Dağıtık Üretim Sistemleri ve Şebeke Entegrasyonu

Ders 2
Dr. Ali Rıfat BOYNUEĞRİ

Dağıtık Üretim Sistemleri Enerji Depolama

- Batarya - Elektrokimyasal Enerji – (Flow, Solid State, Li bazlı, Ni-Cd vb.)
- Ultra Kapasitör – Elektrik Alan –
- Bobin süper iletken – Manyetik Alan -
- Isı – Power 2 Heat (P2H)-
- Kompresör – Basınç-
- Volan – Kinetik Enerji-
- Pompaj Depolamalı Hidroelektrik – Potansiyel Enerji- (yay)
- Hidrojen – Kimyasal-

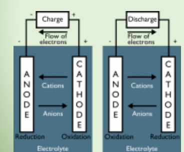
Energy Storage Systems

- The renewable energy systems such as wind, solar, etc. are totally dependent on meteorological conditions. Therefore, there can occur great changes in power production of these resources seasonally, daily and even instantly. This issue results in unbalance between the produced and consumed electrical energy.
- In order to supply the energy requirement in all conditions, energy storage units play an important role. The excess energy generated by the renewable resources is transferred to energy storage units and this stored energy is then used to supply the load demand when the main power sources are not existent or not sufficient.
- Especially for stand-alone systems (no power grid existence) the research and examination on energy storage units show significant importance.
- Energy storage technologies can be electrical or thermal. There is an electrical input-output for electrical energy storage systems while a thermal input-output exist for thermal systems.
- The mentioned electrical energy storage systems can be in form of electrochemical (battery, etc.), kinetic (flywheel, etc.) or potential (pumped hydro, compressed air, etc.). There are also different technologies used for thermal energy storage.

Energy Storage Systems

Electrical Energy Storage Systems:

Batteries:
Batteries are the most mature technology of storing electric energy in chemical form. Batteries are classified as non-rechargable (primary) and rechargable (secondary) batteries. Below is the diagram of charge-discharge of a secondary battery.



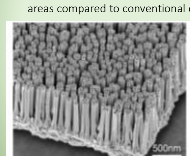
Battery technologies:
- Lead-Acid Batteries
- Nickel-Cadmium Batteries
- Sodium-Sulphur Batteries
- ZEBRA Batteries
- Lithium-Ion Batteries, etc...

Batteries have higher energy densities than many storage types. However, many batteries are prone to operating temperatures, charge-discharge cycles, lower power densities, etc.

Energy Storage Systems

Electrical Energy Storage Systems:

Ultracapacitors:
- Nano-technology! This means so much greater Farads in significantly small areas compared to conventional capacitors.

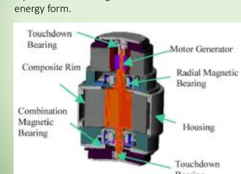


- They have significantly high power densities that is an important advantage for structures like electric vehicles.
- The cycle life of ultracapacitors is assumed infinite.
- Operating temperatures have very limited impact on performance compared to batteries.
- However, they have significantly low energy densities.

Energy Storage Systems

Electrical Energy Storage Systems:

Flywheels:
Flywheel is a rotating mass in one axis that stores electric energy mechanically in kinetic energy form.

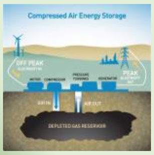


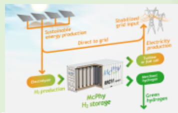
- Charging for flywheels means producing mechanical rotating energy via excess electrical energy in motor mode.
- Discharging for flywheels means slowing down the rotating mass to generate electricity in generator mode.
- The biggest problem is the self-discharge in idle mode!
- Thus they are more suitable for short term storage rather then long term.

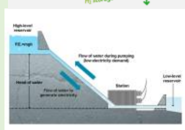
Energy Storage Systems

Electrical Energy Storage Systems:

Other methods:
- Hydrogen energy storage
- Pumped-hydro energy storage
- Compressed-air energy storage







Energy Storage Systems

Energy Storage Unit	Main Advantage	Main Disadvantage	Potential Area of Use
Battery	The most mature energy storage technology	Short cycle life	Electric vehicles, portable appliances, low power renewable energy systems
Ultracapacitor	Long cycle life	Low energy density	Electric vehicles
Flywheel	High power density	High self-discharge (losses in idle mode)	Grid integration of renewable energy systems, some space applications
Pumped-hydro and compressed air	Possibility of storing extremely high amounts of energy	Required terrain conditions	Significantly high power renewable energy systems

Enerji Depolama Sistemleri

Energy Storage

- Energy density
- Power density
- Cell/module management
- Thermal management
- Control and power management
- Life cycle time
- Self discharge
- Efficiency, charging, safety
- Recycling

Enerji Depolama Sistemleri

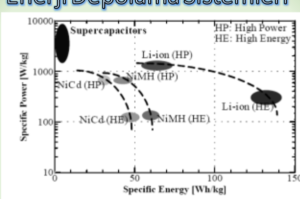
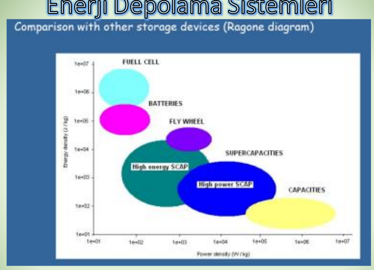


Fig. 4. Specific power versus specific energy of supercapacitor, NiCd, NiMH and Li-Ion battery technology from the SAFT Company.

Özgül enerji yoğunluğu enerji kaynağının birim kütlesinde depolanan enerji miktarını göstermektedir. Özgül güç ise yine enerji kaynağının birim kütlesinin verdiği güç olarak ifade edilmektedir.

