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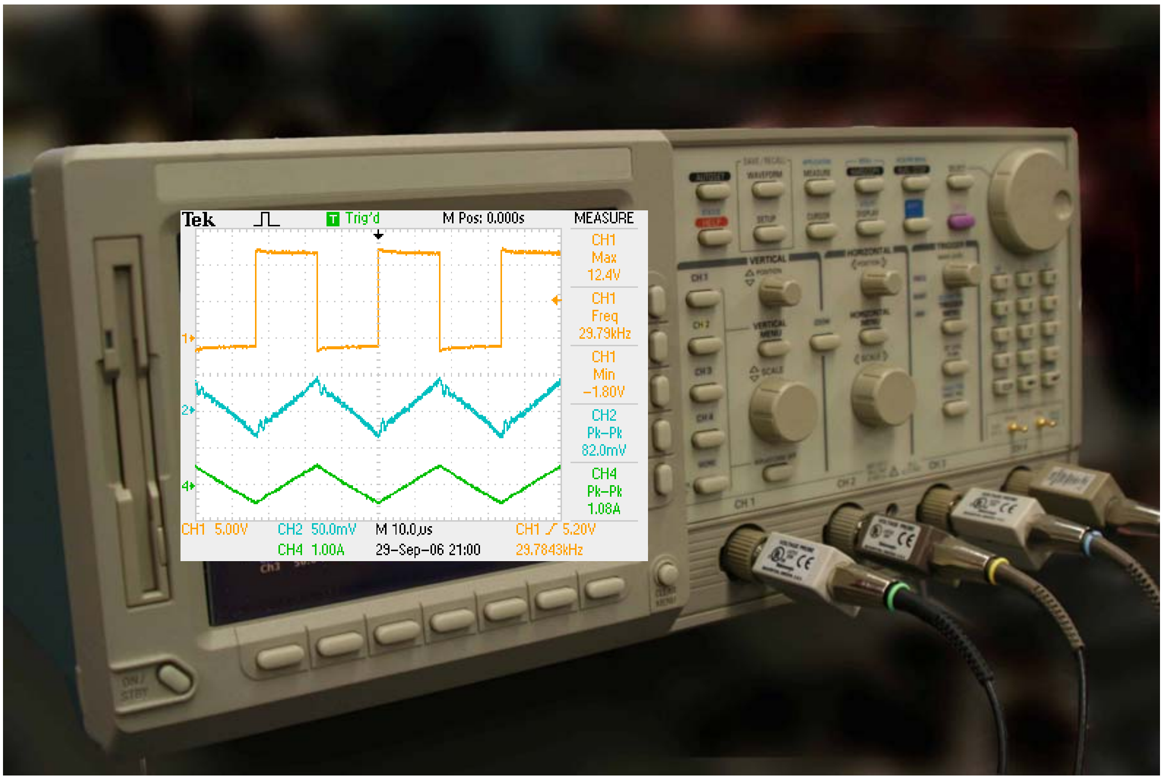
# Ultra Capacitors

## Improving Life Time of Ultra Capacitors




A white paper written by Bose Research Private Limited in collaboration with Norwegian University Of Science And Technology

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*Improving Life Time of Ultra Capacitors* is a white paper written by Bose Research in collaboration with researchers from NORWEGIAN UNIVERSITY OF SCIENCE AND TECHNOLOGY, Department of Electrical Power Engineering, Trondheim, Norway under the guidance of Prof. Tore. M. Undeland. This paper is based on a lot of experimental data taken from experiments done by students. This paper is also accepted for presentation at various IEEE conferences.

# Ultra Capacitors

*Improving Life Time of Ultra Capacitors*

## Summary

While Ultra Capacitors offer high power density, high cycling capability and mechanical robustness. Voltage and current ripple from downstream PWM converters result in their heating and lifetime reduction. This paper discusses how a simple novel design scheme of using a very low value series inductance significantly increases capacitor lifetime.

Ultra-capacitors or electric double layer capacitors (ELDC), are electrical energy storage devices, which offer high power density, extremely high charge and discharge cycling capability and mechanical robustness [1]. Due to these features, Ultra-Capacitors have a high potential of being used in industrial applications. To improve their performance, reliability and lifetime, efficient charge balancing circuits [2], power circuits that do not overcharge or overheat these capacitors due to high ripple voltage or current, are very important. When using Ultra-Capacitors as an energy storage buffer for downstream PWM converters, the resulting voltage and current ripple in them can cause temperature rise and lifetime reduction of the Ultra-Capacitor. Based on extensive practical measurements made on an Ultra-Capacitor bank, a novel design scheme that significantly reduces their operating voltage ripple and operating ripple current resulting in significant improvement of their lifetime performance, is presented in this paper.

