I J C T A, 9(18) 2016, pp. 8853-8857

Modeling of Super-Capacitor Discharge Characteristic Using Power Supply

Aditya Sankar Sengupta*, A. K. Chakraborty and B. K. Bhattacharyya*****

ABSTRACT

In this paper, a super capacitor of 2.85 volt 3400 Farad is used as a power source for a boost converter to yield a constant output voltage for a current in the range of milliamps. Depending upon the output current requirement the super capacitor voltage decays and this decay characteristic will be simulated using buck converter. In this paper, first we discuss the designing of an input voltage based PWM controlled constant output dc-dc boost converter powered by the super capacitor. The input voltage is varying and based on it we endeavor create the methodology for a test circuit which when connected to any circuit in place of super capacitor, will yield the almost same effect. In this paper it is also shown that if we know the power consumed by each and every component in a circuit powered by super capacitor along with the output power of that circuit, we can calculate rate at which the super capacitor voltage will decay and the time for which that circuit would operate when its powered by super capacitor. Thus the voltage and current profile of super capacitor discharge characteristic when it is supplying a certain load can be found out, and also can be modeled using buck converter.

Keywords: Super capacitor, buck converter, boost converter, PWM control.

I. INTRODUCTION

Super capacitor is a marvelous invention of material science that has revolutionized technology. Recently, the number of applications employing the use of super capacitors has hiked since it has a very high energy storing capacity [1] and researchers have also taken keen interest in this field. Super capacitors can also provide the instantaneous power, required due to sudden rate of change of current simultaneously balancing the fast changing power surges [2]. Many circuits and industrial applications are being powered by super capacitors especially the ones where pumping high current has become an issue. Researchers are even trying to develop mega farad super capacitors [3] in order to use it as higher energy storage device to run applications for a considerable period of time. Super capacitors are used in electric hybrid systems [4] and are used along with grid connected photo voltaic (PV) array, in solar and wind generation system [5], and also in hybrid electric vehicles [6]. Super capacitors are also used as energy storage for wind energy applications [7].

Owing to high power density of super capacitors, they can be used in many innovative circuits and researches where we need to pump high current at a low voltage. But the availability and cost becomes an issue. Therefore, the idea is to develop a power supply that can be made to decay at a certain current just like a super capacitor does, this circuit could be employed in any application or research activities to substitute a probable use of super capacitors. The objective of this work is to design an equivalent circuit, the output of which looks like the discharge characteristic of super capacitor. It is known that dc-dc converters can supply constant voltage at a certain current. There a dc-dc buck converter can be used to achieve the same by supplying the buck converter with a switching pulse of exponentially decaying duty ratio from one

* Department of Electrical Engineering, NIT Agartala, Agartala, Tripura, India, *E-mail: aditya.nitagt@gmail.com*

** Associate Professor, Department of Electrical Engineering, NIT Agartala, Agartala, Tripura, India, *E-mail: akcall58@gmail.com*

*** Department of Electronics and Communication Engineering, NIT Agartala, Agartala, Tripura, India, *E-mail: bkbhatta1@yahoo.com*

to zero over a certain period of time. Thus the concept shown here is the use of a buck converter to decay a constant voltage exponentially using an exponentially decaying duty ratio over a certain period of time.