Enerji Depolama Sistemleri



Genel olarak enerji depolama sistemleri, yakıt hücresi ve kondansatörlerin enerji ve güç yoğunlukları

Enerji Depolama Sistemleri

Energy Storage Efficiency

Energy Storage Options	Efficiency
Pumped-Hydroelectric Storage	70% - 80%
Compressed Air Energy Storage	85%
Superconducting Magnetic Energy Storage	98%
Flywheel Energy Storage	80% - 85%
Super Capacitors Energy Storage	? 80% - %90
Battery Energy Storage	60% - 80%
Hydrogen Energy Storage	60% - 85%

Energy Storage Technology Options

Maxwell TECHNOLOGIES

- Batteries:
  - + very high energy density
  - – bad cycling stability / lifetime
  - – Low peak power

- Flywheel Storage:
  - + high energy density
  - – bad cycling stability / lifetime
  - – expensive
  - – low peak power

- Ultracapacitors
  - + high energy density and peak power
  - + promising price development
  - + high numbers of cycles / lifetime (>1.5 M cycles, >10yr)
  - + simple technical system (reliability)

⇒ Ultracapacitors are optimal technology

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Batarya Sistemleri

Energy capacity:
It is the **energy stored in a battery** which is measured in **Watt-hour**
Watt-hour = V * I * hours {since voltage is kept constant, so it is measured in Ah/mAh}

We generally see the battery ratings as 2500 mAh or 4000 mAh while reading the specifications of a smart phone. What does that mean?? Let's see

Example: *2500 mAh it means that the battery has a capability to deliver 2.5A/2500mA of current to the load for 1 hour. The time that the battery works continuously depends upon the load current that it consumes. So if the load consumes only 25 mA of current then the battery can stay alive for 100 hours. How is it?*
*25 mA * 100 hours {so 25 mA of current for 100 hours}*
Similarly 250 mA for 10 hours So on…

Though the theoretical calculations seem ideal but the battery's duration changes based on the temperature and the current consumption etc.

Batarya Sistemleri

C-rate:
Charge and discharge rates of a battery are governed by C-rates. The capacity of a battery is commonly rated at 1C, meaning that a fully charged battery rated at 1Ah should provide 1A for one hour. The same battery discharging at 0.5C should provide 500mA for two hours, and at 2C it delivers 2A for 30 minutes. Losses at fast discharges reduce the discharge time and these losses also affect charge times.

A C-rate of 1C is also known as a one-hour discharge; 0.5C or C/2 is a two-hour discharge and 0.2C or C/5 is a 5-hour discharge. Some high-performance batteries can be charged and discharged above 1C with moderate stress. Table 1 illustrates typical times at various C-rates.

C-rate	Time
5C	12 min
2C	30 min
1C	**1h**
0.5C or C/2	2h
0.2C or C/5	5h
0.1C or C/10	10h
0.05C or C/20	20h

For 1Ah Battery

Batarya Sistemleri

CCA:
Ever since Cadillac invented the starter motor in 1912, car mechanics have explored ways to measure cold cranking amps (CCA). CCA measurements assure that the battery has sufficient power to crank the engine, especially when cold. Typical CCA readings for a car range from 350 to 600A and higher for trucks. SAE J537 specifies that a battery with a CCA reading of 500A can deliver 500A at –18°C (0°F) for 30 seconds without dropping below 7.2 volts.

CCA cannot be "measured," but it can be "estimated" and the process can take a week per battery. A full CCA test is tedious and is seldom done. To test CCA, apply different discharge currents to see which amperage keeps the battery above a set voltage while cold. Table 1 illustrates the test procedures according to SAE J537, IEC and DIN. The methods are similar and only differ in the length of discharge and the cut-off voltages.

SAE J537 CCA test	IEC CCA test	DIN CCA test
Fully charge battery according to SAE J537 and cool to -18°C (0°F) for 24 hours. While at subfreezing temperature, apply a discharge current equal to the specified CCA. (500 CCA battery discharges at 500A.) To pass, the voltage must stay above 7.2V (1.2V/cell) for 30 seconds.	Fully charge battery according to SAE J537 and cool to -18°C (0°F) for 24 hours. While at subfreezing temperature, apply a discharge current equal to the specified CCA. (500 CCA battery discharges at 500A.) To pass, the voltage must stay above 8.4V for 60 seconds.	Fully charge battery according to SAE J537 and cool to -18°C (0°F) for 24 hours. While at subfreezing temperature, apply a discharge current equal to the specified CCA. (500 CCA battery discharges at 500A.) To pass, the voltage must stay above 9V for 30s and 6V for 150s.

Batarya Sistemleri

End-Of Discharge Voltage
For lead acid, the end-of-discharge is typically 1.75V/cell, for NiCd/NiMH 1.0V/cell and for Li-ion 3.0V/cell. If a 1Ah battery provides 1A for one hour, an analyzer displaying the results in percentage of the nominal rating will show 100 percent. If the discharge lasts 30 minutes before reaching the end-of-discharge cut-off voltage, then the battery has a capacity of 50 percent. A new battery is sometimes overrated and can produce more than 100 percent capacity; others are underrated and never reach 100 percent, even after priming.

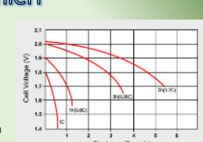
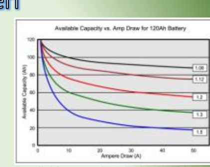


Figure 2: Typical discharge curves of lead acid as a function of C-rate.
Smaller batteries are rated at a 1C discharge rate. Due to sluggish behavior, lead acid is rated at 0.2C (5h) and 0.05C (20h).

Batarya Sistemleri

Peukert Law
The *Peukert Law* expresses the efficiency factor of a battery on discharge. W. Peukert, a German scientist (1855–1932), was aware that the available capacity of a battery decreases with increasing discharge rate and he devised a formula to calculate the losses in numbers. The law is applied mostly to lead acid and help estimate the runtime under different discharge loads.
The Peukert Law takes into account the internal resistance and recovery rate of a battery. A value close to one (1) indicates a well-performing battery with good efficiency and minimal loss; a higher number reflects a less efficient battery. Peukert's law is exponential; the readings for lead acid are between 1.3 and 1.5 and increase with age. Temperature also affects the readings. Figure 1 illustrates the available capacity as a function of amperes drawn with different Peukert ratings.
As example, a 120Ah lead acid battery being discharged at 15A should last 8 hours (120Ah divided by 15A). Inefficiency caused by the Peukert effect reduces the discharge time. To calculate the actual discharge duration, divide the time with the Peukert exponent that in our example is 1.3. Dividing the discharge time by 1.3 reduces the duration from 8h to 6.15h.



Available capacity of a lead acid battery at Peukert numbers of 1.08–1.50. A value close to 1 has the smallest losses; higher numbers deliver lower capacities. Peukert values change with battery type age and temperature:
AGM: 1.05–1.15
Gel: 1.10–1.25
Flooded: 1.20–1.60
Source: Von Wentzel (2008)

Batarya Sistemleri

Ragone Plot

Lithium- and nickel-based batteries are commonly evaluated by the Ragone plot. Named after David V. Ragone, the Ragone plot looks at the battery's capacity in watt-hours (Wh) and discharge power in watts (W). The big advantage of the Ragone plot over the Peukert Law is the ability to read the runtime in minutes and hours presented on the diagonal lines on the Ragone graph.

