Status Report 2003 on Capacitor Storage Systems - *ECaSS®*

Michio Okamura, Okamura Lab., Inc., Yokohama, Japan [1]

Introduction

Electric Double Layer Capacitors (EDLCs or ultracapacitors, supercapacitors) have long been regarded as ideal electrical storages in theory, providing good efficiency at high power with almost eternal lives. However, as long as there were no real products that was true only in PR materials.

Since the last meeting at EESAT 2002, our electricity storage system using capacitors, called ***ECaSS®*** [1] (Energy Capacitor Systems - ECS now got a new registered trade name), has finally yielded four real products in automotive and power-line applications. Although this meeting is devoted to non-automotive applications, they are briefly included here because all kinds of applications would use identical capacitor-cells if the design requirements fell within the same ranges. It would affect production quantity and, thus, their price tags.

Research and development of EDLC in our ECaSS group has yielded significant results featuring very large energy density. The new carbon-carbon electric double layer capacitor named “Nanogate Capacitor”, not a pseudo but an intrinsic EDLC, provides 60 Wh/kg (= 216 kjoules/kg), or two to three times the specific energy of a lead-acid battery.

All of the fruitful results described hereinafter were not yielded by the endeavors of Okamura Laboratory but by those of each client engaged in the development of products.

Automotive Applications

The details are not described here since this meeting is intended for non-automotive areas. Even so, as introduced earlier, some information should be useful because capacitor productions are related to, or common with all fields. There were two major topics in this area. Two of our client companies jumped from testing stages and started selling capacitor-powered vehicles last year.

(a) Capacitor hybrid truck - June 2002
(b) Capacitor hybrid fuel cell vehicle - December 2002

Capacitor hybrid is especially promising for heavy commercial vehicle in which kinetic energy, or recuperated energy is large. That energy is too peaky and powerful to be absorbed by secondary batteries without shortening their lives. Nissan Diesel Motor Co. has been developing capacitor hybrid bus and truck utilizing ECaSS principle since 1996 and completed an automated EDLC production plant in their Ageo factory.

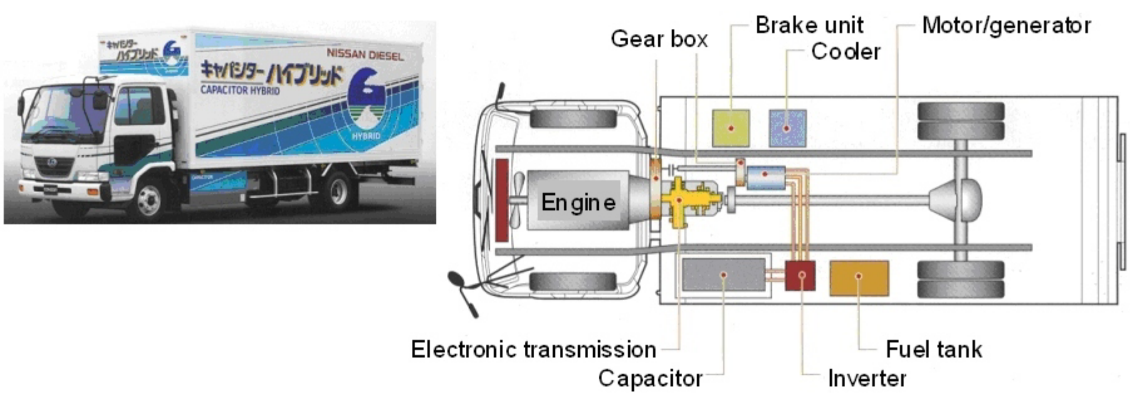

Figure 1: Layout and exterior of the capacitor parallel hybrid truck that made its debut on the market [2]

1 E-mail: michio@okamura-lab.com URL: http://www.okamura-lab.com/

A production model of parallel capacitor hybrid 8-ton truck made its debut on June 2002. The appearance and layout of the truck are shown in Figure 1. The 6.9-liter diesel engine is rated 152 kW and the synchronous motor provides 55 kW. Those two power devices are connected not only in parallel but also in any combination via clutches included in the electronic transmission. With this arrangement, the motor can be cut out from engine to keep good efficiency on brake energy regeneration.[3] When the vehicle starts off, the motor is driving, though the engine and motor work together for large acceleration. Braking energy is almost completely recovered to the capacitor bank, which will last more than 600,000 km or 2,400,000 times of charge/discharge cycles.

