# BATTERY STATE OF HEALTH ESTIMATION THROUGH COUP DE FOUET: FIELD EXPERIENCE

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**Abstract:**
In earlier publications by one of the authors [1 and 2] showed that *coup de fouet*, a phenomenon associated with voltage drop in the early minutes of lead acid battery discharge, was useful tool in determining the battery state of health (SOH). This led to a new two-minute partial discharge test method to estimate the SOH of battery and the verification of this method was made on various VRLA batteries from the field as well as laboratory [1]. In this paper, a simplified *coup de fouet* approach was used to analyze the data collected on various VRLA and flooded batteries in Verizon central office locations. In this approach, the plant load was used to perform the partial discharges by switching off rectifiers. It is shown that the simplified method could be useful in estimating battery SOH.

**Introduction:**
A brief review of *coup de fouet* phenomenon and its use in determining battery state of charge (SOC) and state of health (SOH) was presented in the reference [1]. Pascoe and Anbuky presented a paper at INTELEC 1999 [3] in which the *coup de fouet* was proposed as a useful parameter to determine the SOC of a lead acid battery.

In the paper presented at INTELEC 2000 by one of the authors [1], showed that the magnitude of the voltage dip in the *coup de fouet* region correlates well with the degree of capacity loss due to battery ageing (SOH). Based on this correlation, a new two-minute discharge test for determining the battery SOH was proposed and the verification was made by testing various VRLA batteries from the field as well as laboratory [1]. The method involves measuring the trough voltage (low voltage point) in the *coup de fouet* region at any given discharge rate and battery temperature. Using the predetermined trough voltage vs. battery SOH relationship (a plot of trough voltage vs. SOH) one can easily determine the SOH.

*Coup de fouet* method has several advantages over the conventional battery monitoring techniques as discussed in reference [1]. Although this method is quick, simple and an accurate technique for assessing the SOC or SOH of a battery, it is difficult to implement it in the field for regular battery monitoring. This is due to the fact that a fixed constant load is required for the partial battery discharges and also batteries should be off-line.

In the simplified *coup de fouet* approach, plant load was used for battery discharges by switching off the rectifier. Running partial discharge tests usually for 2 to 5 minutes duration, using the plant load has certain advantages. It is easy to perform these tests on regular basis. No external load is necessary and the battery back up will be uninterrupted.

**Procedure:**
The partial discharge tests were performed on each power plant contained in a controlled environment facility. All the rectifiers were shut down and the batteries were called on to support the load. Voltage measurements were taken on the D.C. bus at short intervals. Typically, these measurements include float voltage, *coup de fouet* trough voltage, the highest voltage after the *coup de fouet* recovery and the plant load. All the discharges were performed under controlled temperature, which is maintained at $25^0C \pm 2\ ^0C$. More details on the data collection can be found in reference [1]. Data was collected on various VRLA and flooded batteries in Verizon central office locations. Batteries that were used in these tests were both of VRLA and flooded type. Flooded batteries consist of lead-calcium (LC)

and lead-antimony (LA). The following scheme explains a typical partial discharge/ charge cycle.

