Modalities Of Supercapacitor Energy Storage In An Energy Harvesting Setup

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Abstract

This paper discusses the methods to store energy effectively in a supercapacitor bank, generated by an energy harvesting setup comprising of a hand cranked generator. Two different topologies are discussed. First setup is a closed loop setup which disconnects the supercapacitor bank via a voltage sense circuit when it charges till a set threshold and other using a buck converter which can operate in short circuited state and stops transferring energy when the programmed output voltage is reached.

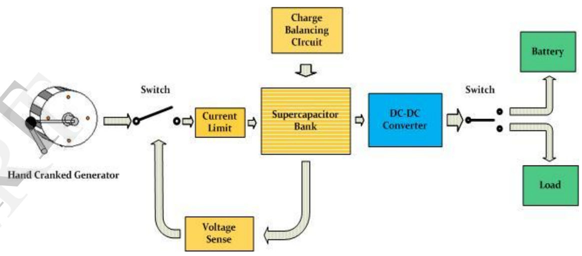
A supercapacitor is rated for 2.5-2.7V which poses a serious challenge to store energy and careful circuit design is required which stops the charging much before the maximum voltage rating (say 2.5V for a 2.7V rated supercapacitor). When supercapacitors are connected in series, then due to slight difference in internal parameters even for the same part number, an individual supercapacitor can go to overvoltage state which must be avoided by using charge balancing circuits. Active and passive charge balancing circuits are discussed and compared.

1. Introduction

Hand held electronics are gaining popularity day by day but their battery life pose a serious constraint as the battery technology has not been able to keep up with the energy hungry electronics. Energy harvesting is one area which can provide an alternative to power small hand held gadgets enabling them to charge from the ambient energy [1]-[3]. Also it can be used to power gadgets in remote areas and off grid places and even in a natural calamity situation where grid supply has been disrupted. Energy harvesting generates energy from everyday movements like running, jogging, opening a door, cycling, exercising etc [4]. These all sources generate energy in an intermittent and abrupt manner which requires an energy storage medium which stores energy rapidly.

That is when supercapacitors come into picture as owing to their low ESR they can be charged and discharged rapidly in a matter of seconds [5]. Also they have very long self-life and a cycle life of more than 10,000 times and can even be short circuited without much damage. This means they provide a very robust energy storage solution. The charging method of supercapacitors is entirely different from batteries as an uncharged supercapacitor acts as a short circuit to a charging source.

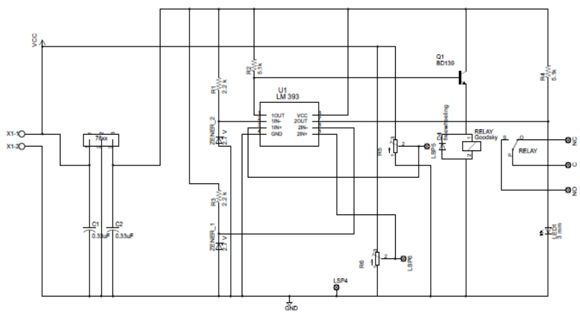
2. Topology I



Block Diagram Topology 1

In topology 1 the hand cranked generator charges the supercapacitor bank via a current limiter .When the supercapacitor voltage reaches a set threshold the voltage sense opens the switch and stops further charging of the supercapacitor bank [8].

The voltage sense part in topology I is made using low energy consuming parts which are powered by the supercapacitor bank itself. LM393 single supply comparator is used for making the voltage sense part.

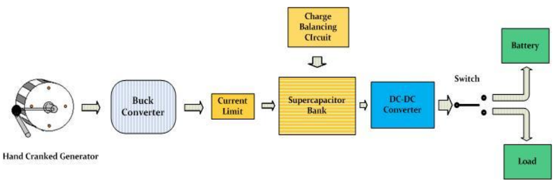


Voltage Sense

Current limit is required as a supercapacitor acts as a short circuit across the hand cranked generator making it very difficult to rotate.

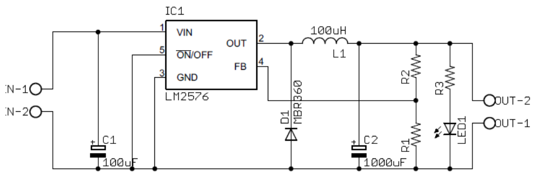
3. Topology II

It is an open loop configuration. It uses a buck converter which can even work at short circuited condition with reduced voltage. As the supercapacitor bank gets charged the output voltage of the buck converter increase until it reaches the output voltage of the buck converter. At his stage the supercapacitor bank stops taking energy. The current limit may or may not be used if the buck converter can withstand short circuit condition.



Block diagram topology 2

While topology 1 ensures faster charging because no energy is wasted in the buck converter, the topology 2 ensures the protection of the supercapacitor bank from overcharging in case of failure of the voltage sense part in topology.



Buck converter

The buck converter is made using LM2576 buck converter IC which includes cycle by cycle current limit.

When the current draw from the buck converter increases than what it is designed for output voltage dip happens which persists until the current draw reaches the designed value. The voltage dip also happens when the input current is less than what it is designed for.

