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Ultracapacitor selection and design for the Regenerative Breaking Engegry Recovery Syetem

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Abstract — Due to the several advantages of the electrochemical double layer capacitor (EDLC) also called the ultracapacitor over the Electrochemical Batteries it is intensively used in the Regenerative Energy Recovery system in the modern controlled electrical drives. Where ultracapacitor can fully charge and discharge in few number no of seconds also it can be served as a short-term UPS during the power interruption condition. In this paper complete selection and design guideline for the selection of the ultracapacitor module. Selection of the mail parameters such as capacitance, voltage rating, and efficiency, number of series or parallel connected cells, conversion losses are discussed. At the end of the paper the design example of the practical drive is presented.

Keywords- Regenerative Energy, Ultracapacitor, Ultracapacitor losses, Ultracapacitor losses.

I. INTRODUCTION

A simplified block diagram of a regenerative drive exclusively based on energy storage concept is given in Fig. 1. The drive consists on an ordinary diode front-end converter equipped with an energy storage device like ultracapacitor. The specific energy and capacitance are much higher than for standard electrolytic capacitors. Also, the specific peak power of the ultra-capacitors is higher than peak power of the existing electro-chemical batteries.

Braking energy is stored into the ultra-capacitor during the drive braking sequence. And during the next motoring sequence, the energy is restored from the ultra-capacitor to the drive. The first commercial applications of the ultra-capacitor based regenerative drives were traction and hybrid car drives. General purpose variable speed drive with such kind of energy saving concept could be used in tooling machines having high demand for frequent and fast start/stop sequence, lift and hoisting applications, , and many other application having a demand for braking. In [2], such a drive concept is analyzed and applied on the rubber tired gantry (RTG) crane. As reported in [3], the fuel saving is 30% to 40% more than the ordinary drive without energy storage concept. Moreover, the diesel gen-set can be re-sized and smaller unit could be used. The ultra-capacitor as the energy storage for short term UPS function in critical industrial applications.

