CUSTOMER-SIDE-OF-THE-METER LOAD-LEVELLING TEST FACILITY

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Introduction

As a result of increasing energy costs, the industrial energy user is constantly faced with mounting operating costs. These higher production costs are eventually passed on to the general consumer who bears the ultimate cost increase. Customer-side-of-the-meter (CSOM) load levelling (peak shaving) is one method presently being evaluated by Johnson Controls Inc. (JCI) for reducing such energy costs. To this end, JCI has recently completed construction of an experimental load-management test facility at the company's battery plant in Milwaukee. The facility utilizes state-of-the-art JCI building control and battery technology.

Cost of electricity in the U.S.A.

In the U.S.A. industrial situation, the cost of electrical energy supplied to a customer is determined by a combination of two factors: (i) the total energy consumed by the customer (kW h); (ii) the customer's peak power demand (kW). The total energy consumption is monitored by the electrical supply authority using a watt-hour meter, and the customer is then billed at a pre-determined rate which may, or may not, vary with the time of day. For example, a typical billing rate for the Milwaukee area is $0.025/kW h. The second factor, the customer's peak energy demand, is determined by a demand meter, which integrates and averages the power usage over 15 min intervals during the day. The customer then pays a monthly demand charge based on the highest single demand reading for the month. Again taking Milwaukee as a typical example, demand charges are $9.00/kW. The total energy cost is the sum of the demand charge and the energy charge.

Simplistically, an industrial energy customer in the Milwaukee area who uses a monthly average power demand of 1000 kW for a total of 480 000 kW h, and has a monthly peak demand of 1600 kW, would expect a monthly energy charge of $12 000 with a demand charge of $14 400 for a total monthly electrical bill of $26 400. If this same customer were to lower the peak demand by 600 kW by installing a load-levelling system, the demand charge would decrease, yielding a nett monthly saving of $5400.

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The JCI Load-Management Test Facility Project is evaluating the concept of battery-based load levelling. Utilizing corporate-wide technologies, this project is acting as a bridge between the Battery Division and the Systems & Services Division of JCI. The corporate expertise in the fields of both industrial batteries and control systems strategically positions JCI to develop and lead the field of load management.

JCI load-management test facility

Electric power is drawn from the supply authority during lower power-demand periods, typically, but not necessarily, at night. At high power-demand periods, electrical energy is drawn from the battery system to reduce the power demand on the electrical-supply authority. When fully operational, the JCI facility will serve many functions. Primarily, the facility will be used for testing and evaluating battery designs presently under development for load-levelling applications. It will also assess the suitability of new battery systems such as zinc/bromine. For this reason, the system has many features and capabilities that would not be necessary in a commercialized facility.

As a load-management facility, it will be used by the JCI Systems & Services Division and the local electrical power-supply authority, Wisconsin Electric Power Company (WEPCO), to evaluate CSOM load-management techniques. This research is part of an effort to develop an advanced energy management system and allow JCI to develop the needed control algorithms for dispatching power to the customer's load. Historically, discussions regarding the need for load management and CSOM energy storage have been ongoing for several years.

Monitoring equipment

As part of the experimental development program, WEPCO has installed monitoring equipment at two locations within the JCI battery plant. This equipment is designed to monitor the amount of power that is generated and consumed by the load-management test facility, as well as its overall effect on the quality of power within the plant.

Wisconsin Electric has also installed current-measuring transformers (CTs) and potential measuring transformers (PTs) on the primary side of the isolation transformer located between the test facility and the factory. These devices are connected to meters that are used to continuously monitor the power coming into, and going out of, the facility. These meters may be remotely accessed and read by WEPCO with the use of a microcomputer/phone line interface. The CTs and PTs are also used by WEPCO to monitor the total harmonic distortion produced on the factory's power distribution by the test facility.

Facility layout

The test facility occupies approximately 200 m^2 of floor space in an area that was previously used for product assembly. The test facility is divided into three areas including a control room, a battery bay, and a transformer room. The 300 kV A facility presently houses a 600 V/1000 A h lead/acid battery (at $C/2$ rate). The battery consists of 5 separate battery strings, each of 120 V, and each outfitted with battery-monitoring test equipment.

Three different battery rack designs were used, including a step rack, two, 2-tier and two, 3-tier racks, to demonstrate the versatility of the battery systems (Fig. 1). The battery racks were built by the JCI System & Services Division. The battery racks, as well as the floor of the battery bay, are coated with an acid-resistant epoxy. The building and rack systems have been suitably designed for the earthquake potential of the Milwaukee area.

The battery operation and testing are controlled and monitored from an isolated control room (Fig. 2). The latter contains the necessary computer and control equipment to operate and manage the battery and inverter system. The control room is slightly raised above the floor level of the battery room for better view of the area. The power equipment is in an enclosed area for safety and security reasons. The high voltage transformers are in another room behind the power inverter.

