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Advanced capacitors and their application

S. Nomoto[a], H. Nakata[a], K. Yoshioka[a,*], A. Yoshida[a], H. Yoneda[b]

[a]Matsushita Electric Industrial Co., Ltd., 3-1-1 Yagumo-nakamachi, Moriguchi, Osaka, Japan
[b]Matsushita Electronic Components Co., Ltd., Uji, Kyoto, Japan

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Abstract

An electric double-layer capacitor is one of the energy storage devices, which consists of carbon polarizable electrodes and electrolytic solution. It has been used for a memory back-up device since 1978 and recently advanced capacitors with higher capacitance and lower resistance are developed for high-rate discharge uses. In the paper, outline of the capacitors, development history and present status of the capacitors, effective factors to capacitor characteristics, and potential application of capacitors are discussed. Electrical characteristics of the newly developed capacitor for power uses, ''UP-Cap'', are described. Future prospect of the capacitors as energy storage devices will be discussed.

Keywords: Capacitor; Electrodes; UP-Cap

1. Introduction

An electric double-layer capacitor (EDLC) is an energy storage device, in which an electric charge is stored in the electric double layer [1] formed at the interface between carbon materials and electrolytic solutions when dc voltage is applied. The EDLC has a pair of polarizable electrodes with collector electrodes, a separator, and an electrolytic solution. The capacitor is charged and the electrical energy stored in the capacitor is discharged at loads. Although an energy density of EDLCs is considerably low compared with rechargeable batteries, the capacitor shows many features, i.e. a higher power density, a stable charge–discharge performance in a wide temperature range, an environmental advantage, etc. Many studies on EDLCs have been carried out in correlation with physical and chemical properties of carbon electrode materials [2]. Fig. 1 summarizes capacitors in market and under development.

2. History and present status of the capacitors

In later 1970s, with increasing application of ICs and LSIs, micro-power sources were required to back-up for microprocessors with lower voltages and currents. Matsushita started to produce EDLCs in 1978, which have been widely used as memory back-up devices in many electrical appliances, e.g. VCRs, cameras, etc. In 1980s, the EDLCs were used for the energy source to drive wristwatches with solar cells. In early 1990s, EDLCs were used as actuator back-up sources for toys, electric appliances, home equipment, etc. Recently, EDLCs with higher capacitances and lower resistances are under development for higher electric power sources in EV systems, electric power storage systems, etc.

3. Effective factors to capacitor characteristics

The EDLC is supposed to be assembled micro-capacitors connected in series and parallel. Fig. 2 summarizes representative relationships of capacitor characteristics and material properties. Specific surface areas, pore size distributions, and tapping densities of activated carbons seriously affect the capacitor characteristics. An electrochemical decomposition voltage of electrolytic solutions is also one of the important factors to determine the energy density of the capacitors. The construction of carbon electrodes and collector electrodes is also an effective factor to capacitor characteristics [3,4].

4. New capacitor for power uses

Recently, Matsushita Electronic Components Co., Ltd., released a new-type capacitor for power uses ''UP-Cap'',

* Corresponding author. Tel.: +81-6-6906-2435; fax: +81-6-6903-0996.
E-mail address: yosida@ctmo.mei.co.jp (A. Yoshida).

