LEAD/ACID BATTERIES IN U.S.A. LOAD-LEVELLING APPLICATIONS

D. S. CARR

International Lead Zinc Research Organization, Inc., P.O. Box 12036, Research Triangle Park, NC 27709 (U.S.A.)

Introduction

In general, load levelling refers to the various techniques employed by electric utility companies to minimize their fuel costs and to improve their generating load factors. Similarly, peak shaving refers to the methods used by large consumers of electricity to reduce their peak-power demand charges. This paper will illustrate how lead/acid batteries are being utilized in energy storage systems in the U.S.A. for load-levelling and for peak-shaving applications.

Electric utility load-levelling options

On the supply side, electric utility companies employ various operating methods to reduce the cost of power generation each day. Normally, as much electricity as possible is generated with the lowest cost fuels. Thus, with the exception of hydroelectric plants, most electric utilities rely upon coal or nuclear fuel to meet their baseload requirements. Then, as demand increases, intermediate loads may be met with gas-fired steam plants. Finally, when peak loads develop (for example, during morning and evening rush hours), relatively expensive oil- or gas-fired combustion turbines are started up to generate additional electricity.

In the U.S.A., load factors on base-load generating units have been declining in recent years (due to under-utilization of night-time power) while peak-load demands have been steadily rising (for example, to provide heat and light during winter months and to provide air conditioning and irrigation in the summer months). As a result, electric utilities have adopted various load-levelling techniques to cope with these widely fluctuating demands for power each day.

Several utility management techniques for load levelling are described in Table 1. Such techniques include: additional power generation (by means of combustion turbines); power imports (purchases of electricity from other utilities); economic incentives (lower rates in return for interruptible power contracts); economic penalties (imposition of demand charges for power

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TABLE 1

Electric utility options for load levelling

Option	Advantages	Disadvantages
Additional power generation — using combustion turbines	Short delivery time; known technology; relatively low cost equipment; short start-up times; suitable for extended power demands	Requires relatively costly fuels (gas or oil *vs.* coal); unsuitable for short intermittent operation; adds to air pollution (combustion products)
Power imports — purchases from other utilities	Flexibility in coping with peak demands; possibly lower in cost than operating combustion turbines (for example, if purchased from a hydroelectric source)	Requires investment in equipment for interconnections with other electrical grid systems; power may not be available if other utility has a peak demand at the same time
Economic incentives — power interruption agreements with customers	Provides load shedding capability at periods of peak demand from industry (e.g., electric furnaces in foundries) and from residences (air conditioners and hot-water heaters)	Requires investment in radio operated remote control switches at customer locations; increased book-keeping; loss of revenue due to load shedding
Economic penalties — peak demand charges	Induce customers to voluntarily shift their power demands to off-peak periods; provide revenues for use of costly fuels for combustion turbines to generate electricity for peak loads	Customers may relocate to other regions having lower cost power available; total revenue may decline if customers shift power demands to off-peak times
Energy storage systems — pumped hydroelectric; compressed air; thermal; electrochemical (batteries)	Provide power at peak demand times; utilize low-cost base-load generating capacity; improve load factors of steam-powered generating equipment; defer investments in costly peaking generation capacity and additional transmission/distribution facilities	Geographical limitations on siting of pumped hydro plants (water shortages in desert areas) and compressed air plants (lack of suitable caverns); environmental limitations (encroachment on recreational areas); high unit costs of novel battery systems

consumed during peak periods); and various energy storage systems (pumped hydroelectric; compressed air; thermal storage; electrochemical energy storage by means of rechargeable batteries). In principle, energy storage systems are used by utilities to convert economical off-peak electrical energy to other forms of energy from which electricity can be readily regenerated during peak demand periods.

Customer-side-of-the-meter peak-shaving options

On the demand side, electric utility customers have fewer energy storage options available, than do utilities, to minimize their costs of electricity during peak demand periods. For example, pumped hydroelectric systems and compressed air energy storage systems have geographical, environmental, and financial limitations that normally restrict their use to the larger electrical utility companies. Nevertheless, utility customers do have several energy storage system options available to reduce their peak demand charges, as described in Table 2. These include: load shedding; thermal storage; cold storage; co-generation; battery storage.