## 1. THE PROBLEM IN SPECIFIC

Both overcharging and temperature rise reduces the lifetime of Ultra-Capacitors. Though the standard temperature rating for Ultra-Capacitors is –25°C to 70°C, ambient temperature rise in combination with high charging voltage, can reduce their lifetime significantly. In general, raising the ambient temperature by just 10°C will decrease their lifetime by at least a factor of two [3]. Thus the maximum operating voltage of an Ultra-Capacitor should be reduced with increasing ambient temperature. Overheating of Ultra-Capacitors occur due to either the high charging/discharging ripple current from the downstream converter or charging over voltage, leading to increased gas generation, decreased lifetime, leakage, venting or rupture. Though for highest energy storage the Ultra-Capacitor must be charged to its maximum rated nominal working voltage, care needs to be taken that the charging voltage ripple does not overcharge the capacitor. Moreover, as Ultra-Capacitors have a higher ESR compared to aluminum electrolytic capacitors, they are more susceptible to internal heat generation when exposed to higher ripple current. In order to ensure a long lifetime, it is [3] thus recommended that the maximum ripple current should not increase the surface temperature of the Ultra-Capacitor by more than 3°C above ambient and thus minimize the operating ripple current and ripple voltage on these capacitors.

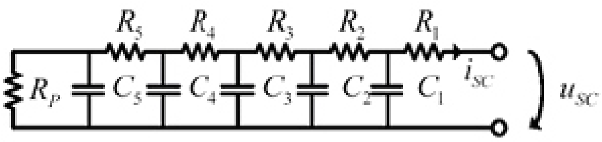


Figure 1a. Model of Ultra-capacitor

In addition to the above issues, the nominal capacitance of an Ultra-Capacitor is applicable only at dc with its capacitance dropping rapidly to near zero at higher frequency [4]. Fig. 1a shows a representative Ultra-Capacitor model where the leakage resistance is represented as $R_P$, the highest and lowest capacitances are respectively represented by C5 and C1 respectively and R1 to R5 are the Ultra-Capacitor's equivalent series resistance (ESR). As apparent from the frequency ($F_{SC}$) response graph given in Fig. 1b, an Ultra-Capacitor cannot significantly attenuate the high frequency voltage ripple generated by a switching PWM converter connected downstream since the large capacitance ($C_{SC}$) measured at dc reduces to a very low value beyond just 100 Hz..

Ultra-capacitors can be simultaneously charged and also used as an energy storage buffer by paralleling them to an energy source, i.e. battery, fuel cell, DC-DC converter [5], etc. The voltage and current ripple caused by the charging converter or the converter that these capacitors intend to provide power back up, can cause over charging or temperature rise of the capacitor.

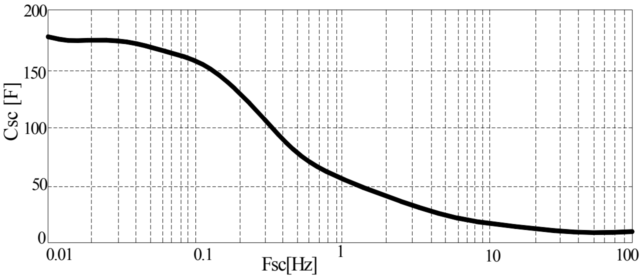


Figure 1b. Capacitance vs. frequencyplot of Ultra-capacitor

## 2. STRATEGIES FOR REDUCING RIPPLE VOLTAGE AND RIPPLE CURRENT

As discussed so far, reduction of both operating voltage ripple and charging/discharging ripple current is necessary for increasing the lifetime of Ultra-Capacitors. Though one solution would be to increase the filter inductance (L1 in Fig. 3) and or reduce the switching frequency of the buck derived DC-DC converter that is usually used for charging or for power conversion downstream, this will significantly increase converter size and cost. Moreover increasing inductance requires higher turns and this increases both the radiated fields from the inductor and the inter-winding capacitance of the inductor. A representation of a practical inductor's inter-winding capacitance series resistance is shown in Fig. 2.

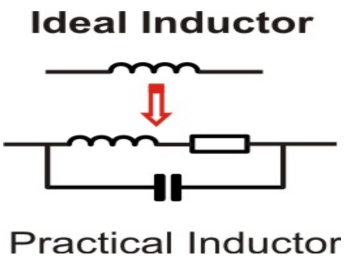


Figure 2. Interwinding Inductor Capacitance

These radiated fields and the feed through noise through the inter-winding capacitance [6] from the inductor mainly couple to surrounding circuits and increase EMI. Thus a better solution would be to use additional filter circuits that attenuate both the voltage ripple and ripple current and thus allowing higher frequency operation of the converter.

