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State of Health Assessment of Lead Acid Cellsasa Function of Conductance

Gauri[1*], Manish Singh Bisht[2], P.C Pant[2], Rajesh Kumar[3], R.P.Gairola[4]
[1"]Dept. of Physics, Birla Campus, HNB Garhwal University Srinagar Garhwal, Uttarakhand, India
[2]Ministry of New and Renewable Energy, Govt. of India, New-Delhi, India
[3]National Institute of Solar Energy, Gurgaon,India
[4] Dept. of Physics,HNB Garhwal University Srinagar Garhwal, Uttarakhand, India
[*]Corresponding Author. E-mail: g.negi10@gmail.com

Abstract: Low performing batteries/cells reduce the efficiency of whole battery bank. Sometimes the condition becomes so severe that it results in malfunction of the whole bank. The state of health analysis of even a single cell/battery through conventional load testing requires a lot of time and wastage of power. It is required to discover and test a method of battery/cell testing which is quick, reliable and can be performed on operational batteries. The aim was to investigate whether the conductance of the flooded and VRLA lead-acid cell indicates real state ofhealthof operational cells and if yes, could there be a reference value of conductance for the cells of a particular capacity or not.

Key Words: Lead acid, conductance, Battery bank, State of health.

Introduction:

Batteries form a very essential part of solar photovoltaic applications. Being a very costly device, it needs to be properly examined in terms of capacity before being deployed in the field. When a number of cells are connected in series to form a battery bank, it becomes very essential that all the cells have equal capacities and each one is performing well. A low-performing cell can lead to enhanced degradation of the whole bank resulting in loss of both money and valuable power generated by the solar modules. In some cases it can even lead to breakdown of the whole plant. But examining the state of health of a battery is no easy task. For capacity test on a battery it is required that the sample is subjected to a number of cycles of charge and discharge under controlled conditions at C10 rate. As per IEC and or BIS* standards a typical capacity test would require about 40 hours per cycle and to perform minimum 10 cycles is mandatory for capacity test. It consumes a lot of time as well as valuable power is wasted in charging and discharging and when a complete bank has to be tested it can take months to finish the testing. The foremost problem isthat you cannot examine the battery once being installed as a bank. For capacity test on each cell you have to dismantle the whole bank resulting in interruption of whole SPV plant. And if the plant is supplying crucial loads you do not have liberty to do that. Normal field procedure of SOC examination is to collect specific gravity readings of the battery/cells, but these will only serve as a superficial prediction of the level of charge of the battery, but not provide information on the storage capacity of the battery.

And in case it is a VRLA cell you have to think of some other options. As batteries degrade through field use, their capacity goes down. The battery bank operator or owner is in dark how to find the state of health of his bank or the faulty battery of the bank which is not performing well. The aim of this article is to present and discuss resultsfor a relatively new method of examining operational field batteries,under actual conditions, which is quick, reliable and does not involve any waste of power. This method is based on assessment of state of health of a battery though its conductance. Conductance describes the ability of a battery to conduct current. In scientific terms, it is the real part of the complex admittance. Various test data have shown that at low frequencies, the conductance of a battery is an indicator of battery state-of-health showing a linear correlation to a battery's timed-discharge capacity test result and trending this measurement can be used as a reliable predictor of battery end-of-life (H. Giess, 1999). This paper also presents a reference value of conductance for the flooded and VRLA lead acid cells of a particular capacity so that they may be used as reference to examine batteries of the same capacity.

The use of conductance measurements to evaluate automotive battery performance was first reported in 1975 by Champlin [1]. It demonstrated a strong positive linear correlation between load tests and measured conductance for automotive batteries. Since then impedance and more recently conductance has been attracting both users and manufacturers to determine battery state-of-health [2-4]. Initially, the conductance testing was limited to VRLA cells only but later the interest expanded to flooded cells and nickel-cadmium cells as well[5]. Now a number of studies have been published on this topic [6-12]. This research work was carried out on two operational battery banks of 240V, 1000Ah each, consisting of 120 cells of 2V, 1000Ah at National Institute of Solar Energy, Gurgaon, Haryana (INDIA). One of these banks was of flooded type while the other one was of VRLA technology. These banks, installed 2 years before, are connected to two different inverters of 10KVA and 50KVA respectively and are being used to power the loads of the campus. Both inverters are hybrid inverters and operate on grid as well as solar power. Both the inverters are also connected to the generator so that battery banks are not consumed to higher DOD. These banks are also provided equalizing charge once in a month to ensure proper health. Regular maintenance and topping up with water is also carried out as per schedule.

