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USE OF THE DC-DC CONVERTER AND A CONTROLLED VOLTAGE SOURCE TO SUPPLY CONSTANT LOAD VOLTAGE WITH ULTRACAPACITOR

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Abstract
Ultracapacitors are gaining very high popularity due to their attractive feature of high power-density. When these capacitors supply a load, its terminal voltage will fall. When the load requires constant voltage, ultracapacitors alone won't work. To supply a constant load voltage, a DC-DC converter can be used along with a controlled voltage source. In this paper, an attempt is made to connect an ultracapacitor with a DC-DC converter and a controlled voltage source to supply constant load voltage. The analysis of the system is carried out by simulating the circuit in MATLAB/Simulink®. The analysis has shown that the system is able to supply constant load voltage even when ultracapacitor voltage is falling.

Key words: Ultracapacitor, DC-DC Converter, Controlled Volatge Source, Load Voltage, MATLAB/Simulink®

I. Introduction

Ultracapacitors (UC), also known as supercapacitors or electrochemical capacitors, are a cutting-edge energy storage technology that offers exceptional performance and potential for various applications. Unlike traditional batteries, ultracapacitors store energy electrostatically, allowing them to charge and discharge rapidly with minimal degradation over time [1]. This unique characteristic makes them ideal for applications requiring quick bursts of power and frequent charge-discharge cycles. One of the key advantages of ultracapacitors is their high-power density, which is significantly greater than battery technologies [5-6]. This attribute makes them well-suited for applications in electric vehicles, where they can provide the rapid bursts of power needed for acceleration and regenerative braking. In addition to transportation, ultracapacitors find use in renewable energy systems to smooth out fluctuations and store excess energy during peak production periods, enhancing grid stability and improving the reliability of renewable energy sources. These capacitors can also be used in the power system devices like dynamic voltage restore [2,3,4,5]. These capacitors are available in the capacity ranging from a few Farads to 30,000 Farads. When ultracapacitors are used to supply the loads, their terminal voltage falls, and state of the charge (SoC) is reduced. Hence, for the applications that demand constant load voltage, ultracapacitors need to be connected with the DC-DC converter and a controlled voltage source.

II. Materials and Methods

Materials and methods employed for the research work carried out are highlighted in the subsequent sections.

2.1 DC-DC converter

A DC-DC converter is a power electronic device that can buck (reduce) or boost (increase) the voltage of the system. These converters are widely used in electronic applications like consumer durables and even in power systems and renewable energy applications.

2.2 Ultracapacitor with a DC-DC converter and a controlled voltage source

Figure 1 presents the simulation diagram in the MATLAB/Simulink® software. MATLAB/Simulink® is a highly robust and versatile software that is used to simulate physical systems. As shown in Figure 1, the system comprises of an ultracapacitor having voltage rating 10 V. The lower limit of discharge for the ultracapacitor is kept at 4 V. The load is operating at 12 V. When the circuit is switched on at t=0 s, ultracapacitor through DC-DC converter supplies load and the load voltage remains constant but the ultracapacitor voltage reduces. Now, to maintain the constant load voltage, at 10 s, generator that is a constant voltage source as shown in Figure 2, is made on.

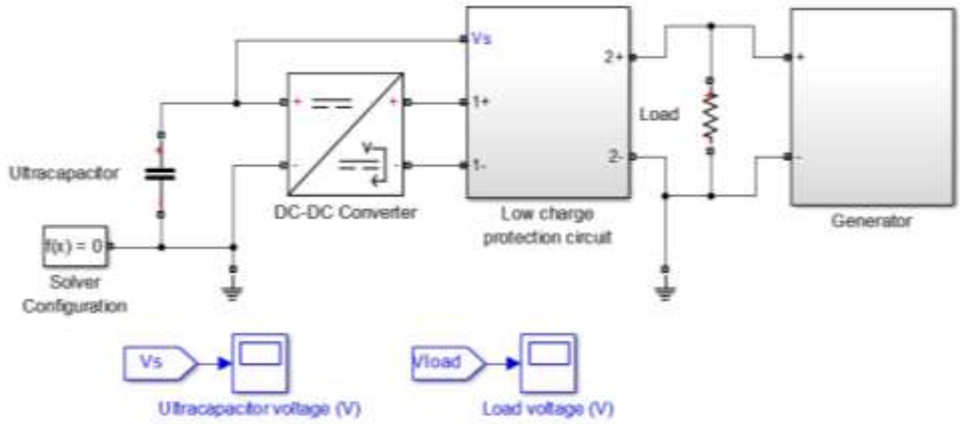

Figure 1. Ultracapacitor with DC-DC Converter and a Controlled Voltage Source Simulated in MATLAB/Simulink®

