be greater than 50% of load voltage where as in without reconfiguration is found 46.15second.
B) In with reconfiguration 175.4J will be delivered to load with 50% of load voltage cutoff limit out of 187.69 where as in without reconfiguration is found 140.46J out of 187.69. In percentage 75% energy is delivered to load in without reconfiguration and 93.73% in with reconfiguration.

Time consumed in 100% voltage dropping under with and without reconfiguration.

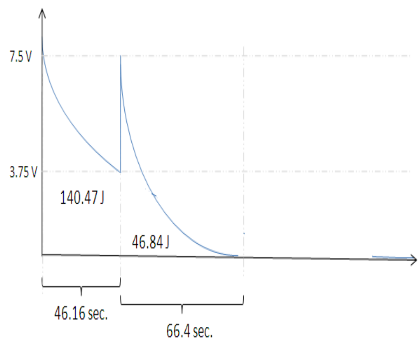

Figure 4: Response of Load voltage with reconfiguration

In without reconfiguration, time required for complete discharge of capacitor is calculated in as follows.

From Eq.4
Energy available = 187.31 J (28)

Time constant = 6.66F ×10=66.6 s.
Energy will be almost consumed in load in 266.4 sec. (29)

Time required in with reconfiguration for complete discharge of capacitor is as follows.
From Fig. 4 and from Eq. 23
Total time =112.8 sec.

Time saving due to proposed scheme in case of 100 % discharge is as follows.
(1-(112.8/266.4))*100=57.67% Faster

Simulation Studies

The proposed scheme is simulated in MATLAB / simulink. The circuit parameters used for simulation in environment is given below Configuration parameter for simulation is Solver is ode25tb, Non adaptive algorithm. Capacitor is of 7.5V, 3.33F, Ideal switches, static range block are the components of simulation.
Simulation work has been done in following two cases.

- Without reconfiguration
- With reconfiguration

Without Reconfiguration

The Simulation model and its output response when reconfiguration of circuit is not done are shown in Fig5 (a) & Fig 5 (b) respectively. Fig 5 show the simulation diagram where 7.5V 3.33F fully charge UC is connected to the 10 ohm load resistance. Fig 5(b) shows the voltage, current, delivered to load. Referring to 5 (b) it takes 266 sec to delivered complete energy to load.

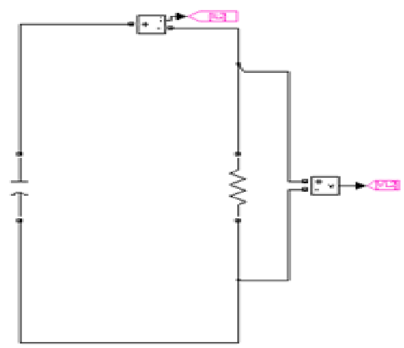

Figure 5(a): Simulation for no reconfiguration

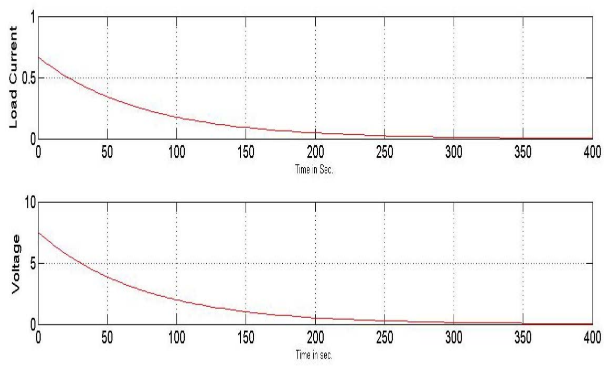

Figure 5 (b): Voltage, current, & energy without reconnection

With Reconfiguration

The Simulation model and its output response when reconfiguration of circuit is done are shown in Fig6 (a) & Fig 6 (b) respectively. Fig 6 (a) show the simulation diagram where 7.5V 3.33F fully charge UC is connected to the 10 ohm load resistance. Fig 6 (b) shows the voltage, current, Comparison of energy delivered to load. Referring to Fig. 6(b) reading are taken.

