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Development and field testing a new battery management technique: railway and reserve batteries in wireless telecommunication tower applications

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Abstract

A new methodology to manage rechargeable battery packs is described.[1] The Battery Health Manager—BHM™ is based on this new technique and is a microprocessor-based device that automatically monitors and manages back-up battery power supplies without disrupting operations.

The BHM™ periodically selects and then subjects each cell (or module) in a battery pack up to a full-load discharge, and is able to "smart" charge to manufacturer's specifications, without removing the cells from the battery string or compromising inter-cell connections. Thus, the BHM™, based on the new methodology, provides the in-service condition and capacity of battery-run emergency power back-up systems without preventing the system from operating in the case of a power failure. The system is configurable to most backup power systems and is chemistry independent. Nickel–cadmium or lead–acid (including flooded and valve regulated types) battery packs can be managed and systems have been demonstrated on battery packs of both types. In general, the technique has very broad applications for use with rechargeable battery packs from the smallest systems used in electronic applications to the largest systems in stationary applications.

The BHM™ determines the battery pack capacity by conducting a discharge–recharge cycle of each cell in the battery pack. From this detailed information on pack capacity, the time of operation on the applicable load can be accurately estimated, e.g. for back-up battery packs in case of grid power failure. The microprocessor-control and signal conditioning allows all battery data to be stored and/or communicated from remote sites or locations to a central control station via the BHM™-NET. Various alarm functions can be user-programmed to application specific requirements, i.e. lowest safe capacity, low electrolyte levels, low pack and/or cell voltages, or external rectifier problems. The BHM™ can be configured in a variety of ways depending on the application.

In this paper, the results of field tests of a 100 A BHM™ system that was operated for the last 2 years in wireless tower sites in Ottawa, Canada are reported. Two standard BHM™ systems, for up to 30 or 100 A charge–discharge will be described, but the system can be scaled up to higher or lower currents by changing the size of the single-cell charger and load module.

The BHM™ discharges the individual cell via an onboard load module. On the standard BHM™ this is set to a maximum of 100 A for the 100 A system and is completely user programmable to on-site load emulation. Recharge is accomplished via the BHM™ single-cell charger, which is powered (as is the BHM™) from the battery pack.

As well as providing a monitor function, the BHM™ "smart" charges and discharges each cell, so that fully cycled, the life of the cell and battery pack is extended, saving more frequent replacement costs of expensive batteries. Cell charging can be programmed as constant voltage, constant current, or even specialized, more sophisticated profiles. This can be accomplished due to the software base control of the BHM™. The charge control has temperature compensation to ensure optimum charging. Charge and discharge cut-off can be set by manufacturers recommended levels, i.e. voltage, current, or time or combinations of these charge parameters.

Keywords: Battery; Pack; Management; State-of-charge; State-of-health; Monitoring

1. Introduction

As rechargeable battery technology has evolved over the past 30 years, the valve regulated lead–acid (VRLA) battery has become the most common type of battery for standby power to support telecommunication systems, uninterruptible power supply applications, and signaling/level crossings as well as other applications in transportation that cannot tolerate an interruption in the power supply should there be a failure of grid power. The usual maintenance practice for these VRLA batteries is to hold them on continuous float charge. However, continuous float charge has been associated with various failure modes of VRLA batteries,

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[1] US Patent issued on May 2001 #6,239,579, other patents approved and/or pending.

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including accelerated plate corrosion, and electrolyte 'dry-out' [1]. It was reported by Feder [2] that in capacity tests of 24,000 VRLA cells from the US, UK and Pacific Rim countries, 60–80% failed well before their intended design life. Therefore, actual field experience with VRLA batteries indicates that achieving safety, long-life, and within-specification VRLA battery performance must become more dependent on the careful monitoring and control of battery operational parameters throughout the life of the battery. Furthermore, knowledge of the status of VRLA batteries, especially available capacity, is critical to many applications in telecommunications and transportation. Although many techniques have been developed to determine the capacity of batteries, it has been often noted that, "the most reliable way to test a battery has historically been doing a full discharge capacity test to a specified end voltage per cell. There can be little debate over what the capacity of a cell or battery is when a properly documented capacity test is performed" [1,3]. In the past, it was necessary to shut down the facility supported by the standby battery in order to conduct a discharge test or to provide an alternative standby battery to support the critical load during the test period. This was a costly and risky approach. However, this paper presents a new method that avoids these disadvantages while providing the ability to conduct full discharge testing combined with a selectable recharge procedures to improve and maintain cell capacity and cell balance in the battery pack.

The capability of a battery to deliver electrical energy is called capacity and is usually measured in ampere-hours. The capacity tells users that at a certain current drain, the battery will deliver an electrical current (amperes) for a number of hours. Although there are many systems available for monitoring the capacity of batteries [4–9], there is no reliable means of determining the capacity of a battery unless the battery is discharged at a certain current level and the time of discharge is measured. For rechargeable cells, the process of cycling (discharge followed by a recharge) will not only provide the capacity information, but will also exercise the battery and by selection of certain recharge procedures can very significantly extend the life and capacity of the battery, e.g. see Nelson et al. [10]. This exercise can

