PROACTIVE BATTERY MAINTENANCE

William Bullis
Reliability Specialist
ChevronTexaco
El Segundo, CA. 90245

ABSTRACT

This paper outlines how we established traditional battery preventive maintenance and testing procedures at our 105 local battery sites. Additionally we have employed various "Conditional Monitoring" tools such as ohmic testing and remote battery monitoring units. The paper will outline our use of a computer based maintenance management system (MMS) to track cost and equipment reliability of UPS and battery assets. I will discuss how we have set the battery monitoring system on the "Company Intranet" so we can access our data from any company network computer as well as anywhere there is an external Internet connection. I will discuss how we use ohmic readings various percentage points above baseline as a test trigger to verify battery health by capacity testing. We are compiling "baseline" vs "failure point" data for each battery by Manufacturer (MFG) and model number. In the future we hope to use the internal resistance failure point as an indicator of asset replacement. The paper will show that there is a consistent correlation between high internal cell resistance and low battery capacity especially in VRLA batteries. The paper will show how we use conditional monitoring to detect different types of battery failure modes in progress. At our plant we have not had an unexpected battery failure since 1996 by using this integrated maintenance system approach. Our goal is to establish a high level of asset reliability and equipment availability by detecting failure modes at the top of the failure curve. Proactive battery maintenance rather than reactive battery maintenance is the only way to go.

INTRODUCTION

In 1991 to 1995 we had several incidents with UPS systems failing during preventive maintenance by third party Contractors. We had failures at sites that were lost in the shuffle and hadn't been worked on in years. This cost us several million dollars in lost profit and fines. At that point we decided to form our own in-house UPS and Battery Maintenance group. We started out with company trained Instrument and Electrical Journeymen. I have listed the general activities below somewhat historically as Phase 1, Phase 2 etc. Some items were performed in parallel and some in series.

PHASE 1

The following items were milestones in our initial efforts to implement a proactive UPS and Battery Maintenance Process. (1995 to 1997)

- Performed a complete UPS and Battery system equipment audit.
- Entered all equipment data into our electronic Maintenance Management System (M.M.S.).
- Performed an audit of all UPS and Battery electrical installation drawings.
- The drawings were corrected after verification.
- Formulated safe maintenance bypass and isolation procedures for each system.
- Received training by local Battery OEM representative for PM of VLA and VRLA Batteries.
- Received training by nationally recognized Battery Test Equipment Company.
- Formulated battery and UPS PM guidelines using O.E.M. and IEEE guidelines as a basis.
- Embedded the custom PM guidelines into our M.M.S.
- Assigned preventive maintenance frequencies to each site. This was entered into the M.M.S.
- Reviewed each site installation and corrected and upgraded items as required, such as installation of external maintenance bypass switch and isolation breakers etc.
- Purchased and employed two Alber'Corp CellCorders with Software.
- Detected weak and failing cells using the ohmic tester.
- Settled into routine PM activities driven by our M.M.S.

PHASE 2

The following items were milestones in our journey to World-Class battery reliability. (1997 to 2001)

- Purchased and employed an Alber'Corp BCT-2000 Load Tester with software.
- Started capacity testing batteries using the BCT-2000.
- Continued ohmic testing and began analyzing test data.
- Found that there was some correlation between high internal cell resistance and low capacity.
- Went to other Chevron sites and assisted them in setting up similar battery maintenance processes.
- Ohmic tested and capacity tested batteries at other Chevron refineries.
- Worked with the Chevron Electrical Reliability Team to standardized on UPS and Battery products.
- Standardized on UPS and Battery electrical specifications and installations.
- Teamed up with other Chevron sites to put together a Chevron UPS and Battery Maintenance Process.
- Attended BATCON every year since 1998. Learned what battery failure detection technologies were available.
- Purchased and installed 22 AlberCorp battery monitors. Monitors helped detect battery problems.
- These monitors now sit on the company Intranet and can be accessed from any licensed company desktop PC.