Typically, if a customer's demand for electricity exceeds a preset limit for a specified period, say, one hour, during the utility's monthly peak demand period, the customer must pay a surcharge (demand charge) for each hour of peak power consumed that month. In the summer, monthly peak demand charges in the U.S. range from $10 to 20/kW, while in the winter they range from $5 to 15/kW. Thus, the option of electrochemical energy storage by means of rechargeable lead/acid batteries should be considered by all those customers faced with large monthly peak demand charges. Such customers might include, among others, commuter railroads, shipyards, chemical plants, and foundries using electric furnaces.

TABLE 2

Customer-side-of-the-meter energy storage options for peak shaving

Option	Description
Load shedding	During utility peak demand periods, customers may shed some of their electrical loads by re-scheduling their energy-intensive work to off-peak hours, or by temporarily turning off unnecessary lights, water heaters, air conditioners, fans, and other electrical equipment
Thermal storage	In cold, winter months, off-peak electrical energy at night can be used to heat stones or to generate and store steam for use in providing heat during daytime hours
Cold storage	During hot, summer months, off-peak electrical energy may be used to make ice for reducing air conditioning loads in the daytime hours
Co-generation	When a customer has stored excess steam, as a by-product of the energy required for industrial processing, it may be used to generate electricity during daily peak demand periods
Battery storage	Low-cost, off-peak electricity can be converted to direct current to re-charge lead/acid batteries; then the customer can discharge the batteries through an inverter to provide alternating current for peak shaving as the electric utility reaches its daily peak

Benefits of battery energy storage systems

For electric utility companies, lead/acid battery energy storage systems offer many managerial, environmental and economic benefits. These are described in Table 3 and include: improved base-load operating efficiency; management of peak loads; dispatched control of co-generated power; load-following capability; enhanced system stability; spinning-reserve credit; mod-

TABLE 3

Electric utility battery energy storage benefits

Benefit	Description
Improved base-load efficiency	Off-peak battery charging increases load factor of steam-powered base-load generators
Peak load management	Peak power demands, up to 4 h in duration, can be met by discharging batteries
Dispatch of co-generated power	Stored energy from co-generators (say, wind energy) can be dispatched during peak demand periods
Load-following ability	As generators are ramped up to operating speed, discharging batteries can meet power demands
Enhanced system stability	Rapid response of stored battery power avoids fluctuations in energy supply to customers
Spinning-reserve credit	Fuel for standby generating capacity can be saved through credits for instantaneous battery power, even while cells are being recharged
Modular construction	System planning can be improved by adding battery modules as needed when peak power demands rise in a local area
Short construction time	Battery energy storage systems can be built in about two years, *vs.* 10 years for a steam plant
Easy siting	Battery power can be installed at dispersed sites to meet peak demands in growing areas
Environmental acceptance	Virtually no emissions emerge from clean, quiet, battery energy storage facilities
Capital expense deferral	Investments in a new power transmission and distribution equipment can be deferred by installing battery power at a local substation
Economy power purchases	Battery storage capability allows additional economy energy (say, off-peak hydroelectric power) to be purchased.

ular construction; short construction time; easy siting; environmental acceptance; deferral of capital costs for new transmission and distribution equipment; purchase of economy power from other utilities [1]. To illustrate these various load-levelling benefits, a 10 MW/40 MW h lead/acid battery energy storage system (in operation at the Chino Substation of Southern California Edison Company) will be briefly described below.

In the case of customer-side-of-the-meter peak-shaving applications, many of the foregoing benefits of battery energy storage systems apply equally well. For example, such benefits would include: management of peak loads; modular construction; short construction time; easy siting; environmental acceptance; purchase of economy (off-peak) power. In addition, through the avoidance of peak-demand charges, customers may realize a relatively short payback period for their battery energy storage systems. (This will vary, of course, with the demand charges of the local electric utility; inflation; taxes; interest rates; operating and maintenance costs; cycle life of the battery; among other factors.)

