New Reconfiguration Technique for Ultracapacitor for Exchange of Energy At A Faster Rate

Akshay A. Kakde, hrikrishna G. Tarnekar

Abstract*: This paper deals with the use of the maximum energy of ultracapacitor at a faster transaction rate. This paperalso deals with the system-modeling, controller design, and faster energy transaction from ultracapacitor bank used in a hybrid electric vehicle. The energy transaction to dynamic load is through parallel-connected ultracapacitor bank and battery combination. The parallel-series topology has been implementing for ultracapacitor and the controller is designed to control energy-transactions from ultracapacitors. The DC-DC converter is only used for voltage regulation. This topology has aimed at the design leading to the excellent energy economy. Further, the main objective is to attain maximum utilization of energy in ultracapacitors during a ride-through condition, in minimum time. Three simulations have been carrying out with hardware implementation to compare these results. This includes energy sharing by ultracapacitor, in case of dynamic load. Hence, the proposed control strategy can provide a satisfactory improvement in energy- efficiency of ultra-capacitors, assuring maximum utilization and faster energy transaction.

***Keywords*: Ultracapacitor (UC), DC-DC Converter, battery, energy calculation, Reconfiguration technique.**

I. INTRODUCTION

Improvements in hybrid electric vehicles have been very fast to minimise pollution from various sources, as an emergent need related to major global issues. Out of these, air pollution is much wide-spread than soil and water pollution [1]. Batteries [2] and ultracapacitors [2,3] are a type of rudiments used for the put in place of old systems based on internal combustion engines. Similarly, new technology is also used for electric vehicles [4-8], trucks, etc. For batteries, its electric power decrease with increases in load on batteries due to operation in difficult conditions, and that's leading to a reduction in a lifetime [9]. To conquer this drawback, more batteries used in parallel combination but that increases the cost of the system. Then one possible solution comes out and that is the system base on the parallel connection [10–19] of a battery and an ultracapacitor, implemented in hybrid energy storage.

An innovative step towards the same is attempted and reported in this paper. Energy management system (EMS) of ultracapacitors with battery combination plays a very vital role in the performance of hybrid electric vehicles [20]. After a particular discharge level of the ultracapacitor, it has been observed that energy supplied from ultracapacitor is not utilized due to the low voltage level [21]. Ultracapacitor energy utilization has a scope of improvement. This paper mainly focuses on the maximum utilization of ultracapacitors energy and faster energy exchange.

Three cases each have reported here for the dynamic motor load. In the first case, as shown in figure 1., the battery is used as the only source to motor load to obtain an additional current requirement during a ride through the condition.

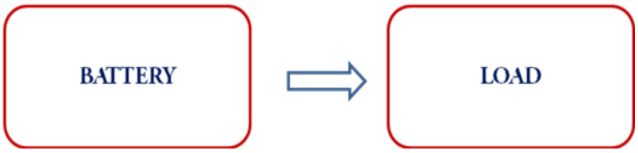

Figure 1. The load connected to the battery only

In the second case shown in figure 2., ultracapacitors bank connected in parallel with battery to provide required additional energy during a ride through the condition of the load. The extraction of energy from ultracapacitors bank is not that much useful beyond 50% discharge [22].

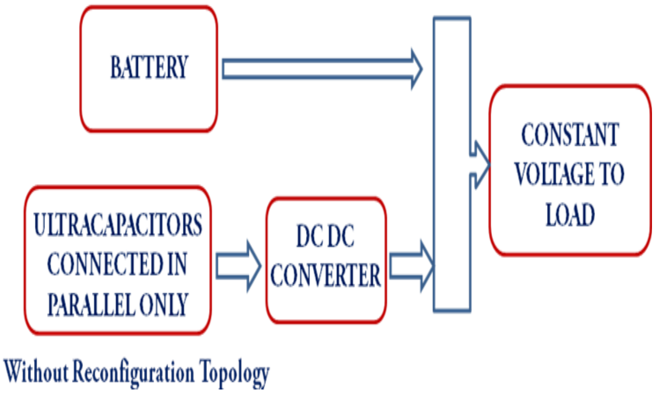

Figure 2. Load shared by battery and ultracapacitors bank (without reconfiguration)

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Hence, the third case has introduced in which topology of reconfiguration of ultracapacitors from parallel to series combination has suggested for faster energy extraction and maximum utilization of ultracapacitor during extra burden of dynamic load [23] is represented in figure 3.

