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# TEN-MEGAWATT LOAD-LEVELLING LEAD/ACID BATTERY PROJECT

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## Summary

To demonstrate the economic and operational feasibility of using lead/acid batteries for load management by electric utilities, a 10 MW/40 MW h battery energy storage plant is being constructed at the 12 kV substation of Southern California Edison Company in Chino, California. This U.S. $13 million project is a cooperative effort by Edison, Electric Power Research Institute, and International Lead Zinc Research Organization, Inc. The design, construction and operation of this plant are presented. The Chino facility is scheduled to begin load-levelling duties in April, 1988. Several related projects in other areas of the world are also described briefly.

## Introduction

The use of lead/acid batteries for electrical-load management in the U.S.A. began almost one hundred years ago in Philadelphia, Pennsylvania. At that time, around 1890, only direct current was generated for a limited number of uses, mainly electric lighting. Electricity was costly to produce, especially when there was no demand for it. So, it made sense to store the surplus energy in a lead/acid battery during periods of low demand (off-peak). When needed at a later time, the direct current from the battery could be discharged.

Later, as electric power generation was converted from direct to alternating current (for improved efficiency in transmission and distribution) the need for battery energy storage systems declined in the area of electrical-load management. In recent years, however, there has been a resurgence of interest in energy storage. This occurred when many electric utility companies experienced cutbacks in construction of large base-load plants while their peak demand levels continued to grow at a gradual, but steady, pace. In addition, as more utilities realized the opportunity to obtain cheaper power from distant hydroelectric sources, for example, particularly during off-peak hours, energy storage became more attractive [1]. Electric utilities are quite familiar with the operation and benefits of pumped hydroelectric facilities

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for the storage and delivery of electrical energy. Unfortunately, environmental and topographical constraints limit their availability as a major, planned resource in most electric-utility generation forecasts.

Thus, when oil prices became very high in the 1970s, there was renewed interest in developing advanced batteries for energy storage. One such study was sponsored jointly by the Electric Power Research Institute (EPRI) and the International Lead Zinc Research Organization, Inc. (ILZRO) [2]. The final report, submitted by C & D Batteries Division in 1975, indicated the technical feasibility and economic viability of a 10 MW/50 MW h lead/acid battery energy storage system for electric-utility load levelling during peak-demand periods.

However, it was not until 1985 that a full-scale demonstration project of such a load-levelling system was organized. At that time, EPRI and ILZRO, in cooperation with Southern California Edison Company (EDISON), agreed to jointly sponsor the design, construction, and operation of a 10 MW/50 MW h (5 h discharge rate) lead/acid battery energy storage plant at a major, high-voltage substation in a high-growth community. In 1987, the system was redesigned for a 4 h discharge rate, to stay within budgetary limits. The site selected by EDISON was their 12 kV substation in Chino, about 50 miles east of Los Angeles, California. It is the aim of this paper to present the progress to date on the Chino lead/acid battery energy storage demonstration project. Several related projects in other areas of the world will also be described briefly.

## Objectives

As a research project, the Chino lead/acid battery energy storage system has the following four major objectives.

(i) To demonstrate operational benefits.
(ii) To validate design, procurement, and installation costs.
(iii) To gain valuable operating and maintenance experience.
(iv) To encourage a utility market for battery energy storage plants.

## Operational benefits

Energy storage by means of lead/acid batteries offers many operational benefits to an electric utility, such as EDISON, including the following:

*(i) Purchase of economy power.* During minimum load conditions when it is not feasible to turn-down local generators further, a battery energy storage system provides an opportunity for EDISON to purchase additional economy power (for example, off-peak hydroelectric power from a distant source).

*(ii) Management of peak loads.* As the EDISON-system load factor has been declining since the early 1970s due to peak demand growing more rapidly than total energy requirements, battery energy storage offers an excellent means of peak-load management.