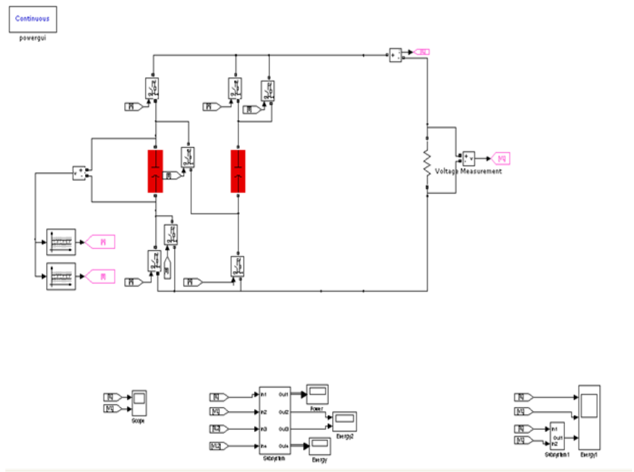

Figure 6(a): Block Diagram for the proposed scheme for simulation using MATLAB

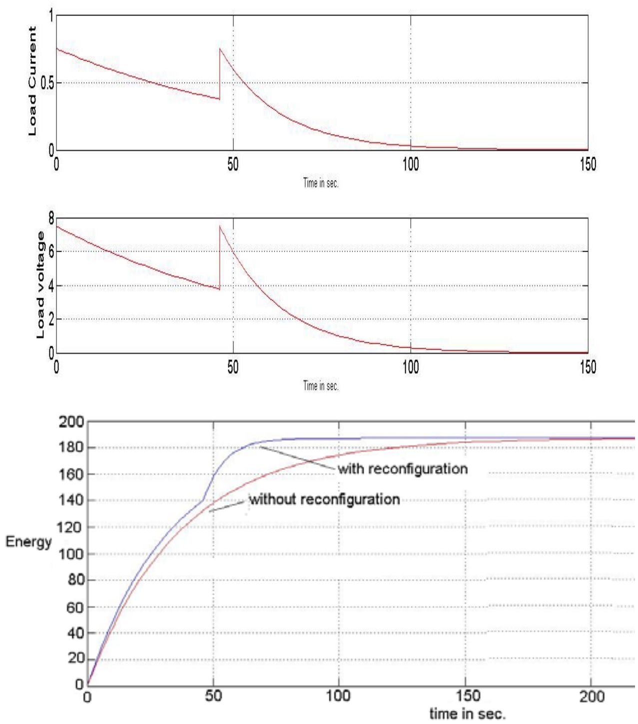

Figure 6(b): Voltage, current, & energy without reconnection

Experimental Verification

Experimental setup is consisting of relay, Super capacitor bank, and control switch.

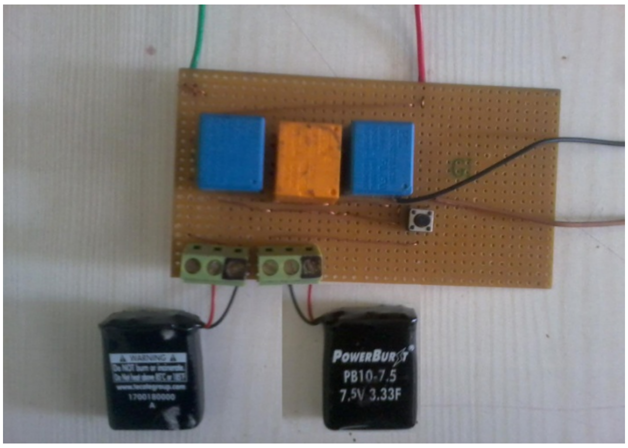

Figure 7: Experimental Set-up

Hardware Results

Comparison of time taken in all actions in hardware setup and simulation is compared. For experimental work

Table 1

Sr. no	Activity	Simulation Reading	Practical Reading
01	All Parallel	46.14 sec	47sec.
02	Series combination	135 sec	140 sec.
03	No switching	266 sec	270sec.
		50% Faster	48% faster

Conclusions

Series parallel combination of super capacitor leads to fast energy transfer. With reconfiguration for 57.7 seconds load voltage will be greater than 50% of load voltage. Whereas without reconfiguration i.e. is found 46.15second.With reconfiguration, 175.4J will be delivered to load with 50% of load voltage cutoff limit out of 187.69 whereas without reconfiguration it is found as 140.46J out of 187.69J 75% energy is delivered to load in without case of no reconfiguration and 93.73% in case of reconfiguration. In case of 100% Energy discharge, process will 57.67% Faster.

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