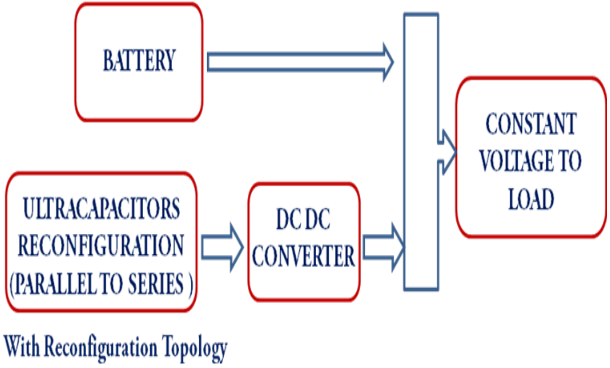


Figure 3. Load shared by battery and ultracapacitor bank (with reconfiguration)

Boost DC-DC converter [24] is only to keep up a constant output voltage of ultracapacitors bank. Improved simulation results and energy calculations are represented here as basic simulation and relevant results already presented in a previous paper [25]. UC bank is connected in parallel in the third simulation circuit. In this, Initially, UC1 and UC2 are connected in parallel. After discharge of ultracapacitors, that is, the voltage level reduces to 50% approximately, this parallel combination reconfigured into series combination for faster energy extraction through it, as shown in Fig 4a and 4b.

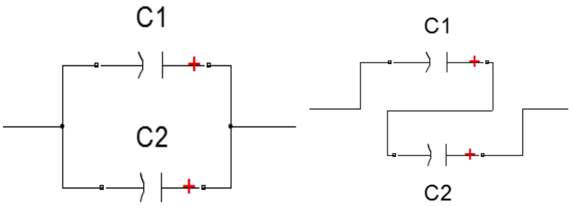


Figure 4a. Reconfiguration of ultracapacitors from parallel to series combination.

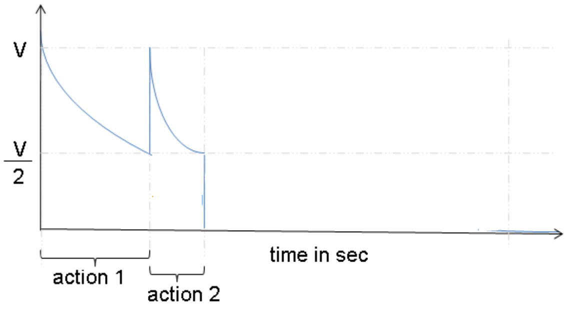


Fig 4b. Effect of reconfiguration

During a literature survey, it has been observing that the maximum papers are on the improvement of the energy system management of ultracapacitor and battery combination. In this paper, the focus is on higher percentage utilization of ultracapacitor energy. With this topology, energy extraction from ultracapacitors is increased and its rate is faster.

II. SIMULATION CIRCUITS

Figure 5. shows the load of DC shunt motor, which is jointly fed by UC and battery. However, Ultracapacitor-bank provides power only during 'ride-through' period. Battery current at no load is considered as base value and if the current is more, then ultracapacitor-bank meets the excess energy-requirement. For maximum utilization of battery and ultracapacitor, it has been decided to use ultracapacitor-energy during ride-through condition only. The motor of small rating has been used during practical verification.

Out of three simulations, the first simulation aims at deciding the value of the base current. Then in the second simulation, ultracapacitors bank provide additional power during the ride-through condition of the load. And in the third simulation, the reconfiguration technique has recommended for maximum utilization and faster energy transaction.

