

CAT[®] ENERGY STORAGE: SYSTEM OVERVIEW

THE WORLD'S LEADING ENERGY STORAGE SOLUTIONS FOR
TELECOM, PEAK SHAVING, LOAD SHIFTING AND MICROGRIDS

August 2015

CATERPILLAR[®]

BACKGROUND AND PROFILE

The market need driving the development of the Cat® Energy Storage solution is often known as peak shaving or load shifting. Zinc-air cells store significant amounts of energy through charging when electricity is inexpensive or available, and then they operate through discharging when electricity is normally expensive or grid power is unavailable. In addition to the proven capability for managing both long and short partial cycles at the lowest cost, other key fundamental advantages include repeated ultra-long discharge time capability, environmentally friendly use and increased safety.

Our fully integrated and Internet-connected software controls continuously capture, self-optimize, learn and transmit information to our control center from every system located around the world. They enable exceptional performance management, lower energy costs and higher reliability.

Lowest Cost of Ownership

The Cat Energy Storage solution is capable of covering both short and ultra-long outages at the lowest possible cost

through proprietary and environmentally sustainable battery technology, as well as fully integrated and Internet-enabled software controls. The core technology has a significantly longer calendar and usage life, along with a lower life-cycle cost when compared with lead-acid solutions. It also tolerates high temperatures, and frequent long or short power cycles do not diminish performance or operating life. Ultimately, the Cat Energy Storage solution delivers multi-year, warranted performance and the lowest total cost of ownership.

Proven, Reliable Breakthrough

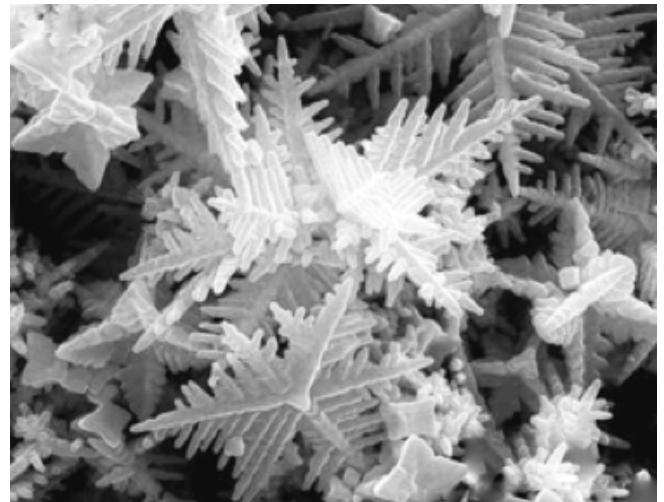
Since the first commercial deployment in 2011, more than 35,000 batteries have been deployed, covering more than 550,000 grid power outage cycles in some of the toughest environments in the world, including some outages exceeding 20 hours. As a result, the system has never failed a customer validation test, missed a promised deadline, or triggered any performance shortfall penalties imposed by a service level agreement (SLA). Customer references are available upon request.

CORE TECHNOLOGY

Working Principle

At the core of the Cat Energy Storage solution is a proprietary and rechargeable zinc-air cell for use in applications such as microgrids and peak shaving. It is the first system that has successfully commercialized a high cycle life, rechargeable metal-air battery, long regarded as the lowest cost way to store an electron.

Zinc-air cells use oxygen from the ambient atmosphere to produce electrochemical energy. As the air-breathing cathode – the positive electrode – is exposed to air, oxygen diffuses through this hydrophobic barrier to the cathode's catalytic active layer, where the reduction of oxygen is promoted in the presence of an aqueous alkaline electrolyte, potassium hydroxide (KOH).



The zinc crystalline structure

Once in contact with the electrolyte, zinc from the anode – the negative electrode – is oxidized, which generates electric current from the oxygen reduction and zinc oxidation reactions. The cathode is an irreducible electrode, which means its physical size and electrochemical properties remain unchanged during discharge, unlike most other closed-cell batteries. This contributes to the long calendar and cycle life of the zinc-air cells.

Advances in the continuous fabrication of thin, high-performance gas electrodes in the 1970s enabled the mass production of the single-use, non-rechargeable zinc-air button cell. The most successful applications of zinc-air batteries in this small form factor have traditionally been in medical devices, such as miniature hearing aids. However, their use was limited to single-use, disposable applications, as is the case with alkaline batteries (AAA, AA, C, D).

Reaction reversibility is the key to the breakthrough in zinc-air energy storage technology, which led to the creation of an electrically rechargeable cell. Leveraging the proprietary aspects of both an advanced anode architecture, smart electronic controls, proprietary ionic liquids and robust gas electrode design has sparked the development of the world's first reliable, rechargeable zinc-air cell. Enabling the rechargeability of the zinc-air cell has lifted this advantageous battery chemistry to a new level of cost effectiveness, usability and application reach. This fundamental performance has been proven by over 550,000 cycles in customer systems comprised of over 35,000 batteries.

