Supercapacitors Outperform Conventional Batteries

By Aditya Sankar Sengupta, Sambit Satpathy, Saraju P. Mohanty, Debasis Baral, and Bidyut K. Bhattacharyya

For all the present day consumer electronic (CE) products especially the ones operating on DC voltage or DC power, supercapacitors or supercapacitor modules would be used in place of battery in these products in the near future for their operation thereby eliminate the need of using batteries and getting rid of all the shortcomings associated with battery technology. All these consumer electronic products require a constant DC voltage for operation due to which a state of the art DC-DC converter module operating solely on supercapacitors without using any battery is envisioned. A proposed DC-DC converter module will deliver the required constant voltage to the CE devices from the supercapacitors corresponding to the dropping or decaying voltage of the supercapacitors or supercapacitor module. This is the first time when the circuit has been designed in which all the electronic components in the design are running properly only on the power drawn from the supercapacitors as also generating a constant voltage from the supercapacitors even though the voltage of the supercapacitors is dropping. This uniqueness of the new design now, will be able to boosts the use of supercapacitors for all consumer electronic systems and products.

1. SUPERCAPACITOR: THE FUTURE POWER SOURCE FOR CE SYSTEMS

The CE systems like laptops and mobile phones have become a part of our day to day life with the advancement in technology of the modern era. CE electronic systems and hand-held devices including camcorders, tablets, and mobile phones, use battery for energy storage. But with the enhancement in specification of these devices, high capacity batteries (e.g. Li-ion) are required. These high capacity batteries need longer time to charge and discharges comparatively faster in order to meet the power requirement for the high specification CE devices. In order to deal with these issues, the concept of using supercapacitor technology in place of battery came into being. Supercapacitor technology has brought forth new possibilities in the field of technology by offering itself the alternate source of power storage and supply. It is because time taken to charge supercapacitor is much lesser compared to battery since the equivalent series resistance of supercapacitor is significantly less compared to the internal resistance of battery [1], [2]. Figure 1 (a) shows some modern day diverse applications in which supercapacitors are used while Figure. 1 (b) shows a supercapacitor based hybrid vehicle in which DC-DC converter is used with supercapacitor and battery.

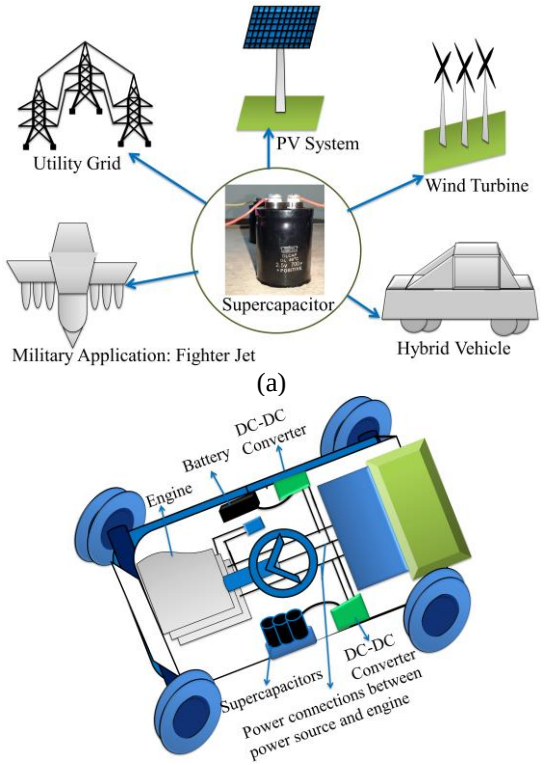


FIGURE 1. (a) Diverse application of supercapacitors. (b) A super capacitor based hybrid vehicle.

Supercapacitor, an invention of material science is deemed to be the future of energy storage and power supply in the field of power engineering and industrial electronics. This article demonstrates a unique as also novel analog buck circuit design that is powered solely by supercapacitors and this prototype has been designed with a view to eventually replacing batteries in CE (consumer electronics) devices in future when the size of supercapacitors would be miniaturized for which researches are going on throughout the world. This article is the first work wherein a circuit solely powered by supercapacitors and devoid of any other power source like battery, wall power is being shown. The prototype demonstrated in this article is the first practical circuit for which supercapacitors are the sole power source. This is the first step towards a battery-less CE systems.