Several examples of successful customer-side-of-the-meter peak-shaving applications of lead/acid batteries are cited below. They include: the Advanced Load Management System of Johnson Controls, Inc.; the Turn-Key System for Battery Based Energy Management at a Johnson Controls, Inc. brass foundry; the Battery Energy Storage System at an automotive battery plant of Delco Remy Division, General Motors Corporation; the lead/acid battery peak-shaving system in operation at the Cresent Electric Membership Corporation.

Lead/acid battery load-levelling systems operating in the U.S.A.

In recent years, several lead/acid battery load-levelling systems have been installed in the U.S.A. as demonstration projects: to validate design, procurement, and installation costs; to demonstrate operational and economic benefits; to gain experience with operating and maintaining such systems; to promote a new market for lead/acid battery energy storage systems. Table 4 summarizes the essential features of the five load-levelling and peak-shaving systems now operating in the U.S.A. A more detailed description of each system is presented below.

Chino Substation of Southern California Edison Company

Southern California Edison Company (Edison) is now operating the world's largest battery energy storage system, a 10 MW/40 MW h facility located at its Chino 220 kV Substation, 50 miles east of Los Angeles. This is a demonstration project operated and maintained by Edison, with participation by the Electric Power Research Institute (EPRI) and the International Lead Zinc Research Organization, Inc. (ILZRO). EPRI supplied the 10 MW Power Conditioning System (to convert the direct current power of the batteries to alternating current power for the Edison system and *vice versa*)

TABLE 4

Lead/acid battery energy storage systems operating in U.S.A.

Energy storage system	Power (kW)	Energy (kW h)	Batteries in system	System voltage/d.c. (V)	Battery type	System floor space	Start-up date
Chino 220 kV Substation — Southern California Edison Company, Chino, CA	10 000 (10 MW)	40 000 (40 MW h)	8256	2000	Flooded cell	48 400 ft^2 (4496 m^2)	August, 1986
Advanced Load Management System — Keefe Avenue battery plant, Johnson Controls, Inc., Milwaukee, WI	300	600	300	600	Flooded cell (40%) Gelled/ sealed (60%)	2000 ft^2 (186 m^2)	May, 1986
Turn-Key System for Battery Based Energy Management — brass foundry, Johnson Controls, Inc., Milwaukee WI	300	580	192	384	Gelled/ sealed	484 ft^2 (45 m^2)	February, 1989
Battery Energy Storage System — automotive battery plant, Delco Remy Division, General Motors Corporation, Muncie, IN	300	600	1200	600	Flooded	2288 ft^2 (213 m^2)	February, 1987
Peak Shaving Battery System — Crescent Electric Membership Corporation, Statesville, NC	500	500	324	648	Flooded	572 ft^2 (53 m^2)	July, 1987

and ILZRO loaned 2000 tons of lead to the project for construction of the 8256 lead/acid battery cells installed at the Chino facility.

Edison began the project in August, 1986, and a two-year test programme was started after completion of the Chino facility in July, 1988. This programme, managed by Edison's Research Division, will demonstrate compatibility and reliability of the lead/acid battery energy storage system in managing loads effectively on a daily basis. Accordingly, the system will be operated in such modes as load levelling, spinning reserve, load following, up/down ramping, and voltage/frequency control. Actual costs to operate and maintain the Chino battery energy storage facility will be determined. Also, methods to reduce operating expenses and to improve load-levelling procedures will be sought.

At the end of the two-year test period, the Chino facility will be transferred to Edison's systems operations. Meanwhile, information obtained from this demonstration project will be transferred to electric utilities and others interested in using battery energy storage for energy management purposes through semi-annual EPRI Project Review Group meetings. In spite of some unexpected operating disturbances, initial performance of the Chino facility has demonstrated its unique load-levelling capability which can defer or replace costly investments in peaking generation capacity. Further details about the Chino lead/acid battery energy storage system are presented in the following paper by Rodriguez *et al.* at this conference.

Advanced Load-Management System of Johnson Controls, Inc.