*(iii) Dispatched control of cogenerated power.* In the case of non-coincident peak generators such as wind energy generators, battery energy storage enables dispatched control of such power output, thereby increasing the value of energy produced by third-party cogenerators and small power producers.

*(iv) Load-following capability.* More efficient ramp-up and operation of intermediate and base-load generators is made possible (by discharging stored energy from batteries while the increased demands for power are being met by the generators coming up to speed).

*(v) Modular construction.* Battery energy storage systems can be expanded (or downsized), as the local or system peak-load requirements change, by adding (or removing) individual batteries, thereby improving system planning.

*(vi) Short lead-time.* Whereas a conventional power plant may require up to ten years to build (including permits, design, construction, financing, etc.), it is possible to install a battery energy storage facility in two years (or less), thereby reducing financial risks due to excess capacity.

*(vii) Virtually no emissions.* Battery energy storage systems do not contribute to acid rain, fly ash, or noise, because they are clean, quiet, and can be operated in ordinary building enclosures.

*(viii) Convenient siting.* The ability to site batteries at major load centers, such as substations, enables deferral of costs for transmission and distribution equipment, increases transformer bank-life, and reduces power-line losses.

*(ix) Enhanced system stability.* Because stored battery power is available almost instantaneously (even while the battery system is being recharged), the system stability can be enhanced by the fast-acting battery response.

*(x) Spinning-reserve capability.* As electric utilities must provide sufficient emergency generating capacity at all times to replace their largest unit in case of failure (known as spinning reserve), battery energy storage systems can dedicate part of their capacity as emergency spinning reserve, especially during off-peak and mid-peak hours.

*(xi) Improved intermediate/base-load efficiency.* By varying the operating schedule for the battery energy storage system in sufficient quantity, the generating units powered by steam can be maintained at more efficient operating points.

A recent analysis estimated that the "intangible" benefits of battery energy storage (foregoing items (iv) - (xi)) could approach $500/kW in reduced capital cost for battery energy storage plants [3] (Note, U.S. dollars are used throughout this paper.) However, it is only by means of actual operation that the true value of battery energy storage systems can be assessed. Thus, the Chino project will provide a full-scale demonstration of the operating benefits to be derived from the use of lead/acid batteries for electrical-load management.

## Chino plant design

The overall battery energy storage facility at the Chino substation is shown schematically in Fig. 1. Preliminary design and cost estimates for a generic 10 MW utility lead/acid battery energy storage plant were made by Bechtel National, Inc. [4].

The Chino plant will comprise two parallel buildings to house the batteries, each 288 ft long by 80 ft wide. They will be connected at the midpoint by a converter and control room 40 × 60 ft in size. Modules, of six cells each (Fig. 2), will be mounted on earthquake-resistant steel frames in two tiers, as shown in Fig. 3. The plant will have a power capacity of 10 MW; an energy capacity of 40 MW h (at a 4 h discharge rate); a footprint of approximately one acre; and a charging cycle of 10 h at night.

At the revised 4 h discharge rate, the 10 MW battery will now comprise 8256 cells (1376 modules, each of 6 cells) in eight strings, with a rated