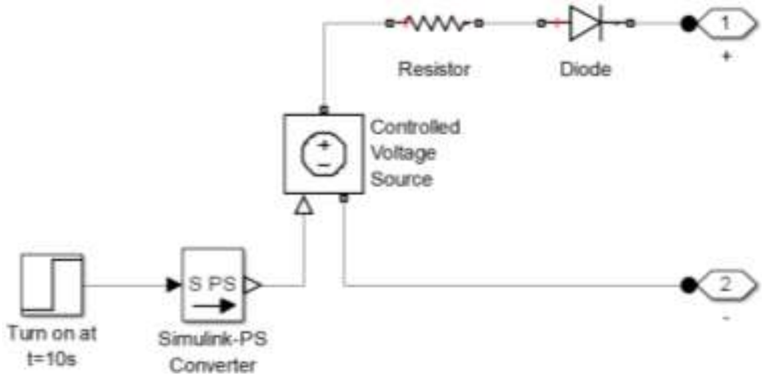

Figure 1. Controlled Volatge Source as a Generator Simulated in MATLAB/Simulink®

III. Results and Discussion

Three cases in the simulations are analyzed. The controlled voltage source (generator) is switched on at 10 s in all these cases, but it is switched off at 15 s, 14 s and a 13.5 s respectively to see the effects on load voltage and ultracapacitor charging and discharging.

3.1 Case 1: Generator Starts at 10 s and switched off at 15 s

When ultracapacitor is supplying load through DC-DC converter, as shown above, its terminal voltage will fall. To maintain the load voltage same, a generator (controlled voltage source) is turned on at t = 10 s and it is kept on till full simulation time of 15 s. The protection circuit disconnects the ultracapacitor when its voltage falls below 4 V. The load voltage is shown in Figure 3 and ultracapacitor voltage is shown in Figure 4. The load resistance has a value 2 ohms, maximum supply side current of DC-DC converter is 100 A, Output voltage droop with output current for a DC-DC converter is 0.01 V/A and rated output power for a DC-DC converter is 100 W. The DC-DC converter has a fixed losses of 0.1 W and its efficiency at rated output power is 95%. It is clear from the results that at 6 s, the UC voltage drops below threshold of 4 V, and hence, it is disconnected by the low charge protection circuit. At this point of time, the load will also get disconnect. When the controlled voltage source at t = 10 s is made on, the load voltage will again be equal to 12 V and at the same time ultracapacitor will start charging and till 15 s, its voltage will reach around 12 V. Hence, when the generator is started the load voltage can be made constant and an ultracapacitor is charged. To verify the performance of the simulated circuit, two more cases are taken.

