Monitoring battery performance in remote-area power-supply (RAPS) systems*

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Abstract

A research and development project has been undertaken to explore the feasibility of a battery monitoring system with specific application to remote-area power-supply (RAPS) systems The pilot sites have returned data that strongly support monitoring of individual cells at RAPS installations The results of the pilot site testing are reported and further research is suggested

Introduction

The Centre for Information Technology and Communications (CITEC) commissioned the construction of sensors and data-logging equipment for installation at two Brisbane pilot sites [1] One of these sites also received a Programmable Logic Controller with variable load to enable it to emulate the Coconut Island RAPS system

Both systems have been designed to record data on string current, cell voltage, cell temperature, cell specific gravity, and cell electrolyte level. Specific gravity sensors have not, however, been installed at either site Since the pilot sites have only one string, string current is system current All sensors provide continuous scale data to eight or twelve bits of precision One site also collects data on system voltage and ambient temperature

Previous research

Buonarota *et al* [2] have developed and proved a model for the state-of-charge (SOC) of cycling batteries used in photovoltaic applications The model does not require specific gravity data This has enormous impact for battery monitoring since it means that the cost of monitoring equipment is significantly reduced whilst still achieving an SOC measurement accuracy of

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within 3%. The model has been used in an automatic system for the on-line evaluation of the SOC of the battery installation at Vulcano.

The space industry has developed further the analysis of monitored battery data. Some researchers [3, 4] in this field have developed expert systems to optimize the performance and life of Ni–Cd cells in space There appears not to be any published information on the application of expert systems to cell management in remote-area power-supply (RADS) systems

Methodology

First pilot site

The pilot site comprises an emergency lighting battery in an empty building It has been fitted with a Programmable Logic Controller* with variable load to enable the site to emulate a RAPS system (Fig 1). The cycle to which it is programmed is shown in Fig. 2.

The monitoring system** is a distributed intelligence system. One logger collects data on system parameters, while other loggers collect data from the distributed cell sensors.

All cell sensors (temperature, electrolyte level, and voltage) are non-intrusive, being glued to the side of the cell or attached to the electrodes The electrolyte level sensor measures the capacitance across the acceptable limits of electrolyte level on the side of the cell It has been suggested that a better location for the temperature sensors would have been on the top of the cell instead of on the sides, but there are arguments in favour of each location. The system parameters monitored include string current, string voltage; ambient temperature.

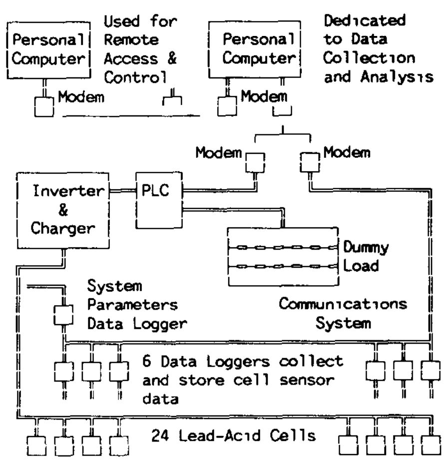

Fig 1 Configuration of first pilot site

*Supplied by Pegasus Designs Pty Ltd, Attunga Lane, Mt Glorious, Qld 4520, Australia
**Supplied by Monitor Sensors, 41 Orme Rd, Buderim, Qld 4556