2. SUPERCAPACITORS VERSUS BATTERY

Supercapacitor has a number of advantages over battery the most important being the charging time which is much less for supercapacitors as compared to batteries [3, 4]. Supercapacitors are hazard free unlike batteries [5] that are prone to explosion. Also supercapacitors have much higher life cycle compared to batteries [4, 5]. Also supercapacitor has a very high power density [6] which is why it can pump a high amount of power in a short time span. Figure 2 shows the power drawn by supercapacitors versus the power drawn by the battery applications as a function of current drawn by the devices. In Figure 2, the green curve is the power consumed by the battery due to it's own equivalent series resistance (ESR), blue curve is the power consumed by the supercapacitors. The black dashed line shows that if the power is too high then one may require fin and fan to cool the battery. If the cooling is not done for a give battery operated system, approximately around 5-10 W, the battery may explode which was observed in various occasion in CE products that exploded due to overheating [7].

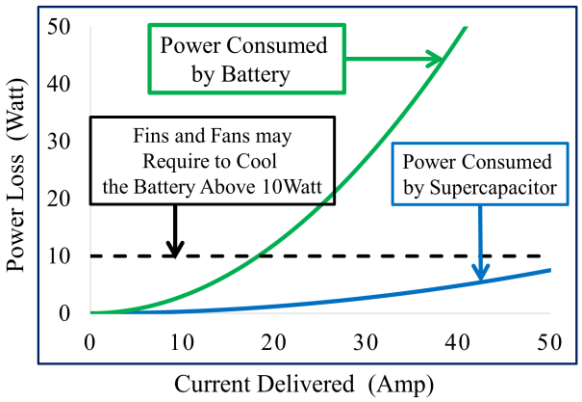


FIGURE 2. Supercapacitor versus Battery.

3. SUPERCAPACITORS: THE STATE OF ART

Supercapacitors are used along with a DC-DC converter and battery in DC microgrids [8], in hybrid vehicles [9], and in hybrid energy storage systems [10]. Supercapacitors are also used in elevators [11] and in wireless sensors [12]. Supercapacitors can also be used in various components of smart cities [13] and also in energy harvesting [14].

Supercapacitors can be use in charging batteries [15] in which supercapacitors are used to provide pulse power. The idea of using supercapacitor in place of Li-ion battery to power CE device like mobile phone is being contemplated [16], [17] but the fast discharge of supercapacitor is a pressing issue that would be taken care of by the advancement of technology in future. It has been claimed that using graphene as the material for supercapacitor attributes to increase in energy density by two to three times [18] i.e. the energy storing capacity of supercapacitor improved. The graphene based supercapacitors could be used in electric vehicles with a view to making the vehicle battery free in future. A new polymer that could be used to construct supercapacitors of an extremely high energy density in future is available [19]. It may also be noted that for the designing, fabrication or development of micro-supercapacitors or miniaturized supercapacitors, researches are in full swing [20, 21, 22].

4. SUPERCAPACITOR POWERED CONVERTER – A PROTOTYPE

The prototype circuit for 'supercapacitor powered battery-less novel buck converter' has been shown in Figure 3 in which all the connection are clearly shown with proper labeling. In Figure 3 it can be observed that the supercapacitors are the sole power source for the entire circuit, and the circuit is devoid of any other power source like battery, wall-power etc and this is the prime innovation in the design. This prototype is composed of two main modules namely the supercapacitor modules bordered by green line and the unique buck converter bordered by sky blue lines. In Figure 3, there are two supercapacitor modules and the yellow wire is supplying positive voltage from one supercapacitor module to the buck converter module while the red wire is supplying negative voltage from the other supercapacitor module to the buck converter module. Each supercapacitor cell is 'nippon ELDC' [23] of 700F and 2.5V. So each supercapacitor module (4 cells in series) has a specification of 175F and 10V. The simulations result for the prototype have been shown for 'R_o' equal to 7.6Ω, V_o equal to 3.8V. Figure 4(a) shows the voltage profile of the supercapacitor modules used in the prototype. In Figure 4(a) the blue curve is the profile of supercapacitor module giving positive voltage green curve is the profile of supercapacitor module giving negative voltage. It can be seen in Figure 4(a) that the blue curve and the green curve are mirror images of each other. This implies that the buck module is drawing equal power from both the supercapacitor modules. Figure 4(b) shows the output voltage of the prototype corresponding to the decaying voltages of the supercapacitor modules. As shown in Figure 4(b), the output voltage takes a constant value till 5694s after which it exhibits a steep drop. Figure 5(a) shows a blue colored triangular wave sequence whose peak voltage is decaying over time and a green colored fixed reference voltage. Figure 5(b) shows the switching pulse generated by comparing the blue colored triangular wave with the green colored reference voltage.