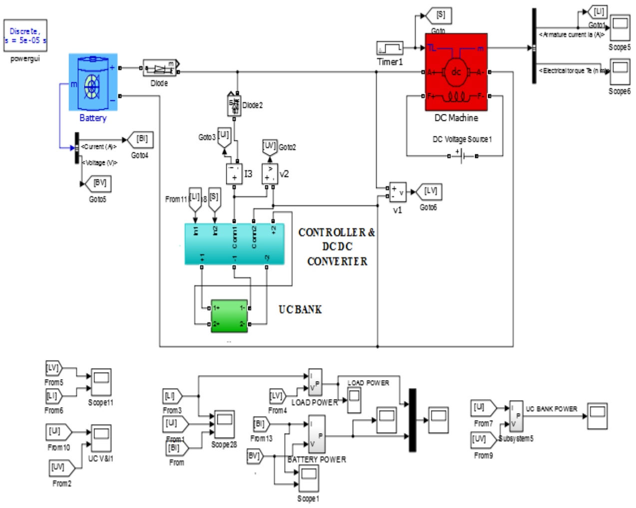


Fig 5. Simulation circuit for case two (without reconfiguration) and case three (with reconfiguration) of ultracapacitors for dynamic load.

III. SIMULATION RESULTS

3.1 Dynamic Load Dependent On Battery Only

As discussed in the early passage, simulations are carried out for dynamic load. In the first case of dynamic load condition, the battery is connected to a shunt DC motor (Table 1). Load initially takes a current of 6 A and at 3 seconds(Sec), it has increased up to 10.2 A and initial voltage of 27.5 V reduces slightly up to 26.9 V. Fig 6a and Fig 6b indicate motor load voltage and current respectively.

Table 1: Simulation DC Motor Specification

MOTOR PARAMETERS	RATINGS
ARMATURE RESISTANCE	*2.58 OHM*
ARMATURE INDUCTANCE	*0.028 H*
FIELD RESISTANCE	*21.3 OHM*
FIELD INDUCTANCE	*156 H*
MUTUAL INDUCTANCE	*0.9483 H*
TOTAL INERTIA	*0.02215 J*
FRICTION TORQUE	*0.5161 N.M.*

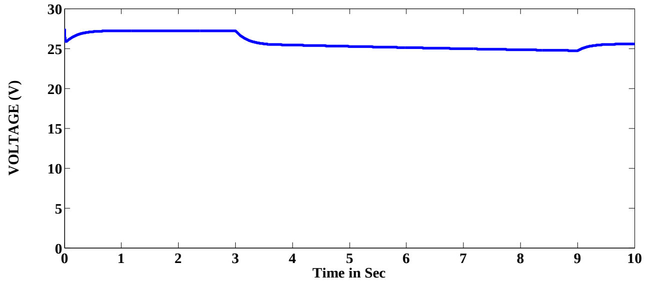


Figure 6a. Load Voltage

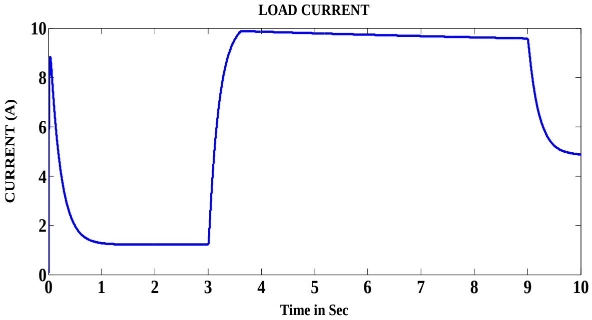


Figure 6b. Load Current.