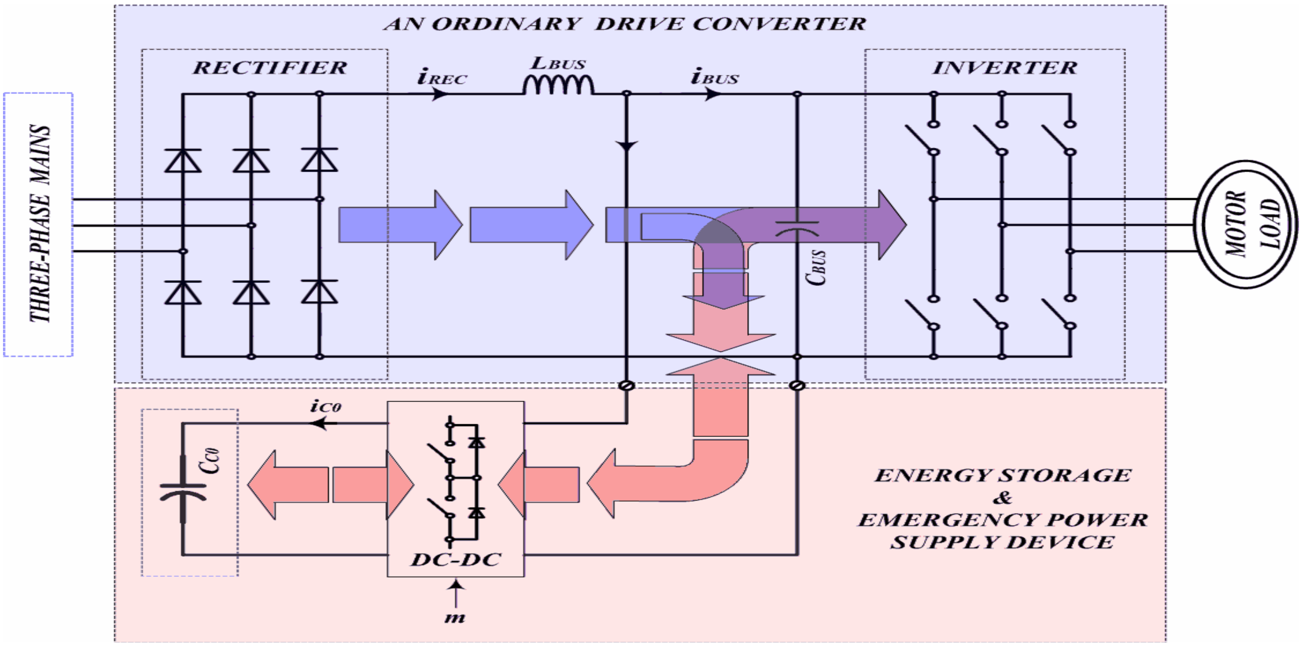


Figure 1. Regenerative Breaking Energy Recovery system with Ultracapacitor as a energy storage

A. *Fundamentals of ultra-capacitors*

The ultra-capacitor is an electrochemical double layer capacitor, which composed of two porous conducting electrodes separated by a separator, Fig. 2. The electrodes are separated by a porous membrane, and impregnated by a solvent electrolyte. With a layer of the electrolyte's ions each electrode forms a capacitor. The capacitance depends on surface of the conducting electrode and size of the ions. The electrodes are made of porous conducting material such as activated carbon. It has a large surface area and very thin layer of the charges which gives specific capacitance up to several faraday. Typical cell voltage of an ultracapacitor is 1 to 2.8V. To obtain higher working voltage, elementary cells are series-connected into one module [3].

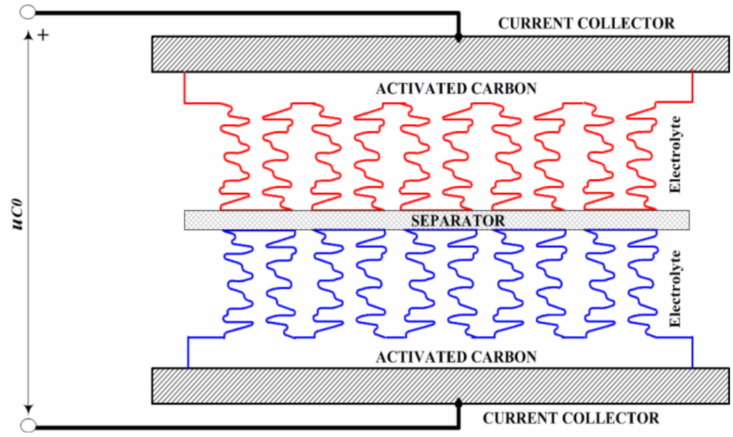


Figure 2. Cross-section of a an electrochemical double layer capacitor with porous electrodes

II. ULTRA-CAPACITORS IN REGENERATIVE ENERGY RECOVERY SYSTEM

A. The ultra-capacitor design objective

Design objective is to select and design an ultra-capacitor module according to the application requirement. Fig. 3 shows an ultra-capacitor module in which main parameters are highlighted which is need to be selected.[4] Main parameters are:
• The module voltage rating,
• The module capacitance,
• The module internal (parasitic) resistance that defines the Conversion losses and efficiency

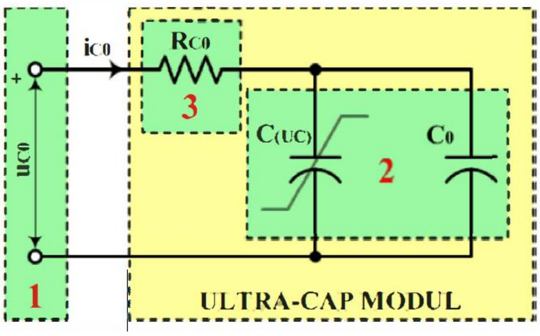


Figure. 3. An ultra-capacitor and parameters to be selected according to the application requirement

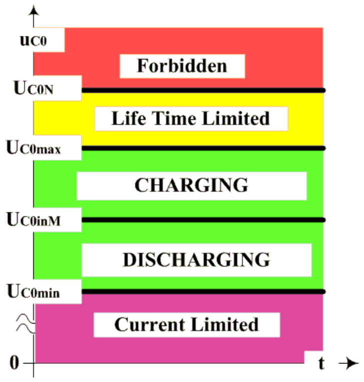
B. Main design steps

Design of an ultra-capacitor for power conversion application can be split into three steps.
• The first design step is selection of the ultra-capacitor module voltage. Voltage rating depends topology of the interface converter
• The second design step is selection of the module capacitance. The module capacitance is selected according to energy storage capability and conversion efficiency.
• The third design step is calculation of conversion losses of the ultra-capacitor module.