Figure 2 illustrates the Ragone plot of four lithium-ion systems using 18650 cells. The horizontal axis displays energy in watt-hours (Wh) and the vertical axis is power in watts (W). The diagonal lines across the field reveal the length of time the battery cells can deliver energy at given loading conditions. The scale is logarithmic to allow a wide selection of battery sizes. The battery chemistries featured in the chart include lithium-iron phosphate (LFP), lithium-manganese oxide (LMO), and nickel manganese cobalt (NMC).

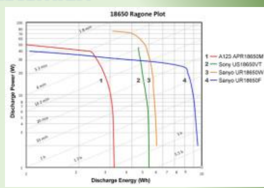


Figure 2: Ragone plot reflects Li-ion 18650 cells.
Four Li-ion systems are compared for discharge power and energy as a function of time. Not all curves are fully drawn out.

Legend: The A123 APR18650M1 is a lithium iron phosphate (LiFePO4) Power Cell rated at 1,100mAh, delivering a continuous discharge current of 30A. The Sony US18650VT and Sanyo UR18650W are manganese based Li-ion Power Cells of 1,500mAh each, delivering a continuous discharge of 20A. The Sanyo UR18650F is a 2,600mAh Energy Cell for a moderate 5Adischarge.

This cell provides the highest discharge energy but has the lowest discharge power.

Source: Exponent

Batarya Sistemleri

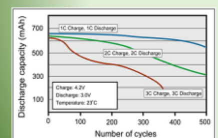
Whether you own an EV, e-bike, a flying object, a portable device or a hobby gadget, the following conditions must be respected when charging a battery the ultra-fast way:

1.The battery must be designed to accept an ultra-fast charge and must be in good condition. Li-ion can be designed for a fast charge of 10-minutes or so but the specific energy of such a cell will be low.

2.Ultra-fast charging only applies during the first charge phase. The charge current should be lowered after the battery reaches 70 percent state-of-charge (SoC).

3.All cells in the pack must be balanced and have ultra-low resistance. Aging cells often diverge in capacity and resistance, causing mismatch and undue stress on weaker cells.

4.Ultra-fast charging can only be done under moderate temperatures, as low temperature slows the chemical reaction. Unused energy turns into gassing, metal-plating and heat.



Type	Chemistry	C rate	Time	Temperatures	Charge termination
Slow charger	NiCd Lead acid	0.1C	14h	0ºC to 45ºC (32ºF to 113ºF)	Continuous low charge or fixed timer. Subject to overcharge. Remove battery when charged.
Rapid charger	NiCd, NiMH, Li-ion	0.3-0.5C	3-6h	10ºC to 45ºC (50ºF to 113ºF)	Senses battery by voltage, current, temperature and time-out timer.
Fast charger	NiCd, NiMH, Li-ion	1C	1h+	10ºC to 45ºC (50ºF to 113ºF)	Same as a rapid charger with faster service.
Ultra-fast charger	Li-ion, NiCd, NiMH	1-10C	10-60 minutes	10ºC to 45ºC (50ºF to 113ºF)	Applies ultra-fast charge to 70% SoC; limited to specialty batteries

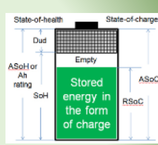
Batarya Sistemleri

State-of-health (SoH)

The three main state-of-health indicators of a battery are:
1.Capacity, the ability to store energy
2.Internal resistance, the capability to deliver current, and
3.Self-discharge, reflecting mechanical integrity and stress-related conditions

Li-ion reveals SoH in capacity. Internals resistance and self-discharge stay low under normal circumstances. SoH is commonly hidden form the user in consumer products; only state-of-charge (SoC) is provided. (See BU-901: Fundamentals in Battery Testing)

SoH is sometimes divided into:
•Absolute state-of-health (ASoH), the ability to store the specified energy when the battery is new
•Relative state-of-health (RSoH), available storage capability when battery is broken in
Note: Unless otherwise mentioned, RSoH refers to SoH.



SoH State-of-health. Generic term for battery health. Capacity is leading health indicator.
ASoH Absolute state-of-health of a new battery.
RSoH Relative state-of-health relating to available capacity
SoC State-of-charge. Generic term for charge level.
ASoC Absolute state-of-charge of a new battery
RSoC Relative state-of-charge; charge level with capacity fade

Batarya Sistemleri

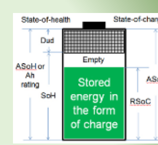
State-of-charge (SoC)

SoC reflects the battery charge level; a reading battery user is most familiar with. The SoC fuel gauge can create a false sense of security as a good and faded battery show 100 percent when fully charged.

SoC is sometimes divided into:

•Absolute state-of-charge (ASoC), the ability to take the specified charge when the battery is new
•Relative state-of-charge (RSoC), available charge level taking capacity fade into account.

Note: Unless otherwise mentioned, RSoC refers to SoC.



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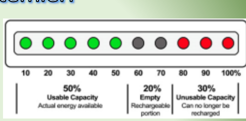
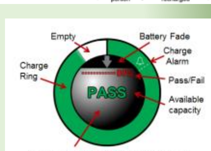
ASoC Absolute state-of-charge of a new battery
RSoC Relative state-of-charge; charge level with capacity fade

Batarya Sistemleri

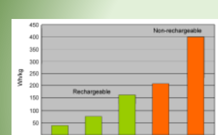
State-of-function (SoF)

SoF reflects battery readiness in terms of usable energy by observing state-of-charge in relation to the available capacity. This can be shown with the tri-state fuel gauge in which the usable capacity is reflected as stored energy in the form of charge (RSoH); the part that can be filled as empty and the unusable part that cannot be restored as dud. SoF can also be presented with the fishbowl icon for a battery evaluation at a glance. Tri-state fuel gauges are seldom used in fear of elevated warranty claims. Some devices offer an access code for service personnel to read SoF.