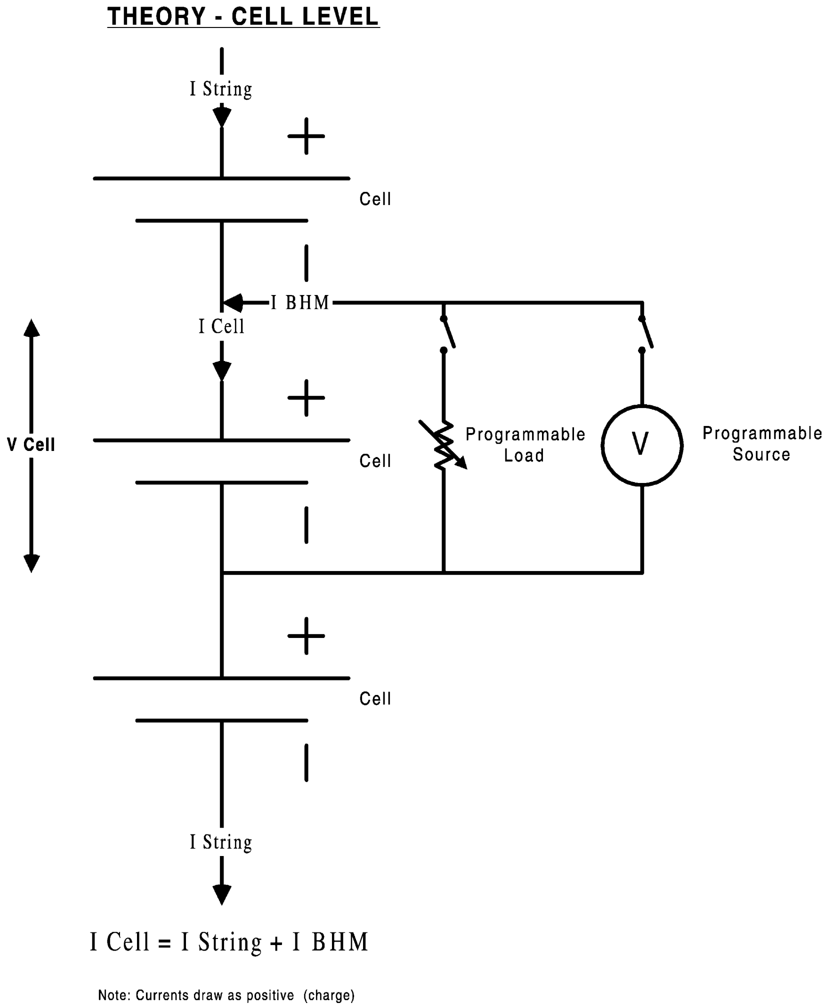


Fig. 1. Theory of BHM^{TM} operation.

be very beneficial, especially, in the case of back-up batteries that are kept on stand-by or under a trickle charge for periods as long as several years.

Battery packs are usually composed of several cells or modules electrically connected in series or in parallel forming a multi-cell (or multi-module) pack configuration depending on the operational requirements (voltage, current, and capacity). Due to the complex nature of a battery and the energy conversion process, external influences, such as non-uniformity of pack temperature or variations in manufacturing between cells (or modules), can cause the various cells that compose a battery pack to age or degrade at different rates. In series connected strings, this leads to a limitation of the total battery pack performance that is dictated by the weakest cell or module of the string. The ability of the new BHM™ technique to selectively cycle cells or modules in a battery pack provides a new tool for battery management and allows weak cells or modules to be identified and possibly some of their capacity to be recovered by special recharge procedures.

The BHM™ does up to full-load discharges on cells or modules in the battery pack to site specific levels, and “smart” charges to manufacturer’s or specially designed remedial specifications or can test to International Battery Standards [11], without removing the cells from the battery string or compromising inter-cell connections. The BHM™ gives the user the in-service condition and capacity of their battery-run emergency power back-up system. This is configurable to most backup power systems using nickel–cadmium or lead–acid cells or batteries. This includes flooded and valve regulated lead–acid as well as other advanced battery chemistries.

During the past 3 years, further development of the BHM™ technology has allowed its extension to

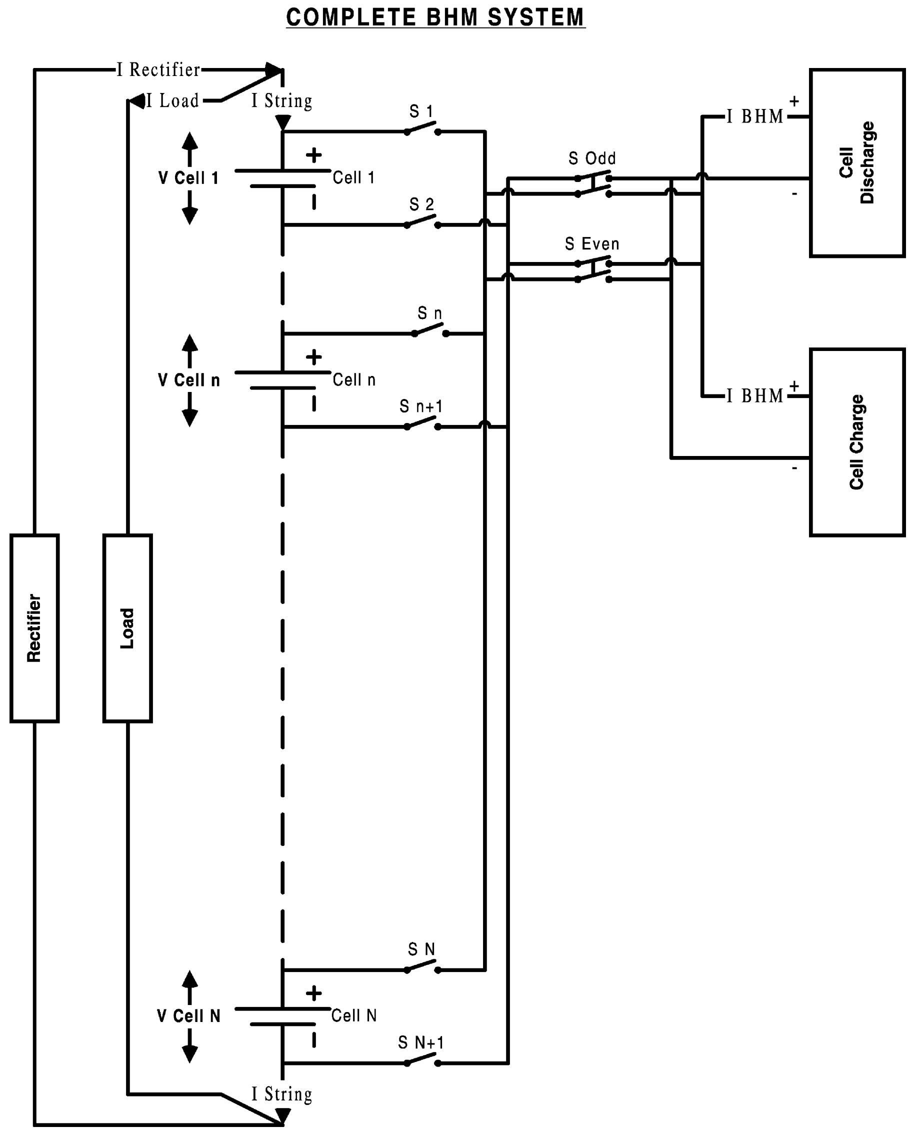


Fig. 2. Schematic of complete BHM™ system.

rechargeable batteries in applications in which the battery is regularly cycled to varying depths of discharge such as in electric/hybrid propulsion systems or in portable appliances. The technology has also been extended for fuel cell management in the form of the fuel cell health manager (FCHM^{TM})—see US Patent [12].