II. SUPERCAPACITOR POWERED BOOST CONVERTER

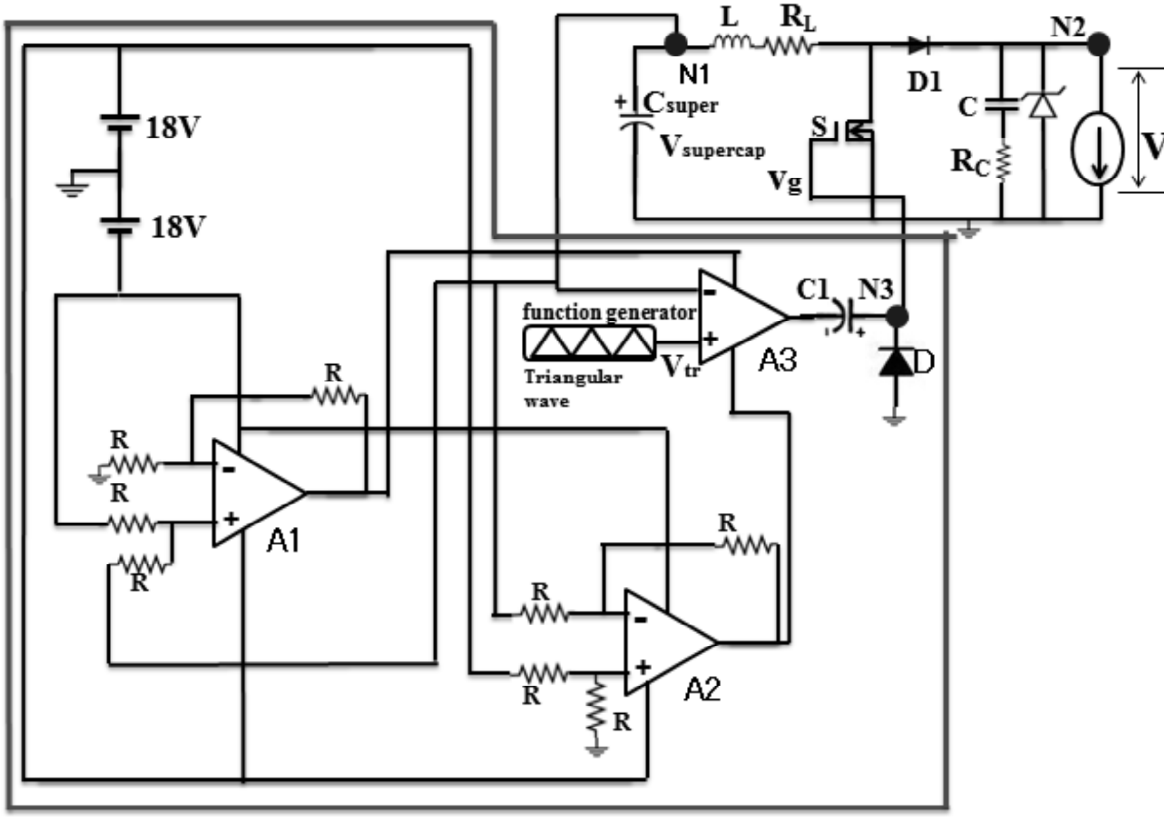


Figure 1: Constant output boost converter supplied by super capacitor

In the figure 1 a super capacitor of voltage 'Vsupercap' and capacitance 'Csuper' is the input power source for a boost converter that is supposed to supply a constant output voltage 'Vo'. 'S' is the controlled switch say a MOSFET, 'D1' could be a normal diode or a Schottky diode for fast recovery and reduced loss, 'L' and 'C' are the capacitance and inductance of the boost converter and 'R_L' and 'R_C' denotes their equivalent series resistance values of the inductor and capacitor respectively. 'Vtr' denotes the triangular wave supplied by function generator. 'A1', 'A2' and 'A3' are op-amps that are used to design the PWM control loop , the purpose of which is to vary the duty ratio 'D' and the amplitude 'V_g' of the switching pulse in such a way that the output voltage of the boost converter remains constant even though the input voltage across the super capacitor keeps on decaying. The output of op-amps 'A1' and 'A2' determine the amplitude of the switching pulse while the output of op-amp 'A3' determines the duty ratio of the switching pulse. It is important to note that in order to yield a constant output voltage proper duty ratio of switching pulse and its amplitude are equally important especially in case of a PWM control loop that keeps the output voltage constant irrespective of the changes in the input voltage. The portion of the circuit inside the red line border alters the duty ratio and amplitude of switching pulse of the boost converter with the decay in input voltage across the super capacitor. An expression for duty ratio and amplitude of switching pulse is shown below:

$$D = 1 - \frac{V_i}{V_o} \tag{1}$$

$$V_g \sim 2(18 - V_i) - 1.54 \quad (2)$$

'V_g' is the amplitude of the switching pulse and 'D' is the duty ratio.

