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Operational experience and performance characteristics of a valve-regulated lead–acid battery energy-storage system for providing the customer with critical load protection and energy-management benefits at a lead-recycling plant

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Abstract

The Power Control Division of GNB Technologies, commissioned on May 13, 1996 a new facility which houses a 5-MW battery energy-storage system (BESS) at GNB's Lead Recycling Centre in Vernon, CA. When the plant loses utility power (which typically happens two or three times a year), the BESS will provide up to 5 MW of power at 4160 VAC in support of all the plant loads. Since the critical loads are not isolated, it is necessary to carry the entire plant load (maximum of 5 MVA) for a short period immediately following an incident until non-critical loads have been automatically shed. Plant loading typically peaks at 3.5 MVA with critical loads of about 2.1 MVA. The BESS also provides the manufacturing plant with customer-side-of-the-meter energy management options to reduce its energy demand during peak periods of the day. The BESS has provided a reduction in monthly electric bills through daily peak-shaving. By design, the battery can provide up to 2.5 MWh of energy and still retain 2.5 MWh of capacity in reserve to handle the possibility of a power outage in protecting the critical loads for up to 1 h. By storing energy from the utility during off-peak hours of the night in the batteries when the cost is low (US4.5¢ per kWh), GNB can then discharge this energy during high demand periods of the day (US$14.50 per kW). For example, by reducing its peak demand by 300 kW, the lead-recycling centre can save over US$4000 per month in its electric bills. The BESS at Vernon represents a first large-scale use of valve-regulated lead–acid batteries in such a demanding application. This paper presents a summary of the operational experience and performance characteristics of the BESS over the past 2 years.

Keywords: Back-up power; Energy-storage system; Lead–acid batteries; Peak-shaving; Uninterruptible power supply; Valve-regulated

1. Introduction

Momentary and sustained electrical power interruptions and voltage depressions represent two of the most difficult and important power quality and delivery problems that face many industrial and commercial users. There is a definite need at many industrial processing plants and commercial users of electrical power to have a dependable, efficient and controllable source of real and reactive power that is available instantly to support large electrical loads even if the incoming utility AC connection is lost. When power is interrupted or lost, the results can be extremely disruptive for critical processes and result in lost production, costly downtime and loss of customer good will, and in certain industries, can lead to environmental damage through the release of toxic emissions into the air. Two years ago, this challenge was faced by GNB Technologies at its lead reclaiming and smelting facility in Vernon, CA [1].

The lead-smelting process at Vernon (Fig. 1) creates lead dust which is recovered through the use of several large exhaust control fans and large containers. In 1997, the plant produced over 120 000 tons of reclaimed lead. When the plant loses its incoming utility power, these control fans (amounting to thousands of horsepower) must continue to run to avoid an environmental incident; lead dust can escape into the air if the fans stop running and can potentially cause environmental problems. To prevent such an incident, GNB considered installing diesel genera-

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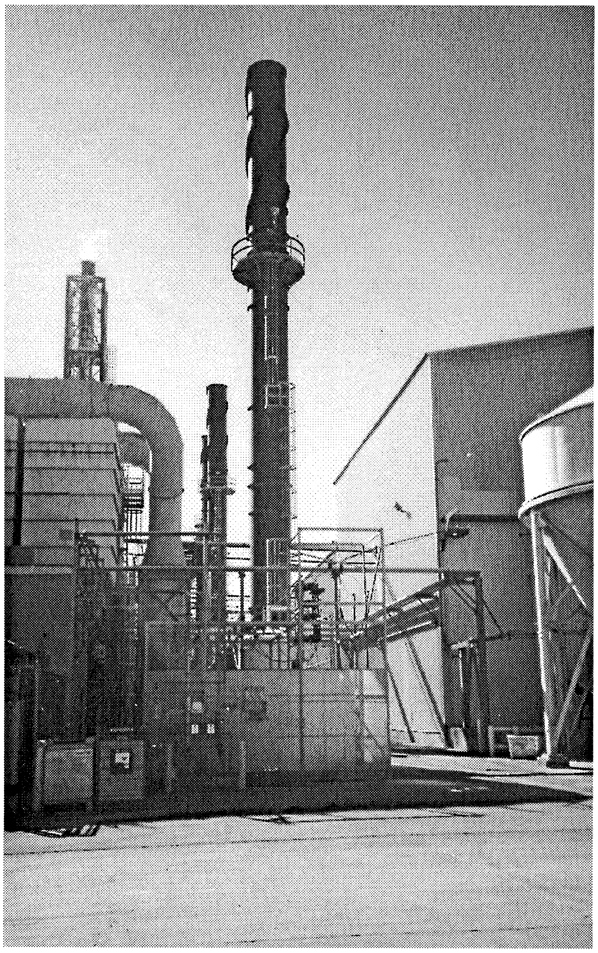

Fig. 1. GNB Technologies recycling centre, Vernon, CA, USA.

tors or several large uninterruptible power-supply (UPS) systems. The company elected, however, to install a battery energy-storage system (BESS). To date, the system has performed quite well and the plant has not been affected by power outages.