In a co-operative project with the Wisconsin Electric Power Company, Johnson Controls, Inc. constructed an Advanced Load-Management System at its Keefe Avenue battery plant in Milwaukee, Wisconsin in May, 1986. The purpose of this project was to examine the commercial viability of lead/acid batteries for customer-side-of-the-meter load management in an industrial setting. Studies were undertaken to evaluate load-management strategies, control-system technologies, battery performance, and system maintenance. After two years of operation, several major conclusions were drawn which led to the design of a commercial, battery-based, energy management system and associated demonstration project at a Johnson Controls, Inc. brass foundry in Milwaukee, Wisconsin (see below).

The initial battery facility comprised 300 lead/acid cells capable of supplying 600 kW h at the 2-hour ($C/2$) discharge rate. Five separate battery strings, each of 120 V, made up the 600 V/1500 A h system. Sixty percent. of the batteries were of a sealed, maintenance-free design. Battery monitoring equipment permitted 300 individual cell voltage measurements (0 - 3 V); 50 module voltage measurements (0 - 20 V); 50 cell temperature measurements; two ambient hydrogen gas levels; and 98 other miscellaneous measurements. The facility occupied about 2000 square feet (186 m^2) of floor space, divided into three areas, including a control room, a battery bay, and a transformer room. A JC/85 Energy Management System and a DSC-8500 digital system controller monitored the electrical consumption of the plant and determined when the batteries were to be charged or discharged.

During weekdays, the energy stored in the batteries was automatically discharged into the Keefe Avenue battery plant when the electrical requirements of the plant exceeded a preset value. Each day the five battery strings were 100% discharged to 105 V/string (1.75 V/cell) and were then fully recharged to 120 V/string. The six-pulse, line-commutated power-conditioning unit could accommodate one to five battery strings in series or parallel configurations. This enabled the system to continue operation even though one, or more, battery strings was off-line for maintenance or for other reasons. Measurements of the total harmonic distortion obtained on the 26.4 kV line reflected no measurable harmonic content which could be attributed to the inverter/converter of the load management facility.

The Johnson Controls, Inc./Wisconsin Electric Power Company Test Project is on-going to determine the minimum ratio of plant power requirements/load management system power for satisfactory use of a six-pulse power conditioning system. At present, the power consumption of the Keefe Avenue battery plant is approximately ten times larger than the full power capabilities of the load-management facility. In situations where a six-pulse system is applicable, it is a viable and economical approach [3].

Johnson Controls, Inc. Turn-Key System for battery-based energy management

A battery-based energy management system was recently constructed within a Johnson Controls, Inc. brass foundry, located in the Milwaukee, Wisconsin, area to verify the feasibility of this concept for decreasing monthly on-peak demand charges. This demonstration system was designed to be commercially cost-effective as a complete turn-key operation. It has been in operation since February, 1989, and has successfully maintained the 1100 kW set point despite a typical monthly peak energy demand of approximately 1650 kW to operate two inductively heated furnaces.

In the Milwaukee area, electric rates for Class 2 users are $7.90/kW and $0.023/kW h. At these relatively low rates, it is possible to consider the use of on-peak charging as a viable means of reducing the size of the peak-shaving battery required. A System Sizing Software Program was developed to depict the amount of energy and the number of batteries required to reduce the daily energy demand by, say, 300 - 500 kW. The calculation included such variable options as the maximum depth-of-discharge of the batteries and the dead-band window needed for purposes of evaluating on-peak charging during periods of low-peak demand. The program showed that fewer batteries were needed when on-peak charging was possible. On the other hand, as the magnitude of the peak shaved was increased, more batteries were required (because less power was available for on-peak charging). Thus, the system size was selected on the basis of capital investment required and the corresponding economic payback.

At the brass foundry, a 300 kW/575 kW h lead/acid battery energy storage system was selected. The complete system was constructed in the shipping/receiving department and occupied a floor space of 22 × 22 ft. A total of 64 maintenance-free, gelled, sealed lead/acid battery modules were used to store energy in the energy management system. Each module had a nominal voltage of 6 V and a capacity of 1500 A h and the *C*/3 discharge rate. The fork-liftable modules were stacked eight-high on standard, steel, factory pallet shelving, to a vertical height of 16 ft, in two rows of 32 modules each. Four, equally spaced air blowers were installed in the aisle between the stacks of battery modules to provide thermal management within each module for maximum performance and battery life. On-peak charging was used extensively and the daily depth-of-discharge (six to seven cycles per day) normally did not exceed 80% of capacity.