Fuel economy tested in M15 mode was improved 1.5 times compared with that of a conventional diesel truck of the same class. Emission decreased as much as 30% CO_2, 44% NOx and 66% PM (particulate matters), conforming to the long-term regulation limits in Japan for this type of commercial vehicle.

Figure 2: Capacitor modules and cell for truck by Nissan Diesel. Three paralleled 128 serially connected 2.7 V capacitor cells totaling 346 V maximum.

Those capacitors shown in Figure 2 have been produced by Nissan Diesel Motor Co. based on ECaSS technology. Although it is a common practice to cool batteries by forced air or liquids, our intention was the operation at a better efficiency with less heat generation and without forced cooling. The new truck has three paralleled 128 serially connected 2.7 V capacitor cells totaling 346 V maximum. For safety reasons, acetonitrile is avoided in the electrolyte of the cell, and a fairly strong modular construction is employed with crash guards.

Since safety is a particularly important issue for commercial vehicles, thorough tests have been carried out on the individual capacitors as well as modules. They did not easily burn and would not explode, even in forced burn and crash situations. Judging from these results, those capacitors are observed to be considerably safe [4].

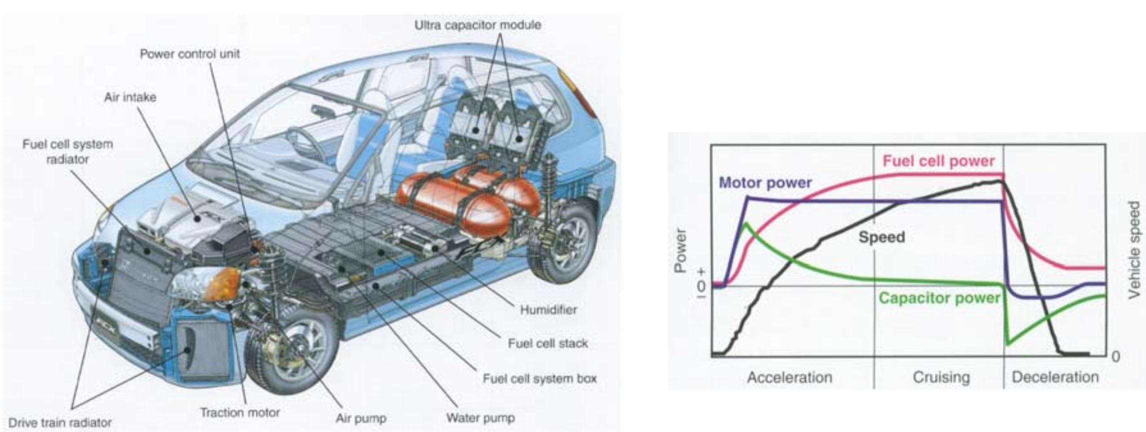

Figure 3: Layout of Honda FCX, fuel-cell/capacitor hybrid, and capacitor's cooperation with fuel cell [5]

As shown in the picture of Honda FCX [5] in Figure 3, a fuel cell vehicle has special advantages in hybridizing with capacitor storage systems. For example, a capacitor hybrid is so ideal and easy to apply for fuel cell vehicle, that a fuel cell system already has a fully sized traction motor and DC/AC converter. Those two parts are usually most costly if it is converted from an engine vehicle. All the power to accelerate and braking are supplied from or stored to capacitors.

The typical status of sharing and distributing power between fuel cell and capacitor storage is illustrated [5] in Figure 3. In acceleration, the capacitor supplies a major part of the motor current, quickly covering the slow rise of fuel cell power. When the brakes are applied, regenerated power and fuel cell power that cannot respond fast enough to decrease are stored into the capacitor. This example is a case of automotive usage, but such a combination with capacitor storage can be adapted to any other stationary fuel cell applications.