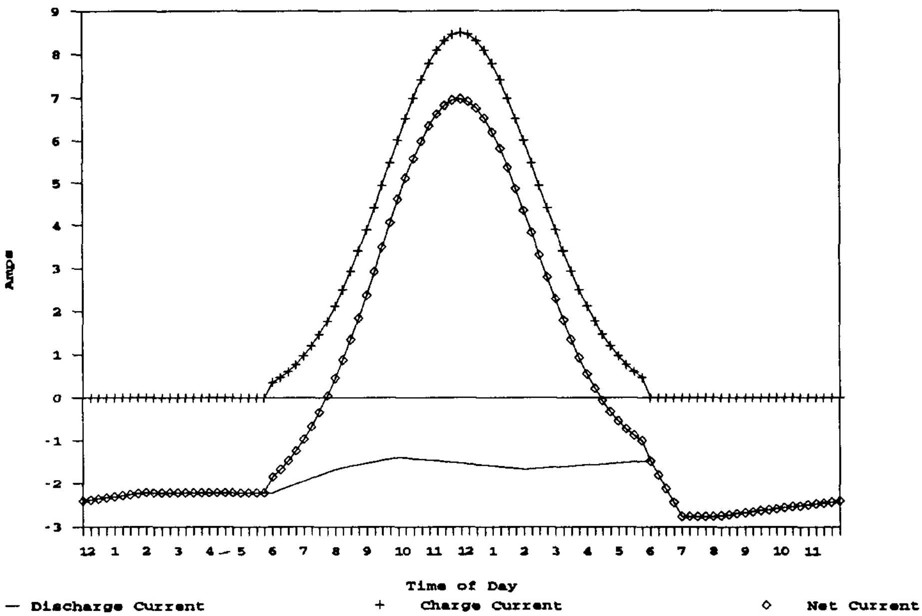

Fig 2 Charge/discharge cycle used for testing

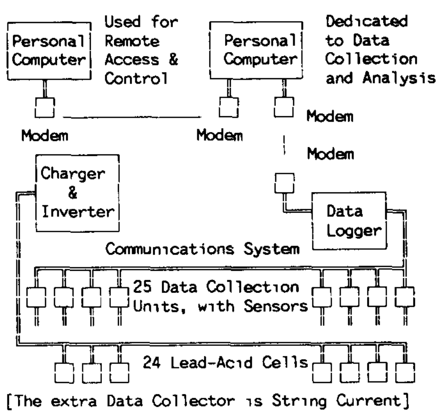

Fig 3 Configuration of second pilot site

Second pilot site

This pilot site (Fig 3) is in a building in current use The monitoring system* is installed on cells used to provide emergency lighting For this reason, there is only a slight variation in the cell conditions. Being a standby power system, there is rarely any load applied to the cells, so they generally float at a state of full charge [5]

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*Data collection and logging system supplied by Pegasus Designs Pty Ltd

The monitoring system has one printed circuit board (PCB) per cell to which four analogue signal sensors may be attached. In a revised design, each PCB would serve multiple cells, and the PCBs would be sprayed with protective lacquer and installed inside a length of plastic cable ducting located above the batteries This would save the expense and inconvenience of so many boxes and connections

The outstanding advantage of the present monitoring system is that there is only one microprocessor in the design, and it is possible to write and download in-house firmware to drive it This provides superb flexibility during system development, although it is of minor consideration for a production design.

Results

Data collected to date clearly demonstrate the enormous value of monitoring every cell in a RAPS installation. From voltage curves during discharge alone, it has been possible to detect cells close to total failure When conventional tests (specific gravity and voltage) had been undertaken previously on these cells by a maintenance technician, they revealed no faults This confirms the superiority of computer analysis of cell condition over the methods presently available to maintenance personnel

Value of monitoring cell voltage

Figures 4–6 vividly depict the final days of five of the twenty-four cells monitored at one of the pilot sites. The three graphs are for the same cells on the same charge/discharge cycle on successive days The observed collapse of cells 1, 11, 16, 20 and 22 would be difficult for a layman to predict on the first day (Fig 4), but the evidence is unmistakable on the following two days.