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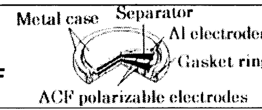
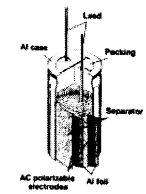
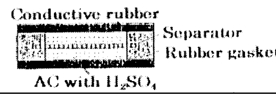
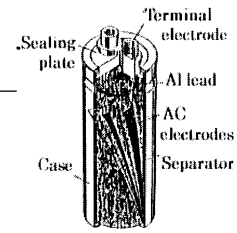
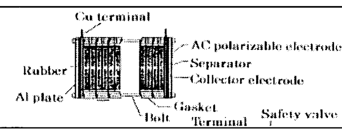
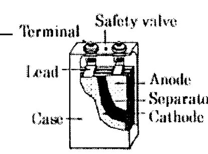
	Polarizable Electrodes	Electrolyte	Construction of Cells		Development
Low Rate Use	Activated carbon (AC) fiber cloth AC/binder pellet	Organic	Coin type ~5.5V/1.5F	 	Matsushita Elna Kanebo Hitachi Maxell
Low Rate Use	AC/binder film	Organic	Jelly-roll tubular type ~2.3V/50F		Matsushita Elna Kanebo
Low Rate Use	AC powder pellet	Aqueous	Stack tubular type ~5.5V/10F	 	Tokin Samsung
High Rate (Power) Use	AC/binder film	Organic	Jelly-roll tubular type ~2.3V/6000F		Matsushita Elna Shizuki Nippon -chemicon Nichicon
High Rate (Power) Use	AC/carbon composite	Aqueous	Stack square type 12V/200F		NEC
High Rate (Power) Use	AC fiber/Al composite	Organic	Stack square type 2.5V/3000F		Maxwell EPCOS
High Rate (Power) Use	AC/binder composite	Organic	Stack square type 2.5V/6000F		Matsushita Asahi glass

Fig. 1. Summary of electric double-layer capacitors.

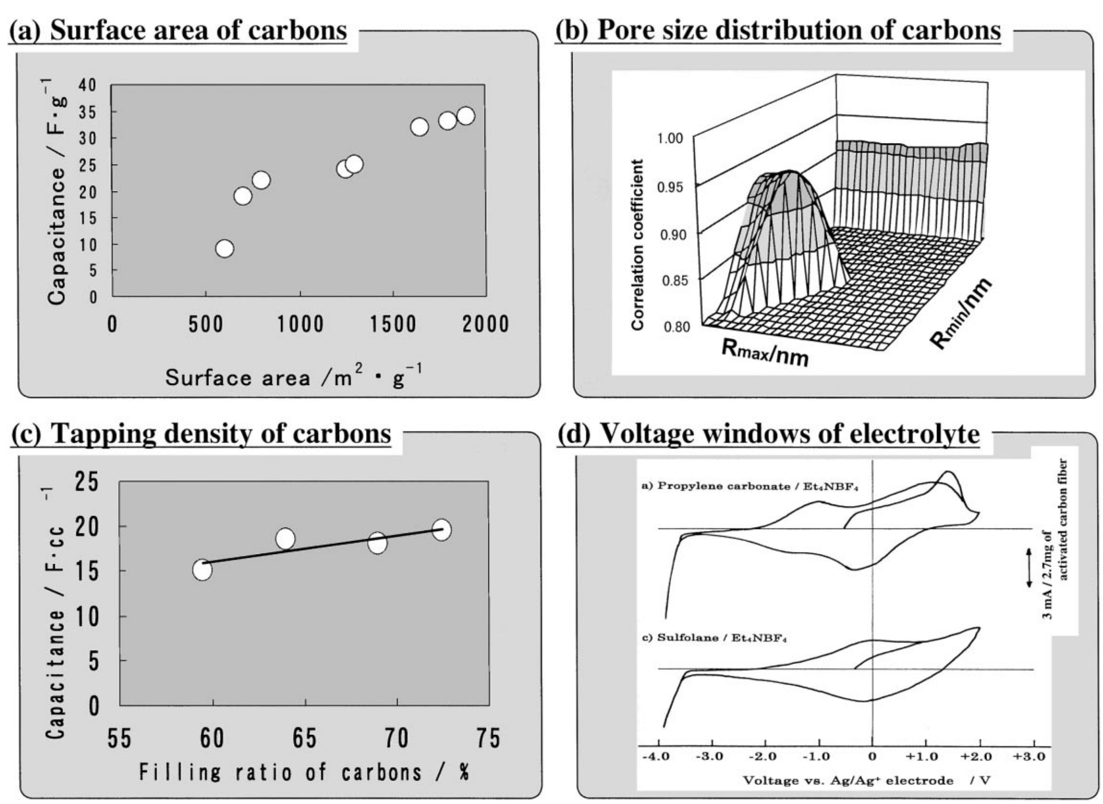


Fig. 2. Relationships between capacitor characteristics and material properties.