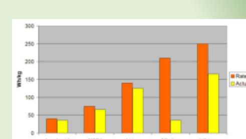




Batarya Sistemleri



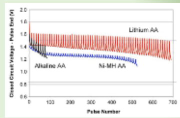
Energy density of secondary and primary batteries

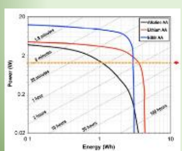


Energy comparison underload.
"Rated" refers to a mild discharge; "Actual" is a load at 1C. High internal resistance limits alkaline battery to light loads.
Courtesy of Cadex

Batarya Sistemleri

Battery type	Nominal voltage	Rated capacity	Voltage cut-off	Rated load	Discharge C-rate
9V	9 volts	570mAh	4.8 volts	620 Ohm	0.025
AAA	1.5 volts	1,150mAh	0.8 volts	75 Ohm	0.017
AA	1.5 volts	2,870mAh	0.8 volts	75 Ohm	0.007
C	1.5 volts	7,800mAh	0.8 volts	39 Ohm	0.005
D	1.5 volts	17,000mAh	0.8 volts	39 Ohm	0.0022





Batarya Sistemleri

Primary Cell	Alkaline	Lithium iron disulfide ($LiFeS_2$)	Lithium-thionyl chloride ($LiSOCl_2$ or LTC)	Lithium manganese dioxide ($LiMnO_2$ or Li-M)	Lithium sulfur dioxide ($LiSo_2$)
Specific energy	200Wh/kg	300Wh/kg	500Wh/kg	280Wh/kg	330Wh/kg
Voltage	1.5V	1.5V	3.6–3.9V	3–3.3V	2.8V
Power	Low	Moderate	Excellent	Moderate	Moderate
Passivation	N/A	Moderate	Moderate	Moderate	Moderate
Safety	Good	Good	Precaution	Good	Precaution
Pricing	Low	Economical	Industrial	Economical	Industrial
Shelf life	10 years	15 years	10–20 years	10–20 years	5–10 years
Operating temp	0°C to 60°C	0°C to 60°C	-55°C to 85°C, higher for short time	-30°C to 60°C some enable from -55°C to 90°C	-54°C to 71°C
Usage	Consumer devices	Swaps alkaline for higher power and long runtime	Horizontal drilling, (fracking). Not for consumer use.	Meter sensing, medical devices, road toll sensors, cameras	Defense; being replaced by $LiMnO_2$

Summary table of common primary batteries. Values are estimated.

Batarya Sistemleri

1.Combining cobalt, nickel, manganese and aluminum raises energy density up to 250Wh/kg.
2.Cycle life is based on the depth of discharge (DoD). Shallow DoD prolongs cycle life.
3.Cycle life is based on battery receiving regular maintenance to prevent memory.
4.Ultra-fast charge batteries are made for a special purpose.
5.Self-discharge is highest immediately after charge. NiCd loses 10% in the first 24 hours, then declines to 10% every 30 days. High temperature and age increase self-discharge.
6.1.25V is traditional; 1.20V is more common.
7.Manufacturers may rate voltage higher because of low internal resistance (marketing).
8.Capable of high current pulses; needs time to recuperate.
9.Do not charge Li-ion below freezing.
10.Maintenance may be in the form of equalizing or topping charge* to prevent sulfation.
11.Protection circuit cuts off below about 2.20V and above 4.30V on most Li-ion; different voltage settings apply for lithium-iron-phosphate.
12.Coulombic efficiency is higher with quicker charge (in part due to self-discharge error).
13.Li-ion may have lower cost-per-cycle than lead acid.

Specifications	Lead Acid	NiCd	NiMH	Li-ion[1] Cobalt	Li-ion[1] Manganese	Li-ion[1] Phosphate
Specific energy (Wh/kg)	30–50	45–80	60–120	150–250	100–150	90–120
Internal resistance	Very Low	Very low	Low	Moderate	Low	Very low
Cycle life[2] (80% DoD)	200–300	1,000[3]	300–500[3]	500–1,000	500–1,000	1,000–2,000
Charge time[4]	8–16h	1–2h	2–4h	2–4h	1–2h	1–2h
Overcharge tolerance	High	Moderate	Low	Low. No trickle charge		
Self-discharge/ month (room temp)	5%	20%[5]	30%[5]	<5% Protection circuit consumes 3%/month		
Cell voltage (nominal)	2V	1.2V[6]	1.2V[6]	3.6V[7]	3.7V[7]	3.2–3.3V
Charge cutoff voltage (V/cell)	2.40 Float 2.25	Full charge detection by voltage signature		4.20 typical Some go to higher V		3.60
Discharge cutoff voltage (V/cell, 1C)	1.75V	1.00V		2.50–3.00V		2.50V
Peak load current Best result	5C[8] 0.2C	20C 1C	5C 0.5C	2C <1C	>30C <10C	>30C <10C
Charge temperature	–20 to 50°C (–4 to 122°F)	0 to 45°C (32 to 113°F)		0 to 45°C[9] (32 to 113°F)		
Discharge temperature	–20 to 50°C (–4 to 122°F)	–20 to 65°C (–4 to 149°F)		–20 to 60°C (–4 to 140°F)		
Maintenance requirement	3–6 months[10] (toping chg.)	Full discharge every 90 days when in full use		Maintenance-free		
Safety requirements	Thermally stable	Thermally stable, fuse protection		Protection circuit mandatory[11]		
In use since	Late 1800s	1950	1990	1991	1996	1999
Toxicity	Very high	Very high	Low	Low		
Coulombic efficiency[12]	~80%	~70% slow charge ~90% fast charge		99%		
Cost	Low	Moderate		High[13]		

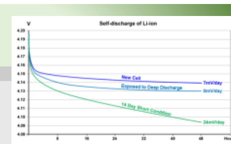
Batarya Sistemleri

Battery system	Estimated self-discharge
Primary lithium-metal	10% in 5 years
Alkaline	2–3% per year (7-10 years shelf life)
Lead-acid	5% per month
Nickel-based	10–15% in 24h, then 10-15% per month
Lithium-ion	5% in 24h, then 1–2% per month (plus 3% for safety circuit)

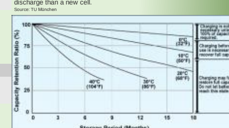
Percentage of self-discharge in years and months. Primary batteries have considerably less self-discharge than secondary (rechargeable) batteries.

State-of-charge	0°C (32°F)	25°C (77°F)	60°C (140°F)
Full charge	6%	20%	35%
40–60% charge	2%	4%	15%

Self-discharge per month of Li-ion at various temperatures and state-of-charge
Self-discharge increases with rising temperature and higher SoC.