The programmable logic controller is imposing exactly the same charge/discharge cycle on the cells on each of the three days, but by the second day the weak cells are absorbing the entire charge and are providing the entire discharge· by the third day their ability to hold charge has deteriorated still further If data had been collected on these cells over a period of months, then trend analysis of the performance over that period would have revealed the problems long before they actually failed

On the fourth day, the PLC was turned off so that the charger could attempt to bring all cells up to a full SOC without interference. By the next day, it was found (Fig. 7) that the charger was gradually increasing the voltage of all the cells until the system voltage reached an acceptable level around midday, at which time the charger switched itself off. Note that some cells came up to voltage faster than others (namely, 4, 5, 10, 15 and 19), and that they were not the same cells that had shown up poorly a few days earlier. These cells are in excellent condition, being recent replacements for other cells identified as being faulty by their behaviour under deep discharge.

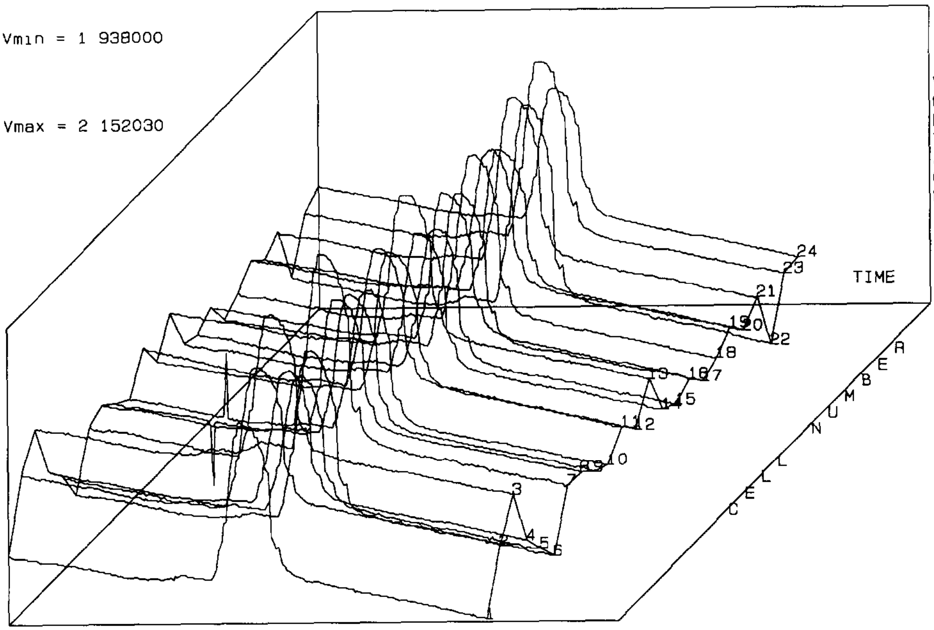

Fig 4 State Library pilot site on 11 5 90

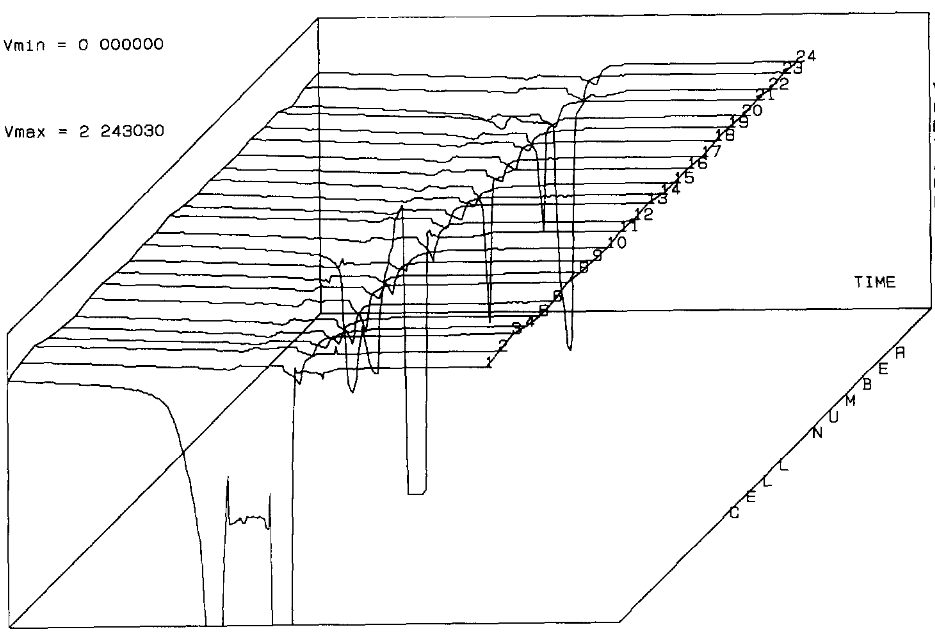

Fig 5 State Library pilot site on 12 5 90

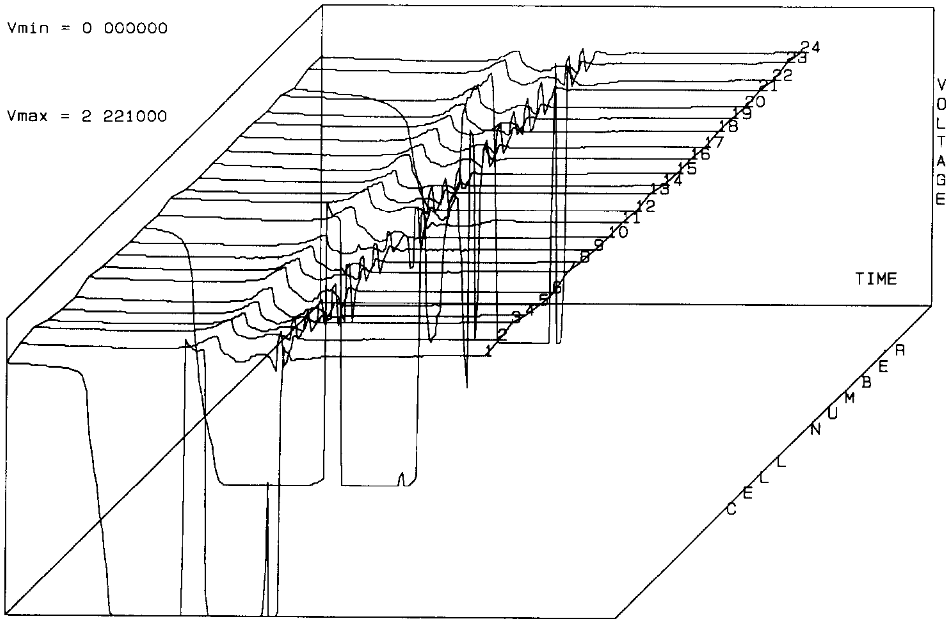

Fig 6 State Library pilot site on 13 5 90

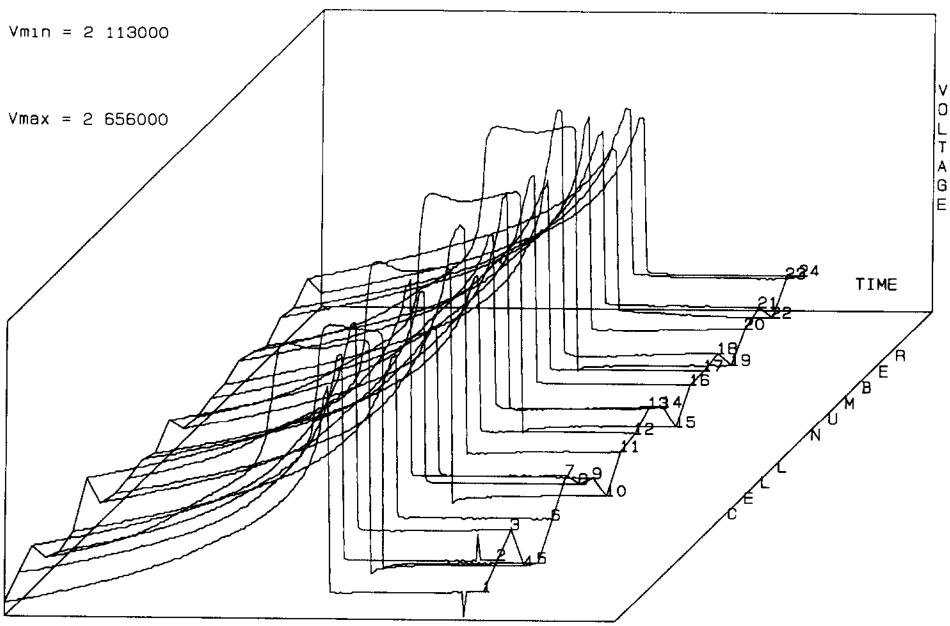

Fig 7 State Library pilot site as at 15 5 90

Again, only frequent scanning over time reveals that they behave differently from the other cells.

Value of monitoring other parameters

While the monitoring of cell voltage is very revealing, monitoring SOC is much more so, and supports prediction of remaining life, helping to elucidate the cause of cell deterioration.