The main utility substation at the Vernon plant is rated at 5.0 MVA. During a typical production day, the average plant loading is about 3.3 MW. Demand spikes can, and do, push the overall loading up to greater than 4.0 MW. When adding up all the environmental controls and power requirements, the combination of these critical loads amounts to 2.1 MW. The BESS was designed to handle up to 5.0 MVA for a maximum of 15 s and provide for a continuous 3.5 MW following the predetermined load shedding of non-critical loads. At a continuous rate of 3.5 MW, the system can provide backup power for 1 h. In addition, the battery was sized with an additional 2.5 MWh reserve capacity for conducting a daily energy management function referred to as 'peak-shaving'.

The BESS at Vernon was primarily installed to protect the critical loads during a power outage at the 4160-V AC level of the plant power distribution system. The plant was built during a time when the distribution feeders out of the substation did not isolated critical loads. Therefore, it was necessary to back up the entire plant vs. just portions of the electrical distribution system. The BESS is fully automatic and operates in parallel with the existing plant loads. During the design phase of the Vernon BESS, tests at the plant revealed that, assuming an outage occurs, it is acceptable to transfer from parallel to series connection of the BESS within 12 cycles. A solid-state transfer switch (1/4 cycle transfer time) is not necessary in this industrial application. The types of critical loads are mainly large electric three-phase induction and synchronous motors.

The Vernon BESS is the largest known installation of its kind in the world owned and operated by an industrial manufacturer to support critical manufacturing process equipment. One of the critical processes at the plant is the operation of emission control systems associated with handling lead dust. GNB's primary concern is to assure the continual operation of these systems during a power outage. To accomplish this, GNB, working with General Electric, designed and built the BESS to provide a source of uninterruptible power in the event of a loss of incoming utility power and, thereby, to protect the critical processes from shutting down. Lead–acid battery recycling plants, like the one in Vernon that is within 8 km of downtown Los Angeles, must operate under stringent state and federal regulations for air-quality standards and environmental protection. The state-of-the-art manufacturing process equipment which GNB uses within the plant 24 h per day, 7 days a week, and year round to control its environmental emissions equipment must have an uninterruptible supply of power. No excuses are allowed.

2. Lead–acid battery system

At Vernon, the battery selected and being used is an advanced valve-regulated lead–acid (VRLA) ABSOLYTE® IIP modular battery system manufactured by GNB Technologies.

For more than 100 years, lead–acid batteries have been used for many essential standby and portable power applications. In the past 20 years, advancements in lead–acid technology and battery construction have lead to the production of large industrial-size, sealed, low-maintenance VRLA battery cells like the one which is being used in the Vernon BESS application.

The VRLA battery cell design is completely sealed and employs a pressure-relief safety valve. This electrochemical device operates on the basis of oxygen-recombination technology, uses a starved electrolyte, absorbed glass-mat construction and has no free acid to spill. The cells store energy efficiently, economically and safely, do not require water addition and, unlike a traditional, flooded, lead–acid battery, do not give off gases during normal charge–discharge operation.

By using the VRLA battery at Vernon, the required floor space needed to house the two strings of cells was reduced by over 50% as compared with using a flooded battery. Since the VRLA cells are sealed, battery cells are arranged three to a module and stacked one-on-top of each other eight modules high. The battery assembly was designed and certified to meet a seismic zone 4 earthquake.

Low maintenance is especially important for utility companies and industrial users having a BESS. Since the Vernon BESS system is unmanned and operates automatically, servicing the system is kept to a minimum with the VRLA battery system and operating costs are lower [2].

3. Battery layout

The battery system, as shown in Fig. 2, consists of two parallel strings, each having 378 GNB model 100A99 2-V VRLA ABSOLYTE® IIP modules connected in series providing a nominal 756 V DC. Each 100A99 module contains three model 100A33 cells connected in parallel. A metal housing for the 2-V cells is used to assemble a single power module. The tray has three basic parts: a container to house the cells, restraint bars to hold the cells within the container, and a clear plastic protective cover to insulate the cell connectors.

The system contains 48 stacks of batteries per string, arranged as 46 stacks 8 high and two stacks 5 high. The total installed weight of the battery assembly is in the region of 305 tons. At the end of each string is a DC disconnecting switch fused at 4000 A. Each of the battery stacks is monitored for voltage, temperature and potential ground faults. Pilot cells, as well as string current and hydrogen sensors, are also monitored [2].