Self-discharge of new and stressed Li-ion cells. Cells that had been stressed with deep discharges and kept at 0V show a higher self-discharge than a new cell.
Source: TU München



Self-discharge of lead acid as a function of temperature. Lead acid should never drop below 60% SoC. Charge more often when warm.
Source: Power-Sonic

Batarya Sistemleri

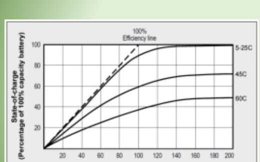
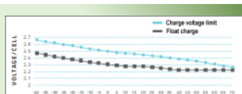


Figure 4: NiCd charge acceptance as a function of temperature. High temperature reduces charge acceptance and departs from the dotted "100% efficiency line." At 55°C, commercial NiMH has a charge efficiency of 35–40%; newer industrial NiMH attains 75–80%.
Courtesy of Cadex



Lead Acid Cell voltages on charge and float at various temperatures. Charging at cold and hot temperatures requires adjustment of voltage limit.
Source: BetaBatteries

Battery type	Charge temperature	Discharge temperature	Charge advisory
Lead acid	–20°C to 50°C (–4°F to 122°F)	–20°C to 50°C (–4°F to 122°F)	Charge at 0.3C or lessbelow freezing. Lower V-threshold by 3mV/°C when hot.
NiCd, NiMH	0°C to 45°C (32°F to 113°F)	–20°C to 65°C (–4°F to 149°F)	Charge at 0.1C between –18°C and 0°C. Charge at 0.3C between 0°C and 5°C. Charge acceptance at 45°C is 70%. Charge acceptance at 60°C is 45%.
Li-ion	0°C to 45°C (32°F to 113°F)	–20°C to 60°C (–4°F to 140°F)	No charge permitted below freezing. Good charge/discharge performance at higher temperature but shorter life.

Permissible temperature limits for various batteries. Batteries can be discharged over a large temperature range, but the charge temperature is limited. For best results, charge between 10°C and 30°C (50°F and 86°F). Lower the charge current when cold.

Batarya Sistemleri

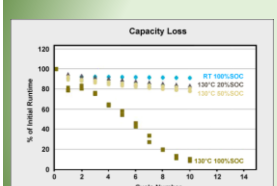


Figure 5: Capacity loss at room temperature (RT) and 130°C for 90 minutes
Sterilization of batteries for surgical power tools should be done at low SoC.

Lithium-ion performs well at elevated temperatures but prolonged exposure to heat reduces longevity. Charging and discharging at elevated temperatures is subject to gas generation that might cause a cylindrical cell to vent and a pouch cell to swell. Many chargers prohibit charging above 50°C (122°F).

Some lithium-based packs are momentarily heated to high temperatures. This applies to batteries in surgical tools that are sterilized at 137°C (280°F) for up to 20 minutes as part of autoclaving. Oil and gas drilling as part of fracking also exposes the battery to high temperatures.
Capacity loss at elevated temperature is in direct relationship with state-of-charge (SoC). Figure 5 illustrates the effect of Li-cobalt (LiCoO2) that is first cycled at room temperature (RT) and then heated to 130°C (266°F) for 90 minutes and cycled at 20, 50 and 100 percent SoC. There is no noticeable capacity loss at room temperature. At 130°C with a 20 percent SoC, a slight capacity loss is visible over 10 cycles. This loss is higher with a 50 percent SoC and shows a devastating effect when cycled at full charge.

Batarya Sistemleri

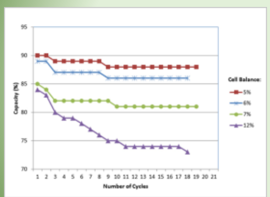


Figure illustrates the cycling performance of five aged Li-ion packs as a function of cell match. The cells are connected in a 2P4S arrangement with a center tap, forming two battery sections.

The capacity differences between the two sections are 5, 6, 7 and 12 percent. When cycled, all batteries show large capacity losses over 18 cycles, but the greatest decrease occurs with the pack exhibiting 12 percent capacity mismatch.

Figure 1: Cycling performance as a function of cell match

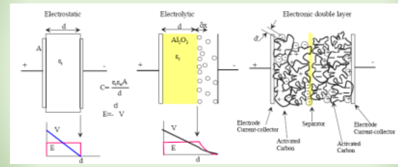
Battery packs with well-matched cells perform better than those in which the cell or group of cells differ in serial connection.

Configuration: 5Ah prismatic Li-ion connected in 2P4S (14.8V, 10Ah)

Ultra-kapasitör Sistemleri

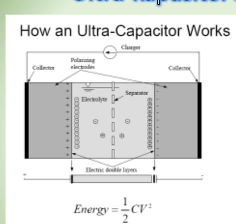
Ultra-kapasitör (Süper-kapasitör, double layer kapasitörler)

Kapasitörler onların enerji depolamasının fiziksel yapısına göre üç kategoriye ayrılmaktadır.



Kapasitörler enerjiyi pozitif ve negatif elektrostatik yüklerin ayrışmasıyla depo eden cihazlardır. Kapasitör iki tane plaka olarak adlandırılan iletkenle, bunları ayıran ve di-elektrik olarak adlandırılan yalıtkandan oluşmaktadır.

Ultra-kapasitör Sistemleri

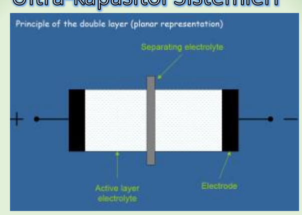


$$Energy = \frac{1}{2}CV^2$$

- **Elektrotlar çok yüksek yüzey alanına sahip delikli malzemeden yapılmıştır (>2000 m2/g).**
- **Ultra-kapasitörlerde elektrostatik yükler iyonlar şeklinde elektrolitte depolanmaktadır.**

Bir ultra-kapasitörde plakaların arasındaki boşluk katı polimerden oluşan elektrolitle doludur. Burada plakalar bataryada olduğu gibi elektrottur. Ancak kimyasal reaksiyonlar gerçekleşmez, sadece elektrot yüzeylerinde iyonlaşma olur.

Ultra-kapasitör Sistemleri



UK sistemleri,

- **Geleneksel kondansatör sistemlerinden daha çok enerji yoğunluğuna,**
- **Geleneksel baterilerden çok daha iyi güç yoğunluğuna**
- **Modüler/yığınlanabilir yapıda istenilen boyut ve güç değerinde**

kullanılabilirler.