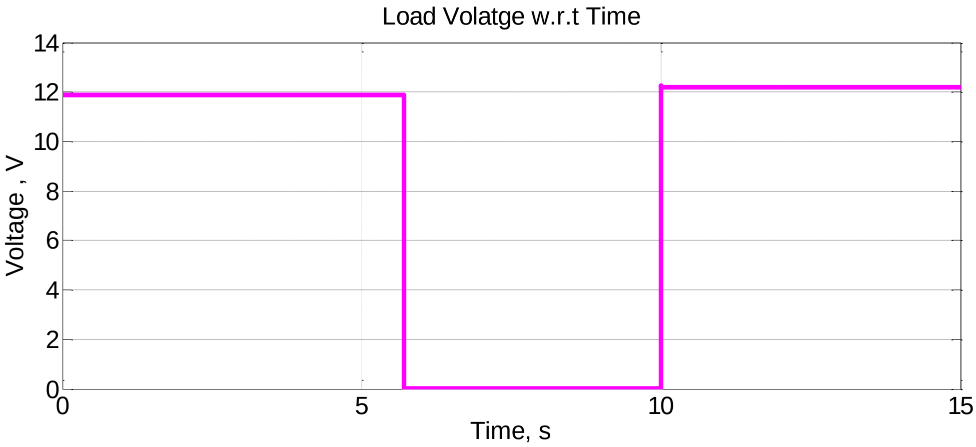

Figure 3. Load Volatge variation for case 1

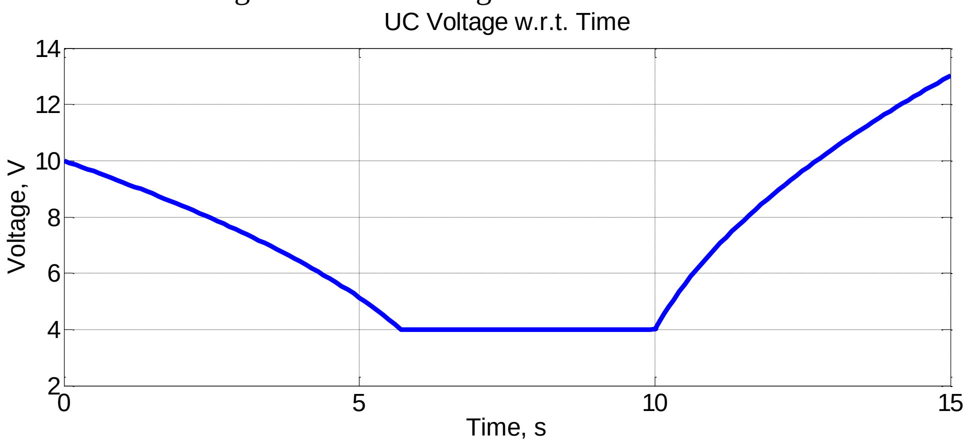

Figure 4. Ultracapacitor Volatge variation for case 1

3.2 Case 1: Generator Starts at 10 s and switched off at 13.5 s

In the above case, generator was kept on till 15 s and hence, the UC voltage was rising around 12 V. In the same circuit, when the generator is switched on at 10 s and switched off at 13.5 s, the load voltage shown in Figure 5 is same as in Figure 3, but the ultracapacitor is getting charged till 13.5 s and then it will supply load and hence, its charging is up to 6 V only. This shows that the circuit is behaving in a proper way.

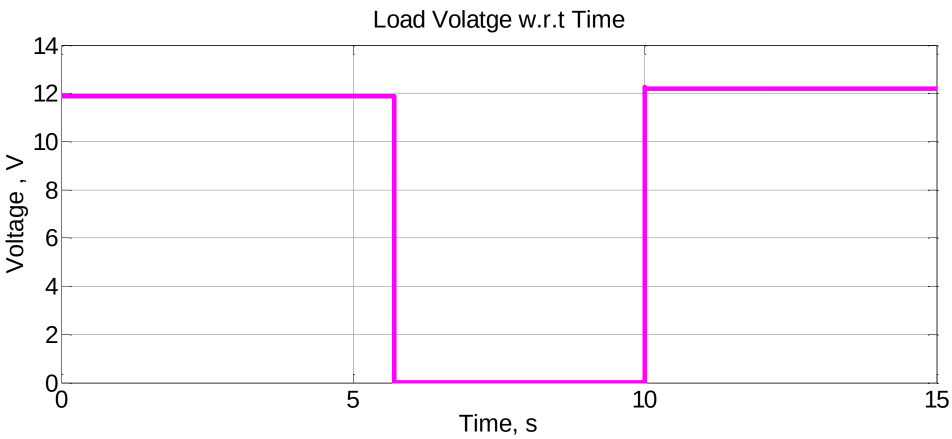

Figure 5. Load Volatge variation for case 2

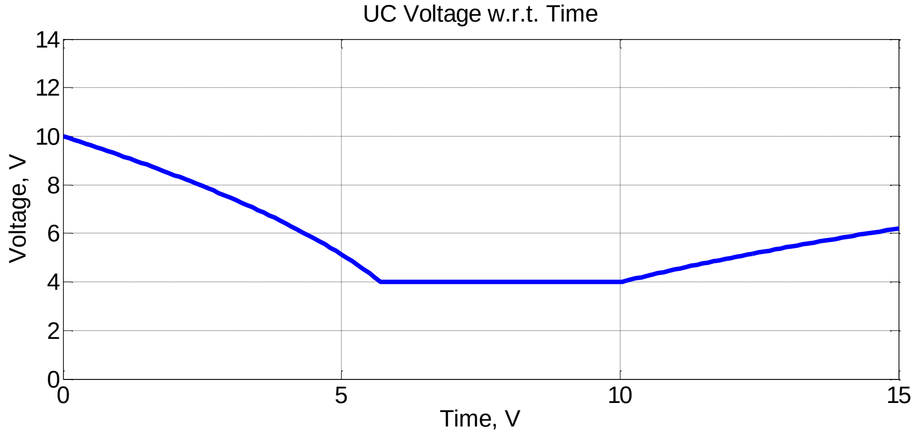

Figure 6. Ultracapacitor Volatge variation for case 2

3.2 Case 3: Generator Starts at 10 s and switched off at 14 s

In this case the generator was kept on from 10 s to 14 s. At 6 s, the UC gets discharged below 4 V and hence, disconnected and generator is switched on from 10 s to 14 s. Looking to Figures 7 and 8 for load voltage variation and an ultracapacitor voltage variation respectively, the load volage follows the same pattern as in the two previous cases but the Uc voltage has now some more time to regain, and its voltage is rising to 9 V. Again, this confirms that the circuit is behaving as expected.