III. VOLTAGE RATING AND CAPACITANCE SELECTION

A. The module voltage rating

In the Fig. 4 definition of the main voltage levels are described where,



1.	U_{C0max}	*Maximum operating voltage*
2.	U_{C0min}	*Minimum operating voltage*
3.	U_{C0inM}	*Intermediate operating voltage*
4.	U_{C0N}	*The ultra-capacitor rated voltage*

Figure 4. Definition of ultra-capacitor voltages,

B. The maximum operating voltage of the ultra-capacitor

It depends on the interface power converter topology and maximum operating dc bus voltage. Here direct non-isolated converter is used as an interface power converter [5], the ultra-capacitor maximum operating voltage is

$$U_{co\ max} \leq V_{BUSmax} \tag{1}$$

C. Minimum operating voltage

The minimum operating voltage of the ultra-capacitor is determined by the dc-dc converter current capability *Icomax* and the conversion power *Pco*.

$$U_{comin} \geq \frac{P_{co}}{I_{comax}} \tag{2}$$

D. intermediate operating voltage

The intermediate voltage U_{C0inM} is long-term average voltage and it is defined as

$$U_{C0inM} \cong \sqrt{\frac{E_{DCH}U_{C0\max}^2 + E_{CH}U_{C0\min}^2}{E_{DCH}+E_{CH}}} \tag{3}$$

Where, E_{CH} and E_{DCH} is charge and discharge energy it can be given by as below.

$$E_{CH} = E_B = n_B \int_0^{T_B} P_0(t)dt \qquad E_{DCH} = E_{RT} = \frac{1}{n_M}\int_0^{T_{RT}} P_0(t)dt \tag{4}$$

E. The ultra-capacitor module rated capacitance

The capacitance selection depends on the application. In a general case, assuming that the ultra-capacitor is a linear capacitor without internal resistance, the capacitance *Co* can be computed as. [5]

$$C_0 \cong (E_{CH} + E_{RT})\frac{2}{\left(U_{C0\max}^2 - U_{C0inM}^2\right)} \tag{5}$$

IV. LOSSES AND CONVERSION EFFICIENCY

The ultra-capacitor losses depend on three parameters: 1) The resistance *Rca*, 2) The capacitance *Co* and 3) The ultra-capacitor initial voltage. And losses are computed as,

$$E_{LOSSES} \cong R_{C0}P_{C0}^2 \int_0^{T_{CH}} \frac{C_0}{C_0U_{C0\max}^2 - 2E_{CH} + 2P_{C0}t}dt = \frac{R_{C0}P_{C0}C_0}{2}\ln\frac{C_0U_{C0\max}^2}{C_0U_{C0\max}^2 - 2E_{CH}} \tag{6}$$

Round trip (charge/discharge) energy efficiency is

$$\eta = 100\left(1 - 2\frac{E_{LOSSES}}{E_{CH}}\right) = \eta(C_0) \tag{7}$$

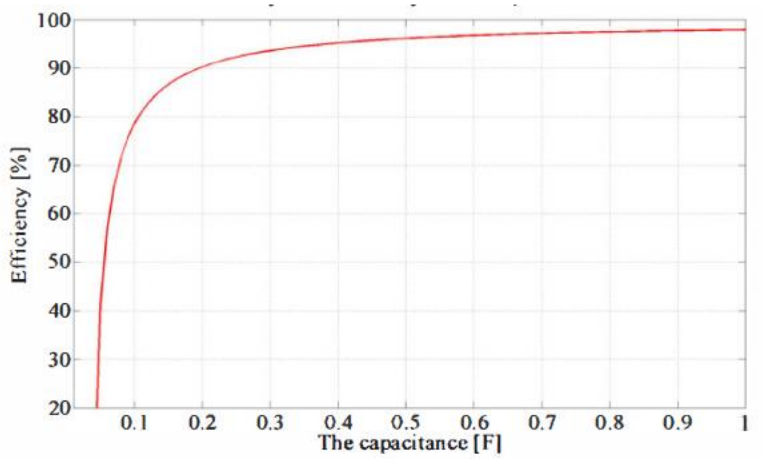


Figure. 5. The conversion efficiency versus the ultra-capacitor rated capacitance *Co.* the conversion power *Pco*=5.5kW.