Figure 3: Photograph of the Ness 2.3V, 2500F Capacitor

Figure 4: Photograph of the Panasonic 2.3V, 1200F Capacitor

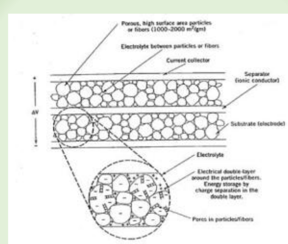
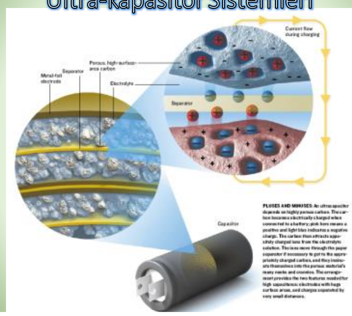


Figure 1: Schematic of a Double-layer Ultracapacitor

Ultra-kapasitör Sistemleri

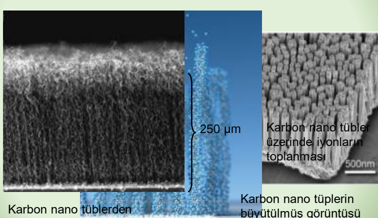


Kapasitörler ve Ultra-Kapasitörler

Ultra-kapasitör

Ultra-kapasitörler

Ultra-Kapasitörler



Karbon nano tüplerden oluşmuş bir orman

Karbon nano tüpler üzerinde iyonların toplanması

Karbon nano tüplerin büyütülmüş görüntüsü

Ultra-kapasitör Sistemleri

Principal types of SCAPs : depends on electrolyte technology

- ✓ Activated carbon electrolytes
- ✓ Electrolytes based on metallic oxides
- ✓ Electronic conductive polymers

Mandatory stack utilisation

Technology	Active carbon	Metallic oxydes	Conductive Polymers
Energy density	2 - 40 kJ / kg	10 - 20 kJ / kg	10 - 40 kJ / kg
Power density	0.1 - 2 kW / kg	10 - 100 kW / kg	100 kW / kg
Rated - Surge voltage	2.3 - 3 V	0.8 - 1.2 V	1.3 - 2.5 V
Cycles	› 100 000	› 100 000	10 000 → 100 000
Cost	Relatively low	high	?

Ultra-kapasitör Sistemleri

UK sistemleri,

- **Geleneksel kondansatör sistemlerinden daha çok enerji yoğunluğuna,**
- **Geleneksel baterilerden çok daha iyi güç yoğunluğuna**
- **Modüler/yığınlanabilir yapıda istenilen boyut ve güç değerinde**

kullanılabilirler.

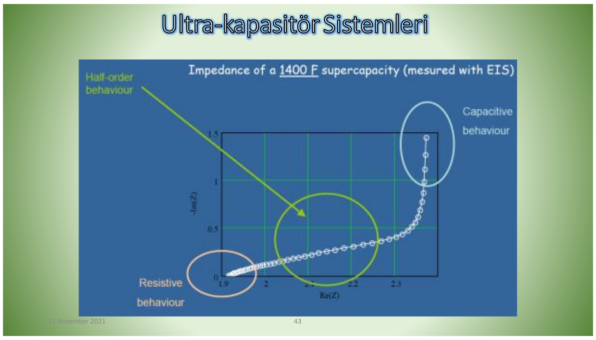
Bir UK'nın şarj ve deşarj zamanları, seri ve paralel bağlanma durumlarına göre mili saniyeler mertebesinden dakikalar mertebesine kadar ayarlanabilmektedir.

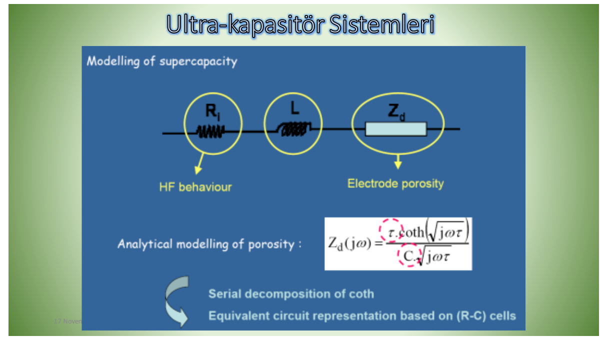
Bakım gerektirmeyen bir işletimi vardır.

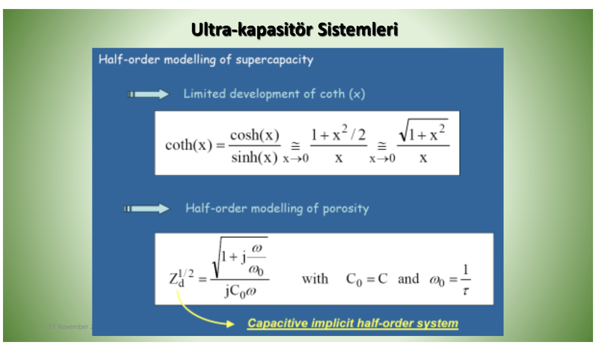
Farad başına en düşük maliyet, yüksek ömür ve çevre dostu olma gibi özelliklere sahiptir. Ayrıca, birkaç Farad'dan birkaç bin Farad'a kadar UK'nın kapasitansı ayarlanabilmektedir.

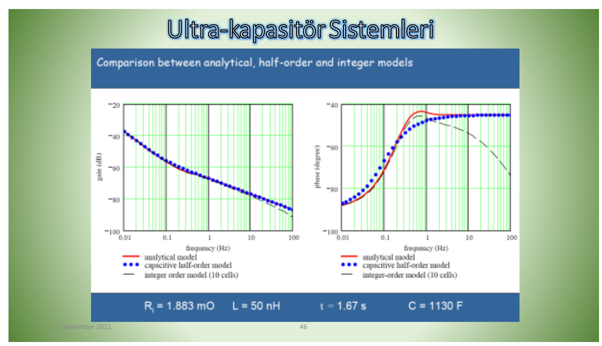
Ultra-kapasitör Sistemleri

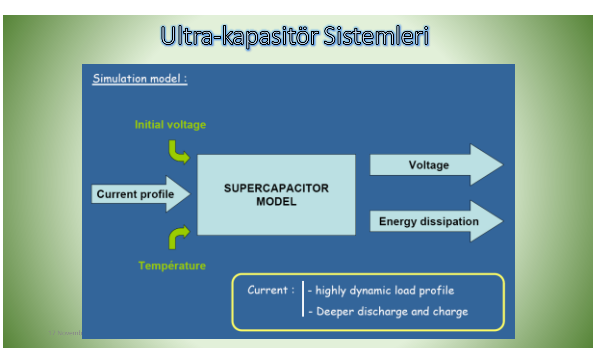
- Aşırı yüksek kapasitans değerleri
- Hızlı cevap verme karakteristikleri
- Yüksek güç yoğunlukları
- Modüler yapı