2. Description of the Battery Health Manager technology

Figs. 1–4 are simplified schematics that illustrate the theory and operation of the BHM^{TM}.

The BHM^{TM} makes use of a bridged connection circuit as shown above in Fig. 1. This enables the voltage and current flowing through the bridged cell (the second cell in this illustration) to be adjusted without interrupting the normal operation of the battery pack (i.e. the current, I_{string}, to the load). The device is based on Kirchoff's law. According to Kirchoff's law, $I_{cell} = I_{string} + I_{BHM}$ (i.e. sum of currents at the node is zero).

The voltage of the treated cell can thereby be adjusted by changing the current, I_{BHM}, through the bridging loop.

Considering the operation of this circuit, it is seen that:

1. If V_{BHM} is set equal to the open circuit voltage of the cell, V_{BHM}^{oc}, then all of the current will flow through the parallel arm and $I_{BHM} = -I_{string}$.
2. In general, if V_{BHM} is less than the "normal" operating voltage of the cell, the current through the cell will be increased with some current flowing backward through the parallel arm.
3. In general, if V_{BHM} is greater than the "normal" voltage of the cell, the current through the cell will be decreased with some current flowing forward through the parallel arm.

The principle of operation applies not only to individual cells but also to groups of cells or modules.

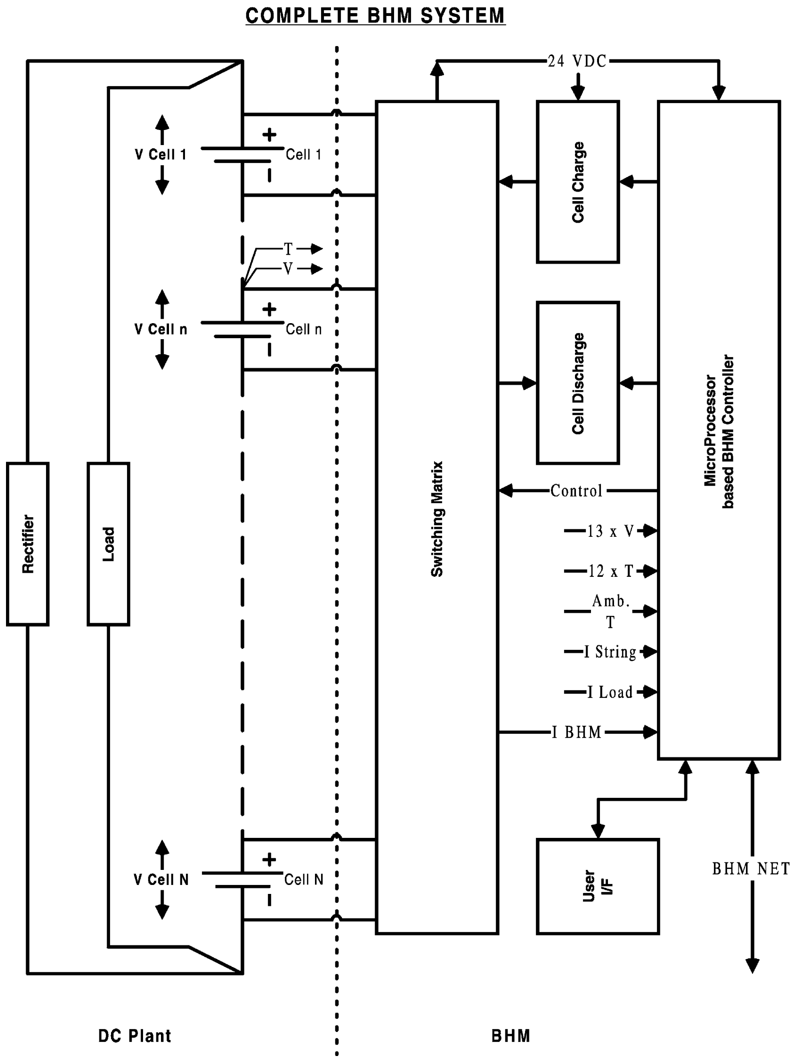


Fig. 3. Block diagram of BHM^{TM} system.