Ultra-capacitors are usually always used for energy storage or energy buffer applications. Their poor high frequency response makes them completely unsuitable for high frequency applications and is therefore more suitable for dc circuits. It is thus proposed that Ultra-capacitors should be connected to any high frequency charging converter with a small inductance of about 20 µH in series to it. The circuit model of the proposed scheme is shown in Fig. 3. L1 is the main converter filter inductance that sets the ripple current magnitude while L2 is the proposed small inductance of about 20 µH.

It is intended that L2 will attenuate the operating ripple current through the Ultra-capacitors and mitigate temperature rise issues in them due to heating caused by the charging/discharging ripple current through the Ultra-capacitors. Further since L2 has few turns due to its small inductance value, its copper losses and cost/size will be low.

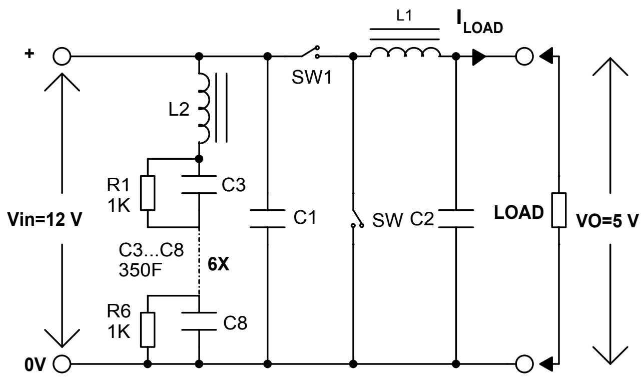


Figure 3. Proposed Charging Scheme

## 3. EXPERIMENTAL RESULTS

To develop a better understanding about the influence of high ripple current through Ultra-Capacitors, measurements were made for a synchronous buck converter with a 58 F Ultra-Capacitor and a current limited 12 V dc source connected at its input. The converter circuit model is shown in Fig. 4. The 58 F Ultra-Capacitor comprised of six 350 F (C1-C6) Ultra-Capacitors connected in series with charge balancing resistors (R1-R6). All measurements were made when the input current reached its minimum steady state value indicating that the Ultra-Capacitors were almost fully charged. R7 kept the converter in CCM and also provided a discharge path for the Ultra-Capacitors. The downstream converter's switching frequency was set to about 100 kHz while the control circuit regulated the output voltage to about 5 V by adjusting the operating duty cycle of the converter to about 40%.

By controlling switch SW1, the effect on the operating voltage/current ripple of an ultra-capacitor with and without the low value inductance in series to the capacitor, was investigated.

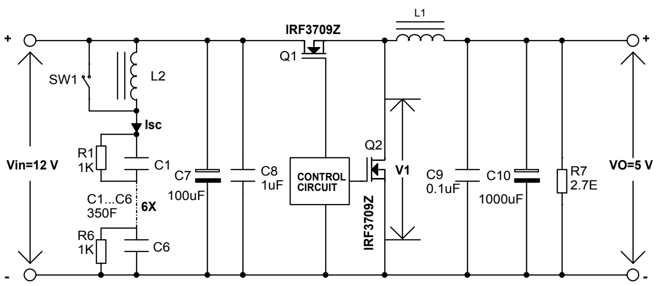


Figure 4. Buck converter circuit model with Ultra-Capacitor at the input.

These are presented in the oscillograms given in Fig. 5 and Fig. 6. In all these oscillograms Channel 1 shows $V_1$ . Fig. 5a shows the charging voltage ripple in Channel 2 and the charging ripple current $I_{SC}$ through the capacitor is shown in Fig. 6a. As seen from these oscillograms, the large voltage ripple or the ripple current generated by the downstream converter, demonstrates the poor frequency response of Ultra-Capacitors. However on connecting a single 20 µH inductance (L2) in series to the Ultra-Capacitor, the voltage ripple and ripple current reduced significantly. With the 20 µH connected, Fig. 5b shows the charging voltage ripple in Channel 2 and the charging ripple current $I_{SC}$ through the capacitor is shown in Fig. 6b.

