Sodium Metal Chloride Battery Quarter Life Capacity Testing and Field Results

Andrew K. Miraldi
Product Applications Manager
FZSONICK, Inc.
Elgin, IL 60123

Abstract
Sodium Metal Chloride (SMC) batteries have now been commercially deployed and successfully operating in stationary backup applications for greater than five years.

This paper will discuss the results of the testing of the quarter service life (5 years) capacity of field installed sodium metal chloride batteries in a standby application (MTSO). The FZSoNick 48TL200 Telecom series batteries will be the subject used in this document. The tests were conducted by the end user's agent and data was collected by both a third-party service vendor and the manufacturer.

Introduction
In general, batteries or battery systems that are not maintained per the manufacturers requirements can be subject to performance or service life degradation. Sodium Metal Chloride batteries have been presented to the market as 'Very Low Maintenance' or even 'No Maintenance' products for standby power and cycling applications. Verification data of the performance of SMC batteries in telecom field installations has been available but most of this data was verification at initial installation or commissioning. The performance data presented in this document will be from installations of product manufactured on average in 2012 and put into service shortly afterward. The testing was planned at the 5-year service life mark, which is approximately one quarter of the manufacturers stated service life of 20 years.

Description of Systems under test
The battery systems under test are installed in multiple telecom facilities in major metropolitan areas in North America. Three sites were chosen as pilot facilities for their geographic diversity and similar installation and commission dates. Identical tests were repeated at each installation. For the security of the facility they will only be referred to by site number.

The nominal configuration of the batteries tested is two redundant banks of four 3200Ah racks of SMC batteries for each bus. Each rack consists of sixteen 48 VDC 200Ah modules. The system is nominally designed around a four-hour discharge rate with the two-hour rate reserved for the event of a single bus failure. At each location, four of the eight racks were randomly chosen for verification, two racks on the DC Bus Marked "A" and two on the DC Bus marked "B". The typical battery recharge rate is set to return 100% capacity in 24 hours.

The total number of battery modules tested was 64 modules per location or 192 total across all the sites.

Figure 1 below represents one of the four 3200 Ah battery systems connected to the bus. The system was isolated from the bus and a resistive load bank was connected to the rack terminals. The voltage measurement was taken at the output terminals of the system.

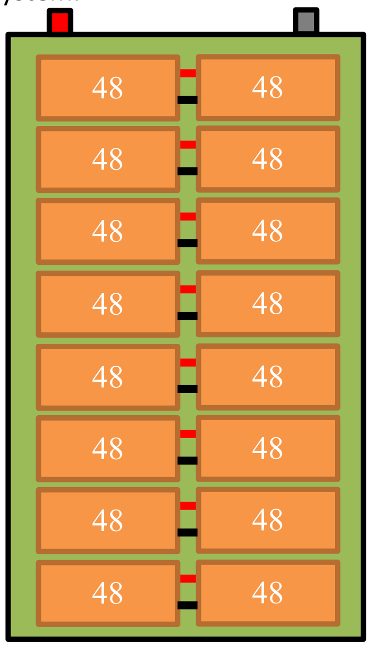

Figure 1. Typical 3200Ah configuration

Table 1 below includes a sample of the production dates of the batteries installed in Site #1 of the test group.

Site #1 Production Date Example					
RACK A1			RACK B1		
BMS s/n	Pack s/n	PROD DATE	BMS s/n	Pack s/n	PROD DATE
4800420108	1203396	6/24/2013	4800380019	1200954	11/8/2011
4800370089	1200562	10/2/2012	4800380015	1200587	10/20/2011
4800380093	1202234	9/27/2012	4800380071	1202229	9/19/2012
4800380087	1202233	9/27/2012	4800390050	1202230	9/19/2012
5079410085	1202283	10/2/2012	4800380056	1200645	10/2/2012
5079410094	1202286	10/2/2012	5530570430	1204966	3/24/2014
4800380009	1200525	10/17/2012	4800380053	1202161	05/09/2012
5530560208	1205220	6/26/2014	4800380050	1202162	9/5/2012
4800380035	1201562	11/16/2011	4800420109	1203452	6/28/2013
4800380032	1200552	10/14/2011	4800370137	1201575	11/18/2011
4800390007	1202266	9/27/2012	4800380017	1201544	11/14/2011
4800380095	1202265	9/27/2012	4800380008	1200976	11/11/2011
4800380075	1202239	9/21/2012	4800370125	1200053	7/20/2011
4800390013	1202240	9/21/2012	4800370142	1201574	11/18/2011
4800390016	1202255	9/24/2012	4800370121	1200641	10/27/2011
4800390014	1202243	9/21/2012	4800370130	1200639	10/28/2011

TABLE 1. Example production dates at Site #1

Test Requirements and Considerations

SMC batteries typically do not have a manufacturer's requirement to perform a load or performance test at installation or during service. Though not a requirement, being a relatively new technology, many end users have chosen to do it for various reasons: system design verification, installation integrity, standard procedure and even out of curiosity.

The data from the commissioning tests performed when the study cases were initially installed is included. This data provides a baseline of performance at the nominal design discharge rate. All sites showed the systems performed at 100 % capacity at time of commissioning. Figure 2 represents a typical discharge graph at time of commissioning. The battery system delivered 800 Amps for 4 hours with the end of discharge voltage being 42.89 VDC. Per the manufacturer's data the system was performing at 100% of rated capacity at time of commissioning.