1. Measurement Technique:

For measurement 5 new samples of same type and capacity as existing ones were purchased from same manufacturer. These new batteries were subjected to capacity test for 10 cycles each at C10 rate and room temperature to have normal filed conditions. The capacity test was performed with the help of a Life Cycle Network (LCN) Machine make Bitrode Corporation, USA. It is a programmable power supply and inbuilt load having automatic data collection feature. It records voltage, current, Ampere-hour, Watt-hour and temperature at preset intervals. At full charged conditions these batteries were examined with the help of a **Battery Analyzermake Midtronics, USA**. The battery analyzer is a digital meter which when attached to the sample provides voltage and corresponding conductance values. Battery conductance is measured by evaluating the voltage response to a small, select frequency AC current signal briefly impressed on the battery. The resultant conductance measurement provides pertinent battery information without the need of bringing the battery to full discharge. As a battery discharges, its conductance and capacity are reduced with a simultaneous drop in power in a predictable manner due to the depletion of conductive active materials. The value in conductance or any other Ohmic measurement can be more directly described as-*An increased internal resistance or reduced measured conductanceof a cell results in a reduction of the expected capacity or discharge performance of the cell (W. Cantor* et.al., *1998.).* Thus, conductance is an indication of battery state of health as well as a function of the charge state of a battery. The battery analyzer is powered by a battery source installed inside and does not draw any power from the bank. The conductance values and corresponding value of voltages were recorded.

A battery analyzer was now used to individually examine in total 240 cells of both the banks and conductance of the cells along with the corresponding voltage was noted. The battery bank was maintained at full charge during the testing and the specific gravity values denoting charged conditions were also recorded. The conductance values of the cells at a particular voltage level were sorted to get maximum inputs for same voltage and conductance.The conductance values of the cells of battery banks were compared with those of new ones. The cells which showed significantly lower conductance values than new batteries were tested for capacity on Bitrode tester. Capacity test was performed on such cells as per the standards and the data was recorded. 10 random samples from the remaining batteries which showed relatively good conductance values were also examined for capacity.

Data Analysis:

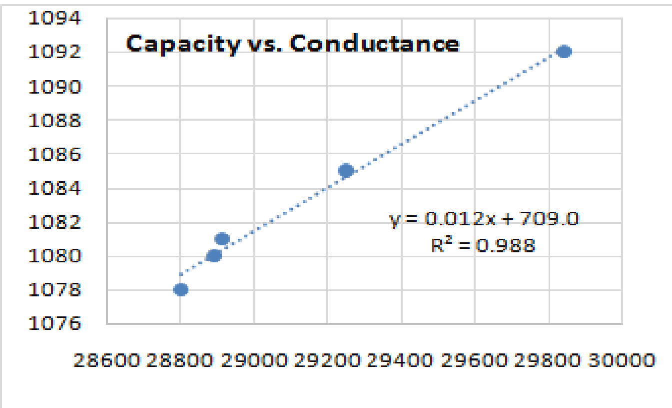

Fig. 1 Capacity vs. conductance of new flooded cells

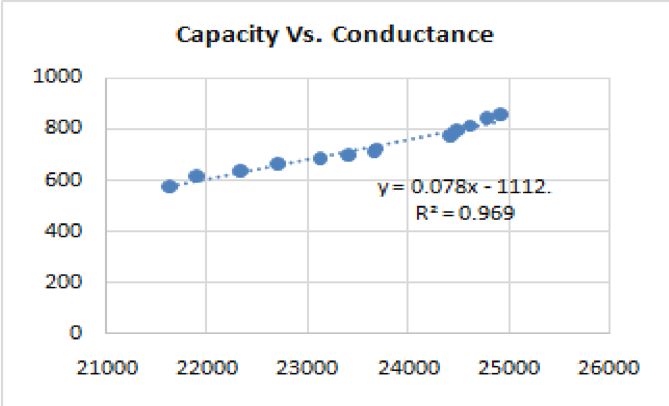

Fig. 2 Capacity vs. conductance of healthy used flooded cells

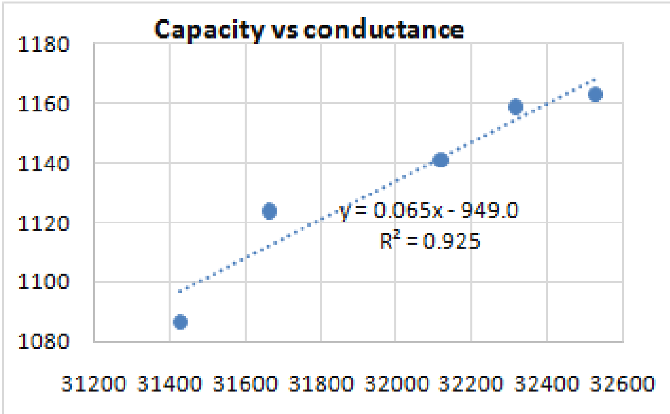

Fig. 3 Capacity vs. conductance of unused VRLA cells

Fig. 1 show the capacity vs. conductance values of new and unused cells or reference cell of flooded type. Each cell is having a capacity greater than their rated capacity. The graph clearly reflects that higher the capacity higher is conductance. The correlation factor for the above values comes out to be 0.988 which denotes a linear relationship between the capacity and conductance. Similarly Fig. 2 shows capacity vs. conductance plot for comparatively healthy used flooded cells.The capacity of these cells had degraded over time and the same was reflected by their reduced conductance and capacity values as compared to the new cells.These are the cells which showed good capacity and conductance values as compared to the reference cells. It also supports the claim that the capacity and conductance bear a linear relationship with respect to each other.

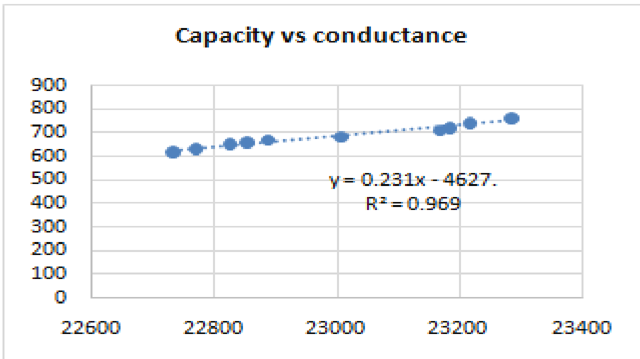

Fig. 4 Capacity vs. conductance of healthy used VRLA cells

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Fig. 3 Reflects the capacity vs. conductance plot of reference VRLA cells denoting a linear relationship between the two.
Fig. 4 also confirms the linear relationship between capacity and conductance of used and comparatively healthy VRLA cells.
During conductance testing some of the cells in both type of banks were found to be having very low conductance values as compared with other batteries in the same bank. These cells were identified and capacity tests were performed on these. Fig.5 and fig. 6 represent capacity vs. conductance plots of flooded and VRLA technology respectively.

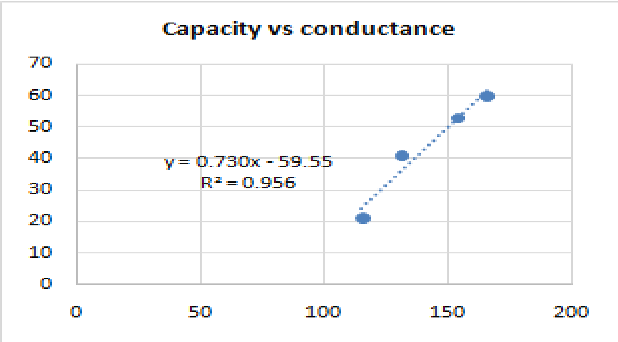

Fig. 5 Capacity vs. conductance plot of very weak flooded cells

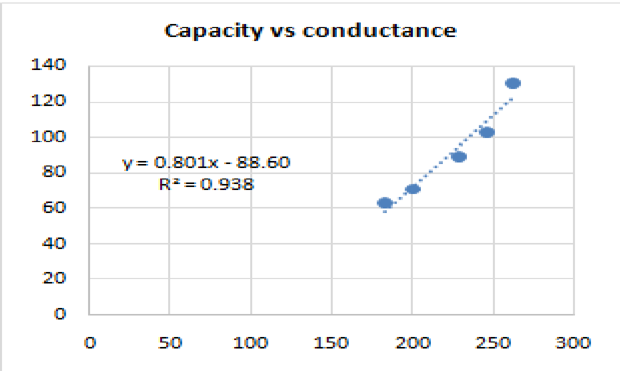

Fig. 6 Capacity vs. conductance plot of very weak VRLA cells

The above figures depict that even at very low state-of-charge conductance bears a linear relationship with the capacity.