The power conditioning system was a dual bridge, six-pulse, line commutated type with 480 V, three-phase a.c. input and a nominal 384 V d.c. bus voltage. During initial battery charging, the system typically operated in a constant power mode, while a constant voltage mode was used for final battery charging under direction of a Johnson Controls DSC 8500 digital system controller. One cabinet (80 × 80 × 24 in.) housed the bridge and firing circuitry, power-factor correction capacitors, and the harmonic inductor. The equipment also had an auto-line fault sensing circuit which safely cleared the system in case of line loss and then restarted the system when the line was back to normal.

The load-following DSC 8500 controller automatically determined daily energy demand set points through forecasting, while limiting the maximum battery depth-of-discharge to 80% under normal operating conditions. When the set point of the previous day was exceeded, the control system automatically increased the daily set point. The complete control system was housed in a wall-mounted cabinet (24 × 24 × 10 in.).

After several months of successful operation at the Johnson Controls, Inc. brass foundry, the Turn-Key System for Battery-Based Energy Management demonstrated that it could rigidly maintain a set point of 1100 kW while employing a dead-band of 8 kW with opportunity charging [4]. The approximate cost of a 300 kW Turn-Key System, excluding installation, was estimated to be $198 000 [5].

Delco Remy Battery Energy-Storage System

Delco Remy, a major manufacturer of automotive-type lead/acid batteries, decided to evaluate the suitability of such batteries for customer-side-of-the-meter load-levelling applications, as part of an ongoing marketing effort. Accordingly, they installed a 300 kW load-levelling system at their Muncie, Indiana, battery plant in February, 1987, and it has been functioning essentially unattended since that time.

The load profile at the Muncie Battery Plant varied widely, from a low of ~6 MW at midnight to a high of around 8.3 MW between 11 a.m. and 4:30 p.m. These loads reflected variations in the power required for: the battery formation department; heaters for the lead pots; air compressors; injection molding machines; heating, ventilating, and air conditioning systems. A load-shedding system had already been installed at the Muncie Plant prior to construction of the lead/acid battery load-levelling system. Although the plant did not have an ideal load profile for levelling, because it tended to be broad in time, the battery energy storage system was sized large enough to provide a good evaluation of the batteries without being prohibitively costly. Also, to minimize the cost of site preparation, the battery system was installed in a building adjacent to the Muncie Plant.

The battery pack consisted of 1200 commercial, heavy duty, truck-sized, 'maintenance free' (no watering and essentially no gassing), lead/acid batteries. The batteries were connected in 24 parallel strings, having 50 series-connected batteries in each string. Based upon accelerated endurance tests, the specific gravity of the sulphuric acid electrolyte was raised from 1.250 to 1.270 in the load-levelling batteries. An open-circuit voltage of 660 V was measured, but under full load it quickly fell to 610 V and then decreased linearly to 575 V in 1.5 h. Full load consisted of a pack current of 480 A, or 20 A per string.

Although this battery system could shave a 300 kW peak for 1.5 h (450 kW h) and still retain satisfactory cycle life at 40% depth-of-discharge, the battery pack was cycled to 50% depth-of-discharge to extend the peak shaving to 2 h (600 kW h). This was possible because fewer cycles per month were encountered than had been anticipated. By the end of December, 1988, a total of 338 invert-charge cycles was completed. A group of five batteries, selected at random within the racks, was used to test the reserve capacity of the battery pack. The results indicated an average reserve capacity of 80%; teardown inspection showed that the positive plates and the separators were in good condition, and the negative plates were normal, except for considerable sponge lead and plate expansion conditions. From this evaluation, it was concluded that considerable life remained in the battery pack.