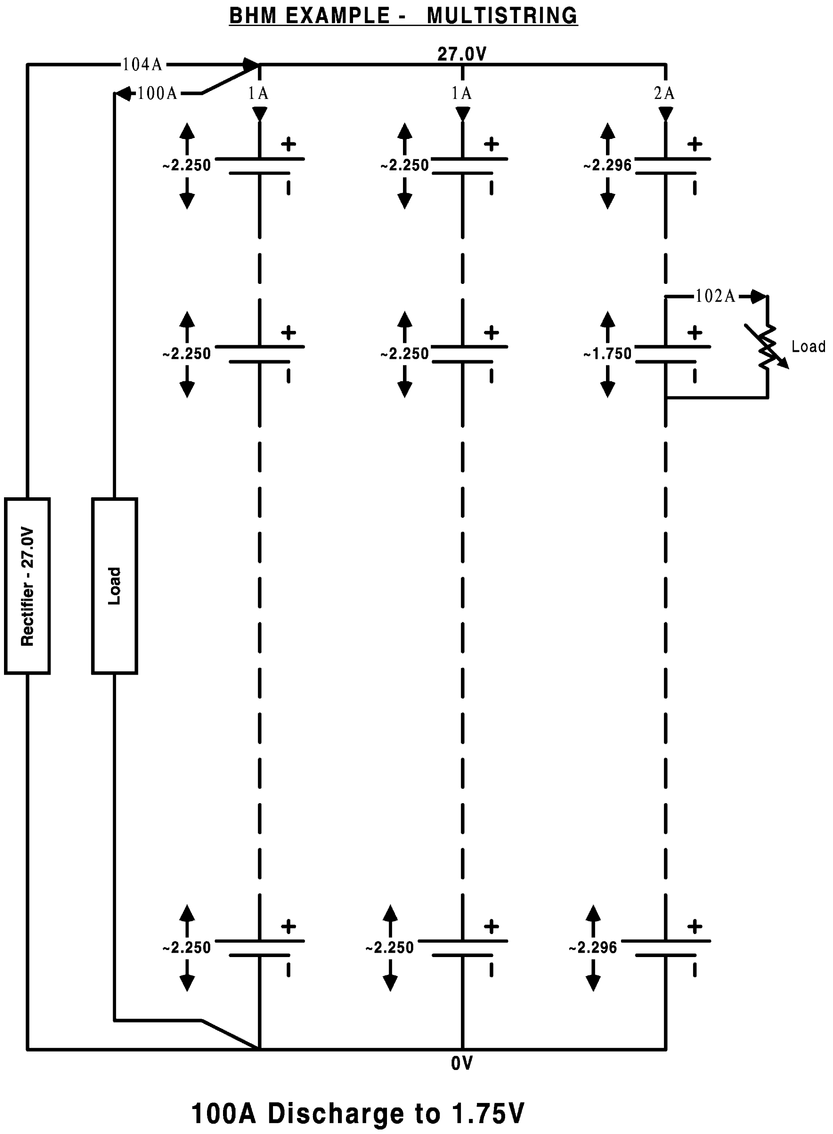


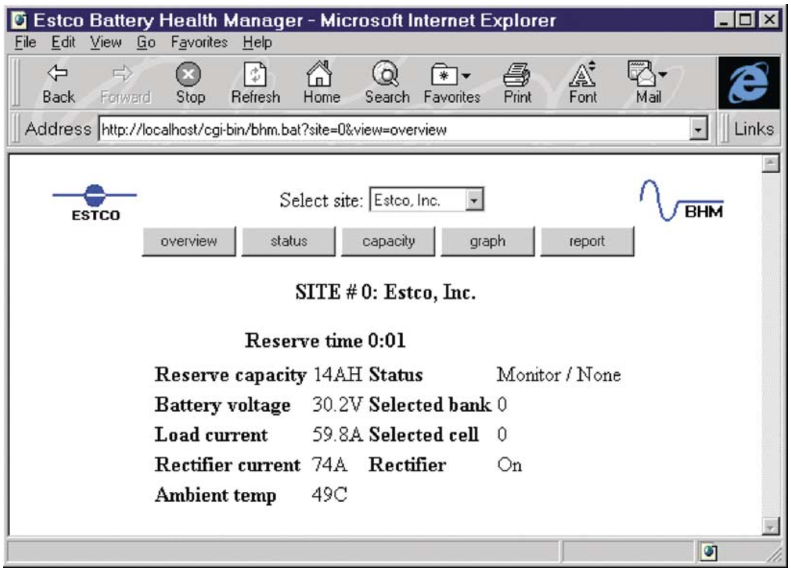
Fig. 4. Schematic of a BHM^{TM} system on a four-string battery pack.

From the above, it is seen that, by controlling an individual cell's voltage–current, the following two benefits can be achieved:

1. Cell/modules can be individually subjected to a wide selection of types of discharge–recharge cycles by adjusting the voltage of the source/load.
2. A weak cell/module can be supplemented or bypassed. Supplementing a weak cell is of benefit from an overall battery pack.

The principle of operation outlined above is implemented in an actual BHM^{TM} system by providing the ability of the source/load to be connected in parallel with any of the other cells in the stack as shown in Fig. 2. The BHM^{TM} will typically include an autonomous microprocessor based controller that constantly monitors all cell voltages and string currents as shown in Fig. 3. In addition, the BHM^{TM} can be configured to operate on a multi-string battery pack as indicated in Fig. 4.

The BHM^{TM} (US Patent #6,239,579) informs the user of the exact capacity of each module and/or cell in the battery pack based on an implementation of the above concepts. This can be translated into time of operation in case of grid power failure. The microprocessor-control and signal conditioning allows all battery data to be stored and/or communicated from remote sites or locations to a central control station via the BHM-NET^{TM} (US Patent, Serial No. 09/446,950). Various alarm functions can be user-programmed to application specific requirements, i.e. lowest safe capacity, low electrolyte levels, low pack and/or cell voltages, external rectifier problems. The BHM^{TM} can be configured in a variety of ways depending on application. A typical screen display for a telecommunication application where the BHM^{TM} can be accessed via a dial-up modem is shown in Fig. 5 below.



Address http://localhost/cgi-bin/bhm.bat?site=0&view=overview

Select site: Estco, Inc.

SITE # 0: Estco, Inc.

Reserve time 0:01

Reserve capacity	14AH	**Status**	Monitor / None
Battery voltage	30.2V	**Selected bank**	0
Load current	59.8A	**Selected cell**	0
Rectifier current	74A	**Rectifier**	On
Ambient temp	49C		

Fig. 5. One of the typical BHM-NET^{TM} display screens programmed in Windows based software.

3. Railway and telecommunication applications of the BHM^{TM} technology

3.1. Development and demonstration of the BHM^{TM} technology

The BHM^{TM} technology was first demonstrated as a result of requests from the railway industry for a technique to determine the capacity of individual cells in “safety critical” battery packs that had to remain in full operation while in use for level crossing and signaling applications. The initial testing of a BHM^{TM} prototype was conducted on flooded nickel–cadmium (Ni–Cd) cells having approximately 200 Ah and in packs of 11 cells connected in series, i.e. 13.2 V nominal. Prior to these tests in which a full 30 A BHM^{TM} unit was built, successful experiments had been conducted with small format sealed Ni–Cd cells using a prototype BHM^{TM} built for proof-of-concept work. A second 30 A BHM^{TM} unit similar to the first was built and set-up to operate on a six VRLA lead–acid cell 12 V battery pack as shown in Fig. 6 below. These two 30 A BHM^{TM} units have operated for over 4 years. Results of a test on a battery pack consisting of 11.25 Ah SAFT Ni–Cd cells are shown in Fig. 7 below. During the cycling of each individual cell it is clear that the pack voltage has remained constant over the 120 h of the cycling.

The BHM^{TM} ability to actively manage as well as monitor rechargeable batteries while they are in full service has suggested that initial applications would be for critical back-battery applications where service interruption is not an option.

Contact with a Canadian wireless telecommunication company in 1999 led to the development of a detailed engineering requirement specification for a 100 A BHM^{TM} system for the large back-up battery packs used in wireless tower sites. Two prototype 100 A BHM^{TM} systems were then built based on these specifications. The initial installation of one system was completed in February 2000 at a wireless tower site in Ottawa. The 24 V battery pack consisted of 48 × 880 Ah VRLA cells configured in four strings. This battery had been in service at this site for several years. The BHM^{TM} system was operated there for 7 months from February to August 2000.