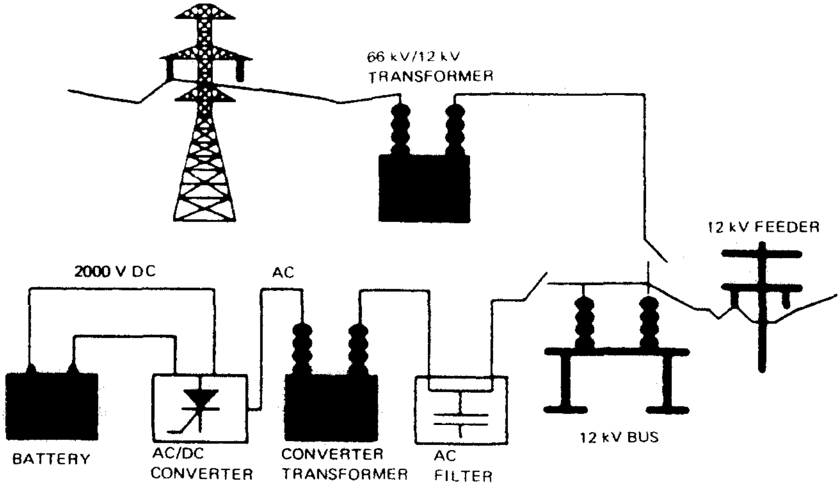

Fig. 1. Overall schematic of Chino battery energy storage facility.

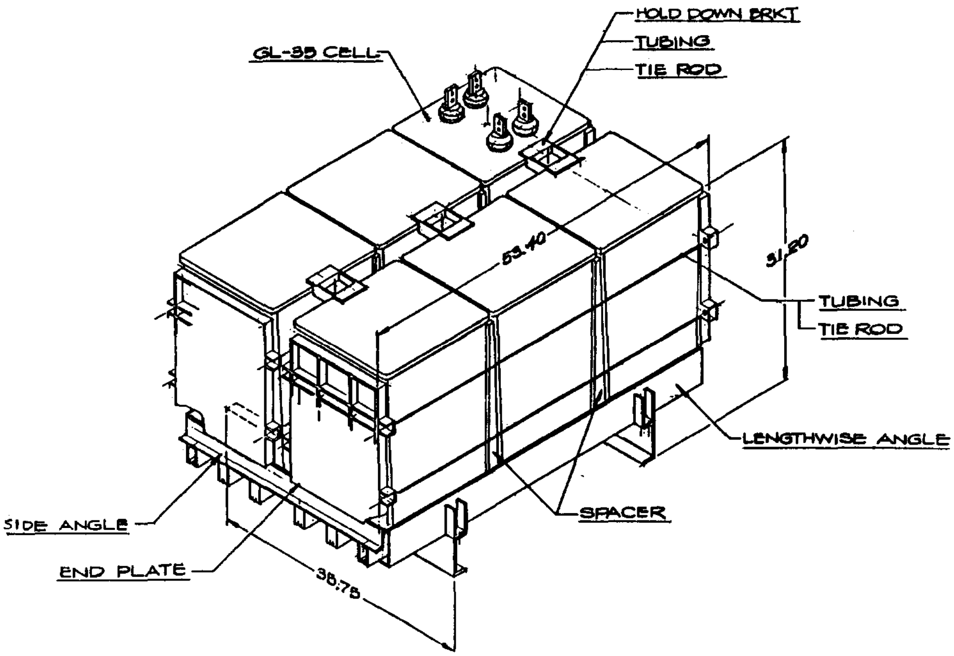

Fig. 2. Sketch of 6-cell battery module at Chino substation.

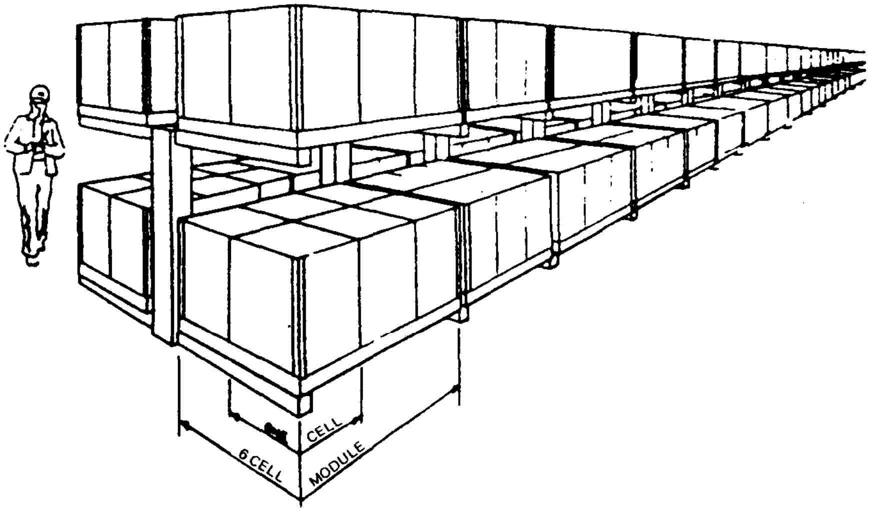

Fig. 3. Two-tier battery modules on earthquake-resistant steel frames.