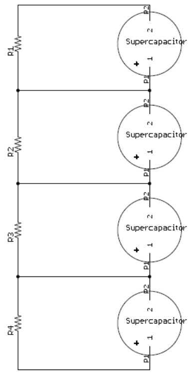
So the buck converter output voltage increases gradually as the supercapacitor bank charges until it reaches the designed value set by programming resistors R1 & R2. At that time since the voltage level in the supercapacitor bank is same as that of the buck converter the bank doesn't take any more charge.

4. Charge Balancing

The supercapacitor bank has been made by connecting individual supercapacitors in series to increase the voltage rating. This causes voltage unbalance problems due to slight difference in internal parameters of the same value supercapacitors [6], [7]. There are basically two types of charge balancing circuits - active and passive charge balancing.

4.1. Passive charge balancing

It consists of a resistor connected across each individual supercapacitor in series. It is a very straightforward method but it causes energy wastage as some current always flows through the resistors and hence is not very efficient.

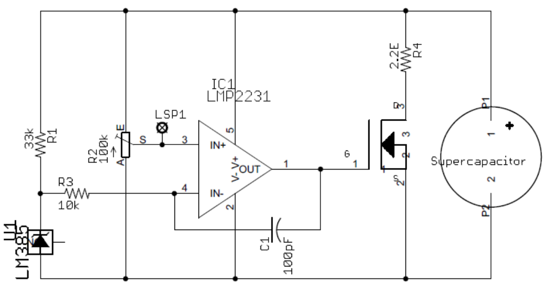


Passive charge balancing

Higher the resistor value slower is the balancing. So there is a trade-off between resistor value and charge balancing time.

4.2. Active charge balancing

It consists of a comparator controlled MOSFET switch. There is a resistance connected across the MOSFET. When the switch closes detecting the overvoltage the supercapacitor is bypassed and the charging current flows to other less charged supercapacitors. Active charge balancing circuit consumes very less energy as balancing current flows only when the overvoltage condition is reached. Otherwise due to use of nano-power comparators, it consumes very less energy in standby mode.



Active charge balancing module

It is made in modular form so that different combinations can be tried out. For each supercapacitor there is a module connected parallel to it.

LMP2231 micro-power op-amp is used for making the comparator section. Also very low Vgs (gate threshold voltage) MOSFET PMV30UN is used for driving it into saturation region once the voltage threshold is crossed. Also the voltage reference is a micro-power device. So overall the active charge balancing circuit consume negligible power in standby mode.

5. Conclusion

The paper demonstrates two topologies for an arrangement for low power energy harvesting and supercapacitor storage device for powering small electronic gadgets. Advantages and disadvantages of both the topologies are discussed. Charge balancing circuits must be used whenever we connect supercapacitors in series. Active charge balancing circuits are superior in performance than their passive counterparts. The energy absorbing ability of this arrangement is much better than battery based energy storage systems in energy harvesting. The arrangement can be used for off grid applications in remote areas. Future work includes developing regenerative brakes for bicycle for urban use where frequent braking is required. So, whenever brakes are applied on a busy road the energy is recovered back in the supercapacitor Bank instead of getting wasted in the brakes.

10. References

[1] Yildiz, F. "Low Power Ambient Energy Harvesting, Conversion, and Storage Circuits" Information Technology: New Generations, 2009. ITNG '09. Sixth International Conference on 27-29 April 2009.

[2] Paradiso, J.A.; Starner, T." Energy scavenging for mobile and wireless electronics", Publication Year: 2005, IEEE Journals & Magazines.

[3] T. Starner and J.A. Paradiso, "Human-Generated Power for Mobile Electronics, "Low-Power Electronics Design, C. Piguet,ed., CRC Press, 2004, chapter 45, pp. 1–35.

[4] Yildiz, F. "Potential Ambient Energy-Harvesting Sources and Techniques" The Journal of Technology Studies

[5] Thounthong, P.; Davat, B.; Rael, S. "Drive friendly" Power and Energy Magazine, IEEE Volume: 6, Issue: 1 Publication Year: 2008, IEEE Journals & Magazines.

[6] Farhan I. Simjee, Member, IEEE, and Pai H. Chou, Member, IEEE "Efficient Charging of Supercapacitors for Extended Lifetime of Wireless Sensor Nodes" IEEE Transactions on Power Electronics, Vol. 23, No. 3, May 2008

[7] Dirk Linzen, Stephan Buller, Eckhard Karden and Rik W. De Doncker, Analysis and Evaluation of Charge-Balancing Circuits on Performance, Reliability, and Lifetime of Supercapacitor Systems: IEEE Transactions on Industry Applications, Vol. 41, September/October, NO. 5, 2005

[8] Manish Anand, A. M. Nagaraj, "Low Power Energy Harvesting & Supercapacitor Storage" IOSR-JEEE Journal Volume 6, Issue 4.

[9] Ned Mohan, Tore.M. Undeland and William. P Robbins, "Power Electronics converters", Applications and Design", John Wiley and Sons, 3rd Edition, 2002.

[10] Rashid M.H., "Power Electronics – Circuits Devices and Applications, Prentice Hall India, 3rd Edition, 2005.