III. CIRCUIT MODELLING SUPERCAPACITOR DISCHARGE PROFILE

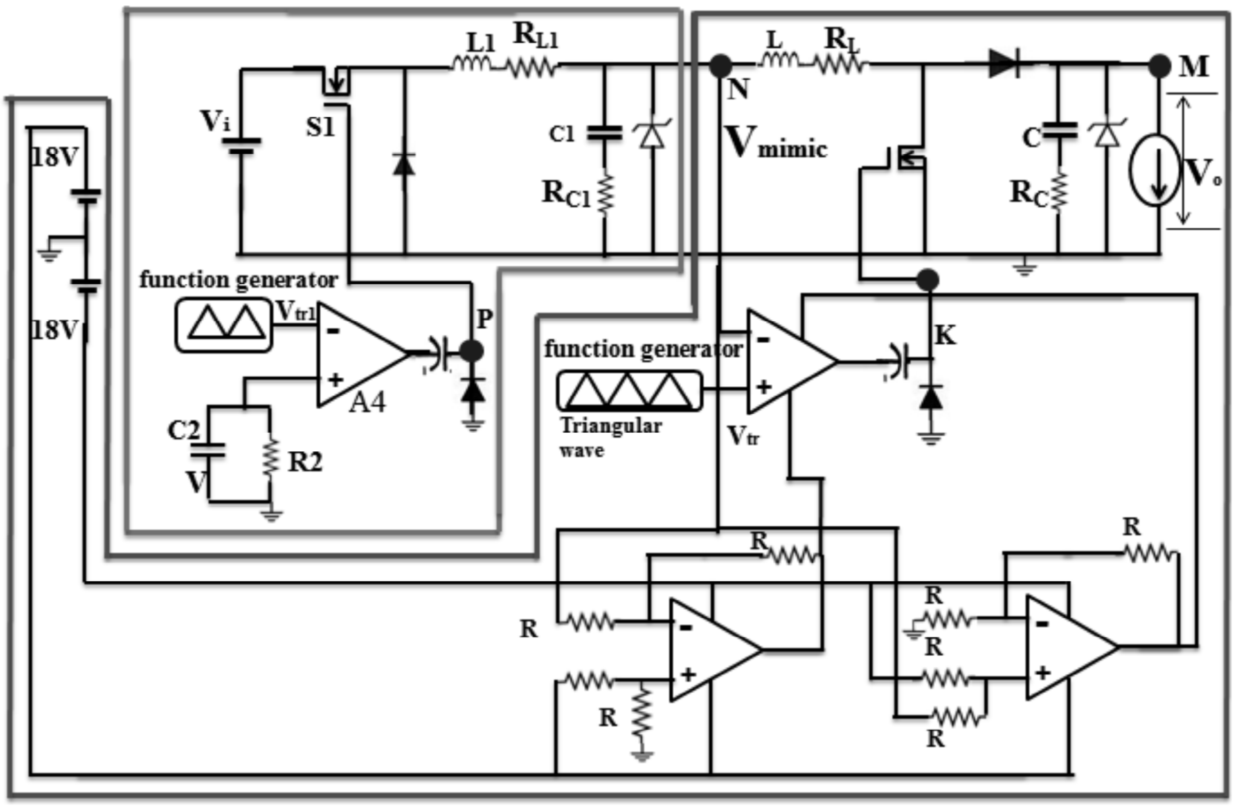