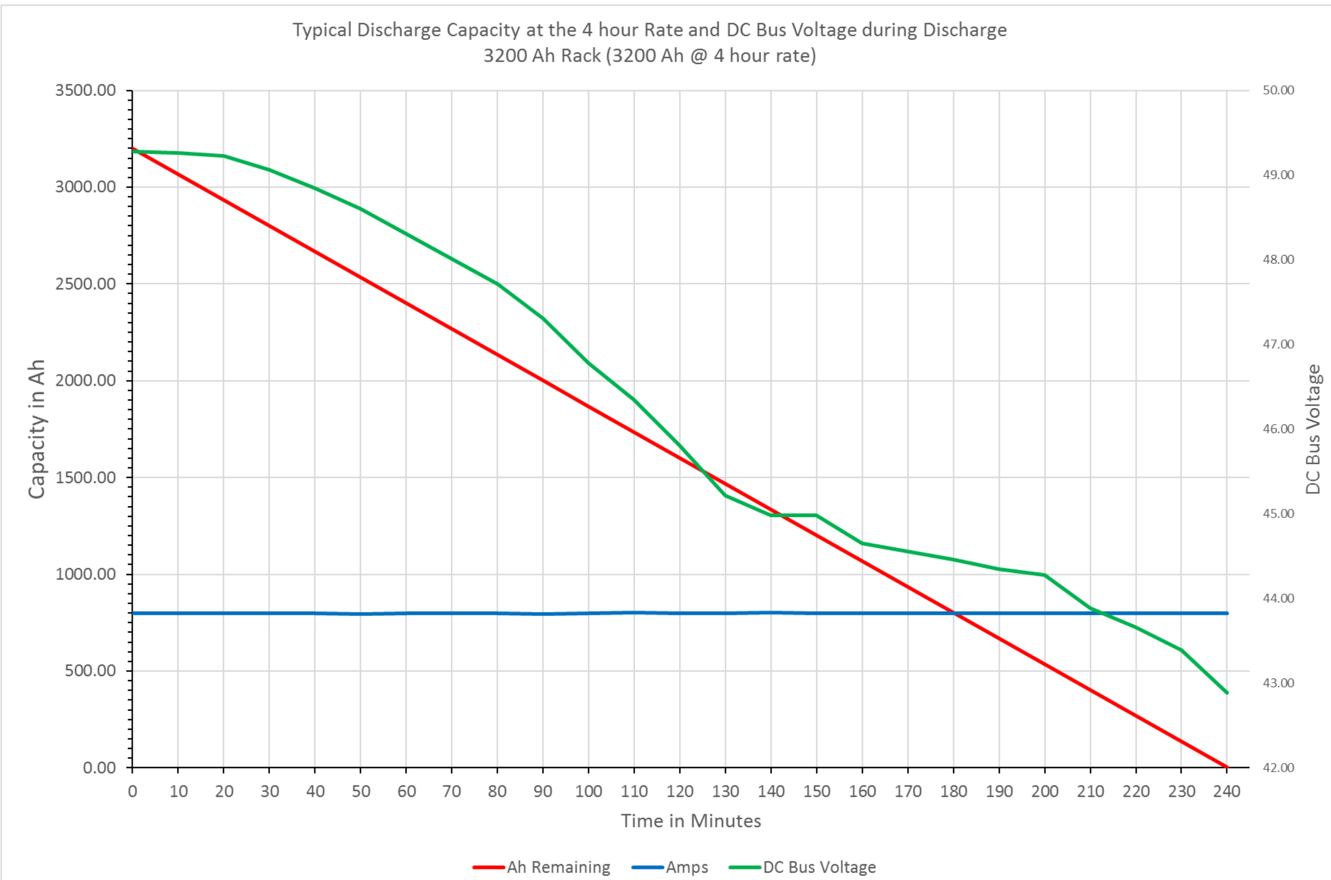

Figure 2. Typical Discharge data from commissioning

The test requirements for in-service battery systems supporting active telecom load must be considered carefully. It is important to the end user to avoid interruption of service or added costs for support equipment while the system is being evaluated and recovering from the test cycle. The systems in the study cases would allow a discharge at a higher than nominal rate and only allow a maximum of 25% of the installed capacity removed during a single maintenance period (approximately 6 hours). This would ensure the system safety while providing sufficient data to verify available capacity and that the system will perform at the worst-case condition of bus fail-over. The test was also designed to minimize the recharge recovery time to return the system to 100% capacity with as little risk as possible.

Test Conditions

The conditions selected were a 30-minute discharge at the 2-hour rate. This should remove approximately 25% of the capacity of the SMC batteries. Per the manufacturer's data, this would be a 30-minute discharge at 1468A. Also per the manufacturer data, the capacity of the SMC battery system is relative to the discharge rate, the calculated capacity of the nameplate rated 3200 Ah system at the 4-hour rate is 3200 Ah and at the 2-hour rate is 2936 Ah. The expectation of capacity removed during this 30-minute discharge at the 2-hour rate would be 734 Ah, and the remaining capacity reported from the battery system would be 75% or 2202 Ah with an end discharge voltage of greater than or equal to 45.5 V.

The tests were conducted at the ambient temperature of the operating facilities which averaged 72^{o} F/23^{o}C at mid-rack level. The typical temperature stratification of any facility and convection of the typical thermal losses of SMC batteries caused the actual conditions that batteries operated in to vary slightly from location to location. The temperature difference between mid-rack and the upper modules in these applications varied as much as +30^{o} F. In all cases the upper modules were subject to a higher ambient operating environment than the lower modules both during its past service life and during the discharge event. Though this differential seems high for a properly designed Telecom battery room, the End User has chosen to design their facility to take advantage of the wide temperature operating range of the sodium battery by allowing a larger temperature differential in the area where the battery system is located.