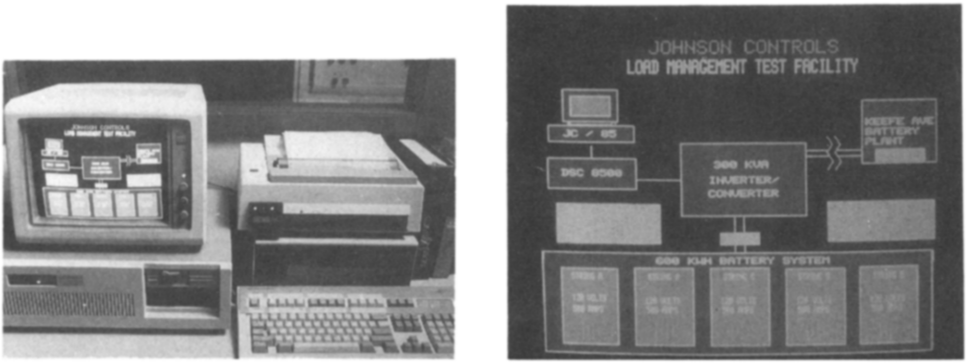
Facility control

The load management test facility was designed and constructed as a series of sub-systems ranging from the power-conditioning system to the battery data collection system. Day-to-day operation of the test facility is handled by a JC/85 personal computer-based energy-management system (Fig. 3). The latter continuously monitors the electrical demand of the battery plant through the plant electrical billing meter and automatically allocates the storage and distribution of electrical energy.

The system can also be controlled manually through several command formats at the computer terminals. In this way, parts of the system, or all of

Fig. 1. Battery rack design.

Fig. 2. Control room.



(a) (b)

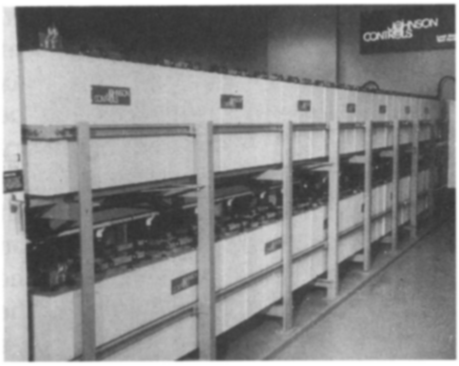
Fig. 3. (a) Computer-based energy management system; (b) exploded view of computer screen.

it, can be isolated from the JC/85 control. Likewise, one or more of the battery strings can be isolated. As battery types within each string are charged during future experiments, the upper voltage limits and the lower voltage cut-offs can also be set, either manually or through the computer terminals.

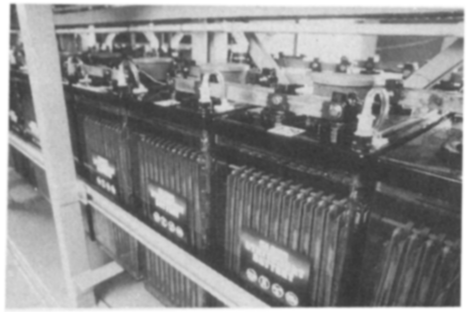
The d.c.-to-a.c. and a.c.-to-d.c. conversions are handled by an automated power conditioning unit that includes the inverter/converter functions. The six pulse, line-commutated, power conditioning unit (PCU) is unique in that it can accommodate 1 - 5 strings of batteries in series or parallel configurations. The associated multi-tap isolation transformer automatically changes its tap position to compensate for the number of battery strings selected for operation. This feature enables the system to continue operation even though one or more battery strings are off-line for maintenance or other reasons. Remember that this system is designed to reduce demand peaks, not to carry the load if the main supply fails. The inverter/converter of the PCU has also been designed to accommodate battery strings of completely different types or designs. Though operated in a 600 V series configuration, each of the 5 battery strings may be charged to individually set upper voltage limits (UVLs), and discharged to individually set lower voltage cut-offs (LVCOs). In this manner, strings of conventional stationary lead/acid, maintenance-free lead/acid, zinc/bromine, or other advanced designs may be tested simultaneously. A 20 kW h zinc/bromine module has recently been installed in the facility.

Batteries under test

The initial facility battery is composed of 300 lead/acid cells capable of supplying 600 kW h at a $C/2$ rate. Fourteen different battery designs are presently on test in the facility. The 5 individual battery strings range in capacity from 1400 A h to 1650 A h at a $C/8$ rate. Of the present battery designs, 60% of the batteries are of a sealed, maintenance-free design (Fig. 4(a)) with the remainder of the batteries being flooded types (Fig. 4(b)).