BECOMING RELIABILITY FOCUSED

At our company Electrical Reliability Conference in New Orleans in October 2001 I was able to show my fellow attendees some battery sites at our El Segundo, California Refinery in real time. I performed a resistance test from this remote location and gave a presentation showing potential failure finds. I knew at that point our El Segundo UPS and Battery Maintenance Group had gone from a total reactive effort to a true proactive effort. The path forward for our Proactive Battery Maintenance Process is to stay focused on total asset management. We want to focus on detecting a potential failure in progress so we can schedule a controlled outage to repair and avert a functional failure. We had a paradigm shift from "My first job priority is to repair equipment." to " My first job priority is to avert an equipment failure." By employing everything from basic "care and feeding" preventive maintenance techniques to "real time" conditional monitoring at critical battery sites we strongly feel we can avert a battery functional failure right at 100% of the time. Each battery site is setup as recommended by our company "Maintenance Practice". Then by performing PM and tracking repair histories, repair cost and maintenance man-hour costs on our M.M.S. we can identify the most reliable and cost efficient equipment to purchase. We have learned that system reliability starts with a good design and equipment specification. We standardize with proven manufacture, type and models of equipment. This gives us a bonus of controlling parts and inventory costs and our maintenance people become expert in maintaining the equipment.

PROACTIVE TESTING

Last year our group went to Hawaii to test the battery systems at our Chevron Hawaii Refinery. I had an opportunity to test seven identical UPS battery strings. The UPS Chargers and Inverters had been previously tested and Preventive Maintenance was performed sometime before I arrived by the UPS OEM. All of the batteries were VRLA type. The batteries were all the same MFG. and Model number. The battery ages were from two years old to seven years old. The batteries were sold to the refinery as 10-year design life batteries. The batteries were all in air-conditioned rooms. Temperatures ranged from 64 degrees F to 71 degrees F. The batteries had been reasonably maintained. I found no corrosion on the connections. The battery float voltages ranged from 134.4 to 135.5 volts on a 120-vdc string. The tests involved 70 each 12 volts VRLA batteries. I didn't have a way to determine how many discharge cycles each string had sustained. I tested each system at the specified 1-hour rate to a final voltage of 1.75 vpc. or 10.5 vdc per battery. We verified all connections were tight and performed an "Ohmic Test" on each set using an Alber ' CellCorder. At that point we connected an Alber' BCT 2000 for the load test. An Infrared gun was used to monitor connections and battery cell skin temperatures during the discharge. The test was paused as required to jump around failed cells. Test results provided us with data that consistently showed that higher than average string resistance cells failed most of the time.

TABLE 1 TEST DATA

Before we view Table 1 I want to explain my approach to analyzing the data. I will begin by explaining the data sheet column headers.

- The column header labeled "Site" is a number assigned to the Hawaii Refinery UPS battery sites tested.
- The column header labeled "Cell" is the battery cell number.

- The column header labeled "Float Volts" is the individual cell float voltage with the Battery Charger on.
- The column header labeled "Start Volts" is the open circuit voltage just before starting the capacity test with the BCT-2000 Load Tester. This was extracted from my load test report.
- The column header labeled "End Volts" is the voltage value of each cell at the end of the capacity test. This was extracted from my load test report. The cells that failed before the 80% capacity point were listed as < 10.5. 10.5 vdc per battery was the final voltage value.
- The column header labeled as "Internal Res." is the internal cell resistance in micro ohms taken with the Alber'Corp CellCorder.
- The column header labeled "Age" is the battery date of manufacture.
- The column header labeled "Temp." is the average skin temp of the battery taken with a hand held Infra Red Gun.
- The column header labeled "Avg. Res. of passed cells" is the average internal resistance in micro ohms of only the cells that passed the test. This was calculated for each individual string.
- The column header labeled "% Cap." is entered as > 80 for all cells that passed the 80% capacity threshold. The actual capacity percent was entered for the failed cells.
- The column header labeled "Delta" is the quotient of dividing the individual cell internal resistance value by the "passed cell average value. This is used to determine if the individual cell is above or below the baseline.