Data collection

The data was collected with more than one source. The source of the data will be indicated where it is presented.

The end user's agent, under contract from the user, was instructed to take independent data. The data they have taken will be identified as "AGENT DATA". The timeframe for the data was established to be the first reading at the 1 minute mark and then a reading every 5 minutes until the end of the test time. The customer's agent took data using typical hand held instrumentation, I.E., Fluke multimeters and clamp on ammeters; this data was inclusive to voltage and current of the string of 16 modules under test. The agent also recorded the displayed measurements of the front panel led display on the visible modules. These measurements included voltage, current, internal temperature and state of charge (in percentage). The capacity consumed was calculated from the time and current data measured.

The manufacturer took data via the battery system monitoring interface. The data they recorded will be identified as "MANUFACTURER DATA". This system provided detailed information on the status of each module while also compiling the voltage and current data in a similar fashion as the string data taken by the agent. The composite data was collected on the same time interval and compared. At the same time, additional information was collected which included reported state of charge, internal temperature, and status. Inventory information such as serial numbers were collected for traceability of the module back to the original factory production dates.

Test results

The following table (Table 2) shows the discharge test results for both measured and calculated agent data and the collected and consolidated manufacturer data from the modules internal measurements circuits.

Test data Site #1 Rack B1									
Time	Agent I	Manf I	Agent V	Manf V	Agent T Avg	Manf T Avg	Nominal Ah	Manf Ah	Agent Ah
0	0.0	0.0	54.90	53.36	266.50	265.31	2936	2936.00	2936.00
1	1467.2	1481.5	46.85	47.08	266.88	265.56	2911	2911.31	2911.55
6	1467.2	1468.4	46.75	46.92	269.13	268.44	2789	2788.94	2789.28
11	1467.2	1468.8	46.54	46.69	270.75	271.69	2667	2666.54	2667.01
16	1467.2	1470.7	46.27	46.41	273.75	275.00	2544	2543.98	2544.75
21	1467.2	1468.8	46.02	46.15	276.63	278.31	2422	2421.58	2422.48
26	1467.2	1466.3	45.75	45.89	279.38	281.50	2299	2299.39	2300.21
31	1467.2	1467.1	45.49	45.63	282.00	284.94	2177	2177.13	2177.95

Table 2. Discharge data for Site #1 Rack B1

The graphs in Figures 3 – 6 are comparisons to the data taken via external measurements by the end user's agent versus the data collected by the manufacturer. The comparison was presented to confirm the accuracy of the internal instrumentation of the battery system and to verify the test conditions were consistent over the test lot.

The data in Figures 3 and 4 are Voltage, Current and internal temperature graphs logged during the discharge event. The tempertures below are the internal operating temperatures, the external temperature of the battery module does rise greater than 10° C above the ambient.