After the removal of the BHM^{TM} from the Ottawa wireless tower site, the telecommunication company offered to extend the BHM^{TM} test program by placing the BHM^{TM} system in another tower site in Manotick, a town south of Ottawa. The tower in Manotick was a new tower installed in June 2000 and was more critical to the wireless network since it represented a link in the Ottawa–Toronto corridor over which considerable data is transmitted. The first test

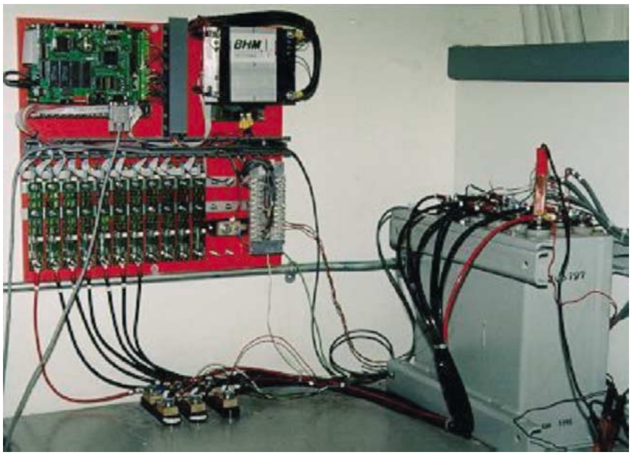


Fig. 6. Prototype 30 A BHM^{TM} system using solid state switching set up on 12 V VRLA battery pack.

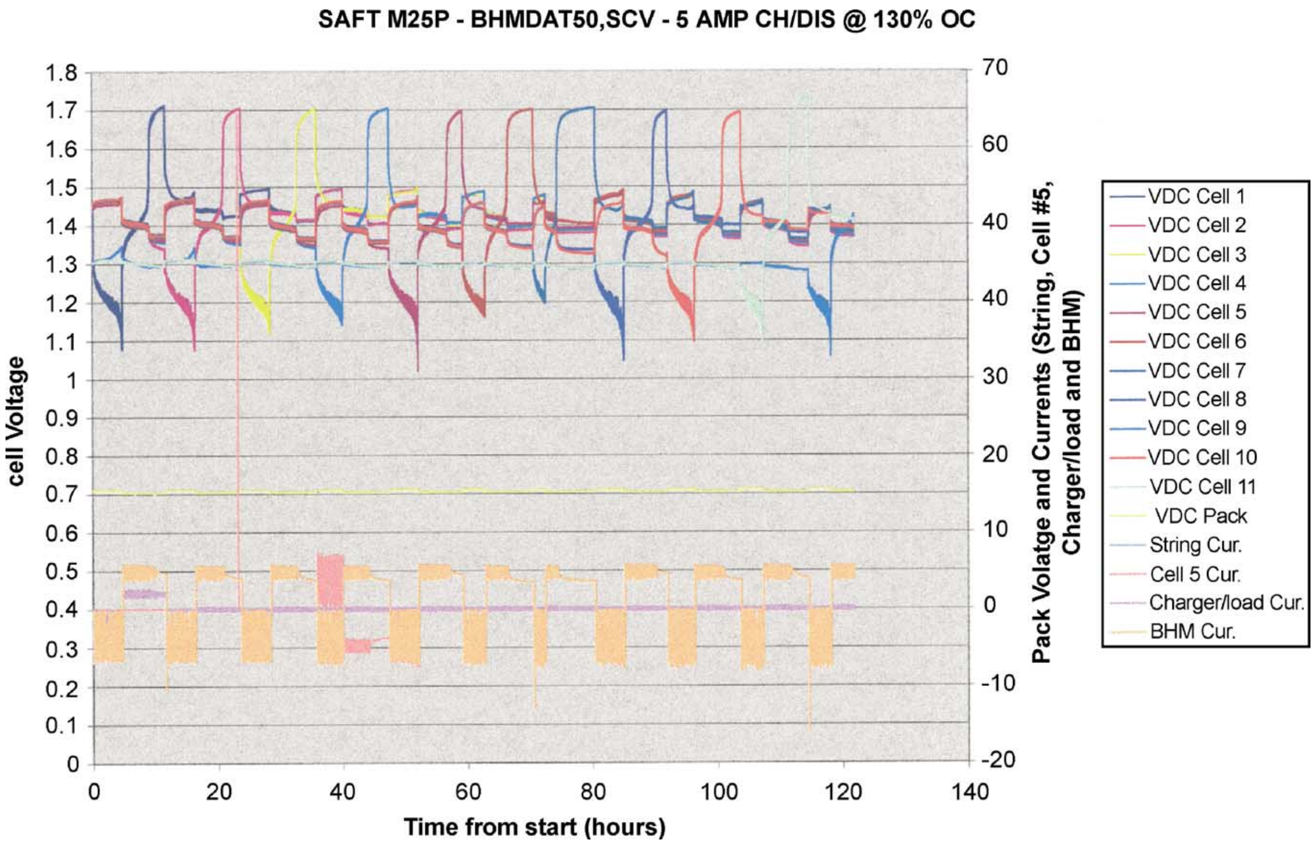


Fig. 7. 30 A BHM^{TM} test results on an 11-cell Ni/Cd battery pack.

in the Ottawa tower site was in a less critical tower since it was in the urban ring system within Ottawa and thus there was more redundancy. One of the primary objectives of the test in Manotick was to demonstrate the remote access software. The Manotick site had a 24 V back-up battery pack consisting of 24 × 880 Ah VRLA cells of the same manufacturer as in the Ottawa site configured in two strings. This battery pack was new at the time the site was installed in June 2000. The BHM^{TM} system was installed on 2 October 2000 and operated there for 14 months. During the operation of the BHM^{TM} at the Manotick site, the remote access software was developed to enable the data to be downloaded at remote computers.

A second 100 A BHM^{TM} prototype began operation for development testing in the ESTCO Laboratory in Ottawa during early 2000. The BHM^{TM} at ESTCO remains in operation (August 2002).

Fig. 8 below shows the 100 A BHM^{TM} system set-up on a 24 V four parallel-string battery pack made up of 880 Ah VRLA cells. There were a total of 48 cells in the pack. To conduct a full discharge cycle test on all cells in the pack took approximately 2 months. Temperature and voltage sensing leads were provided for each cell. The configuration of the BHM^{TM} is in three module types—the upper is the power module with the dc/dc converter and electronic load, the next is the control unit, and the remaining units are interface

Fig. 8. 100 A BHM^{TM} system in wireless telecommunication tower application.

units with the switching relays, one unit for each battery pack string.

Fig. 9 below shows an example of a discharge–recharge cycle on an 880 Ah cell in one of the battery pack strings based on both a discharge and charge current of 100 A. The cycling is conducted while the battery pack remains fully connected to the load and the rectifier. The form of both the charge and discharge can be controlled by the BHM^{TM} system.