energy output of 50 MW h, a discharge current of 5200 A, and a footprint of 10 320 $ft^2$ (excluding aisles). Each cell will have a rated capacity of 3100 A h at 620 A to 1.67 V/cell, a weight of 580 lb, a size of 16.6 × 15.1 × 27 in., and a content of 12 gallons of sulfuric acid electrolyte. Each cell has an energy output (5 h rate) of 6.2 kW h, an energy density (weight) of 10.7 W h lb$^{-1}$, and an energy density (volume) of 1.05 W h in.$^{-3}$. The cells are being built by Exide Corporation according to their 6GW35 design.

The Exide cell design features include: flat-plate construction (type GL 35); 17 lead–antimony alloy positive grids (17.3 × 13.7 × 0.33 in.); 18 lead–calcium alloy negative grids (same size as positive grids); SAN cell jar material; PVC cell covers; a sediment space of 1.3 in.; a separator system (on positive plates) comprising a non-woven glass absorber mat, a perforated PVC retainer, and a microporous rubber separator; an acid specific gravity of 1.28 - 1.29 at top-of-charge; low-torque-maintenance terminal posts of lead-plated copper (two positive and two negative posts per cell); Slide-Lock$^{TM}$ post-to-cover seal, and structural adhesive cover-to-jar seal [5].

The battery specification requirements include: rated discharge requirement, 100% depth-of-discharge, energy output of 65.8 MW h, power 10.5 MW, and a time to 1.75 V/cell of 6.25 h; daily discharge requirement, 80% depth-of-discharge, energy output of 52.7 MW h, power 10.5 MW, and five hour discharge; expected load profile, sine curve, initial power 2 MW, maximum mid-power 10.5 MW, and final power 2 MW; battery lifetime of eight years after 2000 cycles at 80% depth-of-discharge; a daily recharge time of 6 - 10 h; an overall cell energy efficiency of 78% (d.c.-to-d.c.); an overall battery energy efficiency of 75% (a.c.-to-a.c., at terminals of the power-conditioning system); and an energy footprint of 5 kW h ft$^{-2}$ [6].

Environmental requirements for the Chino battery energy storage system include: an ambient operating temperature range of 32 - 117 °F; a seismic rating (earthquake resistance) of Zone 4 (UBC); a horizontal and vertical "G" force rating of 0.3 G; stibine gas emissions: daily eight hour average, $3 \times 10^{-4}$ scfm, total per day, 34 g; arsine gas emissions: daily eight hour average, $1.1 \times 10^{-5}$ scfm, total per day 0.77 g [7].

To store the a.c. energy entering the Chino substation, it must first be converted to d.c. This will be accomplished by means of a power conditioning system (PCS) having a 10 MW capacity; a ramp rate (from no-load standby to full-load) of 0 - 10 MW in 16 ms; a computer-controlled, remotely programmable design; a self-commutated system which provides "black-start" capability, minimizes shutdowns due to voltage variations on the utility line, and permits system testing without connection to the substation; and gate-turn-off (GTO) thyristors arranged in six bridges to provide an 18-pulse output a.c. signal. The General Electric Company will build, test, and deliver the power-conditioning system to the Chino substation.