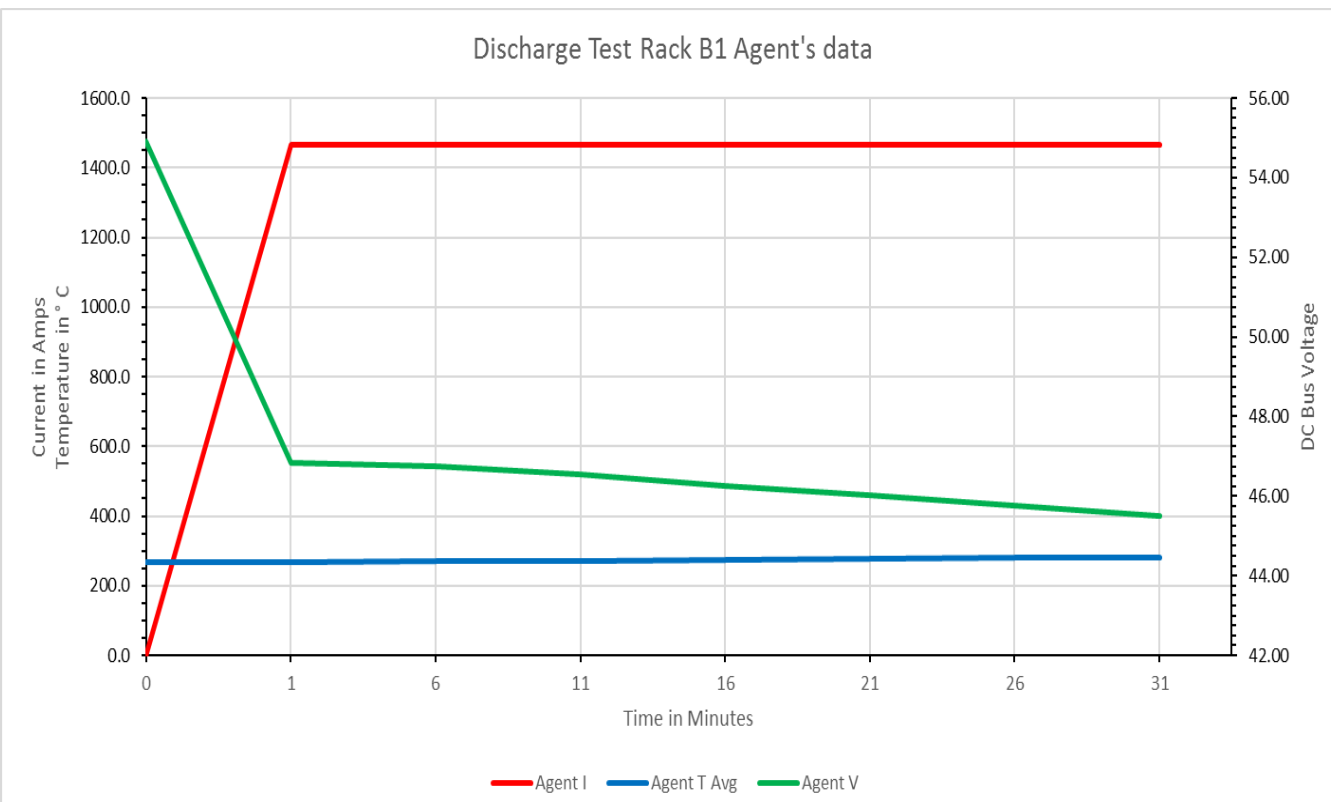

Figure 3. Discharge V and I Site #1 Rack B1 Agent's collected data

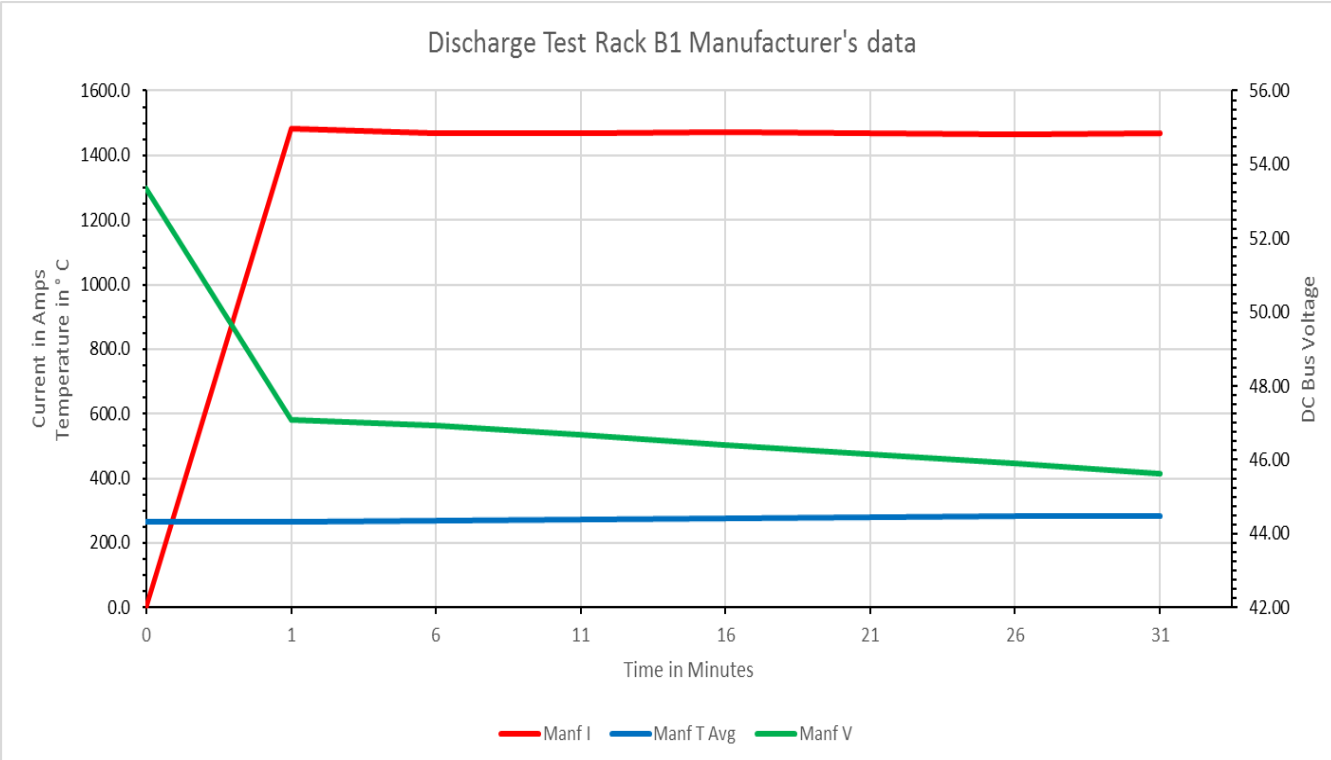

Figure 4. Discharge V and I Site #1 Rack B1 Manufacturer's measured data

The data in Figures 5 and 6 show the actual measured and calculated capacity (Red Line) overlaid on the nominal projected capacity at ± 2%, for first the manufacturer data and then the agents' data.