3.2 Without reconfigured ultracapacitors bank connected in parallel with battery for dynamic load.

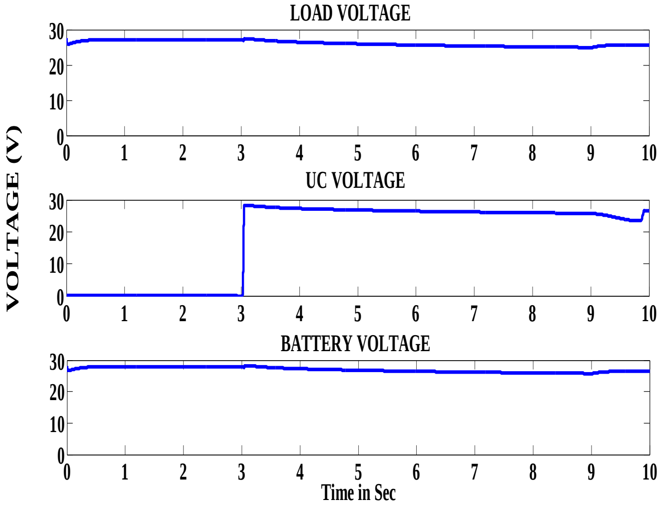


Figure 7a. Voltages Across Load, UC Bank, And Battery

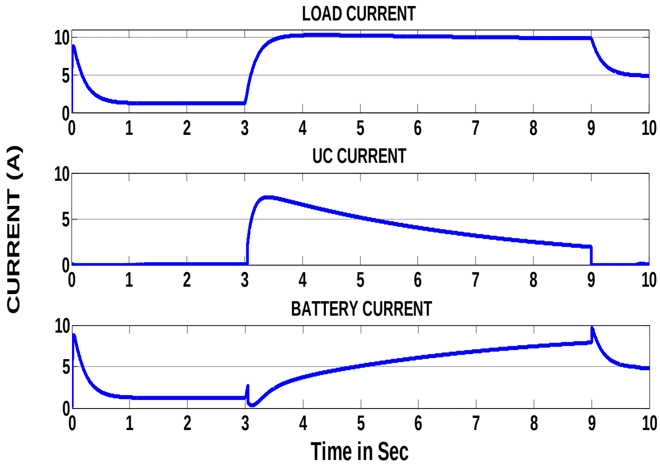


Figure 7b. Load, UC bank, and Battery current

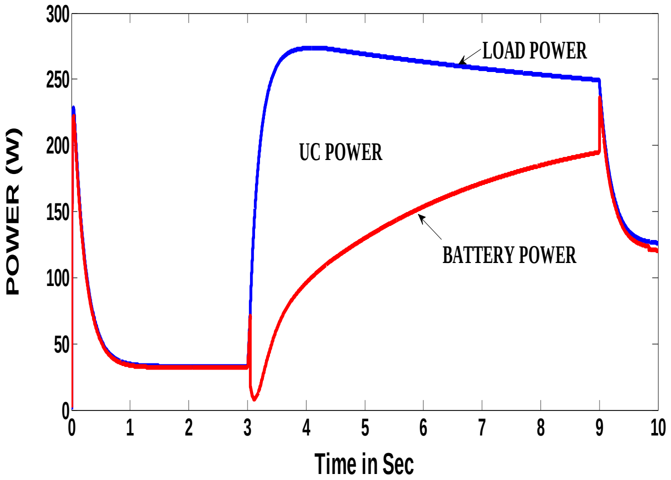


Figure 7c. Power supplied by UC bank
(Show UC-power between Red and blue curves, marking at 5sec, adding a vertical line
And mention the same in the write-up.)

This simulation deals with 'battery' and 'ultracapacitors bank without reconfiguration', for dynamic load. Fig 7a shows voltages waveforms with respect to time (in seconds) for load, UC bank, and battery. Battery voltage is nearly constant and UC bank discharges gradually during a period of extra load. Similarly, in Fig 7b, the current comparison has been shown. Fig 7c indicates power comparison. From that, it has been shown that energy extraction from ultracapacitors bank reduces gradually and load on battery increases.