Cell capacity results from three sets of discharge tests on a two-string battery pack at the wireless telecommunication site near Ottawa are given in Fig. 10. The ratio of charge (Ah) to discharge (Ah) for this battery pack for each of the 24 cells is given in Fig. 11 based on Test 1. The variation in cell capacitance throughout the pack observed in the discharge tests shown in Fig. 10 are seen to become more pronounced in Fig. 11. This is an indication of variations in individual cell characteristics that control discharge and charge acceptance possibly due to cell-to-cell variation in manufacturing.

The BHM^{TM} system is capable of providing cell equalization as well as utilizing advanced charge algorithms such as those recently suggested for VRLA applications by the team working on electric vehicle batteries at the US National Renewable Energy Laboratory (NREL) [8]. These capabilities enable the BHM^{TM} system to significantly extend the life of the battery pack as well as maintain the battery pack capacity. Previous authors have also noted that there is a large

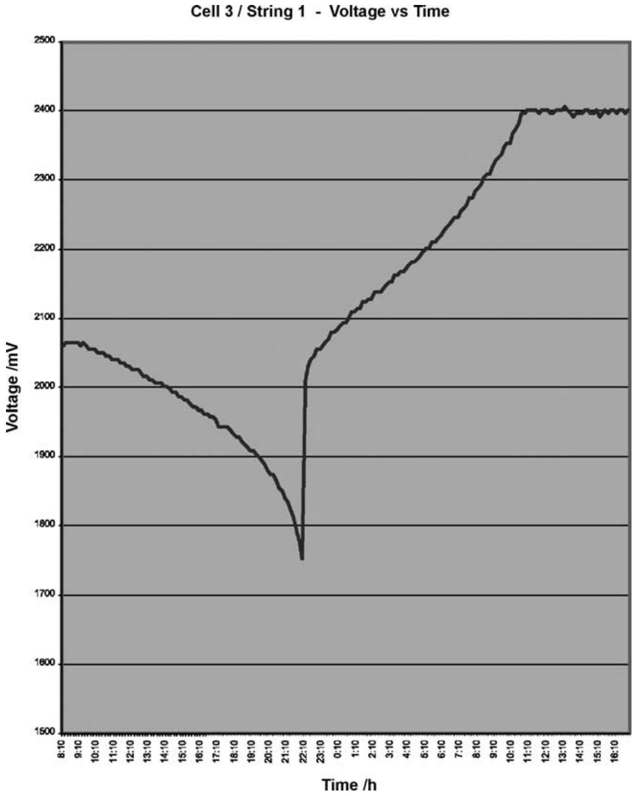
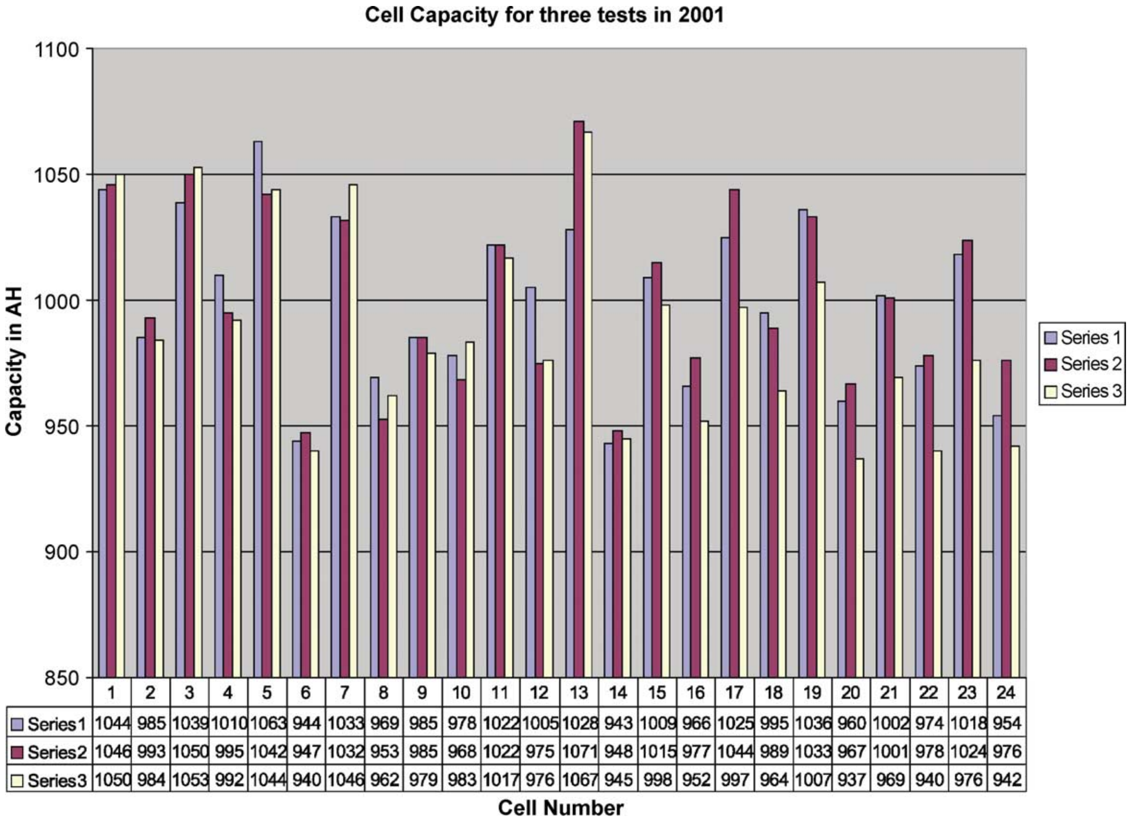


Fig. 9. Single cell cycle data of cell from battery pack using BHM^{TM} system shown in Fig. 8.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Series1	1044	985	1039	1010	1063	944	1033	969	985	978	1022	1005	1028	943	1009	966	1025	995	1036	960	1002	974	1018	954
Series2	1046	993	1050	995	1042	947	1032	953	985	968	1022	975	1071	948	1015	977	1044	989	1033	967	1001	978	1024	976
Series3	1050	984	1053	992	1044	940	1046	962	979	983	1017	976	1067	945	998	952	997	964	1007	937	969	940	976	942

Fig. 10. Cell capacities from BHM^{TM} test on telecommunication back-up battery pack.