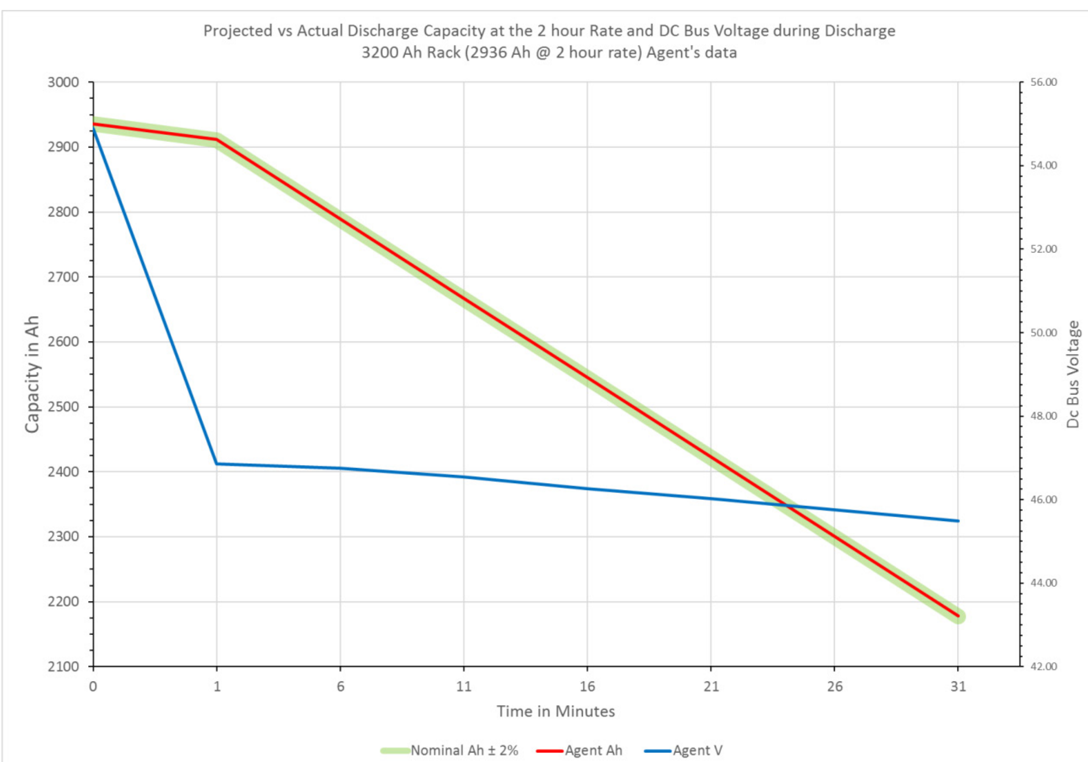

Figure 5. Discharge Capacity Site #1 Rack B1 Agent's collected data

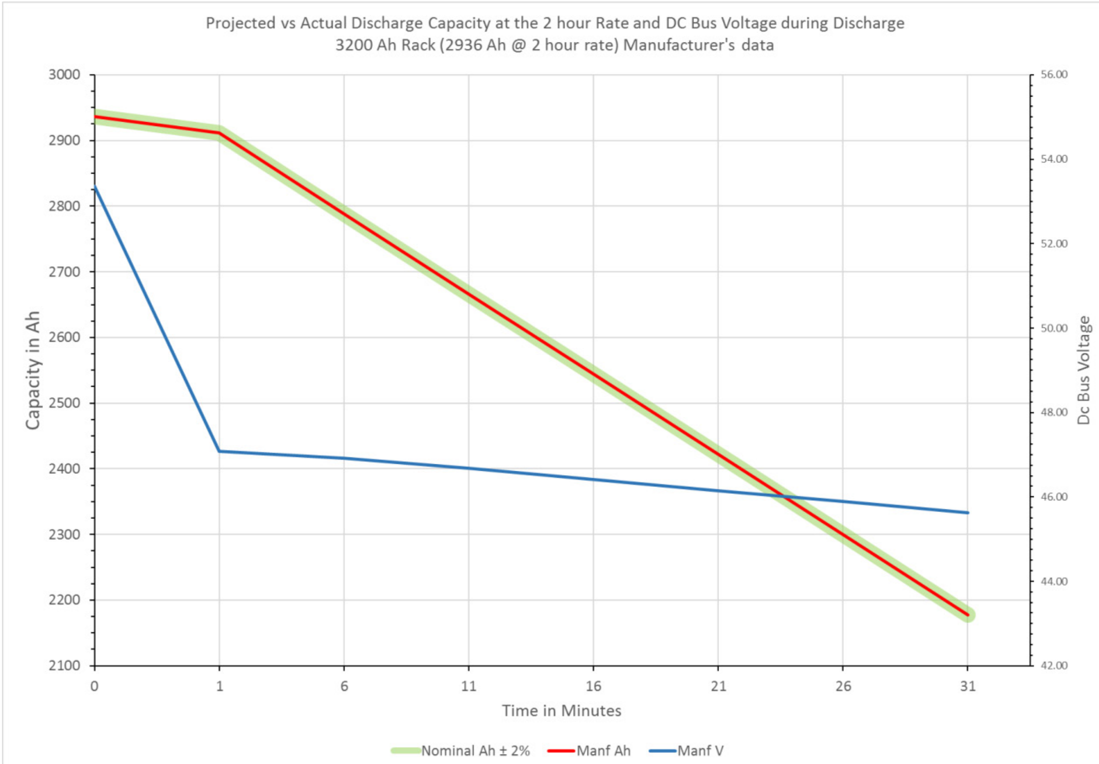

Figure 6. Discharge Capacity Site #1 Rack B1 Manufacturer's Measured data

The graph in figure 7 shows the discharge extrapolated until the end of the two hour discharge time if the discharge were to continue until the battery system disconnected. The manufacter data shows us the points where the battery system is at 75% SOC, the two conditions that indicate this are: 1) the remaining capacity is at or above 2202 Ah and 2) the voltage of the battery is above or equal to 45.5 VDC.