## Present costs and future prospects

In the U.S.A., the major competitor of battery energy storage is the combustion turbine. The turbine has had considerable technical development with particular attention in recent years to reducing starting failures and forced outages. Since both power sources are capable of providing peaking power, the selection of a battery storage plant will depend largely on its capital, operation and maintenance costs compared with those of combustion turbine plants. The lack of environmental impact of batteries compared with combustion turbines will be an advantage for battery storage.

The present cost of the Chino battery energy storage plant, a first-of-a-kind demonstration facility in the U.S.A., is \$13.3 million, or \$1330/kW. This comprises \$10 million from Southern California Edison Company, for the batteries and balance of plant costs; \$2.3 million from the Electric Power Research Institute, for the power-conditioning system as well as for an engineer of record; and \$1 million worth of lead (2500 tons) for the batteries from ILZRO members in North America and Australia, plus two non-member companies in the U.S.A. The estimated cost of a standardized lead/acid battery energy storage plant in the future is \$6 million, or \$600/kW [8].

## Operation and maintenance

Site preparation for the Chino lead/acid battery energy storage demonstration project will begin on July 13, 1987, and it is scheduled to be in operation by April 30, 1988. After two years of testing and evaluation, the facility will be transferred from the research department to the system operation of Southern California Edison Company (SCE).

In addition to factory and site testing of the power-conditioning system, there will be a thorough investigation of facility performance under all the expected operating modes, such as voltage and frequency control, load levelling, load following, and rapid start-up/shutdown. Also, the performance and thermal testing of sample battery cells at an independent laboratory will occur.

Load shapes used to test the Chino facility will include demand curves for various industrial users, substation load shapes (see Fig. 4), and system wide load shapes. The tests will be designed by SCE and EPRI and implemented by SCE staff. The EPRI Engineer-of-Record (EOR) will be responsible for witnessing the tests, and documenting the results for the U.S.A. utility industry at-large. The cost and benefits of operating a battery energy storage plant will be derived from these tests.

The EOR will also record the actual facility performance, efficiencies of the plant components, and the overall facility efficiency. This effort will last for about two years. Prior to issuing these operation and maintenance reports, the EOR will document the design and construction phases of the facility from selection of the battery and PCS suppliers up to initial plant operation. All of these resulting documents will be issued as EPRI reports [9].

United Engineers & Contractors, a Raytheon Company, completed the final design and specifications for the Chino facility in April, 1987. They will also continue to serve as the EOR for the balance of the demonstration project.

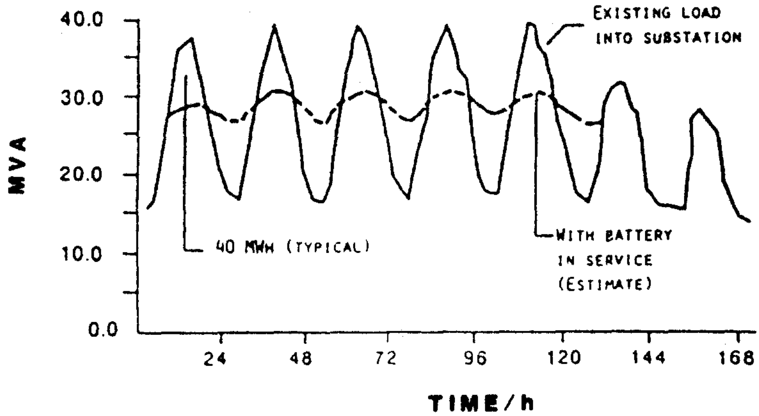

Fig. 4. Load shape at Chino substation for one-week period in August 1985.

## Other lead/acid battery energy storage applications

The Chino Battery Energy Storage Project is just one example of electrical utilities utilizing lead/acid batteries for load levelling and other utility applications. In Japan, a 1 MW/4 MW h lead/acid battery energy storage plant began load-levelling service at the Tatsumi substation of Kansai Electric Power Co., Inc. in September, 1986. Built by Japan Storage Battery Co., Ltd., the improved lead/acid load-levelling battery employed cells with tubular positive plates and flat negative plates; had a nominal voltage of 2 V and a nominal capacity of 7500 A h; weighed 560 kg; and had overall dimensions of 1150 X 505 X 375 mm.