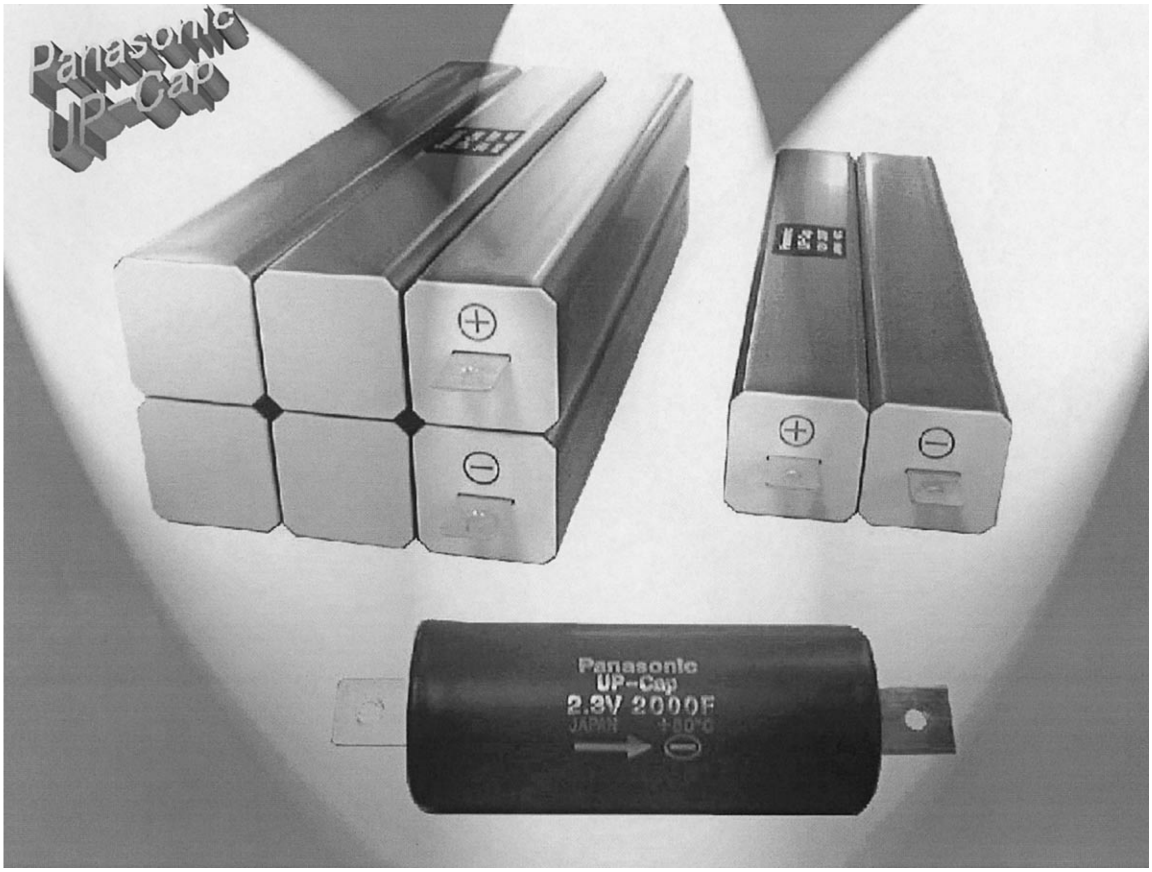


Fig. 3. Appearance of the newly developed capacitors, ‘‘UP-Caps’’.