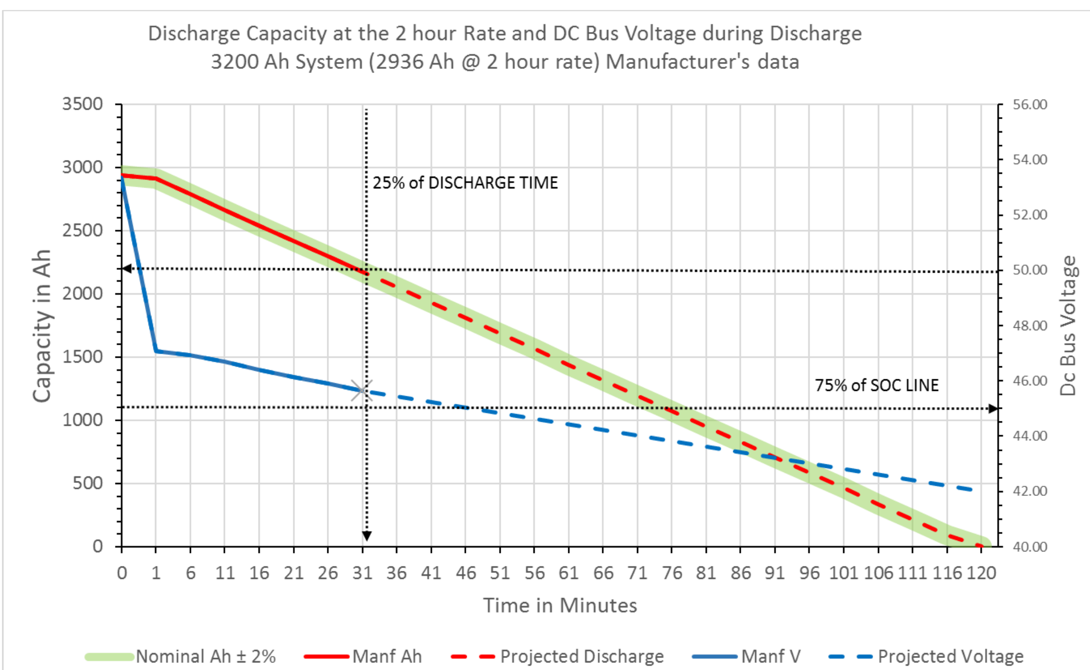

Figure 7. Discharge Capacity Site #1 Rack B1 Measured data

Module Faults or Alarms

SMC Batteries operate under the control of a battery management system. If this system detects a condition that is outside of its operating envelope, the battery will enter an alarm state and remove itself from the bus. If this occurs, the battery system will continue to operate and reduce its capacity for the offline battery module.

Figure 8 shows the projected capacity of the system if modules enter the alarm state. The dark green line superimposed on the light green line indicates the measure of capacity overlaid on a ± 2% tolerance of nominal capacity. The Violet, Orange and Red lines indicate the projected capacity if one, two, or three modules fail respectively. The vertical dark green bars are the -20% tolerance of the system. Capacity below these bars are below the 80% design rule generally applied to back up systems.