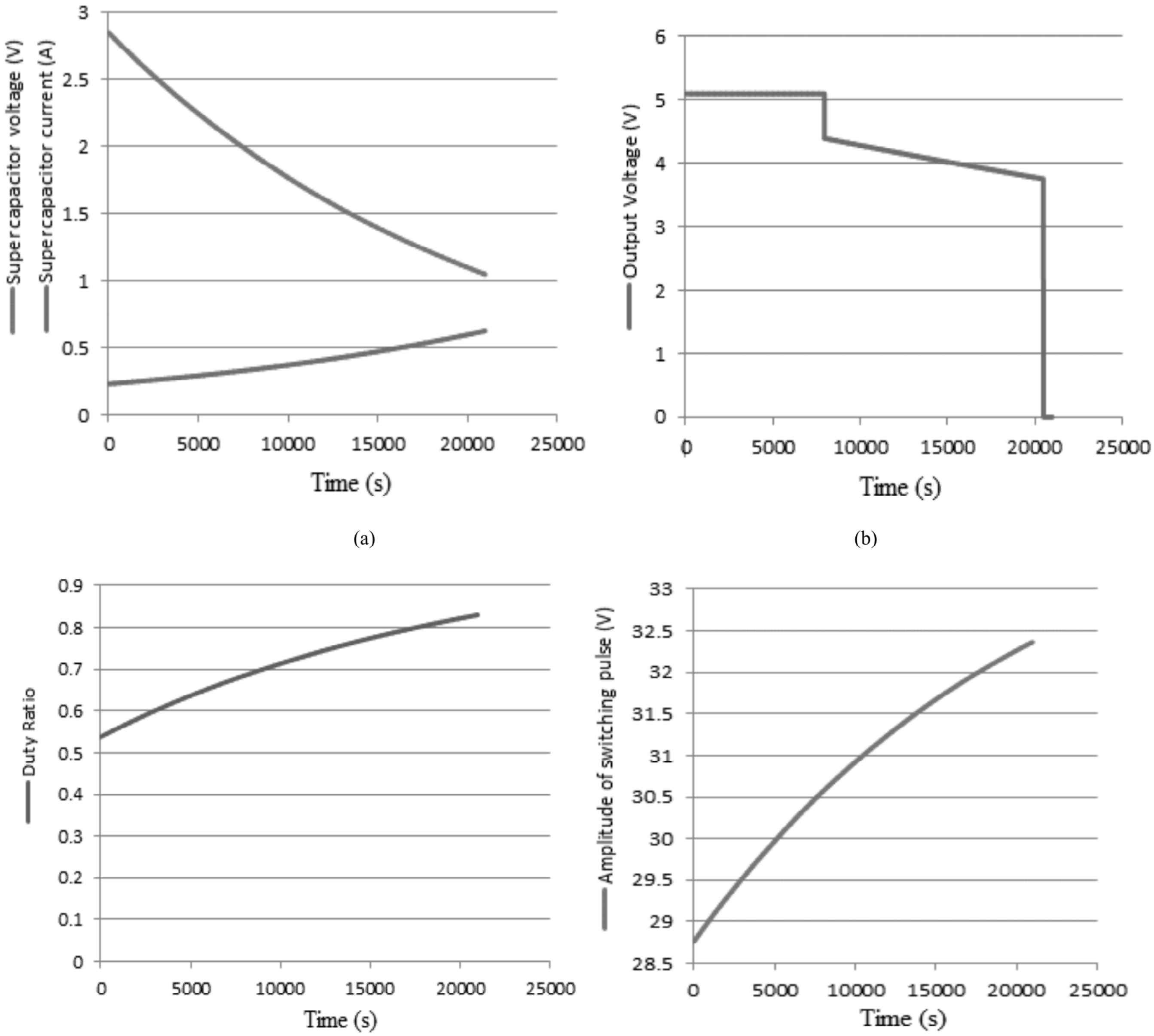
Figure 2: Circuit simulating super capacitor discharge profile