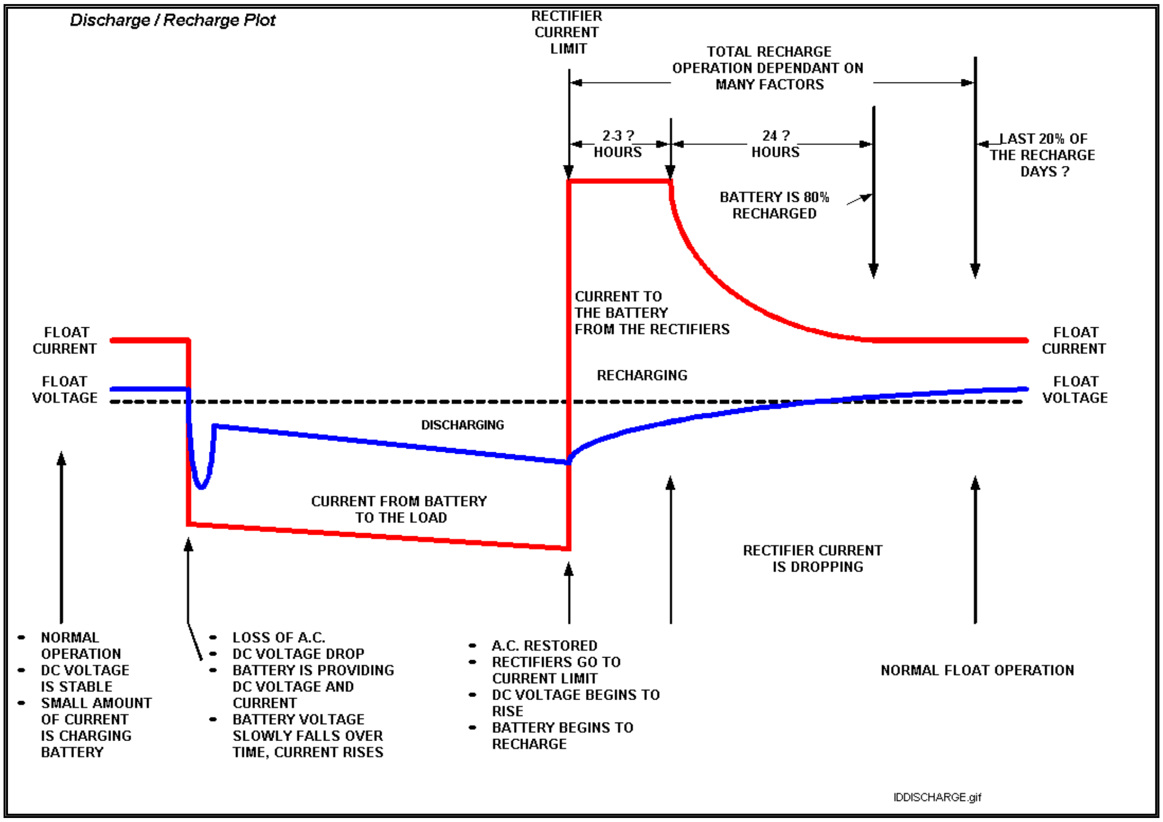


**Figure 1: A typical discharge/ charge cycle showing the plant voltage and current variations with time.**

| STR | TYPE | MANU. DATE | TEST DATE | AGE MON | AH RATE | LOAD | FLOAT | LOW V. |
|---|---|---|---|---|---|---|---|---|
| 1 | LA | Jun-84 | Nov-98 | 41 | 1176 | 60 | 52.2 | 46.7 |
| 1 | LA | Aug-96 | Feb-00 | 42 | 2415 | 550 | 52.07 | 46.23 |
| 1 | LA | Apr-95 | Dec-99 | 44 | 1680 | 28 | 52.08 | 47.4 |
| 3 | LA | Feb-95 | Oct-99 | 44 | 5550 | 809 | 52.08 | 46 |
| 1 | LA | Feb-96 | Mar-00 | 49 | 3030 | 735 | 52.85 | 46.12 |
| 1 | LA | Apr-91 | May-98 | 85 | 710 | 26 | 52 | 47.4 |
| 1 | LA | Oct-90 | Nov-97 | 85 | 1345 | 65.5 | 52.1 | 47.3 |
| 1 | LA | Mar-91 | May-98 | 86 | 860 | 26 | 52 | 47.4 |
| 1 | LA | Mar-93 | May-00 | 86 | 860 | 60 | 52.3 | 47 |
| 1 | LA | Mar-91 | May-98 | 86 | 1190 | 23 | 52 | 47.6 |
| 1 | LA | Sep-92 | Dec-99 | 87 | 2880 | 132 | 52.1 | 47.1 |
| 1 | LA | Jan-85 | Mar-99 | 170 | 1680 | 86 | 52.1 | 46.9 |
| 1 | LA | Mar-86 | May-00 | 170 | 1680 | 95 | 52.1 | 46.9 |
| 1 | LA | Oct-84 | Dec-98 | 170 | 1680 | 105 | 52 | 47 |
| 1 | LA | Aug-85 | Oct-99 | 170 | 3700 | 309 | 52.09 | 46.34 |
| 1 | LA | Jun-84 | Nov-98 | 173 | 1176 | 60 | 52.2 | 46.7 |
| 1 | LA | Jun-86 | Oct-99 | 173 | 1680 | 40 | 52 | 47.6 |
| 2 | LA | Sep-84 | Feb-99 | 173 | 1950 | 328 | 52.12 | 46.7 |