UPS and Power line Applications

Uninterruptible Power Supplies using EDLC made by Shizuki Electric Co., Nishinomiya, Japan started to be sold two years ago and expanded in a series of 200, 100, 50 kVA and 30, 20, 10 kVA. In addition, a schedule is shown for 2000, 1000, 500 kVA. The manufacturer is confident of the advantages over both battery and electrolytic UPSs. Their 100-kVA systems, which incorporates eight modules of 20 EC-L type cells, sustain up to one second of full interruption of the power.

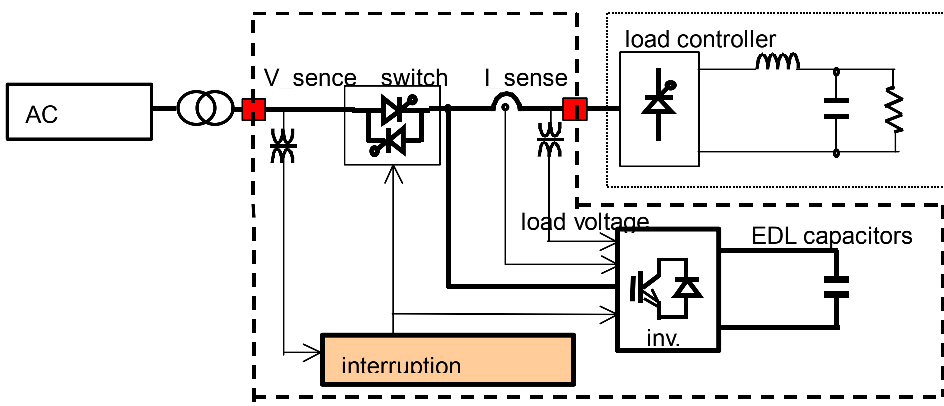

Figure 3: System diagram of 50, 100 and 200 kVA capacitor UPS by Shizuki Electric. [6]

The EC-L type capacitor is designed to provide 95% discharge efficiency at 30 - 60 seconds discharge, so the one second UPS will require an exceptionally quick and high power discharge. This is only allowed in this type of application, where AC interruption will not happen too frequently. Equivalent circuits, or SPICE models of their capacitor module used here, are shown in Figure 2. The simple RC model (a) does not work accurately for a 1 second discharge but a model with a three-stage RC array (b) yielded accurate enough behavior for real operation.

The feature of this product is that the guaranteed backing up time is selected as one second. Such a short back

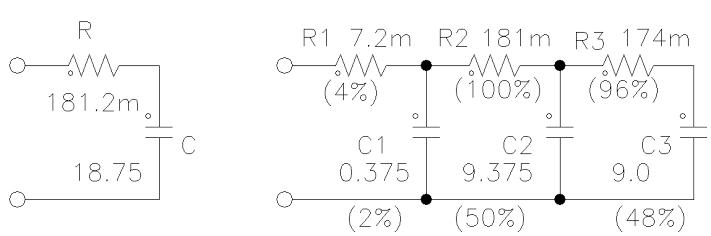

Figure 2: Simplified (a) and detailed (b) circuit model of Shizuki FML-2A 8s-2p module [6]

up is difficult for batteries, and such a long compensation is practically impossible for electrolytic capacitors. The system diagram of this UPS is shown in Figure 3. The specifications include converter operation DC 400-265 V, a switching time of within 2 mili-seconds and the covering of a one second backup more than ten times at a 20 second interval. There are several papers describing these product details [5], though they are written in Japanese.

Other than UPSs, there are various applications for EC-L type capacitors in that area, such as peak load leveling for co-generative stations, fuel-cell systems, and power line stabilization.