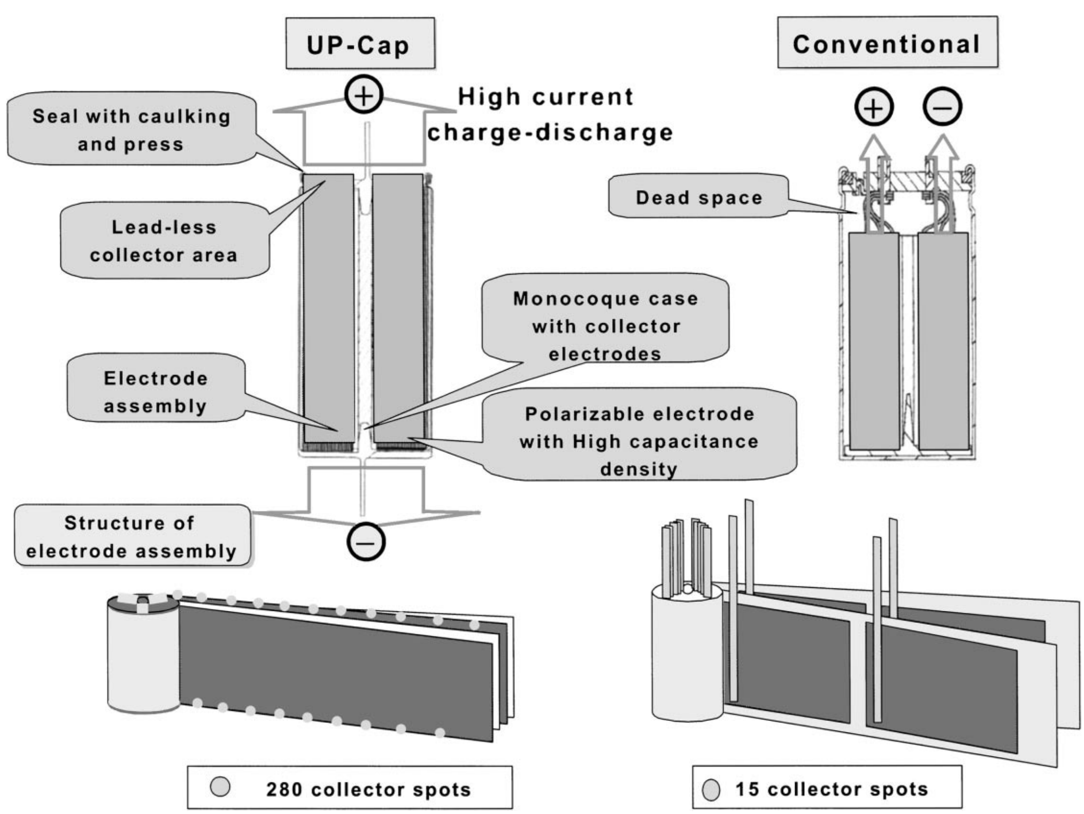


Fig. 4. Structure of the ‘‘UP-Cap’’.

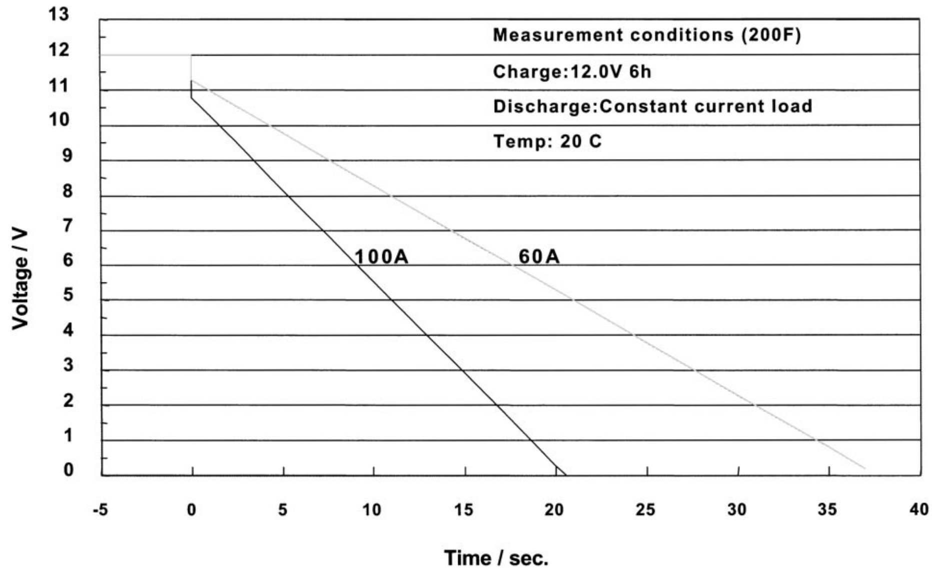


Fig. 5. Representative discharge characteristics of the "UP-Cap".