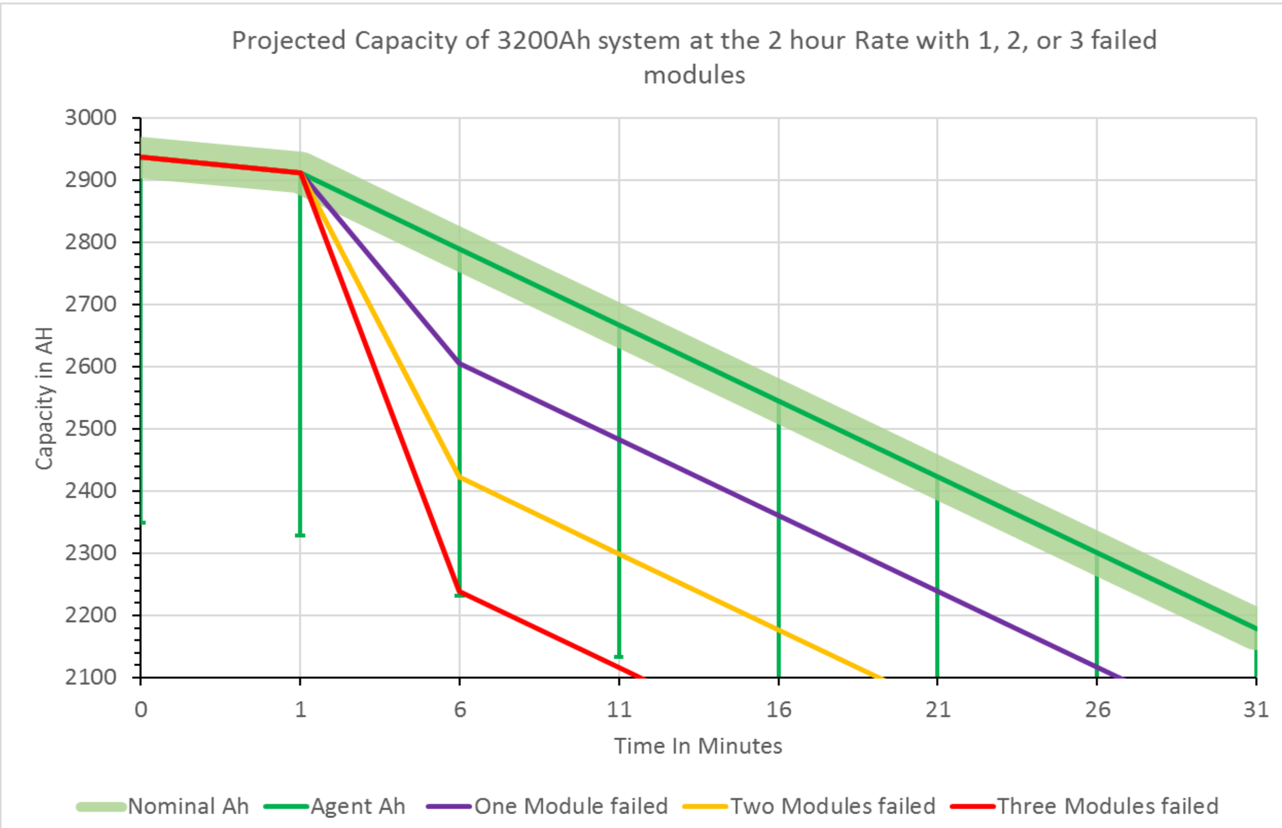

Figure 8. Discharge Capacity of a System when modules fail

Thermal Considerations, Internal

The SMC batteries also have thermal characteristics that can be measured. The internal temperature rise is considered a measure of performance. If the internal temperature exceeds the maximum limit, the battery system will reach end of discharge and disconnect from the bus. Referencing the data in Table 2, the internal temperature average was between 282 and 284 ° C. The manufacturer data indicates that 350° C is the maximum internal operating temperature. Since the temperature rise of an SMC battery is relative to the discharge rate, if the discharge rate stays constant, the temperature rise will be linear. The data can be straight line extrapolated to determine the temperature at the end of discharge after the partial discharge test. In the test system, the graph in Figure 9 shows the extrapolated data from the tests as dashed lines. The internal temperature would reach 350° C at the 120-minute mark.

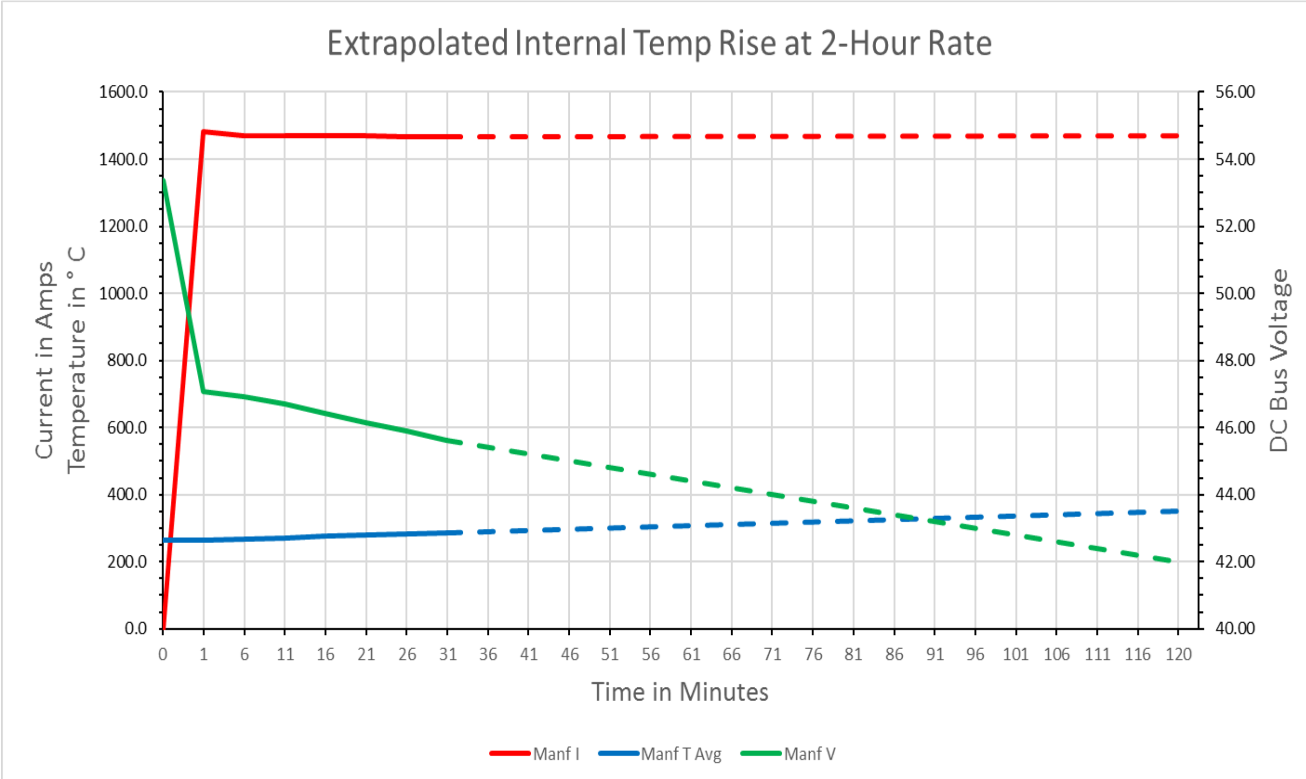

Figure 9. Extrapolated Internal Temperature Rise at the 2-Hour Rate

Thermal Considerations, External

All batteries/battery systems have connections and/or terminals, SMC batteries are no exception. Any external thermal changes to the battery system or its connections may be symptomatic of a potential issue such as a loose connection or a module/cell that could be failing. Thermal examination of the battery system via infrared is an option to verify that this condition does not exist. The following figures represent a Pre-Discharge test (Figure 10 left) and Post discharge test (Figure 10 right) examination of the system. The examinations were taken in sync with the agent's data collection period. The data would reveal any large-scale changes that could be indicative of a potential issue or problem. In the case of the test system, no connection problems or rapid temperature rises were detected.

The difference in maximum temperature scales of the images indicate the temperature rise during the discharge event. The maximum observed external temperature rise during the test was 14° F (136° - 122°F).