A line-commutated, six-pulse, 480 V, three-phase inverter was built for this project by Omnion, a subsidiary of Wisconsin Power and Light Company. It had a 300 kVA peaking capability; a power factor of 0.9; a maximum harmonic distortion below 4%; and a one-way efficiency of 95%. In the reverse mode, it was used to charge the batteries at a constant current of 480 A until the current tapered to about 200 A; then charging was continued at 775 V. As the current dropped further to 30 A, a top charger cut in to complete the charging and to float the batteries at 690 V (corresponding to a single 12 V battery charge voltage of 13.8 V).

The load-levelling system was housed in a separate building (40 × 50 ft) adjacent to the main manufacturing plant. A control room (12 × 24 ft), located along one side of the main room, contained an IBM XT computer with associated controls: the inverter–charger, top charger, and the d.c. power switching panel. The a.c. power mains and the racks of batteries were located in the main room.

The cost of installation of the Delco Remy load-levelling system was approximately \$400 000. This comprised the inverter–charger (\$180 000); instrumentation (\$100 000); batteries (\$60 000); balance of plant (\$50 000, including battery racks at \$15 000); and top charger (\$10 000). After initial trials, the large instrumentation system was discarded in favor of a small, compact program, contained in the IBM XT computer. It produced a constant readout of battery pack voltage and current, and kW h reserve.

During a 17-month period (February, 1987 through June, 1988), the total electric utility savings for 304 off/on cycles of operation were \$47 589. These load-levelling savings were based upon a demand charge of \$13.20/kW (kV A) at the Muncie Battery Plant of Delco Remy Division of General Motors Corporation [6].

Crescent Electric Membership Corporation Peak-Shaving Battery System

Cresent Electric Membership Corporation (CEMC) is one of 27 electric membership corporations (EMCs) operating in the State of North Carolina. The EMCs are not power producers, but purchase electricity from one of the power producing utilities in the State and then resell the power to their customers. Thus, for example, CEMC purchases all of its power from Duke Power Company of Charlotte, North Carolina.

If CEMC is drawing power when Duke Power Company reaches its own system peak, then CEMC must pay a demand charge for the month (coincident peak billing of \$16.40/kW). To minimize such demand charges, CEMC has instituted an extensive load-management program whereby customers agree to have radio-controlled cut-off switches installed on their air conditioners and water heaters. Then, when a system peak is anticipated at Duke Power Company, CEMC activates its load-control switches to cut off power temporarily to its customers' air conditioners and water heaters. In return, such customers receive a reduced monthly billing for electricity.

To evaluate the economic benefits of using a lead/acid battery energy-storage system for peak shaving in a utility environment, a 500 kW h battery ($C/1$ rate) was installed by the North Carolina Alternative Energy Corporation (NCAEC) at the CEMC substation near Statesville, North Carolina, in July, 1987. The system included a 500 kW/500 kW h battery manufactured by GNB Incorporated of Langhorne, Pennsylvania, and a 500 kW power converter, controller, and float charger, manufactured by Firing Circuits Incorporated of Hartford, Connecticut. The battery was rated 500 kW at the $C/1$ rate, 300 kW at the $C/2$ rate, and 200 kW at the $C/3$ rate.

After three years of testing in New Jersey at the Battery Energy Storage Test (BEST) Facility, the 500 kW h battery system was purchased by NCAEC from the Electric Power Research Institute (EPRI) and shipped by truck to Statesville, North Carolina. The costs associated with the acquisition, relocation, and installation of the battery energy storage system totalled \$155 000:

Crescent Electric Membership Corporation Costs

Item	Cost ($)
System acquisition/administration costs	25 000
Battery relocation costs	32 000
Power conditioning modifications/relocation	13 000
Construction cost, North Carolina	85 000
Total	155 000

It is estimated that a new lead/acid battery energy-storage facility could be built in North Carolina at a cost of $260 000. Thus, the battery cost would be $80 000; the power-conditioning system would cost $100 000; and construction/installation costs would amount to $80 000, for a total of $260 000.