V. THE MODULE CELLS SELECTION AND CONENCTION ARRANGEMENT

In sections III and V we have defined voltage and capacitance rating of the ultra-capacitor module according to the application requirements. In this section we will briefly describe process for the module elementary cells selection and connection arrangement.[6] One can compute number of series connected cells as,

$$N = \mathrm{int}\left(\frac{U_{C0N}}{U_{C0N1}}\right) \tag{8}$$

Where, U_{coN1} is voltage rating of an individual cell.

If the individual cell capacitance is greater than capacitance of cells on the market, M cells have to be connected in parallel to achieve the required capacitance Number of parallel connected cells is,

$$M = \mathrm{int}\left(N\frac{C_{01}}{C_{01D}}\right) \tag{9}$$

Where, C_{OlD} is capacitance of a cell.

VI. A DESIGN EXAMPLE

The design specification is given in Table below. The ultracapacitor module was designed for a 5.5kW schneider ATV71 variable speed drive.

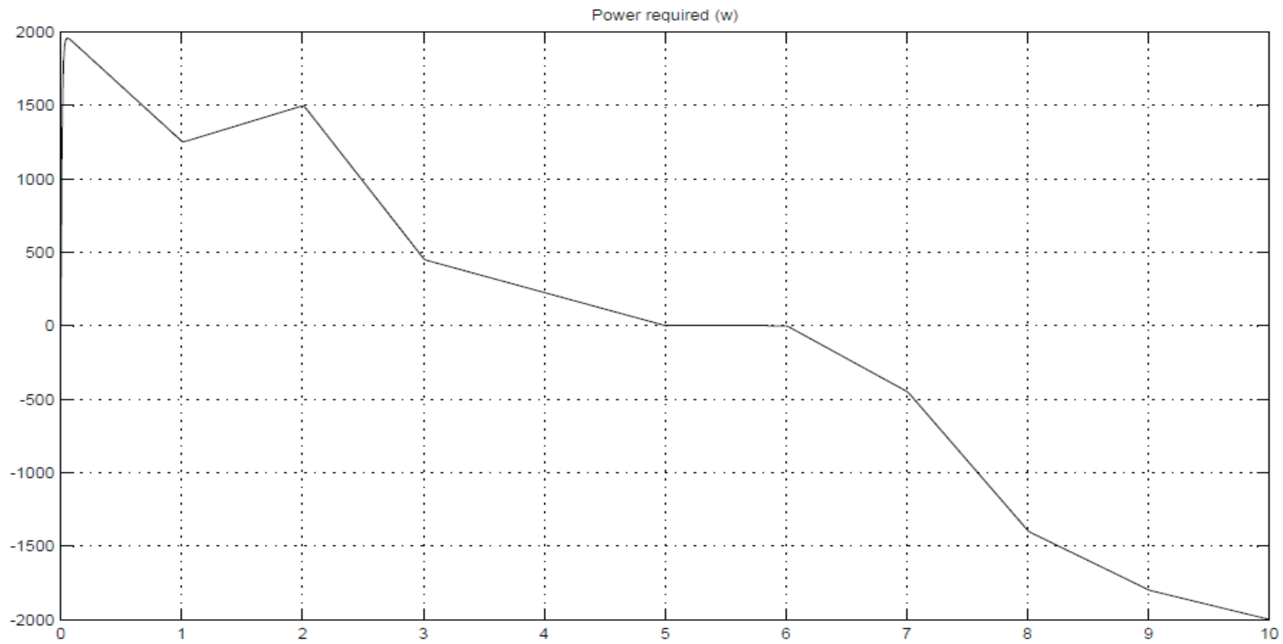
Application	Variable Speed Drive
Nominal Power	5.5 Kw
Ride Through time	1 s
Breaking time	15 s
Conversion Efficiency	>90%
Maximum DC Bus voltage	800 V

Design and selection of this drive is shown in the table as below.