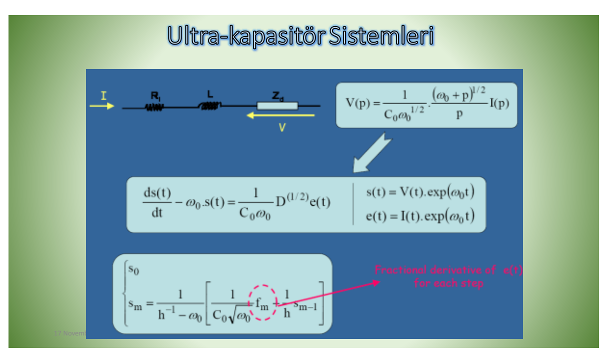

Ultra-kapasitör Sistemleri
Impedance of a 1400 F supercapacity (mesured with EIS)
Half-order behaviour
Capacitive behaviour
Resistive behaviour
-Im(Z)
Re(Z)


Ultra-kapasitör Sistemleri
Modelling of supercapacity
R_i
L
Z_d
HF behaviour
Electrode porosity
Analytical modelling of porosity :
Serial decomposition of coth
Equivalent circuit representation based on (R-C) cells


Ultra-kapasitör Sistemleri
Half-order modelling of supercapacity
Limited development of coth (x)
Half-order modelling of porosity
with
and
Capacitive implicit half-order system


Ultra-kapasitör Sistemleri
Comparison between analytical, half-order and integer models
gain (dB)
phase (degree)
frequency (Hz)
analytical model
capacitive half-order model
integer order model (10 cells)
R_i = 1.883 mO
L = 50 nH
C = 1130 F

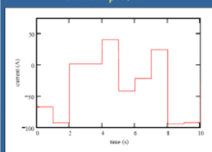

Ultra-kapasitör Sistemleri
Simulation model :
Initial voltage
Current profile
SUPERCAPACITOR MODEL
Voltage
Energy dissipation
Température
Current :
- highly dynamic load profile
- Deeper discharge and charge


Ultra-kapasitör Sistemleri
I
R_i
L
Z_d
V
Fractional derivative of e(t) for each step

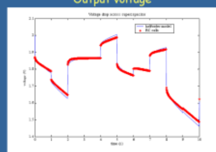
Ultra-kapasitör Sistemleri

Application : T = 25 °C $U_{initial}$ = 2 V

Current profile



Output voltage



10 (R-C) cells

half-order model

Validation of half-order modelling

Ultra-kapasitör Sistemleri

Applications of supercapacities

- Utilisation in automotive vehicles (hybrid or not)
  - ✓ less requests of battery
    - → increase its lifespan
  - ✓ performances independant of the battery state,
  - ✓ under-to dimension the principal source of energy,
  - ✓ increase the power available in transient state,
  - ✓ recover the braking energy,
  - ✓ increase the vehicle autonomy.
- Utilisation in power systems for power electronics interfaces (FACTS, wind mill...)

Ultra-kapasitör Sistemleri

Maxwell — *Ultracapacitor Applications*

- **Breaking energy recapture and initial acceleration**
  Stationary and on-vehicle Ultracap power installations that are able to store the braking energy of trains and release it during acceleration. Important cost savings due to significant reduction of primary energy consumption.
- **Voltage stabilization**
  Stationary installation able to maintain a constant voltage level. Installation along the track at critical points where the power net is weak and voltage sags may occur. Costly interruption of the power network are strongly reduced as the installation delivers the energy needed to maintain the power net at constant voltage level.
- **Diesel engine starting**
  Ultracap modules are used to start huge diesel engines of locomotives and diesel-electric trains. The modules are able to supply the needed power in a volume and weight strongly reduced compared to battery systems. Further advantages are the robust construction, the wide temperature range, the high reliability and no maintenance.
  Reference:

Ultra-kapasitör Sistemleri

Maxwell — *Traction Applications*

- **Door actuator**
  Medium size ultracapacitors are used to ensure a reliable functioning of electrical doors.
- **Tilting trains**
  Ultracapacitors are ideally suited to furnish the power needed to activate the tilting system of advanced tilting trains.
- **Support of switch drives**
  Ultracapacitors guarantee the following two demands: Cover the peak power demands and support of switch drives in case of a power outage in the seconds range.
- **Security applications**
  On-vehicle and stationary applications that require power bursts during several seconds. On-vehicle applications are GPS systems, signal horns etc. Stationary applications are automatic acoustic and optical warning units. Here Maxwell small cell ultracapacitors are ideally suited thanks to their high reliability and long lifetime.

Ultra-kapasitör Sistemleri

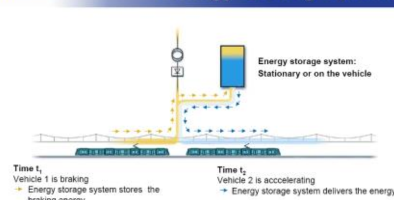
Maxwell — **Mass Transit Systems Demands**

- Provide public transportation for increased demand for mobility due to a steadily increasing population
- Improve energy efficiency of operating systems
  - Energy costs represent the most important part of the operating budget
  - Energy resources to be used optimally for environmental protection and conservation
- Improve network reliability through rail network voltage stabilization