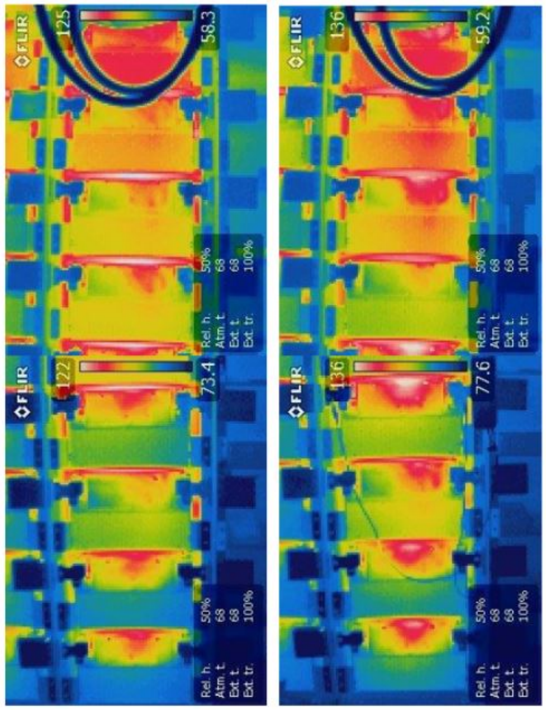

Figure 10. IR Image of test subject Pre-discharge test (left) and Post Discharge(right)

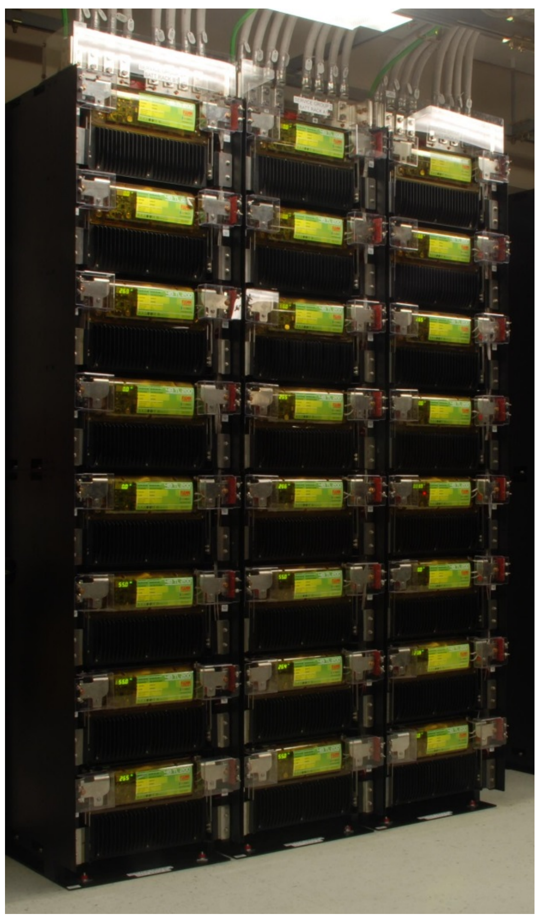

Figure 11. Image of test subjects

Conclusions

To simplify this document, in most cases the data from one of the systems at one of the test sites was selected to represent the results of the test. The balance of the data has been analyzed in the same fashion. The test subject was selected because it represents the typical results of the test repeated at all the locations on all the systems described above with no significant differences from one site to another.

SMC battery end voltage is determined by either the user or the operation of the BMS;

1. The end voltage is chosen by the user. This is typically determined by the lower voltage limit of the load while taking the voltage drop of the distribution system into consideration. A typical value for the telecom market would be 42.0 Volts. The capacity of the system is measured when the storage system reaches this level. The manufacturer’s data gives the user the capacity available at various voltage levels and discharge rates for this purpose.
2. The end voltage is determined by the BMS. The absolute minimum end voltage is specified in the manufacturer’s data sheet at various discharge rates and currents. This voltage level is the minimum voltage at the terminals that the battery will maintain until it is mechanically disconnected from the DC Bus. This disconnection occurs when 100% of the capacity is expended from the module. The data is represented as the minimum value that would be achieved over the entire operating temperature range during the design life of the product.

SMC battery capacity is evaluated by measuring the amp hours delivered up to the point the battery reaches the user determined end voltage or the BMS disconnects it from the bus. In the four-hour discharge referenced in Figure 2, the data shows that the discharge ended at approximately 42.7 V while the capacity remaining approached zero. In this case the battery system capacity delivered is calculated by I * T = C or 800 Amps for 4 hours equals 3200 Amp hours. The end voltage being greater than the specified voltage does not indicate the capacity is greater than 100%. Given that the battery is specified to operate from -20^{o} to $+60^{o}$ C the higher disconnect voltage can be mainly attributed to the test conditions being in the mid-point of the ambient temperature range and secondly that the product has only been deployed for 25% of the service life and had experienced a very low number of full discharge cycles.

The results of the testing show that SMC batteries can perform as specified and as designed in the application of the test study. The test of multiple locations and systems has provided data that shows the consistent performance over many modules and time.

Bibliography

1. Roveda, A, " 48TL200 discharge voltages," FZSoNick Oct 3, 2014.
2. “I&O Manual 48TL200”, FZSoNick May 2016
3. Miraldi, A.D, Dole, D, Miraldi A.K, “Using Advanced Technologies in the next Gen of high power Density Telecommunications facilities” Battcon 2012.
4. Miraldi, A.K, Restello, S, “Sodium Metal Chloride Battery Safety in Standby Applications” Battcon 2013.