3.3 Battery and reconfigured ultracapacitors bank connected in parallel for dynamic load.

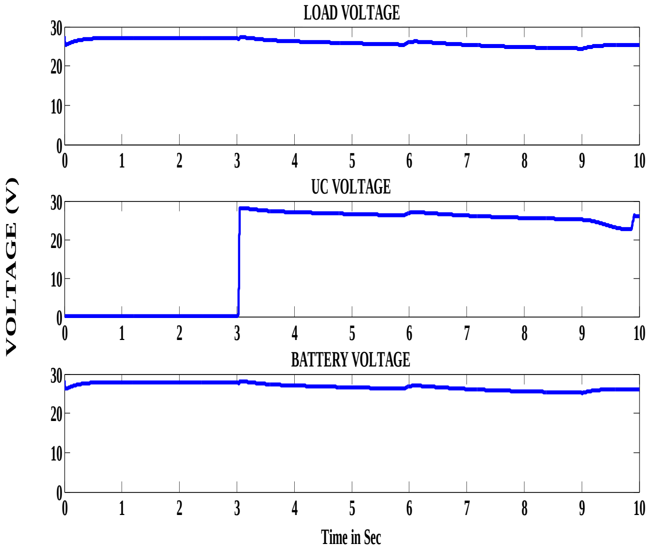


Figure 8a. Voltages at Load, UC bank, and Battery

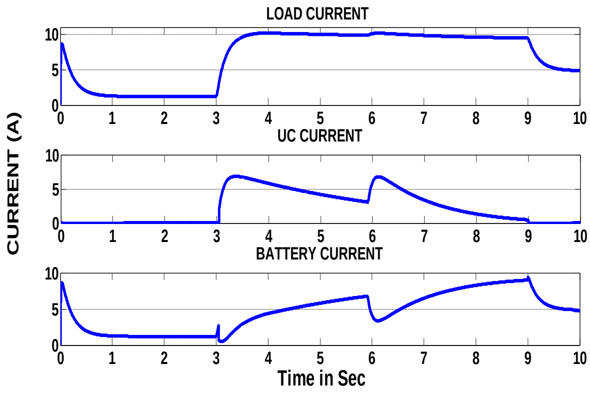


Figure 8b. Currents in Load, Battery, and UC Bank

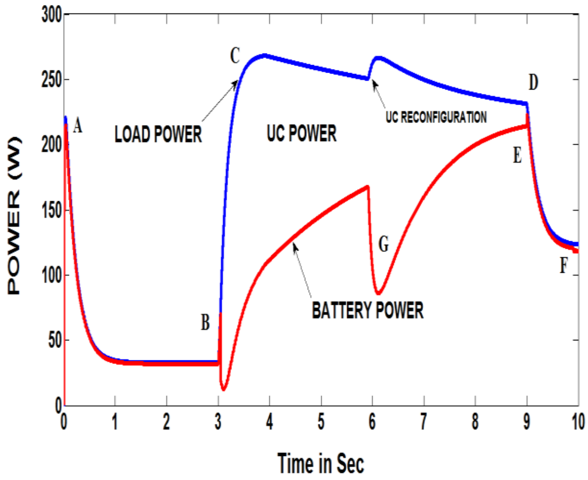


Figure 8c. Power supplied by UC bank
(Show UC-power between Red and blue curves, marking at 5 sec, adding a vertical line
And mention the same in the write-up.)

Current and voltage association of Load, Battery, and UC bank are shown in Fig 8a and Fig 8b respectively. There is a negligible disturbance to the load side due to reconfiguration. Fig 8c shows, power supplied from UC bank, which indicated with the area cover under the curve BCDEGB. Whereas, ABCDEF indicated the total energy essential in load side from which, are covered under ABGEF is an actual remaining burden on the battery. The calculations of energy extraction from UC bank in all simulations are reported in next below the stage.