**Table 1: Data collected during the discharge test. STR#: number of strings, Batt. Type: Type of battery, Date Manu: Manufacturing date, Date Test: Date tested, Age: battery age in months, Ah rate: battery Ah rating, Load: Discharge load in A, Float: Float voltage before the start of the test in V, Low V: Trough voltage in the *coup de fouet* region in V.**

| Age Mon | Size Ah | Discharg Rate, A | Float V | Trough Vol, V | Dis. C rate | Coup d f Vol. dip, V |
|---|---|---|---|---|---|---|
| 41 | 1176 | 60 | 52.2 | 46.7 | 0.0510204 | 5.5 |
| 42 | 2415 | 550 | 52.07 | 46.23 | 0.2277433 | 5.84 |
| 44 | 1680 | 28 | 52.08 | 47.4 | 0.0166667 | 4.68 |
| 44 | 5550 | 809 | 52.08 | 46 | 0.1457658 | 6.08 |
| 49 | 3030 | 735 | 52.85 | 46.12 | 0.2425743 | 6.73 |
| 85 | 710 | 26 | 52 | 47.4 | 0.0366197 | 4.6 |
| 85 | 1345 | 65.5 | 52.1 | 47.3 | 0.0486989 | 4.8 |
| 86 | 860 | 26 | 52 | 47.4 | 0.0302326 | 4.6 |
| 86 | 860 | 60 | 52.3 | 47 | 0.0697674 | 5.3 |
| 86 | 1190 | 23 | 52 | 47.6 | 0.0193277 | 4.4 |
| 87 | 2880 | 132 | 52.1 | 47.1 | 0.0458333 | 5 |
| 170 | 1680 | 86 | 52.1 | 46.9 | 0.0511905 | 5.2 |
| 170 | 1680 | 95 | 52.1 | 46.9 | 0.0565476 | 5.2 |
| 170 | 1680 | 105 | 52 | 47 | 0.0625 | 5 |
| 170 | 3700 | 309 | 52.09 | 46.34 | 0.0835135 | 5.75 |
| 173 | 1176 | 60 | 52.2 | 46.7 | 0.0510204 | 5.5 |
| 173 | 1680 | 40 | 52 | 47.6 | 0.0238095 | 4.4 |
| 173 | 1950 | 328 | 52.12 | 46.7 | 0.1682051 | 6.5 |

**Table 2: Summarizes the calculated data (last two columns) using the same data from Table 1.**

**Results and discussion:**
Typical data collected during the discharges are shown in table 1.

The main difference between the data collection done in earlier references [1 and 2] and in the present study is the load that was used for battery discharges. In references [1 and 2] the load used for battery discharge was fixed either at C/8 or C/3. In the present tests, the load was not constant as the plant load was used for testing purpose. The tests were performed with the existing plant load at the time of testing. This poses a real challenge for meaningful analysis and interpretation of the data, as it is known that the *coup de fouet* is largely influenced by the load (discharge rate) [3]. As the normalized load increases, the trough voltage