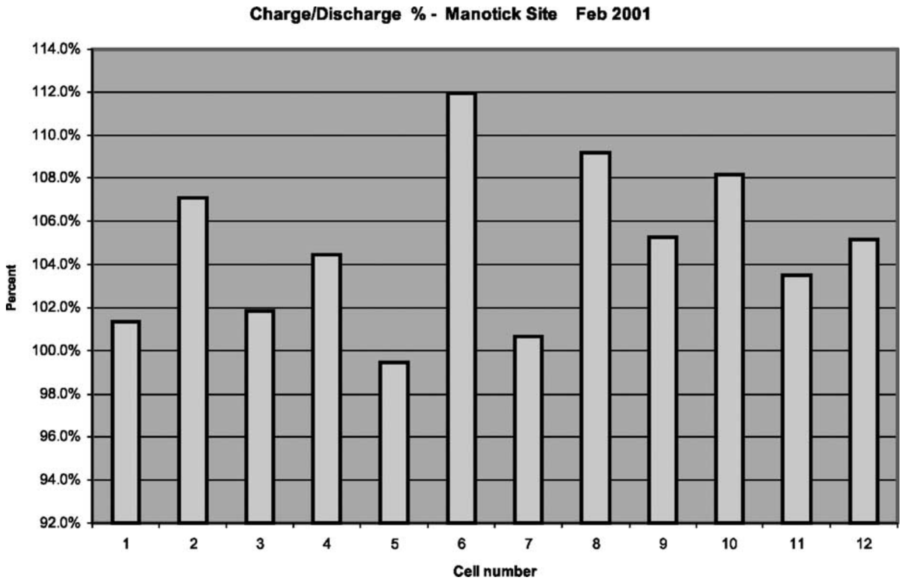


Fig. 11. Ratios of charge/discharge for one string of telecommunication battery pack.

variation in cell parameters even from the same cell manufacturing batch [13] and that no single method is able to provide sufficient diagnostic information to accurately determine the battery capacity [14]. In addition, methods based on battery impedance require that the battery be monitored over a long period in order to build up a database from which capacity can be determined.

3.2. Installation details and analysis of results

The BHM^{TM} installation/removal was undertaken after mid-night and was completed at the Ottawa site within 4 h by two ESTCO staff and in less time at the Manotick site since the battery pack was half the size. Telecom staff was on site during the installation and removal of the BHM^{TM} equipment.

The BHM^{TM} at the Ottawa site was installed in a 19 in. rack with the cabling to the battery pack led through cable trays suspended from the ceiling of the shelter. The tests began at this site with the installation of the 100 A BHM^{TM} system shown above in Fig. 8 consisting of the following:

- one system controller;
- one 100 A power unit;
- four 12 cell interface units (only two interface units were required for the two bank battery pack at the Manotick site).

Monitored systems included:

- ambient temperature;
- battery bank current;
- system load current;
- system voltage;
- individual battery cell voltages;
- individual battery cell terminal temperatures.

Data was collected by visiting the site on a regular basis in order to download files from the BHM^{TM} into a laptop computer. Results of two tests are given in Table 1.

Findings:

Temperature:

- ambient temperature varied from 24 to 28 °C;
- maximum increase in battery cell terminal temperature while under load was 3 °C for a maximum current of 80 A.

System load:

- the average system load observed was 200 A.

System voltage:

- constant at 26.9 V.

The BHM^{TM} monitors the load on the site and maintains a database from which the available up-time at the site can be calculated from the battery pack capacity. The up-time estimate can be adjusted for actual load experienced during a power outage. Figs. 12 and 13 are typical load results obtained by the BHM^{TM} from the tower site in Manotick.

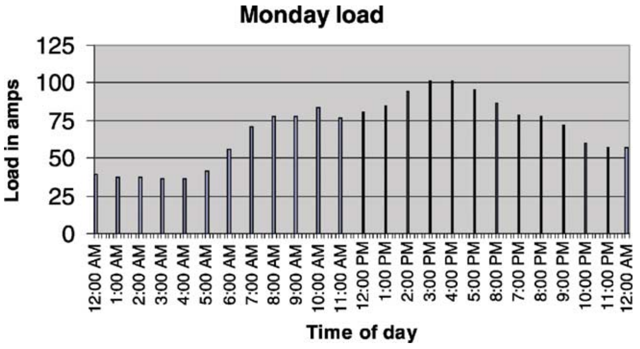


Fig. 12. Daily variations in wireless tower load for Manotick, Ont., Canada.

Table 1
Reserve battery cell capacities (Ah) and deviation from nominal cell capacity of 880 Ah (%) from BHM^{TM} test results from two Ottawa area wireless towers

Test 1; 00/02/22; Merivale site											
Bank 1	(Ah)	(%)	Bank 2	(Ah)	(%)	Bank 3	(Ah)	(%)	Bank 4	(Ah)	(%)
Cell 1	951	108	Cell 1	902	102	Cell 1	925	105	Cell 1	946	107
Cell 2	913	103	Cell 2	907	103	Cell 2	889	101	Cell 2	925	105
Cell 3	945	107	Cell 3	895	101	Cell 3	921	104	Cell 3	955	108
Cell 4	889	101	Cell 4	869	98	Cell 4	850	96	Cell 4	963	109
Cell 5	928	105	Cell 5	933	106	Cell 5	971	110	Cell 5	954	108
Cell 6	909	103	Cell 6	880	100	Cell 6	880	100	Cell 6	950	107
Cell 7	931	105	Cell 7	804	91	Cell 7	921	104	Cell 7	962	109
Cell 8	884	100	Cell 8	889	101	Cell 8	863	98	Cell 8	904	102
Cell 9	930	105	Cell 9	973	110	Cell 9	913	103	Cell 9	940	106
Cell 10	898	102	Cell 10	902	102	Cell 10	861	97	Cell 10	913	103
Cell 11	917	104	Cell 11	992	112	Cell 11	917	104	Cell 11	954	108
Cell 12	859	97	Cell 12	944	107	Cell 12	889	101	Cell 12	935	106
Maximum Ah	951	108		992	112		971	110		963	109
Minimum Ah	859	97		804	91		850	96		904	102
Average	912.8	103		907.5	103		900.0	102		941.8	107