Optimization of the operating costs and the voltage stabilization

Ultra-kapasitör Sistemleri

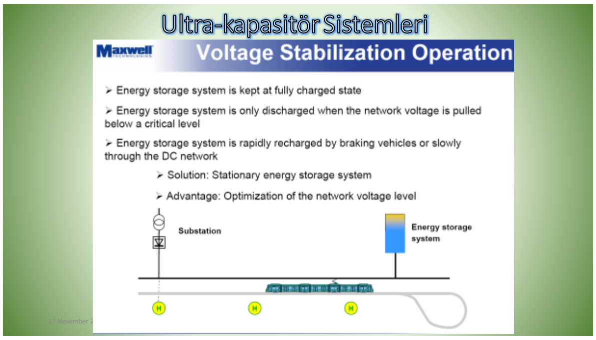
Maxwell — **Energy Saving Operation**

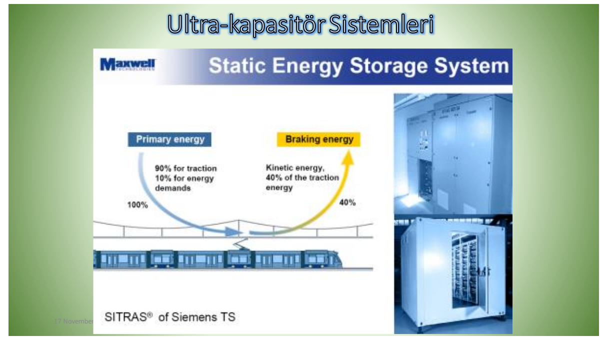


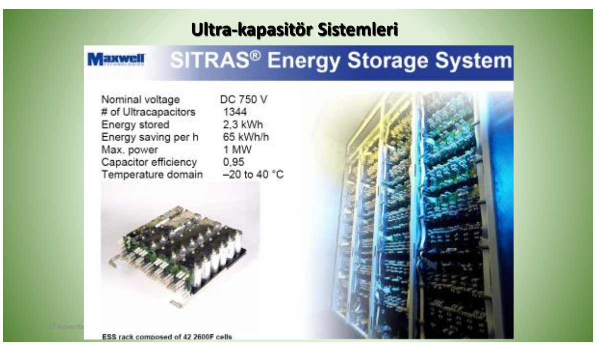
Application: Time shifted delivery of the stored braking energy for vehicle re-acceleration

Solutions: Possible with either stationary or on-vehicle energy storage system

Advantage: Cost savings through reduced primary energy consumption

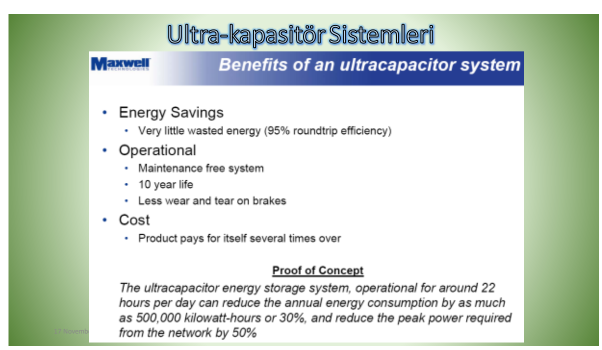

Ultra-kapasitör Sistemleri
Maxwell
Voltage Stabilization Operation
➢ Energy storage system is kept at fully charged state
➢ Energy storage system is only discharged when the network voltage is pulled below a critical level
➢ Energy storage system is rapidly recharged by braking vehicles or slowly through the DC network
➢ Solution: Stationary energy storage system
➢ Advantage: Optimization of the network voltage level
Substation
Energy storage system


Ultra-kapasitör Sistemleri
Maxwell
Static Energy Storage System
Primary energy
Braking energy
90% for traction
10% for energy demands
100%
Kinetic energy, 40% of the traction energy
40%
SITRAS® of Siemens TS

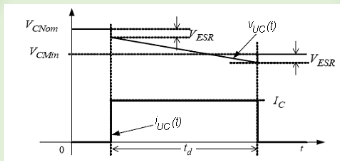

Ultra-kapasitör Sistemleri
Maxwell
SITRAS® Energy Storage System
Nominal voltage DC 750 V
# of Ultracapacitors 1344
Energy stored 2,3 kWh
Energy saving per h 65 kWh/h
Max. power 1 MW
Capacitor efficiency 0,95
Temperature domain –20 to 40 °C
ESS rack composed of 42 2600F cells


Ultra-kapasitör Sistemleri
Maxwell
SITRAS® Installation Examples
Dresden
Hellerau
Full-time service since September 2002
Cologne
Schlebusch
Full-time service since July 2003
Madrid
Sainz de Baranda
Full-time service since


Ultra-kapasitör Sistemleri
Maxwell
On-Vehicle Energy Storage System
600 BCAP0008
Weight: 450 kg
Max output: 300 kW
Forced air cooling
Volume: 1900 x 950 x 455 mm
MITRAC™ Energy Saver of Bombardier Transportation

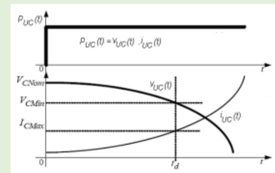

Ultra-kapasitör Sistemleri
Maxwell
Benefits of an ultracapacitor system
• Energy Savings
• Very little wasted energy (95% roundtrip efficiency)
• Operational
• Maintenance free system
• 10 year life
• Less wear and tear on brakes
• Cost
• Product pays for itself several times over
Proof of Concept
The ultracapacitor energy storage system, operational for around 22 hours per day can reduce the annual energy consumption by as much as 500,000 kilowatt-hours or 30%, and reduce the peak power required from the network by 50%

Ultra-kapasitör Sistemleri



Sabit akım altında bir UC modülünün deşarj profili

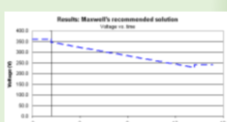
Ultra-kapasitör Sistemleri



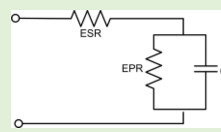
Sabit güç altında bir UC modülünün deşarj profili

Maxwell Technologies

- PC2500
  Ultra capacitor
- Bid by Bobby Maher
  - Director of Technical Sales Maxwell Technologies



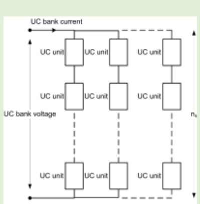
Ultra-kapasitör Sistemleri



UK için klasik eşdeğer model

(Reduced order model)

Ultra-kapasitör Sistemleri



Bir UK modülünün istenilen gerilim ve akım için düzenlenmesi.

Ultra-kapasitör Sistemleri

Maxwell Boostcap BMOD0165 P048 UK'nın teknik özellikleri

Specification	Value
Capacitance	165 F
Voltage	48.6 Volts DC
DC Resistance	6.1 mΩ
AC Resistance (@ 1kHz)	5.2 mΩ
Weight	14.2 kg
Volume	12.6 L