IV. ENERGY CALCULATIONS

$$E_{UC} = E_{Total} - E_{Batt} \quad (1)$$

$$E_{UC} = E_{UC1} + E_{UC2} \quad (2)$$

$$E_{UC1} = \frac{1}{2} C_1 V_1^{\,2} \quad (3)$$

$$E_{UC2} = \frac{1}{2} C_2 V_2^{\,2} \quad (4)$$

$$E_{Batt} = V_{Batt} \text{x}\, I_{Batt} \text{x} t \quad (5)$$

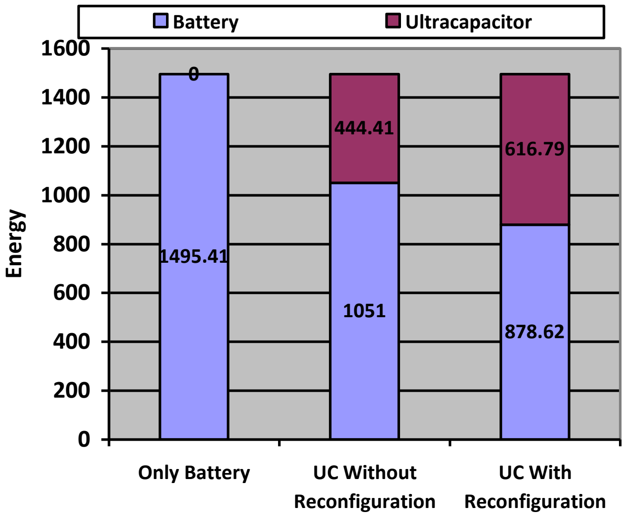
Where,

Euc= Ultracapacitor bank energy,
E_{UC1}= first Ultracapacitor energy,
E_{UC2}= second Ultracapacitor energy,
E_{TOTAL}= total energy supplied to load,
E_{Batt}= battery energy,
C_1 and C_2 = First and second Supercapacitor present in Supercapacitor bank,
V_1 and V_2 = voltage across first and second Supercapacitor respectively,
$V_{Batt}$and I_{Batt}= battery voltage and current respectively,
t = time in second.

Table 2. Comparative energy analysis between with and without reconfiguration of ultracapacitors for dynamic load.

DYNAMIC LOAD ENERGY (J)			
Simulations	CASE 1	CASE 2	CASE 3
Total energy required	1790.20	1790.20	1790.20
ENERGY REQUIRED DURING RIDE THROUGH CONDITION			
The energy required during Ride through period (3 Sec to 9 Sec)	1495.41	1495.41	1495.41
BATTERY ENERGY			
Battery energy during Ride through a period	1495.41	1051.79	878.62
UC BANK ENERGY			
Without reconfiguration	-	444.41	-
With reconfiguration during Ride through period	-	-	616.79
% energy sharing by UC bank during Ride through period	-	29.71%	41.24%
% more energy extraction from UC bank	-	-	36.70%

Table 3. Comparative analysis of battery and ultracapacitor energy



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Graph software is used to calculate the area under the curve for energy calculations. Comparative energy calculation and analysis of the system dynamic load is represented inTable 2. Ultracapacitors of 5 F, 16 V has used for simulations purpose. Simulation is carried for 10 sec during all cases, for static load ride through a period is 3 to 7 Sec and for dynamic load, it is 3 to 9 Sec. It has been observed that more energy can be extracted from ultracapacitors by using reconfiguration topology as shown in Table 3 The same amount of percentage energy has been extracted from the ultracapacitors bank in less time of 01 sec. 36.70% more energy is extracted from ultracapacitors during dynamic load condition.

V. HARDWARE CIRCUIT

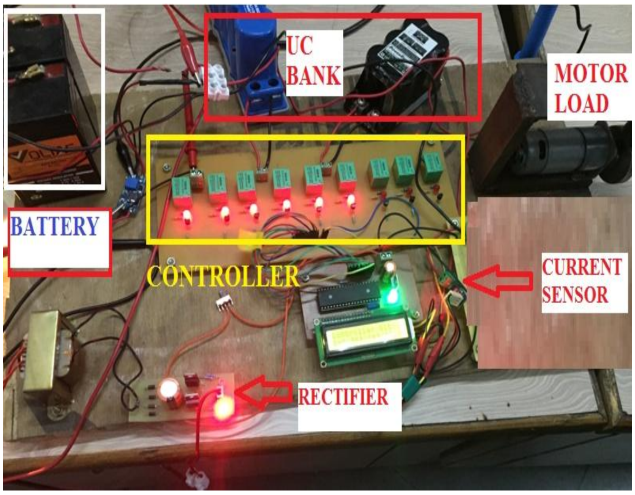

Figure 9 Hardware Circuit

In the hardware system, a resistive load connected across the parallel combination of ultracapacitor and battery as shown in figure 9. Controller circuit designed to control switching action during operation of the circuit. Initially, the required load power served by the battery. When load power demand increases then Supercapacitor power utilized in combination battery power to serve load.