It is possible to develop a model of battery SOC that uses only voltage and current in the calculations. Gosden [6] is working on a model for electric vehicles and Buonarota *et al.* [2] have developed one for photovoltaic applications

Discussion

Neither of the data collection systems described above is absolutely ideal for RAPS battery monitoring systems. Each of the two systems had a number of outstanding positive aspects, but a number of desirable improvements came to light as the project progressed The experience has, however, placed the authors in a position to design and build a system that will meet RAPS requirements very well.

The most important essentials to emerge are: a fully programmable logger that supports asynchronous communications to a PC; theoretically sound sensors of practical design (preferably non-intrusive), an efficient sensor data communications system using a minimal number of components; software to make the most of the data collected.

Over-engineering of the electronics will increase reliability in the harsh, remote environment in which these systems will typically be installed. Selection of components with little spare capacity is inviting problems. Selection of connectors, wires, etc., that are capable of withstanding the acidic environment is critical All electronic equipment must be well protected from the acidic atmosphere.

An independent power supply is essential Drawing power from the system voltage is acceptable, but drawing it from a subset of cells can give rise to difficulties.

Reliability is of the essence, and simplicity of equipment design located at the remote site will help achieve increased reliability.

It is advisable to put an oscilloscope on the charger and inverter outputs before any equipment is designed or purchased. It is more than likely that there will be intolerable noise in the output, and the monitoring equipment will have either to cope with that noise or the charger/inverter will have to be fixed/replaced. If ignored, this noise will lead to false sensor readings, data corruption, or even microprocessor 'hanging' that may only be remedied by a site visit

Data communication costs can be decreased markedly if the selection process is moved from the host computer to the data logger. Not all the data collected is useful, and transmission of unusable data wastes money. Collection of the most valuable data and avoidance of useless data requires custom programming of the data logger. For this reason, off-the-shelf loggers with inbuilt programs supplied by the manufacturer are very unlikely to be as satisfactory as a general purpose microprocessor capable of being custom programmed specifically for the task. Market availability of programmers dictates that the microprocessor has a CPU for which a cross compiler is available to run under MS-DOS. This in turn necessitates substantial memory map allocation to EPROM or EEPROM in the microprocessor.

Conclusions

Battery cell monitoring at RAPS sites is technically viable with present technology. Sufficient market demand and expert knowledge now exists to built an expert computer system both for diagnosing lead/acid cell behaviour over time and for making recommendations to those responsible for the management of the installation.

Battery monitoring enables more efficient use to be made of batteries for energy storage, thereby increasing the viability of environmently harmless energy generation technologies.