Clean and Safe

Zinc-air technology is arguably setting a new standard for what's possible in environmentally responsible energy storage. But what's even more impressive about the Cat Energy Storage solution is that it achieves this status without compromising cost, reliability, life or performance. The emphasis on sustainable product attributes has now achieved a universal acceptance in most markets around the globe. A product's true environmental impact or life-cycle assessment (LCA) on natural resources, health, safety and society in general are now being taken into consideration in most buying decision processes. There are two recognized green standards that drive a product's life-cycle environmental impact: environmental sustainability and societal health and safety.

Environmental Sustainability applies to products that can be recycled at the end of life, use sustainable materials, and are made from materials synthesized or extracted/mined with minimal impact. Fundamental to zinc-air technology is a reliance on sustainable materials in the construction of the cell and ancillary equipment. Raw materials such as zinc, carbon, water, potassium and consumer-grade acrylonitrile butadiene styrene (ABS) plastics are readily available and, for the most part, they are easily reclaimable and recyclable at the cell's end of life (EOL). Due to the abundant nature of the zinc-air cell raw materials, the technology provides an extremely sustainable platform for rapidly scaling manufacturing. Analysts for Meridian International Research have recognized zinc as the only metal that can sustain large battery production in volumes. This is not the case with other battery types comprised of earth-scarce materials that are either hard to mine or found only in isolated reserves controlled by a few countries.

Societal Health and Safety relates to products that do not produce toxic or harmful emissions, contain no toxic constituents known to cause severe or irreversible environmental damage, do not pose adverse human health risks, and are inherently safe with respect to fire or explosion. The zinc-air cell architecture is fundamentally safe with respect to thermal runaway or fire hazards due to its fail-safe discharge dynamics. All reacting oxidant is stored outside the cell until the reaction is desired and, unlike all solid-state batteries, the system discharges using ambient air. This fundamental attribute makes zinc-air one of the safest energy storage products deployable today. In addition, the zinc-air aqueous alkaline electrolyte is environmentally benign and does not contaminate ground water or other sensitive natural resources.

System Configuration

The Cat Energy Storage solution represents the latest breakthrough in safe, long-life, high temperature-tolerant, reliable and cost-effective energy storage technology. It is ideally suited for backup mission-critical DC loads, load shifting, renewables integration, microgrid storage and other grid storage applications. At the core of the Cat Energy Storage solution is the building block of energy modules consisting of rechargeable zinc-air cells. These energy modules have integrated intelligence and are self-governing to autonomously balance the ampere-hour (Ah) discharge of the contributing zinc-air cells. The zinc-air cells making up the energy module are arranged in a series and managed by a single intelligent power module (IPM) node.

Since the individual energy modules behave just like a large-capacity 52-volt battery string, they are essentially sub-systems that can be arranged in parallel to each other and added or removed from the system based on the power and energy needs of the customer. This innovative and effective means of self-governing battery management is core to the zinc-air system architecture and yields increased redundancy and reliability.

Inside the standard IP55 environmental enclosure, shown in figure 1, a dedicated shelf supports each of the power modules. Each energy module is controlled by a dedicated IPM electronics unit conveniently co-located inside the electronics bay, which is accessible on the side of the unit. Each energy cell can be removed individually for service and inspection. This configuration enables superior technician service access and controller interrogation simplicity.

Energy module power cables (bus bar) terminate inside the ventilated electronics bay located on the end of the cabinet. For efficient use of space and ease of service, all electronics are conveniently mounted on the wall in a co-located arrangement as in Figure 2.

Energy Module – The Core Building Block

A differentiating feature of the Cat Energy Storage solution is the ability to scale up the system when additional power or energy capacity is required. The core of this capability is the energy module building block, which constitutes the basics of all zinc-air systems. At any time during the lifetime of the module, additional building blocks can be added without affecting the system string voltage or disturbing the power cell balancing, which can be a problem with other storage systems. This auto-compensating feature provides the most economic means for allowing the customer to incrementally adjust for changing power or energy demands over time.

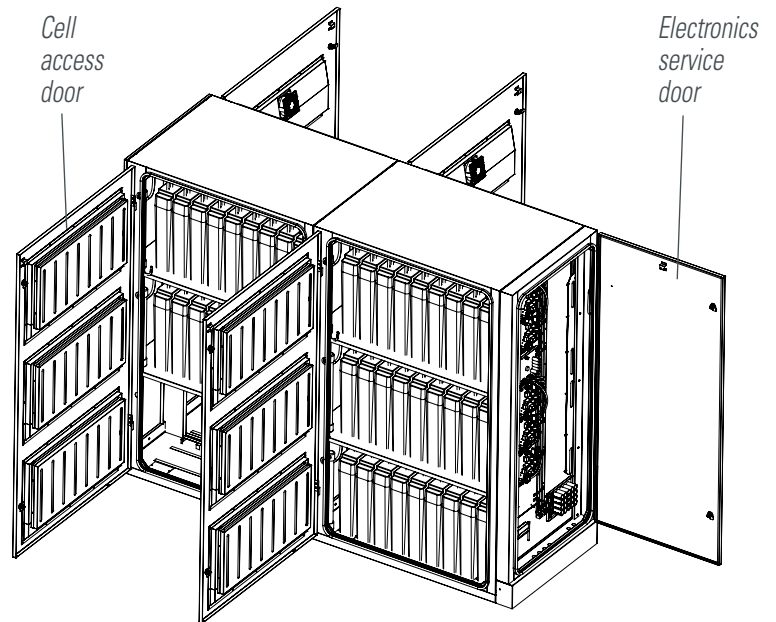


Figure 1: The Cat® Energy Storage solution zinc-air system building block and energy module orientation in an IP55 all-weather cabinet. It can also be supplied with indoor racks (not shown).