Reference Value of Conductance:

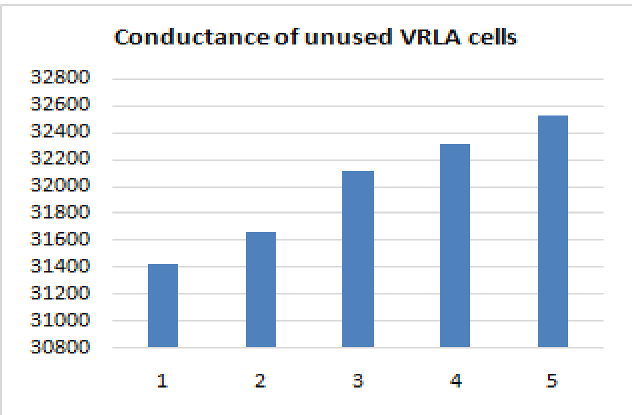

Fig. 7 Conductance of unused VRLA cells of 1000Ah

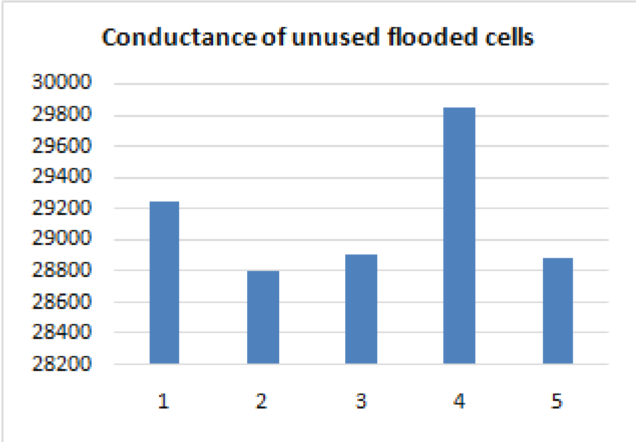

Fig. 8 Conductance of unused flooded cells of 1000Ah

Both the above figures depict that the conductance values for 2V, 1000Ah cells of both the technologies are above a certain mark in new and unused cells. Considering Fig. 2 and Fig. 4 for used and comparatively healthy cells it is confirmed that the conductance values lie in a specific range. Though the results are not highly accurate but they do specify a range in which the conductance values should lie for a specific capacity of batteries.

2. Conclusion:

The conductance value of a battery reflects the integrity of inter-cell connections, ionic conductivity of the electrolyte, specific gravity of the cells and the actual battery state of charge. The test results are the product of the internal electrical resistance of the cells and reflect the combined influences of the mechanical state of health in the cells and the electrochemical condition or efficiency of the grid/plate structures.
As a battery ages, the positive plate will deteriorate and change chemically adversely affecting the ability of the battery to perform. This normal aging process begins when the battery is activated during the formation process at the end of the battery production lineand will continue for life of the battery.
For power provisions, this means that conductance can be used to track changes and detect battery defects, shorts, open circuits and prolonged undercharging, which will reduce the ability of the battery to perform. Conductance test measurements become a valuable tool to identify the point at which the battery is approaching its end of service life. The test results reflect that the conductance technology may be a useful tool to examine new or field batteries for their state-of-health. Conductance bears a linear relationship with the battery capacity which is a direct indication of battery health. This linear relationship is maintained even at low state-of-health of the batteries. Using conventional load testing methods to determine battery capacity requires time and power whereas conductance testing method is quick and reliable. Though exact capacity cannot be predicted but it can provide a tentative idea of battery health. It could prove useful for examining batteries in large quantities such as tenders or inspections where load testing seems impossible for each sample.

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