Future research

CITEC has shown that a monitoring system is feasible. Although data are still being collected, no further development is being undertaken. Current research could provide a platform from which interested parties could build a commercial system.

The Buonarota model [1] of battery SOC in a photovoltaic application is an excellent starting point for development of a system to manage a battery installation. If the appropriate cell parameters are monitored during a sufficiently lengthy period of discharge that immediately follows a state of full charge, and if the discharge current remains within acceptable limits, then the cell capacity can be calculated. The latter would need to take into account variations in temperature and current during the discharge period, and the precise formula would be specific to a particular brand and model of cell. Manufacturers' data are typically specified for a constant discharge current. Nevertheless, laboratory testing and some skillful mathematics will generate a formula that allows up to 30% variation of discharge current from the mean during the monitored discharge period. In many cases, this will permit the use of live data, thus avoiding the inconvenience of a controlled discharge of the installation to test the cells. In other cases, normal evening discharge may be supplemented with controlled discharge to a dummy load in order to bring the discharge during the test period closer to optimum conditions. The result of these calculations (adjusted back to the theoretical result of constant temperature and discharge current) could then be compared with the 'manufacturers' capacity curve and the remaining life of the battery (can be) accurately predicted' [7]. Such a system would optimise the life of cycling batteries and be a marketable product

Acknowledgements

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Note added in proof

Since the paper was presented, data have been collected from an actual RAPS system at Ithaca TAFE College (Fig 8). Data collected at this site have included string voltage, cell voltage, string current, ambient temperature, cell temperature, cell electrolyte level and cell specific gravity. As the string voltages show, the actual voltages (Ithaca TAFE 6.1.91–30 1 91 String Voltage) agree very closely with the earlier controlled charge/discharge cycle (Figs 4–7). The data collection equipment was provided by Monitor Sensors P/L Collection of specific gravity data was most interesting since previously this had not been achieved

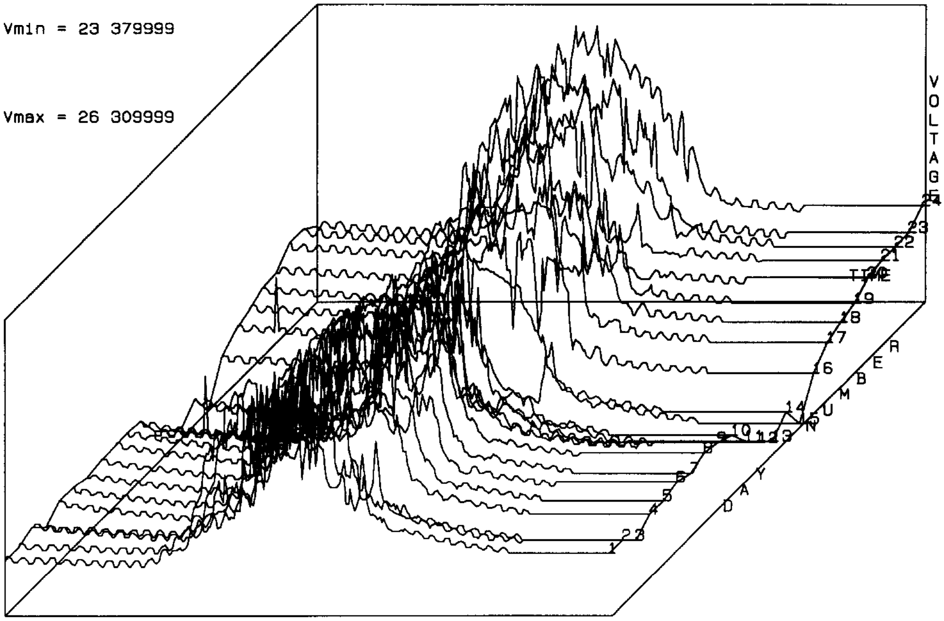

Fig 8 Ithaca TAFE string voltage 6 1 91–30 1 91