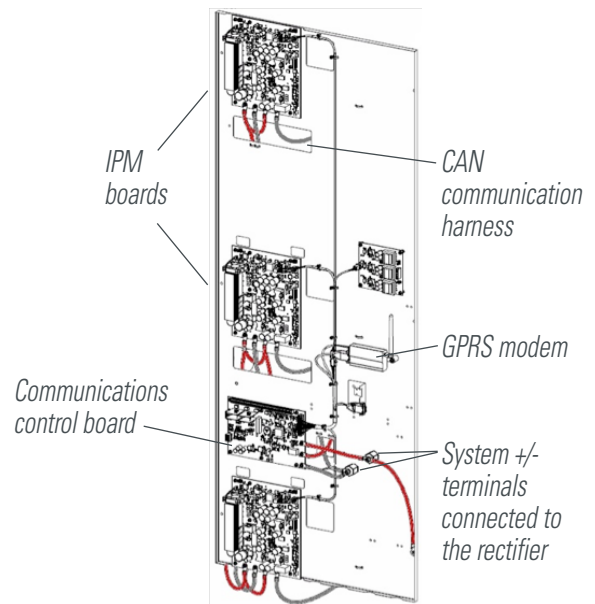
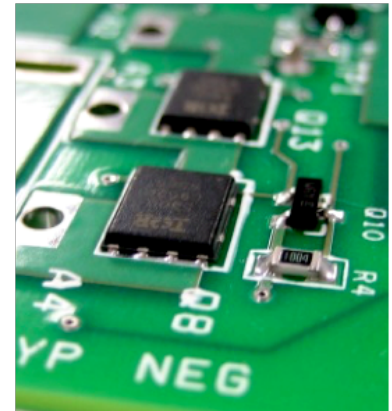


Figure 2: Cat Energy Storage solution electronics panel.

Individual Energy Module Specifications

Peak Power	0.75 kW to 4.50 kW
Energy Delivery (kWh) @ E/10	6.0 kWh to 40.1 kWh
Total System Weight	502 kg to 2,297 kg
Ambient Temperature Range	0°C to 50°C

INTEGRATED INTELLIGENCE



Integrated into the Cat Energy Storage solution is a world-class, Internet-enabled software and controls suite that captures crucial information from every fielded battery in a relational database. This combination delivers superior analytics for our customers to understand power reliability, optimize system performance, and provide insight on operating cost optimization and service management.

Customers use a web-based interface to monitor the solution, and a wireless general packet radio service (GPRS) transmitter sends data and information from the system to a hosted server. These servers function as the central coordinating component, and a database stores information received from

the system over the communications network. This system serves as both the network interface and graphical user interface for accessing data information from the server and database, analyzing the information, displaying the information and sending command information to the server through the communication network.

Several data centers around the world monitor every Cat Energy Storage solution in the field 24/7. They are poised to take proactive action in the event of any issues impacting the performance of the deployed units, providing our customers the highest possible availability wherever these solutions are deployed.

CHANGING THE GAME OF GRID STORAGE



Given the intermittent nature of renewable energy generation, energy storage solutions have become a critical component of microgrid and peak shaving applications.

The Cat Energy Storage solution delivers our customers power and energy at levels unrivalled by any other battery technology company.

The core building block of this solution is the energy module, which can range from 0.75 kW to 4.50 kW and deliver from 6.0 to 40.1 kWh of energy. The unique structure of the Cat Energy Storage solution will allow for future generations of energy modules to be arranged in parallel, stringing together systems with peak power capabilities scalable beyond 5 kW and more than 40 kWh of energy. Each energy module is controlled independently, and customers can easily add additional energy modules as loads increase over time.

For more information, visit www.cat.com/powergeneration.

Proven Technology

Unlike most other new or advanced energy storage technologies, the Cat Energy Storage solution has actually been proven in the market in high volumes with multiple large commercial customers around the globe. The competitive advantages and performance have been validated by repeat customer orders following multiple years of operation. The Cat Energy Storage solution is the first commercially successful implementation of rechargeable zinc-air technology, with more than 35,000 batteries used in customer applications today.

Customer Benefits

In summary, the Cat Energy Storage solution delivers a unique set of benefits when compared with similar quality competitive solutions, including:

- Lowest initial cost and total cost of ownership
- Scalability at any time during the system lifetime, preserving cash and significantly improving internal rate of return
- Unrivalled peak power and run time performance
- Proven reliability
- 100% transparency of performance via our web interface
- Remote monitoring and control for optimized system performance and network availability
- Significantly improved safety and environmental impact over competing technologies

BUILT FOR IT.™

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