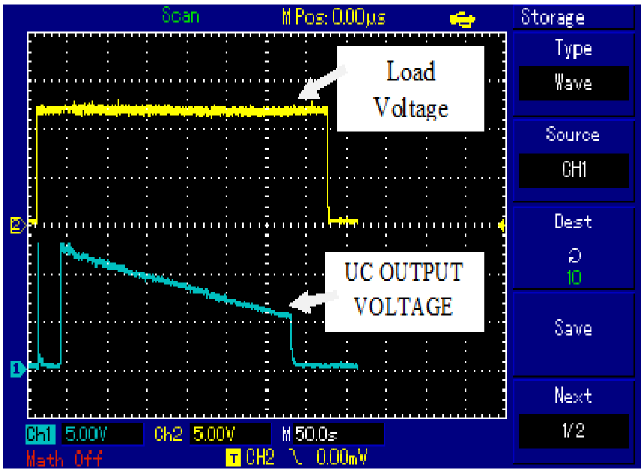

Fig 10 Load Voltage and UC controller output (without reconfiguration)

Figure 10 shows a waveform of the parallel-connected UC voltage and load voltage. The voltage of UC bank decrease gradually but the voltage across load maintained constant by using a DC-DC converter. It has clearly indicated in the figure, without reconfiguration technique, Ultracapacitor power is not utilized after the approximate discharge of Ultracapacitor bank.

$V_{UC}=V_{UC1}=V_{UC2}$ (Parallel Combination) (6)

$V_{UC}=V_{UC1}=V_{UC2}$ (Parallel Combination) (7)

$V_{UC}=V_{UC1}+V_{UC2}$ (Series Combination) (8)

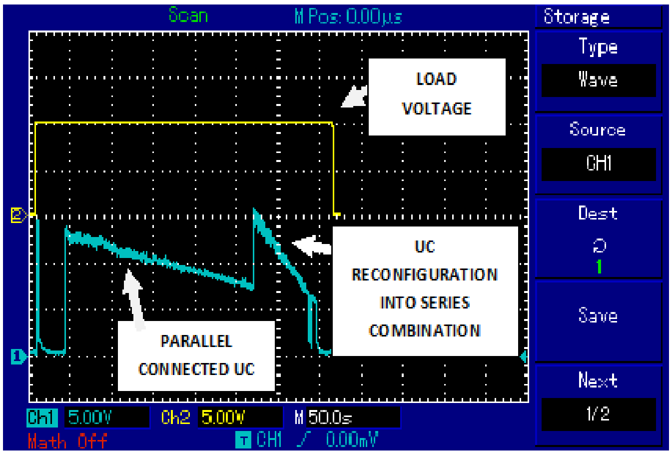

Fig 11 Load Voltage and UC controller output (with reconfiguration)

In figure 11 shows the implementation of the reconfiguration technique of Ultracapacitor. Parallel-connected Ultracapacitors are discharges gradually up to 50 % SOC then reconnected into the series combination. Due to this, faster energy extraction from Ultracapacitor has achieved. The maximum utilization of Ultracapacitor energy during the same time period.

VI. CONCLUSION

Energy comparisons based on simulation results for dynamic load have been carried out and analyses reported here. Three cases for the dynamic load are represented and comparative figures of voltage, current and power have been reported here. UC bank power is utilized, only during the ride-through condition. Controller circuit has been successfully designed and implemented for switching of ultracapacitors. The implementation of the DC-DC converter is successfully carried out for maintaining voltage level and smooth operation of parallelly connected ultracapacitors bank and battery. It is clearly observed in case two that, the increased extra load on the battery hs been reduced by 30.23 % due to load shared by ultracapacitors bank during dynamic load. This load on the battery is further reduced in case three, to 41.24 % during the same load due to DC-DC converter and reconfigured ultracapacitor bank for static and dynamic load respectively. This result indicates reconfiguration topology can further reduce the load on the battery by extracting more energy from ultracapacitors bank at a faster rate. Results showed 36.70% more energy is extracted from ultracapacitors bank as compared to case two during a ride through a period of dynamic load. This will further help to increase battery life.

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