Test 2; 00/05/07; Merivale site			Test 1; 2/1/19; Manotick site						Test 2; 4/1/12; Manotick site		
Bank 1	(Ah)	(%)	Bank 1	(Ah)	(%)	Bank 2	(Ah)	(%)	Bank 1	(Ah)	(%)
Cell 1	997	111	Cell 1	978	111	Cell 1	1010	115	Cell 1	968	110
Cell 2	920	104	Cell 2	1022	116	Cell 2	1063	121	Cell 2	1022	116
Cell 3	941	106	Cell 3	1005	114	Cell 3	944	107	Cell 3	975	111
Cell 4	897	101	Cell 4	1028	117	Cell 4	1033	117	Cell 4	1071	122
Cell 5	949	107	Cell 5	943	107	Cell 5	969	110	Cell 5	948	108
Cell 6	896	101	Cell 6	1009	115	Cell 6	985	112	Cell 6	1015	115
Cell 7	897	101	Cell 7	966	110	Cell 7	1036	118	Cell 7	977	111
Cell 8	877	99	Cell 8	1025	116	Cell 8	960	109	Cell 8	1044	119
Cell 9	945	107	Cell 9	995	113	Cell 9	1002	114	Cell 9	989	112
Cell 10	872	99	Cell 10	1044	119	Cell 10	974	111	Cell 10	1046	119
Cell 11	896	101	Cell 11	985	112	Cell 11	1018	116	Cell 11	993	113
Cell 12	864	98	Cell 12	1039	118	Cell 12	954	108	Cell 12	1050	119
Maximum Ah	997	111		1044	119		1063	121		1071	122
Minimum Ah	864	98		943	107		944	107		948	108
Average	912.6	103		1003.3	114		995.67	113		1008.2	115

Test 2; 4/1/12; Manotick site			Test 3; 5/1/19; Manotick site					
Bank 2	(Ah)	(%)	Bank 1	(Ah)	(%)	Bank 2	(Ah)	(%)
Cell 1	995	113	Cell 1	983	112	Cell 1	992	113
Cell 2	1042	118	Cell 2	1017	116	Cell 2	1044	119
Cell 3	947	108	Cell 3	976	111	Cell 3	940	107
Cell 4	1032	117	Cell 4	1067	121	Cell 4	1046	119
Cell 5	953	108	Cell 5	945	107	Cell 5	962	109
Cell 6	985	112	Cell 6	998	113	Cell 6	979	111
Cell 7	1033	117	Cell 7	952	108	Cell 7	1007	114
Cell 8	967	110	Cell 8	997	113	Cell 8	937	106
Cell 9	1001	114	Cell 9	964	110	Cell 9	969	110
Cell 10	978	111	Cell 10	1050	119	Cell 10	940	107
Cell 11	1024	116	Cell 11	984	112	Cell 11	976	111
Cell 12	976	111	Cell 12	1053	120	Cell 12	942	107
Maximum Ah	1042	118		1067	121		1046	119
Minimum Ah	947	108		945	107		937	106
Average	994.4	113		998.8	114		977.8	111

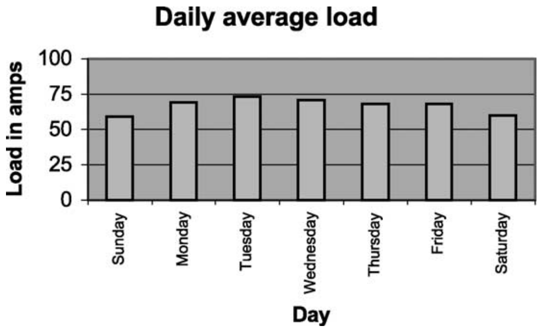


Fig. 13. Average daily load over 1 week for wireless tower in Manotick, Ont. Canada.

3.3. Ottawa (Merivale) site results

The battery pack at the Ottawa (Merivale) site consisted of four individual battery banks of 12 cells of 880 Ah nominal capacity each connected in parallel to form one large 24 V battery of 3520 Ah nominal capacity.

The test cycle consisted of sequentially discharging an individual cell to 1.75 V followed by recharging to 2.40 V and/or holding until 120% of nominal capacity had been replaced. Maximum discharge and charge current limits were 80 A.

Two tests were completed at the Ottawa (Merivale) wireless tower site, a full battery pack test taking approximately 6 weeks to cycle each of the 48 cells once. Test 1 consisted of cycling all 12 cells in all four of the battery banks. Test 2 consisted of cycling all 12 cells in only Bank 1. See Table 1 for complete data on discharge tests.

Results of Test 1:

- All battery banks exceeded the nominal battery capacity.
- Total battery capacity observed was 3662 Ah.
- Estimated operation time at the average system load would be 18.3 h.
- Weakest cell observed was battery Bank 2, cell 7, 91% of nominal capacity.
- Average cell capacity of the battery was 104% of nominal.

Results of Test 2 compared to Test 1:

- Average cell capacity remained the same.

3.4. Manotick site results

Three tests were conducted on the battery pack at this site and the capacity data obtained is shown in Table 1 earlier. The battery consisted of the same type and manufacture of cells, but had two banks of 12 cells rather than four banks, as in the Merivale site. The Manotick site battery pack had been installed for 1 year and from Table 1, it can be calculated that the average cell capacity in this battery pack was 7% greater than in the Merivale site.

The BHM^{TM} data from the Manotick site could be downloaded and reviewed using a dial-up modem from off-site computers.

From the results shown in Fig. 10, it can be seen that there is no meaningful trend in the cell capacity from test to test. There is also a similar degree of cell-to-cell capacity variability in this battery pack as was observed in the Merivale site battery pack.

4. Summary

A new cell/module-based technique to manage battery packs has been developed and tested by ESTCO. Research results from field tests in telecommunication and rail applications being conducted by ESTCO validate the practicality of this approach. The BHM^{TM} technique has several significant advantages that result from the ability of the technique to provide a cell/module-based electrochemical management of the battery pack. The considerable advantages of this technique are not available without use of the BHM^{TM} approach to electrically access each cell/module of the battery pack that can be achieved during normal battery pack operation.

Advantages for the BHM^{TM} battery management technique include:

- Permits the use of “smart” charging algorithms at the cell/module level to extend the life of battery packs.
- Provides the battery user with battery capacity based on the standard and most reliable method, the discharge method, without risk of loss of backup should a power failure occur during the test.
- Substitutes for a weak cell/module to ensure battery pack meets operational requirement until serviced.
- Maintains the capacity of battery packs while providing a method for cell/module equalization.
- Provides a battery pack management tool that can be operated while the battery pack remains operational.
- Provides a very accurate value of the available capacity of the battery pack on the system load at all times since the load is monitored and thus actual battery back-up time is available.
- Remotely manages the battery pack and reserve power system on a telecommunication or railway site.

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