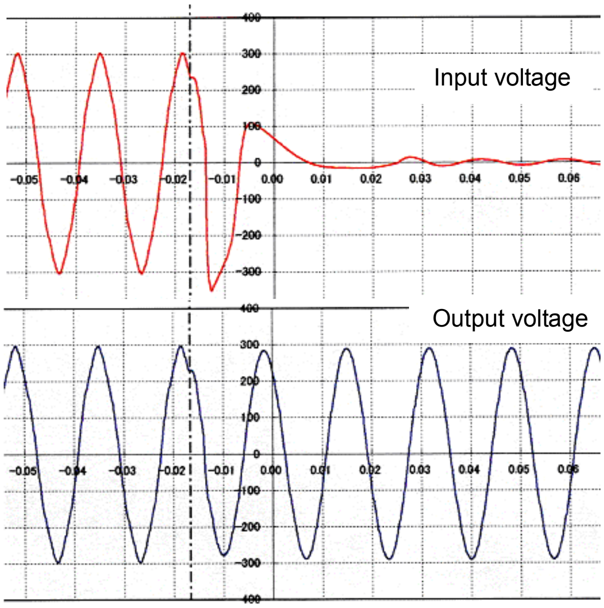

Figure 6: Input and output voltage at an interuption of power.[6]

Figure 7: 100kVA UPS and 20-cell capacitor module by Sizuki Electric Co. [6]

New Capacitor Development

Research and development of EDLCs in our ECaSS group has yielded a significant result. “Nanogate Capacitor” made its debut on October 2, 2003 by JEOL, Ltd [7]. At the present sample evaluation stage, the mass production model of ECaSS capacitors can be estimated as 60 Wh/kg, 90 Wh/lit for a high energy EC-B type cell, and 30 Wh/kg with 8 kW/kg power density for a high power type EC-L cell [8].

The specific energy of “Nanogate Capacitor” is five to ten times our present ultracapacitor, two to three times that of lead-acid battery, almost equal to NiMH, and close to Li-ion large-scale batteries, where they have to suppress energy density for life and safety. In many battery applications, capacitors can replace them because of the capacitors’ features, such as much longer life, safer, lower environmental load, and higher efficiency.

Figure 8: “Nanogate Capacitor” by JEOL [7]

“Nanogate Capacitor” depends not on a pseudo capacitance but on symmetric or carbon-carbon electric double layer principle. The electrode does not incorporate activated carbon but specially treated “Nanogate Carbon” to obtain large capacitance density together with high withstanding voltage.

“Nanogate Capacitor” with ECaSS technique will bring up capacitor storage to be competitive with any other storage methods, and open up a wide area of applications. Because of this big development, our plan and schedule for mass production of EDLCs are now being remodeled completely. A revised schedule will be publicized in the near future.

References

[1] M. Okamura, “High Energy Density Capacitor Storage Systems”, EESAT 2002.
[2] Nissan Diesel Co., CONDOR Capacitor Hybrid Truck, Catalogue, June, 2002
[3] S. Nishikawa, M. Sasaki, S. Okazaki, S. Araki, T. Miyata and M. Nishikawa, “Development of Capacitor Hybrid Truck” Proceedings of Jidosha-Gijutsu-kai, 20025217, July (2002) (in Japanese with English extended summary).
[4] S. Araki, M. Sasaki, I. Notsu, Y. Yamada, T. Kawaji and H. Ono, “Development of Electric Double Layer Capacitors for Hybrid Vehicles” Jidosha-Gijutsu-kai, 20005567, October (2000) (in Japanese).
[5] K. Tamenori, N. Oki, S. Kato, K. Yamamoto, A. Anekawa and M. Noguchi. Application Studies of Electric Double Layer Capacitor System for Fuel Cell Vehicle. Advanced Automotive Battery Conference. Nice, 2003
[6] T. Mutoh, “Development of Line Voltage Sag Compensator using Electric Double Layer Capacitors. Denshi Gijyutu, vol.44, no.11, 52-58, 2002. (in Japanese)
[7] JEOL website, October 2003, URL = http://www.jeol.co.jp/english/newsroom/2003/031003.htm
[8] M. Okamura and H. Nakamura, “ECaSS - System/Capacitor Improvements and Discussion” The 13th international seminar on double layer capacitors and similar energy storage devices. Dec.8-10 (2003)(under preparation)