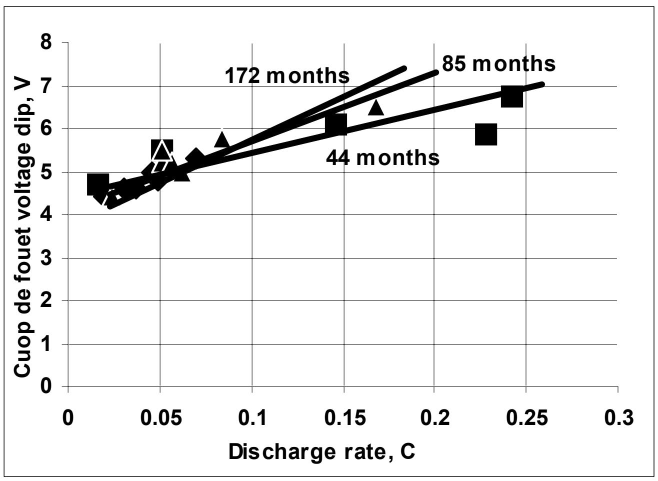


**Figure 2:** ***Coup de fouet*** **voltage dip as a function of normalized discharge rate for 48V flooded LA batteries is shown. Batteries are of 44, 85 and 172 months of age.**

decreases or the magnitude of the dip in the voltage (ΔV) increases. The dependency of the ΔV on the load, in terms of discharge rate is shown in the figure 2. ΔV is calculated by subtracting the trough voltage from the float voltage and the discharge rate in terms of C (normalized load) is calculated by dividing the load with the Ah capacity. The calculated discharge rate and the ΔV are shown in the last two columns of the table 2.

In figure 2, the dependency of the ΔV on the normalized load is shown for flooded LA batteries with the same age. As can be seen from the plots, ΔV increases linearly as the normalized load increases. For simplicity, only three sets of data for the batteries with 44, 85 and 172 months of age are shown. It also can be seen that the slope of the plots increases as the battery age increases. This behavior is in agreement with results

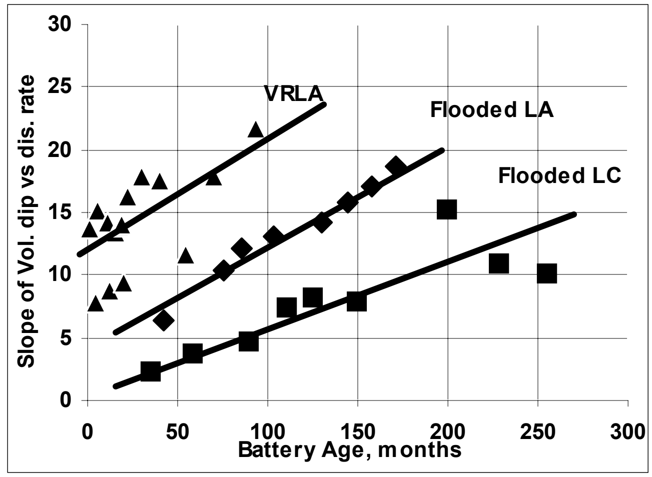


**Figure 3: Slopes of** ***Coup de fouet*** **voltage dip vs. discharge rate obtained from figure 2 (for flooded LA batteries) are plotted as a function of battery age. Data for VRLA and flooded LC batteries is calculated and shown here.**

presented in reference [1]. Slopes of the plots were calculated using least square curve fit method. The slopes thus calculated for different age batteries are plotted in figure 3 as a function of battery age for three types of batteries. As can be seen from the Figure 2, the slopes of *coup de fouet* voltage dip vs. discharge rate are increasing linearly with age of the battery. The reason for the differences in the values for different batteries might be due to the differences in the designs.