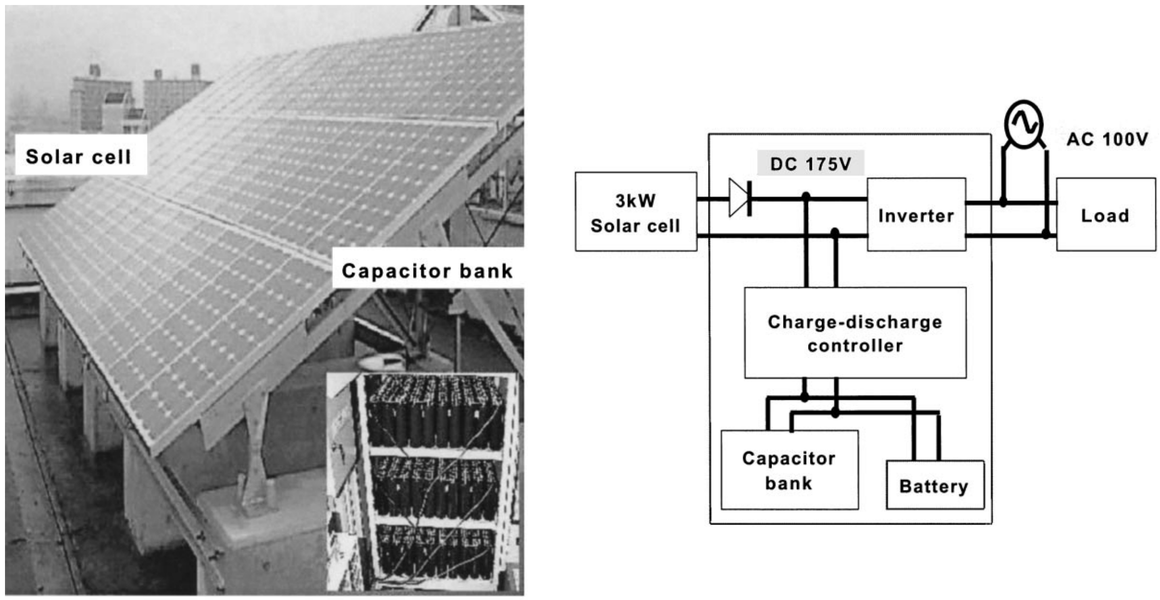
which shows higher capacitance density and almost half times lower resistance compared with conventional EDLCs. Newly developed activated carbon materials, polarizable electrode layers with a high filling density of activated carbons, and a new construction of collector electrodes, realized a high performance of the new EDLC. Fig. 3 shows an appearance of the UP-Caps.

In the UP-Cap, a pair of the aluminum foils with activated carbon layer and separators are wound to obtain a jelly-role type electrode assembly. In the case of conventional capacitors, several pieces of aluminum foil ribbons are welded to the aluminum foil to collect charges. On the other hand in the case of UP-Cap, the electrode assembly with conductive margins is pressed and laser-welded with an aluminum case and an aluminum collector plate at the margins, which resulted in a very high efficiency of a charge collection. Fig. 4 shows a structure of the UP-Cap compared with a conventional capacitor. The edge of the aluminum case is caulked with a press to seal the cell. The axial-lead-type structure of the cell resulted in capacitors with very low inner resistance which can be charged and discharged at very high current loads. Fig. 5 shows representative discharge characteristics of the UP-Cap unit in which six capacitors are connected in series. At high current loads, i.e. 60 or 100 A, the capacitor unit shows very stable discharge characteristics. A 10 s of back-up time was obtained even with a current load of 100 A at −25°C for the UP-Cap. Consequently, the new capacitor shows very good back-up performance.