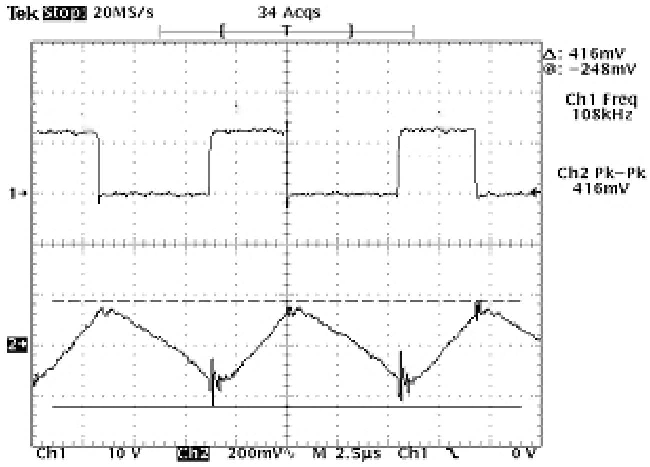


Figure 5a. Operating Ripple Voltage without L2

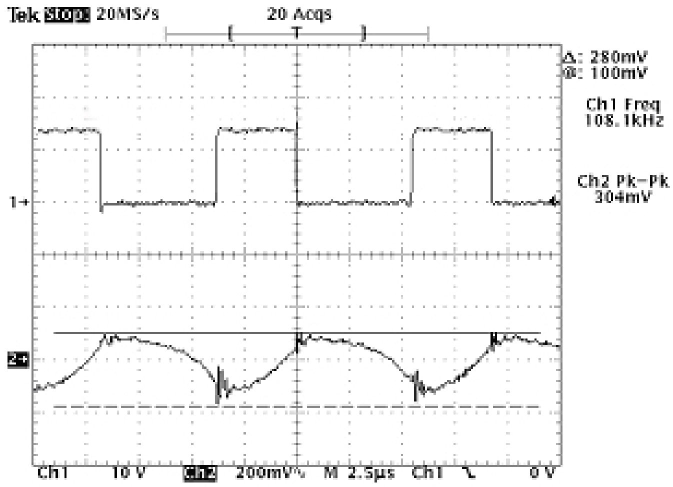


Figure 5b. Operating Ripple Voltage with L2

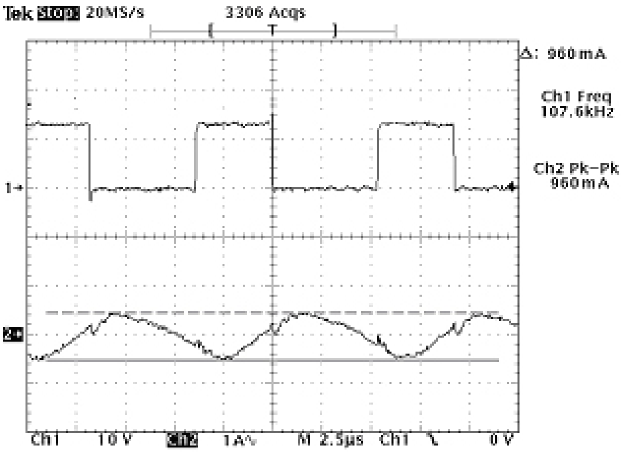


Figure 6a. Operating Ripple Current without L2

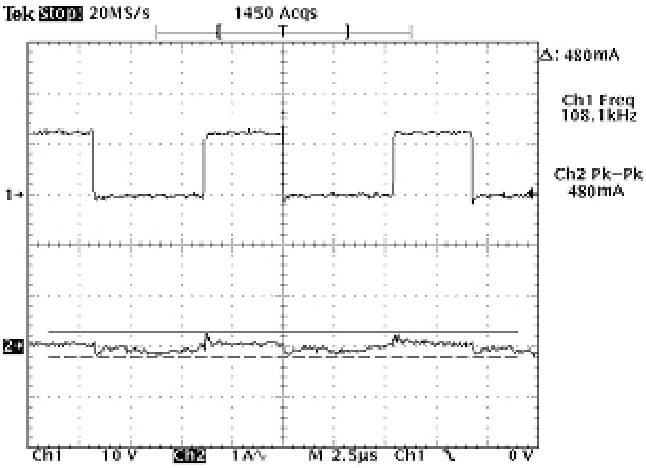


Figure 6b. Operating Ripple Current with L2

Thus with only the Ultra-capacitor connected, the high operating voltage ripple and the ripple current through the Ultra-Capacitor would cause overcharging and heating of the capacitor. On connecting the 20 µH inductance (L2) in series with the Ultra-Capacitor, not only could the voltage ripple be reduced significantly but the ripple current could also be reduced. While the reduction in the operating ripple voltage was about 25%, the ripple current responsible for capacitor heating reduced even more significantly. It can be seen in Fig. 6 that though the peak to peak ripple current reduced by about 50%, the reduction in the average value of the ripple current was even more significant

## Conclusion

This paper discusses how downstream PWM converters can generate high voltage and current ripple in Ultra-Capacitors used as a energy storage buffer and thus result in their heating and lifetime reduction. Based on extensive measurements, the proposed simple novel design scheme of using a very low value inductance in series to an Ultra-Capacitor helped significantly reduce both the voltage ripple and ripple current of an Ultra-Capacitor by more than 40%, resulting in increase in capacitor lifetime. The change in capacitance and ESR of an Ultra-Capacitor with frequency is also highlighted.