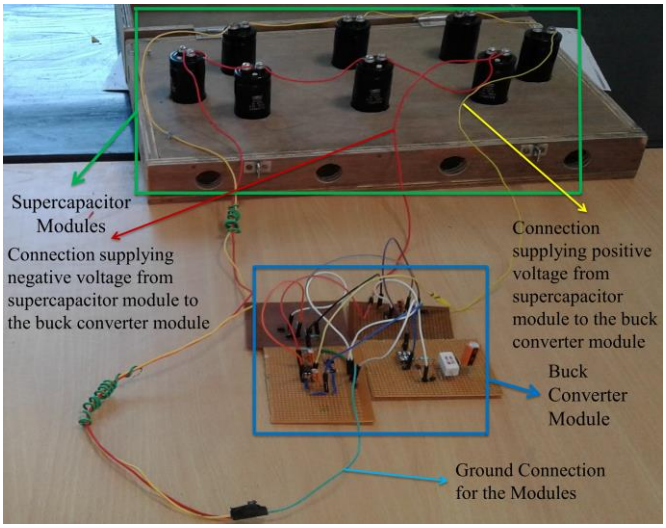
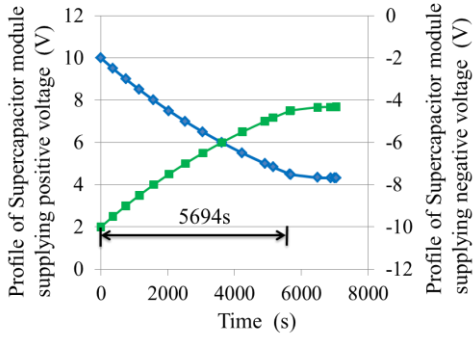
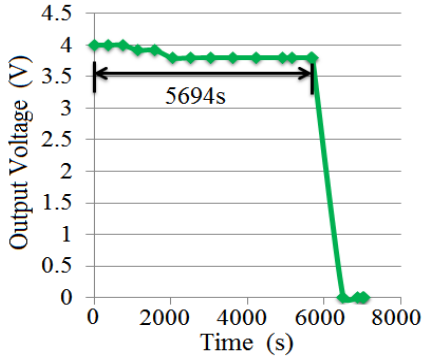


FIGURE 3. Prototyping of supercapacitor powered battery-less buck converter.

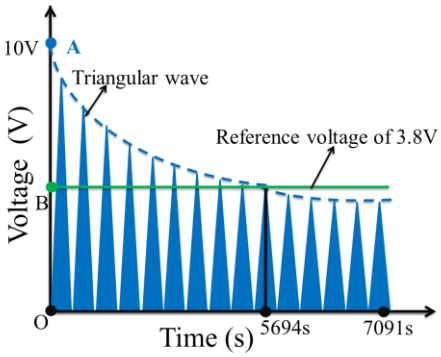


(a)

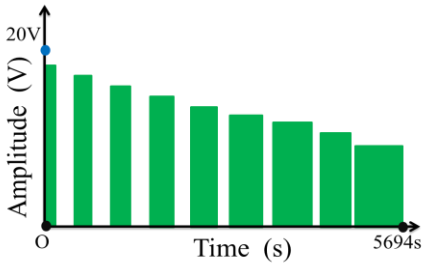


(b)

FIGURE 4. (a). Voltages of supercapacitor modules. (b) Output Voltage of prototype



(a)



(b)

FIGURE 5. (a) Triangular wave and fixed reference voltage. (b) Switching pulse.

It is observed from Figure 5(a) that the peak of triangular wave decreases over time with the decay of voltage of the supercapacitor modules and correspondingly the duty ratio of switching pulse increases and amplitude decreases. Thus demonstrates the reason behind the prototype yielding a regulated output corresponding to the decaying voltages of supercapacitor modules.

5. CONCLUSIONS

It is validated that voltage of both supercapacitor modules are decaying over time in exactly similar manner and the prototype yields a regulated output voltage. Thus proving the fact that prototype is fully functioning. Hence it can be concluded that the first successful prototype of a circuit powered solely by supercapacitors has been successfully designed and demonstrated thereby giving a start and paving the way for a battery-less circuit technology especially in applications working on a constant dc voltage. In future, when material scientists and physicists will have designed high capacitance micro supercapacitors especially with relatively higher working voltage, this prototype can be used in place of battery in any and every CE device as per requirement thereby eliminating, completely the use of battery in CE devices and systems. We envision that a hybrid supercapacitor and battery cell pack is a solution for future for high capacity and fast charging in smart cars and smart medical devices [24].

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