In the circuit shown in figure 2 the portion of the circuit inside the green border is the circuit modeling the super capacitor voltage decay, and the portion of the circuit inside the red border is the same as the one shown in figure 1. 'V_i' is the voltage of the input power supply,'L1' and 'C1' are the capacitance and inductance of the buck converter and 'R_{L1}' and 'R_{C1}' denotes their equivalent series resistance values of the inductor and capacitor respectively. 'A4' in figure.2 is an op-amp that is responsible for generating a switching pulse of decaying duty ratio at the point 'P'. The value of C2 and R2 in the above circuit can be set according to the rate of decay and the voltage at which C2 is charged i.e. 'V' should be equal to 'Vtr1' i.e. the peak voltage of the repeating triangular wave. At the node 'N' the buck converter generates the discharge profile of super capacitor. In figure.2 it is shown that the circuit inside the green border is buck converter and the duty ratio of the switching pulse for this dc-dc buck converter will exponentially decay from 1 to almost zero. The discharge profile of super capacitor modeled by the portion of circuit bordered by green also depends upon the output current drawn by the portion of circuit bordered by. The decaying voltage and its corresponding current together constitute the discharge profile of a super capacitor.

IV. SIMULATION RESULTS

The MOSFET used is 2N7000, op-amp LM358P is used, diode 1N4007 and zener diode 1N4733A is used C2=4700μF and R2=3.3M&!. '$V_{SUPERCAP}$=2.85V' and 'C_{SUPER}=3400F', 'V_i=2.85V'. The simulation results are shown for a load current draw of 100mA.

4.1. Simulation results for figure 1 are shown below



(a) (b)

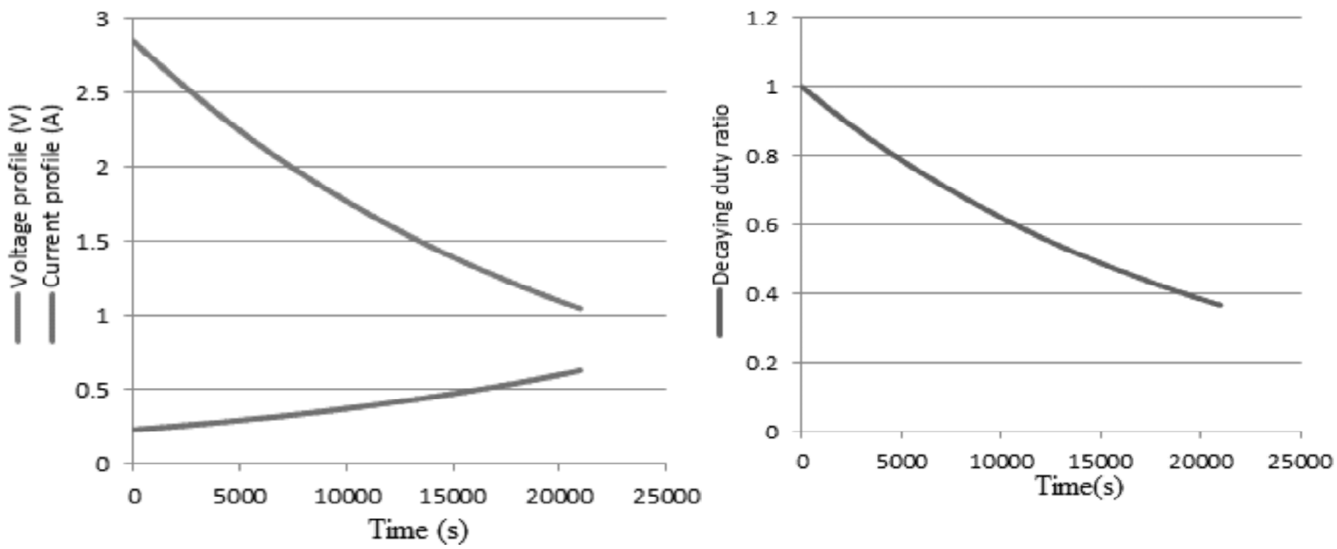
(c) (d)