The *coup de fouet* voltage dip values at C/8 discharge rate for VRLA batteries are calculated form the

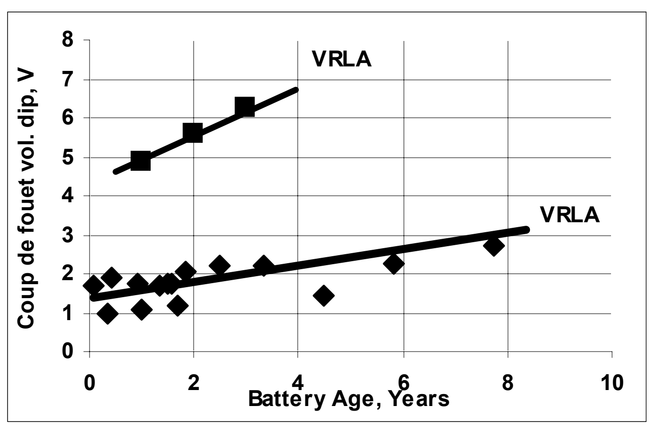


**Figure 4:** ***Coup de fouet*** **voltage dip as a function of battery age is plotted. Data is calculated for C/8 rate for VRLA batteries. Data for VRLA 12V30Ah battery is converted for 48V string.**

corresponding values from figure 2 and plotted in figure 4 as a function of battery age. For comparison purpose, the values of similar battery reported in the reference [1] are plotted. This battery is 12V and 30Ah of capacity. It can be seen that the values of *coup de fouet* voltage dip for 12V30Ah battery are higher than the VRLA batteries whose Ah capacities range from 200 to 10,000. Although the behavior of the plots is similar in nature, the slopes are different.

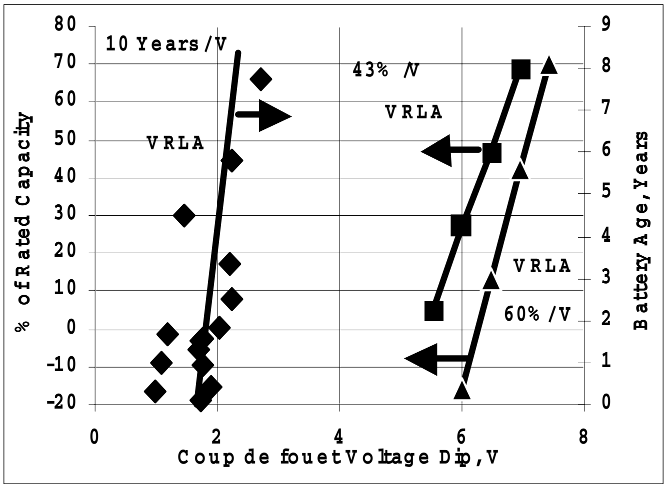


**Figure 5: The drop in rated capacity% as a function of *Coup de fouet* voltage dip is shown for VRLA 12V125Ah and 2V375Ah batteries (two right most). Battery age as a function of *Coup de fouet* voltage dip for VRLA battery is plotted (left). The numbers correspond to the slopes of the lines.**

In figure 5, VRLA battery age as a function of *coup de fouet* voltage dip calculated @ C/8 discharge rate is plotted. For comparison purpose, the data for 125 and 375Ah batteries from reference [1] is converted to 48V string and also plotted. Although the behavior of the plots is similar in nature, the values are different as seen in figure 4. The slopes of the plots indicate that for every volt of *coup de fouet* voltage dip correspond to ten years of aging for VRLA battery and about 50% of rated capacity loss for the 125 and 375 Ah batteries.

**Summary and conclusions:**

Simplified *coup de fouet* method was used to analyze the data collected in Verizon central office locations. Normalization of the loads with respect to the battery Ah capacity was necessary since the discharge loads were not constant for routine partial discharge tests. The linear dependency of the *coup de fouet* voltage dip (ΔV) on the normalized load is in agreement with the results reported in the reference [3]. The slope of (ΔV) vs. the normalized load linearly increases with the battery age as expected from the data presented in the reference [1]. Accurate estimation of battery capacity using the *coup de fouet* data is not possible at this stage as the correlation between the *coup de fouet* data and the actual battery capacity information is not available at this time. Nevertheless, an attempt was made to estimate the battery capacity by comparing the data from the reference [1] as shown in the figure 5. This comparison indicates that after 10 years of usage, the battery looses its 50% of Ah capacity. In order to verify this estimation, full discharge capacity is needed. These results will be reported in the future.


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**References:**


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