4. Uninterrupted operation

There are two types of disturbances that the BESS protects against, namely, power interruptions and short circuits. A power interruption is the loss of one or more of the three-phase lines feeding the plant. Since the BESS acts as a voltage source in parallel with the loads, the plant load will not experience the interruption and will continue to operate normally. The BESS control system will automatically open the plant main breaker, based upon a measured current imbalance or reverse power flow, and isolate the plant from the incoming utility lines.

Short circuits can occur as phase-to-ground or phase-to-phase and will affect the entire plant. The strategy for dealing with short circuits is to isolate the plant from the fault and to re-establish voltage to the loads as quickly as possible. Timing for this to occur is approximately 200 ms. The BESS is designed to continue to operate through these short circuits. After the plant main incoming breaker is tripped, a signal is sent to the plant PLC to shed all non-critical loads and restart some critical loads if necessary.

Following a power interruption, the BESS is set to re-synchronize automatically and connect to the utility when power is restored. When first installed, the control function on re-synchronization was set in the manual re-closure of the main breaker. Shortly after the first power outage back in July of 1996, it was decided to set the control function of re-synchronization on automatic and not manual control. This action was taken because, following the first power outage event, the system performed exactly as designed and tripped the main incoming breaker. The utility outage lasted for only about 90 s. The plant technicians forgot, however, to transfer the power back to the utility and the BESS continued to carry the entire plant loading for almost 2 h before the low-voltage battery alarms alerted the plant personnel that they were still operating off the BESS. Without being in the operations control room at the smelter, one cannot distinguish the

Fig. 2. VRLA battery strings.

difference between utility power or BESS battery back-up unless visibly looking at the BESS monitoring control screen. The BESS is an unmanned facility and the audible alarm in the control room, which indicated the BESS was operational, was not heeded.

5. Reduction of utility power demand peak

Besides providing back-up power in the event the plant loses utility power, the BESS also provides for daily load shedding of power and energy to save money. In most countries like the USA, reducing the peak demand for power during peak periods of the day can lower an electrical bill if controlled properly. An electric utility company or supplier typically charges a different rate per kW on demand vs. the rate for kWh energy consumed. The rates can vary greatly between suppliers, summer and winter seasons, or time-of-day usage. Peak demand periods are generally when utility companies charge small and large industrial or commercial users a fixed amount per kW.

A BESS like the one in Vernon can provide savings by reducing the monthly demand peak for power by conducting daily peak-shaving. By pre-programming the BESS, it becomes an automatic process whereby the system is programmed to peak shave all power requirements over a set value. By storing energy into the batteries during off-peak hours (at night) when rates for energy are low, then, by discharging this energy on demand during the peak demand periods when rates are high, the overall electric bill can be lowered. For example, at the Vernon BESS facility, the cost of energy at night is US4.5¢ per kWh. During the peak demand period of the day, the utility company charges the customer at a rate of US$14.25 per kW. The local utility company monitors electric usage once every 15 min. The highest kW demand during any 15-min period sets the overall value for the month regardless if it is reached only once. Therefore, by reducing the demand by 1 kW, basically, the customer can lower its electric bill by US$14.20 for every kW it can peak shave. In other words, if the highest period for demand during the month was set at 3400 kW, the customer is billed a demand charge of US$48 450 plus the energy it uses (US$14.25 × 3400 kW). If there was a power spike during the month that reached 4000 kW and it lasted only 30 s, and, assuming the utility recorded that value, the demand charge billed would have been US$57 000 plus the energy used. The BESS can automatically cover the additional power requirements for the 30 s and, thereby, prevent the additional demand charge of 600 kW at US$14.25 per kW that would have cost the customer an additional US$8550 in demand charges for the month.

6. Improvement of power factor correction

One additional cost benefit in operating the BESS at Vernon is a reduction in the monthly penalty charge for power factor. A given amount of electric power can be supplied in various ways from a given voltage source. A utility company can supply a given number of watts with a relatively high current and low power factor or with a smaller current and a high power factor. The minimum current at any given voltage will be drawn when the power factor is at unity. Because the conductors, or other apparatus supplying a load, must be large enough to handle the current without overheating, a greater capital investment is required on the part of the energy supplier to supply a given number of watts at a low power factor than would be required at a higher power factor. Utility rates for large-scale energy users reflect this difference in capital investment cost by some form or other rate penalty for drawing power at a lower power factor. It is advantageous for the user to take action to raise the power factor of loads to save on the energy bill at the end of month. The capital investment of a BESS at the GNB Recycling Centre in Vernon has benefited by improving the power factor demand. Having the necessary power conditioning system and harmonic filters (capacitor bank), the system has improved the overall plant power factor from a typical 0.87 to a 0.94, current lagging. The benefit is cost saving of about $400 per month.