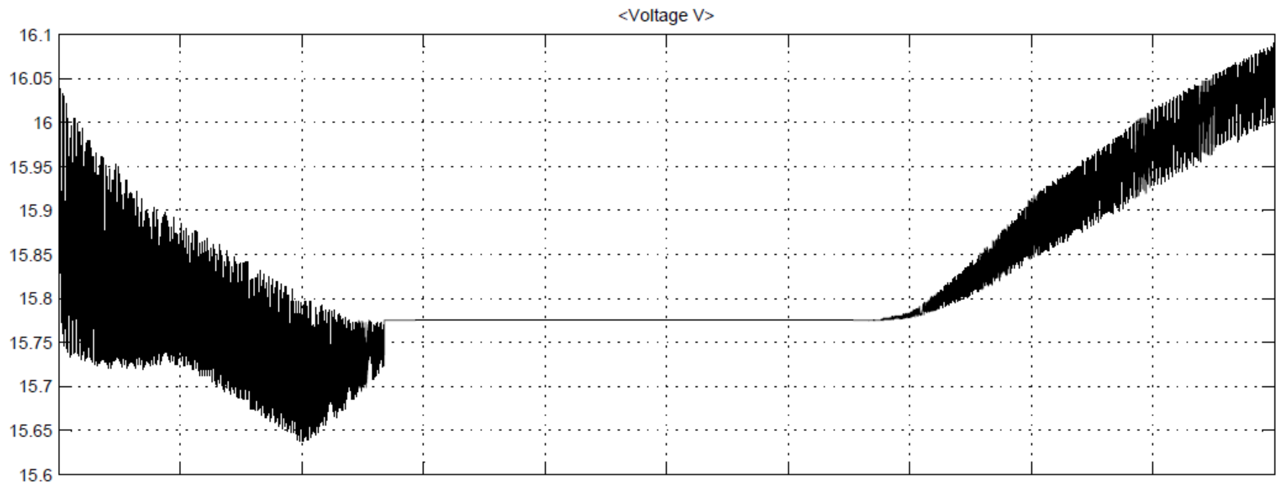
Design Step and Description	Equation	Calculation Results
Step 1 Maximum operating voltage	$U_{co\,max}$	780 V
Step 2 Minimum operating voltage	$U_{comin} \geq \frac{P_{co}}{I_{comax}}$	375 V
Step 3 intermediate operating voltage	$U_{C0inM} \cong \sqrt{\frac{E_{DCH}U_{C0\max}^2 + E_{CH}U_{C0\min}^2}{E_{DCH} + E_{CH}}}$	$\cong \sqrt{\frac{1*5500*780^2 + 15*5500*375^2}{1*5500 + 15*5500}} =$ $= 412.14V$
Step 4 Rated capacitance	$C_0 \cong (E_{CH} + E_{RT})\frac{2}{\left(U_{C0\max}^2 - U_{C0inM}^2\right)}$	$= (15*5500 \quad +1*5500 \quad)\frac{2}{\left(780^2 - 375^2\right)}$ $= 0.4F$
Step 5 Series connected sub-cells	$N = \operatorname{int}\left(\frac{U_{C0N}}{U_{C0N1}}\right)$	$N = \frac{800}{2.8} = 286$
Step 6 Capacitance of the Module	$C_{01} > C_0 N$	$C_{01} > 0.4 * 286 = 114F$