5. Application of the capacitors

EDLCs have been applied to many kinds of electrical equipments and systems as energy back-up devices. Small coin-type EDLCs are used as memory back-up devices for microcomputers at less than mA-rate-load in VCRs, handy telephones, pagers, etc. Tubular-type EDLCs have such a low inner resistance that they are used as back-up devices for actuators at less than A-rate-load in toys, measuring equipments, traffic signals, electric thermo pots, etc. to drive motors or LEDs [5,6]. Many applications of the power-type EDLCs have been studied in the system of electric heated catalysts, EVs, elevator systems, cordless devices, etc. In these capacitor-systems, EDLCs work as energy-storage devices for a temporary period in which EDLCs are charged by solar cells, batteries, AC sources, inner combustion engines, fuel cells, etc.

Recently, we have carried out an experiment on an output-power-leveling of a photo-voltaic generation with capacitors, with a support of NEDO Japan. Fig. 6 shows an appearance and a construction of the "output-power-leveling system with a capacitor bank for solar cell system" The system consists of a 3 kW solar panel, a converter, a power link inverter, and a capacitor bank. The capacitor bank consists of 70 pieces of a 2400 F cell connected in series or three 70 pieces of a 6000 F cell connected in parallel. The system has been working with optimized algorithm and software developed for a high energy efficiency. Fig. 7 shows a representative result of the experiment. With the capacitor bank of 70 pieces of a 2400 F cell, an output fluctuation was controlled for 3 min. An output fluctuation rate $\Delta P_{ac}/\Delta P_{pv}$ was below 14.3%, where ΔP_{ac} and ΔP_{pv} were differences between a maximum and a minimum value of an ac output and an output power of a solar cell, respectively. V_{gc} is a voltage of the capacitor bank. An 88% of efficiency was obtained for the system working. In the experiment of the 6000 F cell-bank, not only a considerable decrease of an ac output fluctuation, but a longer back-up period of the output were obtained.



(a) Appearance of the system **(b) Construction of the system**

Fig. 6. The output power leveling system.

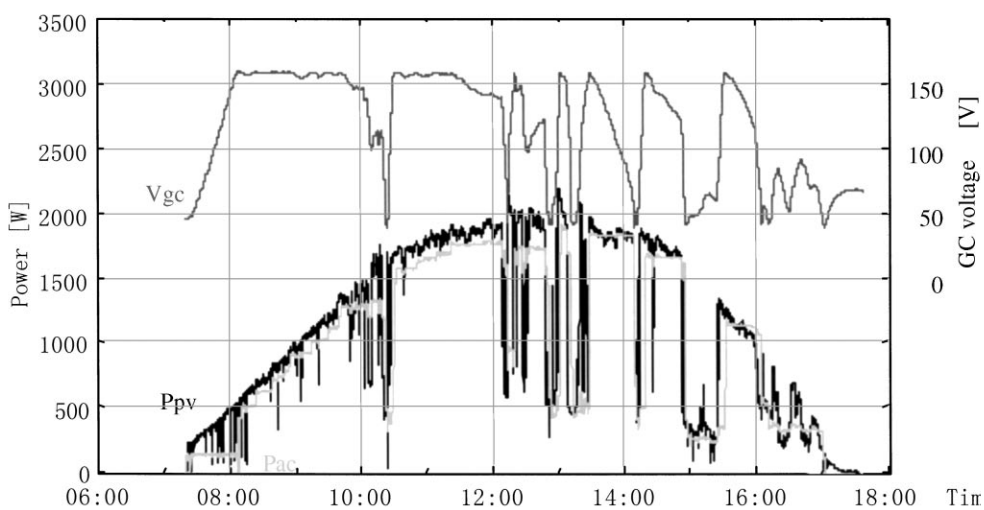


Fig. 7. An output-power-leveling of a photo-voltaic generation with capacitors.

6. Future prospect of the capacitors

To attain high energy density and power density, high reliability, low cost of EDLCs, and electric circuits for efficient charges–discharges of EDLCs, development of new material for electrodes and electrolytic solutions, and power electronics study with inverter–converter components are significant. In the next century, we hope the EDLC-system with primary energy sources will play an important role in the field of energy storage or energy management.

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