Figure 3: (a) Original discharge profile of super capacitor (b) Output voltage (c) Duy ratio (d) Amplitude of switching pulse

Figure 3(a) shows the super capacitor discharge profile ie the super capacitor voltage and current while it is supplying a constant load through the boost converter and figure.3(b) shows the output voltage obtained at node ‘N2’ of figure.1. Figure3(b) and figure.3(c) show the duty ratio and amplitude of switching pulse obtained at the node ‘K’ of figure 1.

4.2. Simulation results for figure 1 are shown below

The circuit proposed in figure 2 is supposed to yield a voltage and current characteristic at the node ‘N’ which should look the discharge characteristic of super capacitor.



(a) (b)

Figure 4: (a) modeled discharge profile of super capacitor (b) Exponentially decaying duty ratio

Figure 4(a) shows the voltage and current profile obtained at node ‘N’ of figure 2 which looks almost exactly like the super capacitor discharge profile shown in ifure.3(a). Figure 4(b) shows the exponentially decaying duty ratio that decays the power supply like a discharging super capacitor.

V. CONCLUSION

In this paper figure 1 shows the circuit wherein a super capacitor supplies an application of 5.10V drawing 100 milliamps. In this work a circuit has been designed to mimic the super capacitor discharge profile to supply the same or similar application. So it is also evident from the simulation results that using the proposed circuit we can get an idea as to how long a certain application running on super capacitor will perform without failing, without actually using the super capacitor. From the simulation results it is seen that the modeled discharge profile of super capacitor shown in figure 3(a) matches the original discharge profile of super capacitor shown in figure 4(b) signifying that the model proposed in figure 2 is capable of simulating the super capacitor discharge profile for any application and a high value super capacitor can be substituted by the equivalent circuit model shown in figure 2 wherever applicable.

REFERENCES

[1] Alfred Rufer, and Philippe Barrade, “A Supercapacitor-Based Energy-Storage System for Elevators With Soft Commutated Interface”, IEEE Transactions on Industry Applications, vol. 38, NO. 5, september/october, 2002.

[2] Sathish Kumar Kollimalla, Mahesh Kumar Mishra, and N. Lakshmi Narasamma, “ Design and Analysis of Novel Control Strategy for Battery and Supercapacitor Storage System,” IEEE Transactions on Sustainable Energy, vol. 5, no. 4, october.

[3] Ezzat G. Bakhoum, “ New Mega-Farad Ultracapacitors,” IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, vol. 56, no. 1, January, 2009.

[4] Jian Cao, Member, and Ali Emadi, “ A New Battery/UltraCapacitor Hybrid Energy Storage System for Electric, Hybrid, and Plug-In Hybrid Electric Vehicles”, IEEE Transactions on Power Electronics, vol. 27, no. 1, January, 2012.

[5] Tianpei Zhou and Wei Sun, “ Optimization of Battery–Supercapacitor Hybrid Energy Storage Station in Wind/Solar Generation System”, IEEE Transactions on Sustainable Energy, vol. 5, no. 2, April, 2014.

[6] Alireza Khaligh, and Zhihao Li, “Battery, Ultracapacitor, Fuel Cell, and Hybrid Energy Storage Systems for Electric, Hybrid Electric,Fuel Cell, and Plug-In Hybrid Electric Vehicles: State of the Art”, IEEE Transactions on Vehicular Technology, vol. 59, no. 6, July, 2010.

[7] Chad Abbey and Géza Joos, “Supercapacitor Energy Storage for Wind Energy Applications,” IEEE Transaction on Industry Applications, vol. 43, no. 3, May/June, 2007.