VII. MATLAB/Simulink Results

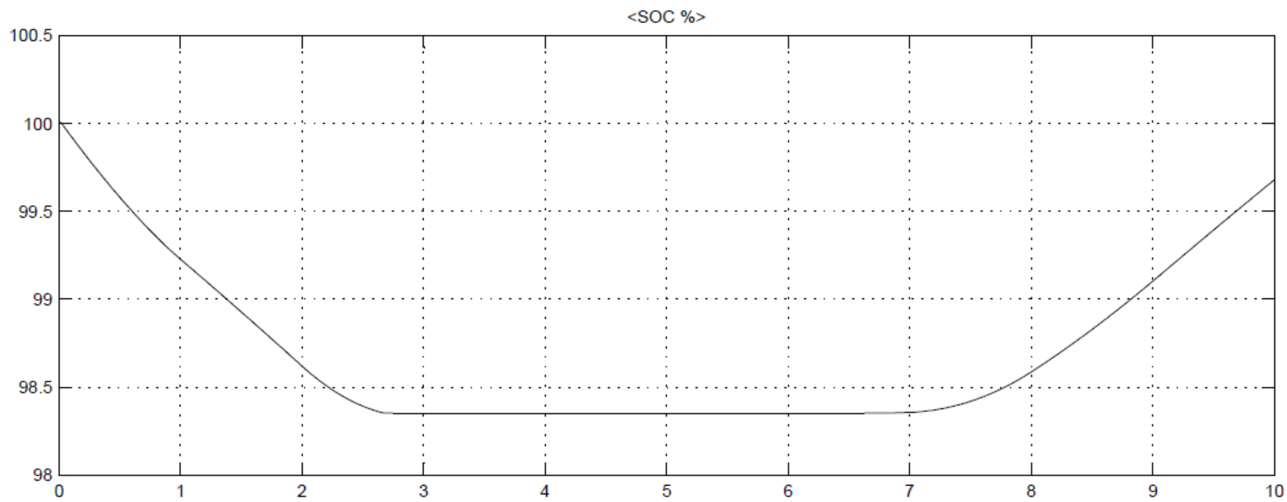
The ultra-capacitor module has been tested on a variable speed drive used in an application with demand for 15s braking at nominal power and ride-through capability. Simulation waveforms the ultra-capacitor State of charge, Ultracapacitor voltage depicted in Fig. 6. Ultracapacitor is connected to the DC bus via DC-DC bi-directional buck-boost converter and the load profile of the drive is also given in the waveforms.



(a)



(b)



(c)

Figure 6. (a) Power Required to Drive. (b) Ultracapacitor Terminal Voltage (c) State of Charge of Ultracapacitor.

VIII. CONCLUSION

A procedure for selection and design of an ultra-capacitor module for Regenerative Breaking Energy Recovery applications has been discussed and presented in this paper. Selection procedure of the main parameters such as the ultra-capacitor voltage, capacitance, no of series and parallel cells have been described in details. Presented design procedure is simulated in the MATLAB/Simulink using the parameters of the Practical drive and capacitor charge/discharge profile is satisfactory analyzed from the state of charge waveform.

REFERENCES

[1] B. E. Conway, "Electrochemical supercapacitors, fundamentals and technological applications", Academic/Plenum Publisher, New York 1999.

[2] Sang-Min Kim and Seung-Ki Sul, "Control of rubber tired gantry crane with energy storage based on supercapacitor bank," *IEEE Trans. Power Electronics*, Vol. 21, No. 5, pp. 1420-1427, September 2006.

[3] A. von Jouanne, P. N. Enjeti and B. Banerjee, "Assessment of ride-through alternatives for adjustable-speed drives," *IEEE Trans. Industry Applications*, Vol. 45, No. 4, pp. 908- 916, July/August 2009.

[4] P. J. Grbovic, "Ultra-capacitors in power conversion: analysis, modelling and design in theory and practice", Tutorial, ECCE 2011, IEEE Energy Conversion Congress and Exposition, Phoenix, Arizona,September 17-22, 2011

[5] P. J. Grbovic, P. Delarue and P. Le Moigne, "A Three-Terminal UltraCapacitor Based Energy Storage and PFC Device for Regenerative Controlled Electric Drives," IEEE Trans. Industrial Electronics, Vol. 59,

[6] J. M. Miller, "Ultra-capacitor applications", The Institute of Engineering and Technology, UK, April 15" 2011,

[7] P. J. Grbovic, P. Delarue, P. Le Moigne and P. Bartholomeus, "The ultra-capacitor based controlled electric drives with braking and ridethrough capability: Overview and analysis," IEEE Trans. Industrial Electronics, Vol. 58, No. 3, pp. 925-936, March 2011.