We have determined after reviewing numerous ohmic test reports for the same model and manufacture battery that internal resistance values were grouped closer by using site specific values. There wasn't as much deviation using this method compared to using a universal baseline reading for the same battery. This is probably because in an individual system the same amount of discharge cycles, temperature excursions, and other physical events and conditions are experienced equally by each cell as a rule. Normally most batteries in an installation are from the same factory batch and are the same age. Thus each system with Brand X batteries has an average healthy internal resistance value that is unique to the system in comparison to the generic internal resistance values of all Brand X cells that are fully charged but have not been installed into a system.

TABLE 1

Site	Cell	Float Volts	Start Volts	End Volts	Internal Res.	Age (years)	Temp.	Avg. Res. of passed cells	% Cap.	Delta
1	1	13.54	12.73	11.27	4453	7	70	4577.8	> 80	0.972737996
1	2	13.732	12.75	11.42	4599	7	70	4577.8	> 80	1.004631045
1	3	13.652	12.81	11.31	4453	7	70	4577.8	> 80	0.972737996
1	4	13.58	12.78	11.29	4307	7	70	4577.8	> 80	0.940844947
1	5	13.652	12.72	11.01	4924	7	70	4577.8	> 80	1.075625846
1	6	13.38	12.37	10.52	4981	7	70	4577.8	> 80	1.088077242
1	7	13.376	12.69	11.39	4307	7	70	4577.8	> 80	0.940844947
1	8	13.388	12.54	11.37	4680	7	70	4577.8	> 80	1.022325134
1	9	13.612	12.49	10.119	4680	7	70	4577.8	> 80	1.022325134
1	10	13.64	12.61	< 10.5	4394	7	70	4577.8	> 80	0.959849709
2	1	13.624	12.359	11.339	4453	7	70	4717.6	> 80	0.943912159
2	2	13.756	12.332	11.02	4964	7	70	4717.6	> 80	1.052229947
2	3	13.744	12.318	11.034	4964	7	70	4717.6	> 80	1.052229947
2	4	13.36	12.3	11.302	4745	7	70	4717.6	> 80	1.005808038
2	5	13.416	12.298	11.263	4453	7	70	4717.6	> 80	0.943912159
2	6	13.464	12.244	11.277	4672	7	70	4717.6	> 80	0.990334068
2	7	13.464	12.587	< 10.5	5620	7	70	4717.6	73	1.191283704
2	8	13.536	12.652	11.3	4891	7	70	4717.6	> 80	1.036755978
2	9	13.448	12.536	11.34	4599	7	70	4717.6	> 80	0.974860098
2	10	13.184	12.66	< 10.5	45854	7	70	4717.6	0.3	9.719772766
3	1	13.7	12.135	11.64	4453	7	70	4796.7	> 80	0.928346572
3	2	13.904	12.191	< 10.5	6277	7	70	4796.7	66	1.308608001