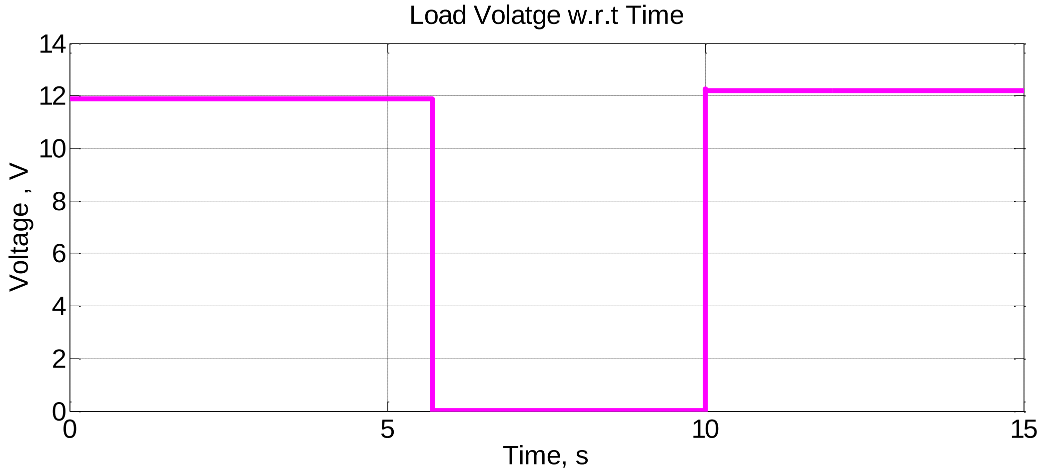

Figure 7. Load Volatge variation for case 3

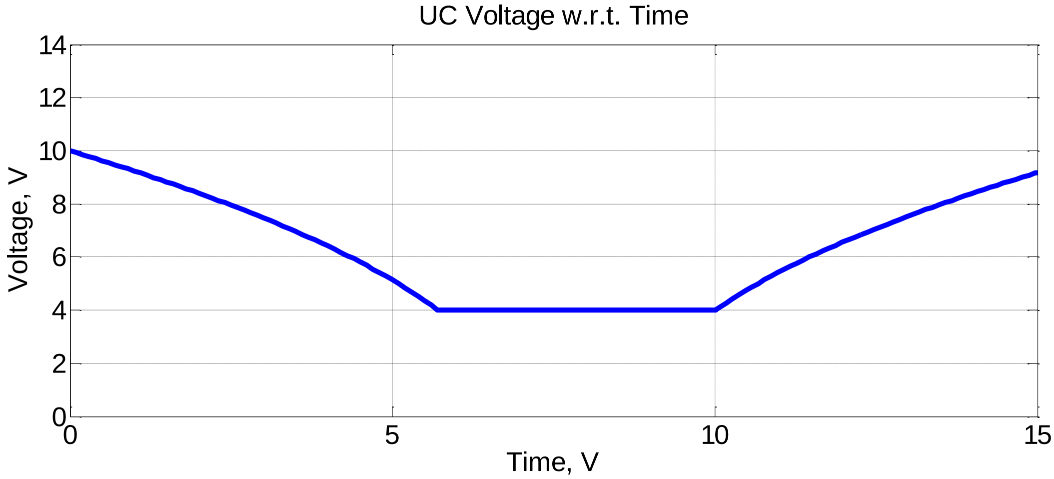

Figure 8. Ultracapacitor Volatge variation for case 3

IV. Conclusion

The paper presents an idea of supplying the constant load voltage to load via ultracapacitor, DC-DC converter and a controlled voltage source. MATLAB/Simulink® software was used to simulate the circuit. The load voltage was constant during the switch on time of either ultracapacitor or controlled voltage source. Three cases were simulated to observe the expected output and it was observed to be satisfying.

VI. Conflict of interests: There is No conflict of interests for the author regarding this research work and a research paper.

VII. Acknowledgement

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