The Lectric XP Energy Bar, Voltage Display, versus Reality, Version 1.0

By R. G. Sparber

It only takes one ride on a Lectric XP up a steep hill to realize that the Energy Bar should be taken with a grain of salt. Looking at the voltage display is no better, although it does offer more precision. What is going on here?

Precision Versus Accuracy

In the digital world, precision refers to the number of digits displayed. The voltage display has three digits, with the smallest increment being 0.1 volts. The Energy Bar has ten blocks, so it is identical to showing a single digit.

Accuracy refers to how close a value is to the true value.

It is possible to have high precision while also having low accuracy. For example, your calculator might display a ten-digit number (high precision) yet only be valid in the first digit (low accuracy).

You Can't Always Get What You Want…

The Rolling Stones got it right. What you want is a display showing your distance until the battery is empty. Speed, terrain, wind, total weight, the temperature of the battery, tire pressure, and battery age have a major effect on how far you can go on your battery.

The best you can get is an estimate of the remaining energy in the battery. Even this is not so easy to do well. However, it is easy to get an approximate reading.

Voltage

Measuring the voltage at the battery is easy and can be done with high precision. I found this table at Battery voltages. | Electric Bike Forums - Q&A, Help, Reviews and Maintenance (electricbikereview.com). You will see in the discussion that even this table is brought into question.

BATTERY	48V 13S
%	Volts
100.0	54.6
95.0	53.8
90.0	53.0
85.0	52.3
80.0	51.5
75.0	50.7
70.0	49.9
65.0	49.1
60.0	48.4
[redacted]	[redacted]
50.0	46.8
[redacted]	[redacted]
40.0	45.2
35.0	44.5
30.0	43.7
25.0	42.9
20.0	42.1
15.0	41.3
10.0	40.6
5.0	39.8
0.0	39.0

With a high degree of precision, the author equates the battery's State Of Charge to the voltage. No mention is made of how they know the percentages, but I have a good guess which will be presented later.

Graphs can be found on the web showing the State of Charge versus voltage. They vary significantly over temperature and the number of charge cycles performed. Furthermore, these tables only show the nominal[2] values and not how much they change due to manufacturing.

If these were the only problems, we could improve the accuracy by cutting this table into separate columns. At full charge, slide the 100.0% entry up or down until it matches the measured voltage.

Unfortunately, this would not help while riding. There is another factor that has a far more significant effect: current.

[2] "Nominal" means the name. For example, we talk about 120VAC powering our appliances in our homes but the actual voltage can be 100VAC to 140VAC. The local power company explained that they sell power, not voltage.

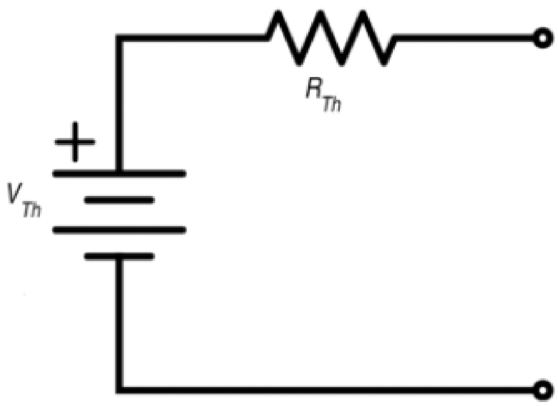
Current

It is hard to ignore that the voltage drops as you ride up a hill and then rises again as you go down the other side. No, this is not the bike recharging the battery.

The Non-technical Explanation

I have a soft sponge. As I put weight on the sponge, it compresses. Remove the weight, and the sponge returns to its original thickness. This original thickness represents the battery voltage when you are not riding. The weight represents energy being drawn from the battery. The more energy I draw (more weight pushing down), the lower the voltage (thinner sponge). Stop drawing energy (remove the weight), and the voltage will rise back up (sponge springs back up).

The Technical Explanation



A battery can be modeled by an ideal voltage source, $V_{Th,}$ and an ideal resistor, R_{Th}. When no current flows, the voltage measured at the terminals will equal V_{Th} because there is no voltage drop across R_{Th}. As the current increases, more voltage is dropped across $R_{Th,}$ so the measured voltage drops. All of this happens while V_{Th} remains unchanged.

The measured voltage is, therefore, a function of both V_{Th} and the current.

Real World

While riding, throw a glance at the voltage display. You will see how much the voltage changes as a function of terrain. This is particularly dramatic going up a steep hill and drawing 20 amperes. Compare that voltage reading to going down that same hill and drawing nothing.

If you want to use voltage as an approximate indicator of the battery's State Of Charge, you should stop the bike and wait for the voltage to stabilize. This can take 30 seconds to 2 minutes.

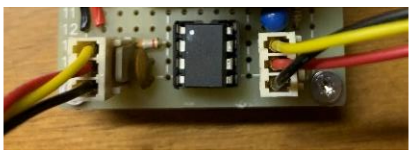
Ampere-Hours

If you look at the specifications on your battery, you will see a nominal voltage and a quantity of ampere-hours (Ah). Mine says 48 volts and 10.4 Ah.

Ampere-hours is a common way to measure the battery's State Of Charge. When fully charge, my battery ideally holds 10.4 ampere-hours. Looking at the units, we see that this is current multiplied by time. This means that my battery can ideally supply any current multiplied by any time that equals 10.4. For example, I can draw 1 ampere for 10.4 hours (1 x 10.4 = 10.4); 10.4 amperes for 1 hour (10.4 x 1 = 10.4); or 2 amperes for 5.2 hours (2 x 5.2 = 10.4).

Notice that since we are only looking at reducing the initial ampere-hours by the current over time, variations in battery voltage have no effect on our accounting.

If you ride on level ground with no wind, the current will remain constant. Add changes in elevation and wind, and the current will vary widely. You will crash your bike trying to perform the ampere-hour calculation in your head.



My solution is to add a small computer that measures the current once per second and subtracts it from the initial ampere-hour value.

The result is displayed on two red LEDs mounted on my handlebars. This scheme tells me the State Of Charge with a precision of ±5%. While far from perfect, it is an improvement over measuring voltage.

I welcome your comments and questions.

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