3	3	13.9	12.193	11.358	5912	7	70	4796.7	> 80	1.23251402
3	4	13.752	12.656	11.676	4659	7	70	4796.7	> 80	0.971292764
3	5	13.416	12.562	11.683	4672	7	70	4796.7	> 80	0.97400296
3	6	12.232	11.576	< 10.5	30691	7	70	4796.7	0.1	6.398357204
3	7	13.4	12.535	11.694	4599	7	70	4796.7	> 80	0.958784164
3	8	13.388	12.603	11.72	4516	7	70	4796.7	> 80	0.941480601
3	9	13.848	12.511	11.645	4672	7	70	4796.7	> 80	0.97400296
3	10	13.812	12.508	11.688	4891	7	70	4796.7	> 80	1.019659349
4	1	13.28	12.258	11.514	4672	7	70	4677	> 80	0.998930939
4	2	13.348	12.929	< 10.5	5065	7	70	4677	61.5	1.082959162
4	3	13.388	12.276	11.552	4588	7	70	4677	> 80	0.980970708
4	4	13.384	12.319	11.596	4588	7	70	4677	> 80	0.980970708
4	5	13.012	11.909	< 10.5	5056	7	70	4677	25.3	1.081034851
4	6	13.856	12.522	11.566	4599	7	70	4677	> 80	0.983322643
4	7	13.796	12.48	11.553	4672	7	70	4677	> 80	0.998930939
4	8	13.688	12.453	11.528	4745	7	70	4677	> 80	1.014539235
4	9	13.08	11.065	< 10.5	65000	7	70	4677	0.1	13.89779773
4	10	13.58	12.961	11.561	4875	7	70	4677	> 80	1.04233483
5	1	13.272	12.86	< 10.5	5065	2	64	4803	71	1.05454924
5	2	13.412	12.96	11.55	4684	2	64	4803	> 80	0.975223818
5	3	13.404	12.94	11.54	4599	2	64	4803	> 80	0.957526546
5	4	13.508	12.85	11.48	4981	2	64	4803	> 80	1.037060171
5	5	13.348	12	11.52	4758	2	64	4803	> 80	0.990630856
5	6	13.244	12.1	< 10.5	5682	2	64	4803	41	1.183010618
5	7	13.248	12.69	< 10.5	5119	2	64	4803	53	1.065792213
5	8	13.528	12.77	11.37	4981	2	64	4803	> 80	1.037060171
5	9	13.344	12.78	11.5	4672	2	64	4803	> 80	0.97272538
5	10	13.604	12.19	11.59	4946	2	64	4803	> 80	1.029773059
6	1	13.63	12.6	11.25	4380	5	64	4620	> 80	0.948051948
6	2	13.68	13.07	11.15	4526	5	64	4620	> 80	0.97965368
6	3	13.7	13.07	11.22	4526	5	64	4620	> 80	0.97965368
6	4	13.7	13.08	11.11	4534	5	64	4620	> 80	0.981385281
6	5	13.63	13.04	11.17	4672	5	64	4620	> 80	1.011255411
6	6	13.54	12.83	< 10.5	4924	5	64	4620	> 80	1.065800866
6	7	13.69	12.84	11.26	4693	5	64	4620	> 80	1.015800866
6	8	13.72	12.98	11.23	4758	5	64	4620	> 80	1.02987013
6	9	13.81	12.89	11.28	4588	5	64	4620	> 80	0.993073593
6	10	13.76	12.96	11.21	4599	5	64	4620	> 80	0.995454545
7	1	13.57	12.86	< 10.5	4095	5	71	4252	> 80	0.963076199
7	2	13.59	12.84	11.21	4314	5	71	4252.6	> 80	1.014438226
7	3	13.58	12.85	11.31	4387	5	71	4252.6	> 80	1.031604195
7	4	13.6	12.85	11.29	4241	5	71	4252.6	> 80	0.997272257
7	5	13.61	12.83	11.35	4372	5	71	4252.6	> 80	1.028076941
7	6	13.62	12.85	11.34	4095	5	71	4252.6	> 80	0.962940319
7	7	13.64	12.79	11.31	4241	5	71	4252.6	> 80	0.997272257
7	8	13.61	12.81	11.11	4314	5	71	4252.6	> 80	1.014438226
7	9	13.62	12.77	11.32	4241	5	71	4252.6	> 80	0.997272257
7	10	13.56	13.06	11.19	4226	5	71	4252.6	> 80	0.993745003

TABLE 2 TEST DATA

On Table 2, I show failed batteries only. As you can see the top three batteries failed catastrophically only seconds after the load bank was turned on. Look into the "Delta" column and you can see that all of the failed cells were above the average healthy resistance value for the individual string. Failure percentage values were from 5% above baseline in the lowest one to more than one thousand percent above the baseline in the worst case.