7. Peak-shaving energy

When automatically set to provide peak-shaving of energy usage, the BESS will supply all the power and energy requirements over and above the maximum level established. The maximum level set at Vernon may vary monthly and has been established via researching and analyzing the data showing the electric usage over the past 24 months. The term peak-shaving is associated with the amount of energy (kWh) that is used, whereas demand peak reduction described in Section 5 of this paper is associated with the amount of power (kW) required to handle the plant loads. By purchasing and storing off-peak energy at night, the plant at Vernon pays US4.5¢ per kWh. That same energy costs the plant US5.7¢ per kWh during peak hours of the day. Peak-shaving energy is, but not necessarily, an additional cost-saving benefit in addition to the reduction in demand charges. The driving factor is the difference in the time-of-day rate cost of energy being charged by the utility. Savings are offset when taking into consideration the cost associated with recharging the battery following a daily discharge.

8. Operational experience at Vernon

It should be noted here that justification of installing a BESS at Vernon solely on the basis and merits of providing peak-demand reduction, peak-shaving of energy and improvements in overall power factor demand, are not favourable. The BESS would never pay for itself. However, that point is secondary since the primary justification for installing the BESS at Vernon is to provide emergency power backup to the critical environmental controls, filters, and fan motors controlling lead dust. Any savings derived from the BESS via daily energy management are considered as added benefits. As of this date, the BESS system has successfully supported three power outages and prevented the plant from shutting down and, therefore, has prevented environmental incidents which are generally accompanied by heavy fines or possible law suits.

During daily demand peak reduction and on-peak management of energy usage, the BESS is able to discharge and deplete the battery up to 50% of its battery capacity while the remaining 50% is dedicated specifically to provide for emergency back-up power to the critical environmental loads.

In July 1997, an active demand reduction and peak-shaving program was initiated. During the first few months, the level at which the BESS was set to activate was quite high with regard to the average demand for power. In the months of July through August 1997, the BESS was programmed to supply all demand for power and energy at a level above 3400 kW. This setting permitted GNB to observe the operation of the BESS and to understand better how the system responded to power demands while barely exercising the battery. Recordings show the battery easily handled peak demands which reached as high as 3900 kW. These spikes, however, only lasted for a few minutes. Typically, the plant demand will range between 2900 and 3400 kW depending upon the month and time-of-day. The idea is to set the output level of BESS at a point which will offer the highest dividends in lowering the overall plant demand and, at the same time, not discharge the battery reserve beyond the 50% capacity set aside for emergency purposes. At a constant discharge of 357 kW, the BESS has adequate capacity to run for 7 h and discharge 2.5 MWh of energy. The peak hours for demand in Vernon are between 1:00 and 7:00 PM PST Monday through Friday. So as not to miss this time window, the BESS is set to engage 1 h before and disengage 1 h after the required time window.

Since the plant loads do not always run at a constant rate, the power demand fluctuates up and down. Assuming the BESS peak-shaving set point was at 3200 kW and the plant demand was running at 3600 kW, the BESS would automatically control the amount of power being supplied by the utility. The utility would provide the 3200 kW and the additional 400 kW demand would be supplied from the BESS VRLA storage battery. At that rate, the battery would exceed the capacity of 2.5 MWh set aside for energy management ($400\ \text{kW} \times 8\ \text{h} = 3.2\ \text{MWh}$). It is probable, however, that the plant demand is not constant and typically tapers off to 2900 kW during the last few hours of the demand period.

Setting the level of peak-shaving operation has been a balancing act between past experience, current plant loading, production forecasts, and working up to a point where the battery is being discharged to about 20% DoD (depth-of-discharge) daily. As of August 1998, GNB has gained the confidence to lower the peak-shaving set point to 3100 kW. When the plant is running at an average of 3350 kW during the on-peak demand-period, the BESS currently provides the plant with an average of 1 MWh of capacity during the 8 h of on-peak operations. Initially, it was believed the plant loads were flat. Results show, however, that there are production level swings that push the demand for power up-and-down and do create voltage spikes that are anything but flat.

Data from the Vernon BESS has been accumulated and analyzed to determine the monthly cost savings brought about by demand peak-shaving. During the period from July 1996 through July 1998, records and utility bills show that the overall actual savings has averaged about US$2800 per month. There are also the avoidance cost savings which do not get billed since the BESS provided power reduction. Over the past 24-month period, the savings have been approximately US$65 000 plus the avoidance costs/savings, i.e., value placed on interruptions, value placed on voltage dips. At this time, it is difficult to assess the value of avoidance costs since in some cases the voltage spikes exceed 1 MW, but only for a few seconds. It is unsure whether the utility company would or would not have recorded the events and actually billed the customer. At best, it is thought that the BESS can save the customer about US$75 000 per year. At the present time, the Vernon plant spends an average of more than US$100 000 per month for electric power and energy consumption.

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