(a)



(b)

Fig. 4. Batteries under test: (a) gelled-electrolyte; (b) flooded electrolyte.

Each battery string contains a minimum of two different battery designs. Maintenance-free and flooded designs are grouped accordingly for charging purposes.

In conjunction with the load management studies which are ongoing in the facility, the latter also serves as a test bed for battery development. Thus, the facility has been outfitted with state-of-the-art battery monitoring equipment. The JCI advanced battery monitoring system is a comprehensive battery system which has been developed to minimize routine battery maintenance and at the same time to extend battery life. The system will make use of state-of-the-art computer and battery technology to supply the user of the battery-based energy-management system with a totally maintenance-free system. The status of the battery will be automatically monitored, recorded, and the proper action taken in response to an abnormal condition. Each complete subsystem is being designed to interface with the JCI JC/85 building control computer through the DSC 8500 interface unit. All subsystems, including the JC/85, are line powered during normal operation and are automatically switched to auxiliary battery power upon line failure.

At present, there is scope to monitor the following items:

- 300 individual cell-voltage measurements (0 - 3 V)
- 50 module voltage measurements (0 - 20 V)
- 50 cell temperature measurements
- 2 ambient hydrogen gas levels
- 98 other miscellaneous measurements.

Data collection

Each of the five strings of 60 cells is equipped with a 100-point data logger and associated fuse box. Sixty pairs of sensing leads connect each fuse box to the individual cells. For safety, each sensing lead is separately fused within the box before connection is made to the data logger. The data logger system used for this project is a Doric Inc., Digitrend 245. The system has a main data logger unit with four satellite data loggers. Each of the individual units is capable of handling 100 data points, for a total of 500. Required scanning time for the total 500 points is 8 s. The information is then sent from the data logger by a RS232 bus to a Digital Equipment Corp., Microvax computer for display and analysis. The voltage and temperature data may be displayed in either numeric or graphic format for both a detailed or cursory view of the battery performance.

During daily operation of the load management system, the battery test data are stored at 1 - 5 min intervals. At the end of the day, the information is stored on computer hard disk and a report printed that describes the performance of the individual battery types being tested. Figure 5 shows the voltage *versus* time behaviour of the five individual battery strings during a constant current discharge at 210 A. The observed differences in performance are directly related to the various design parameters being tested within each battery string.

Detailed inspection of the battery system is made available through several other computer display screens. Battery-group voltages within a string are displayed graphically or in numerical form. A bar graph enables the operator easily to see when a battery deviates from the string norm. The numerical form gives an accurate measure of the actual group voltages (±0.5 mV). Battery temperatures and voltages are displayed in modules of six. The module temperatures can also be displayed graphically. Temperatures, of course, are affected by test conditions such as discharge and charge current, ambient temperature and location in the room, as well as by electrochemical efficiency and internal resistance.

A hydrogen-sensing system is used for safety and for purposes of keeping permanent records of the nominal hydrogen levels in the battery bay. Two hydrogen sensors are located within the battery bay. The main sensor display is mounted within the control room for safety. This main unit is used to control an auxiliary blower and equipment-shut-down functions. At a pre-

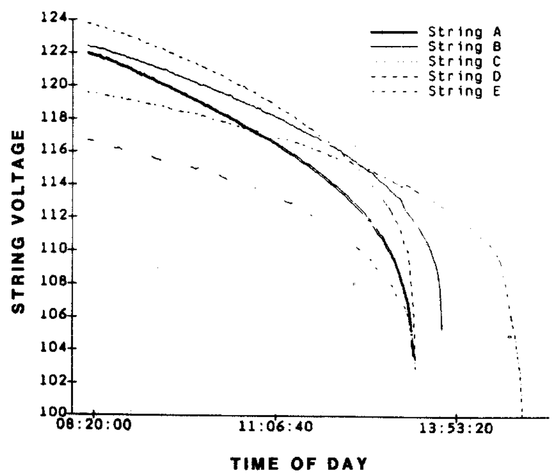


Fig. 5. Performance of battery strings during constant-current discharge test.

set warning level of 1% hydrogen, the auxiliary blower is turned on, thus increasing the battery bay air flow to more than 10 air changes per hour. At a second pre-set level of 2% hydrogen, the battery strings are isolated to stop all gas generation. The lower explosive limit for hydrogen is 4%.

Conclusions

The potential for CSOM load-levelling is rapidly approaching the commercial level. Thus, the battery industry faces the challenge to develop the lead-supply technology and battery-production technology to support what has been demonstrated in the laboratory. At present, the cost of the battery in a commercialized version of the JCI facility is foreseen as being considerably more than the switch gear and controls. This cost relationship must come into balance before the full commercial impact will be realized.