Experience at CEMC has shown that the Duke Power Company peak can be predicted for approximately 95% of the time. It is estimated that over the course of one year the battery will be discharged at the average of the $C/2$ rate output, or 300 kW. Therefore, CEMC may expect annual savings of about $56 000 through the use of its lead/acid battery energy storage system (12 months/year × 300 kW/month × $16.40/kW × 0.95 = $56 088/year savings). Anticipated maintenance requirements at the CEMC battery energy storage facility are 16 man-days/year. If a loaded labor rate of $16 h^{-1} is assumed, the estimated yearly operating costs would be $2048 (16 days/year × 8 h/day × 16 h^{-1} = $2048/year). Based upon the foregoing assumptions, the annual net savings realized by CEMC, through the use of its lead/acid battery energy-storage facility, would amount to approximately $54 000 ($56 088 savings in demand charges − $2048 maintenance costs = $54 040/year).

Finally, the estimated payback period for a new 5 kW lead/acid battery energy storage system in North Carolina would be around five years ($260 000 plant cost/$54 040/year operating savings = 4.8 years payback period).

Between July, 1987 and March, 1989, the CEMC battery underwent 46 discharges at 200 kW; 10 at 300 kW; and 24 at 500 kW. A total of 4500 kW were shaved, for total savings of $74 369 in demand charges. A battery capacity test was conducted in March, 1989, and the results compared favorably with the battery capacity rating, even though the battery was over five years old. Total battery cycles are less than 400, and fewer than 100 cycles/year are expected in the future. Thus, the battery at Crescent Electric Membership Corporation will probably fail due to old age rather than to excessive use. Overall, the battery will be a good economic investment [7].

Economic aspects

The Electric Power Research Institute has estimated that by the year 2000 energy storage requirements in the U.S.A. will increase to 18 GW (18 000 MW), or about 3.5% of the total generating capacity. This compares with present estimates of stored energy capacity of 14% for Italy; 10% for Japan; and 6 - 7% for France, U.K., and F.R.G.

Of the total 18 000 MW of stored energy capacity expected in the U.S.A. by the year 2000, about 14 000 MW are expected to be provided by pumped hydroelectric plants and compressed air energy storage facilities. Thus, the potential for battery energy storage in the U.S.A. is estimated to be 4000 MW by the year 2000. Based upon the Chino battery system, a potential market for 800 000 tons of lead could emerge in the U.S.A. by the year 2000 (4000 MW × 2000 tons lead/10 MW at Chino = 800 000 tons lead). In addition, if up to eight customer-side-of-the-meter (CSOM) lead/acid battery energy-storage systems, similar to the system at Crescent Electric Membership Corporation (500 kW h, or 0.5 MW h), are installed by the year 2000 in each of the 50 States of the U.S.A., another potential lead market of 10 000 tons could develop. (Thus, 8 CSOM batteries/State × 50 States × 0.5 MW h × 50 tons lead/MW h = 10 000 tons of lead.)

The U.S. Department of Energy predicts that by the year 1995 the peak demand for electricity will exceed the available supply in several regions of the U.S.A. In fact, by the year 2000, the expected shortfall of electricity generating capacity in the U.S.A. will exceed 100 gigawatts based upon existing plants, plus plants under construction minus retirements of old plants. Accordingly, to provide a means of preventing such predictable future brownouts and blackouts in the U.S., the Department of Energy is working with the Electric Power Research Institute to develop the use of new, maintenance-free, sealed lead/acid batteries for energy storage and subsequent load levelling.

To realize the potential new markets for lead, it will be necessary to conduct research on improved lead/acid battery designs. That is, advanced lead/acid batteries must be developed with greater charge acceptance, lower maintenance, longer cycle lives, and lower costs. In this way, the strong position of lead/acid batteries can be maintained in the emerging market for load-levelling and peak-shaving applications in the U.S.A.

Conclusions

On the basis of five successful load-levelling and peak-shaving installations in the United States of America, it may be concluded that such energy management systems represent a new and commercially viable application for lead/acid batteries. In fact, a turn-key system (lead/acid batteries, inverter, and controls) is now available in the U.S.A. for customer-side-of-the-meter peak-shaving applications. As more lead/acid battery energy-storage systems are built, it is expected that the unit costs ($/kW) of such systems will become more competitive against other battery systems now being developed. In addition, research is continuing on ways to improve the performance and cost-effectiveness of lead/acid batteries for load-levelling applications in the U.S.A.

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