The Tatsumi battery plant consisted of 526 cells connected in series; had a nominal voltage of 1052 V; and was equipped with automatic water filling devices, electrolyte agitation pumps, and sensors to monitor battery performance. After six months of trouble-free operation between 90% and 35% depth-of-discharge, the Tatsumi battery is still operating at 86% efficiency (d.c.-to-d.c.). Under constant-current charge/discharge cycles, the life of the battery was found to be 3000 cycles by virtue of such improvements as an electrolyte-agitating device. System testing of the Tatsumi lead/acid battery energy storage plant will continue for a total of two years [10].

In Germany, the Berliner Kraft und Licht (BEWAG)-AG supplies electric energy and district heating in the municipal area of Berlin (West). Due to the political situation, BEWAG's electric power plant has been operated since 1952 as an insular system, without any connection to a superimposed grid. As a result, the operation of such an insular system is characterized by two major problems, namely, spinning reserve and load frequency control. To solve these two problems, an 8.5 MW lead/acid battery energy storage demonstration plant was installed in BEWAG's Steglitz power station in Berlin. It began operating in December, 1986.

The Steglitz advanced lead/acid battery was built by Hagen Batterie AG. Its main characteristics include: single-tube positive plates with less than 3% antimony in the lead-alloy spine; lead-plated, expanded-copper-metal negative flat plates instead of cast-lead grids [11]; electrolyte specific gravity of 1.28 at 30 °C; automatic water filling system; and electrolyte agitation by means of an air-lift pump.

The battery comprises 7080 cells connected in 12 parallel strings of 1180 V (590 cells) each. A five-cell monobloc-container, equipped with a heat exchanger for thermal management, was adopted as a standard design for several different uses. Each module has a nominal voltage of 10 V, a capacity of 1000 A h, and a weight of 380 kg. Every battery string is equipped with its own auxiliary charger to perform equalization charges with d.c. currents of admissible harmonic current content. The expected service-life of the BEWAG battery is eight years [12].

In Australia, a joint project between the Australian Lead Development Association and CSIRO is examining the technical feasibility of utility load levelling by means of lead/acid battery energy storage systems on that continent. A load-levelling capability of up to 5 MW is under consideration.

In South Africa, AEG is installing a 4 MW lead/acid battery energy storage system at a gold mine. The battery will be used for load levelling as well as for emergency standby power [13].

## Projected need for energy storage

The need for energy storage facilities is international. EPRI has estimated that U.S. utilities should provide a demand for one million tons of lead for battery energy storage by the year 2000. This estimate is based on the assumption that lead/acid batteries will comprise 0.5% of U.S. generation and that energy storage facilities will increase from the current 3% of total generation capacity to 3.5%. That conservative value can be compared with current estimates of stored energy capacity of 14% for Italy, 10% for Japan and 6 - 7% for France, England and Germany.

The battery share of the U.S. storage capacity in the year 2000 is estimated at 4000 MW of a total of 18 000 MW, with the difference shared equally by pumped-hydro and compressed-air systems. The estimated requirement of one million tons of lead assumed the batteries would have five hours of stored energy and would require 100 lb of lead per kW h [14].

## Conclusion

The use of lead/acid batteries for electrical-load management appears to have achieved a milestone in 1987, with the planning or installation and operation of battery energy storage systems in the U.S.A., Japan, Germany, Australia, and South Africa. The results obtained from these demonstration projects should encourage electric utility companies worldwide to install such systems to cope with increasing demands for power during peak periods on a daily or seasonal basis. Thus, load levelling and related applications for lead/acid batteries face a bright future indeed.

## Acknowledgements

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