TABLE 2

Site	Cell	Float Volts	Start Volts	End Volts	Internal Res.	Age (years)	Temp.	Avg. Res. of passed cells	% Cap.	Delta
4	9	13.08	11.065	< 10.5	65000	7	70	4677	0.1	13.89779773
2	10	13.184	12.66	< 10.5	45854	7	70	4717.6	0.3	9.719772766
3	6	12.232	11.576	< 10.5	30691	7	70	4796.7	0.1	6.398357204
3	2	13.904	12.191	< 10.5	6277	7	70	4796.7	66	1.308608001
5	6	13.244	12.1	< 10.5	5682	2	64	4803	41	1.183010618
2	7	13.464	12.587	< 10.5	5620	7	70	4717.6	73	1.191283704
5	7	13.248	12.69	< 10.5	5119	2	64	4803	53	1.065792213
4	2	13.348	12.929	< 10.5	5065	7	70	4677	61.5	1.082959162
5	1	13.272	12.86	< 10.5	5065	2	64	4803	71	1.05454924
4	5	13.012	11.909	< 10.5	5056	7	70	4677	25.3	1.081034851

TABLE 3 TEST DATA

On Table 3, I show all batteries that were above baseline passed or failed. I have highlighted the failed cells below and you can see that there are four cells in the grouping of the failed cells that passed. You can also see by looking in the "Delta" column that below 5% above baseline there were no failures.

TABLE 3

Site	Cell	Float Volts	Start Volts	End Volts	Internal Res.	Age (years)	Temp.	Avg. Res. of passed cells	% Cap.	Delta
4	9	13.08	11.065	< 10.5	65000	7	70	4677	0.1	13.89779773
2	10	13.184	12.66	< 10.5	45854	7	70	4717.6	0.3	9.719772766
3	6	12.232	11.576	< 10.5	30691	7	70	4796.7	0.1	6.398357204
3	2	13.904	12.191	< 10.5	6277	7	70	4796.7	66	1.308608001
3	3	13.9	12.193	11.358	5912	7	70	4796.7	> 80	1.23251402
2	7	13.464	12.587	< 10.5	5620	7	70	4717.6	73	1.191283704
5	6	13.244	12.1	< 10.5	5682	2	64	4803	41	1.183010618
1	6	13.38	12.37	10.52	4981	7	70	4577.8	> 80	1.088077242
4	2	13.348	12.929	< 10.5	5065	7	70	4677	61.5	1.082959162
4	5	13.012	11.909	< 10.5	5056	7	70	4677	25.3	1.081034851
1	5	13.652	12.72	11.01	4924	7	70	4577.8	> 80	1.075625846
6	6	13.54	12.83	< 10.5	4924	5	64	4620	> 80	1.065800866
5	7	13.248	12.69	< 10.5	5119	2	64	4803	53	1.065792213
5	1	13.272	12.86	< 10.5	5065	2	64	4803	71	1.05454924

CONCLUSIONS

By establishing a proactive reliability focused maintenance process for battery systems you can detect failure events in progress. This will dramatically increase your equipment reliability and availability. In this proactive posture failures can be detected and managed offline. Using the three tables I list the following conclusions to the Hawaii test can be made.

- Only cells above the individual battery internal resistance baseline failed.
- There were 0% failures in cells that were below the individual battery internal resistance baseline.
- From 0% to 5% above baseline there was a 0% failure rate.
- From 5% to 9% above baseline there was a 57% failure rate.
- From 9% and 23% above baseline there was a 66% failure rate.
- Above 23% of baseline there was a 100% failure rate.
- The higher the internal resistance rate is above the baseline the more the failure rate increases.
- Monitoring internal resistance values within a system is more accurate than using a universal ohmic baseline value to detect possible weak and failing batteries.

ACKNOWLEDGEMENTS

I want to thank Greg Gray and Randy Bathauer who are team members in the El Segundo UPS and Battery Maintenance Group for all of the help and valued input to this effort since 1995. We started out from scratch and today we have a work process we can take pride in. I want to thank Bruce Carter for removing the roadblocks and for his strong support in obtaining funds for this effort. I want to thank Fred Mintun who gave me some of the ideas that helped form the vision we have about our proactive maintenance process. I want to thank Larry Robinson who trusted us enough to give us the financial support and sustained support to put this thing together.

REFERENCES

- IEEE 1188-1996, IEEE Recommended Practice for Maintenance, Testing and Replacement of Valve Regulated Lead Acid Batteries for Stationary Applications.
- IEEE 450-1995, IEEE Recommended Practice for Maintenance, Testing and Replacement of Vented Lead Acid Batteries for Stationary Applications