Some comments on “Peukert’s” compensation—why we don’t use it, and (incidentally) why we don’t use temperature to compensate the “amp hours” or “% full” displays

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Some have asked if the TriMetric or PentaMetric uses Peukert’s compensation to determine the “percent full” display. It does not. The reason is that that doing so can give misleading reading for “battery % full” reading. The same type of discussion applies to using temperature compensation to compute % full. Here is why.

Peukert’s equation explained:

First, I should explain what “Peukert’s equation” is. Any lead acid battery, or for that matter any other battery, has a value of what is called “capacity”, which describes how much total charge (which approximately represents “energy”) that it can store when fully charged. Capacity is always expressed as “amp hours”. The number of amps describes the rate at which the flow of electrons go in or out of the battery. The capacity is a measure of the total number of electrons that you can get out of the battery when starting from a fully charged battery until all the energy is discharged. (To be more precise, the total energy in the battery is the product of amps times volts times time of discharge—but the value of volts doesn’t vary too much during discharge.)

Here’s how the “capacity” of a “12V” lead acid battery is measured: The battery is first charged until it is completely full, at a temperature of 25 degrees C. (77° F) Then a voltmeter is put on the battery to measure the volts of the battery, which for a (six cell) lead acid battery starts at about 12.6 volts. Then a load is connected to discharge the battery that has a certain number of <u>fixed</u> amps—and at the same time the voltage is observed, and a stopwatch is started to see how long it will keep going. During discharge the voltage gradually drops as the battery loses energy. When it gets down to 10.5 volts the time T (in hours) that it has taken is multiplied by the amps value, A of the load. The product =T x A is the “capacity” in “amp-hours”.

However it turns out that the exact capacity depends on the size of the load: a larger load (number of amps) will result in a lower capacity. Of course it is obvious that a larger load will discharge a battery faster—but even the product of amps times hours will be less. For example, if a load of 10 amps requires 20 hours to discharge down to 10.5 volts, you might think that a load of twice that amount, at 20 amps, would run for half the time, or 10 hours, since that would require the same number of electrons coming out of the battery. That’s almost correct, but it turns out that it will go for a little less than 10 hours. That is why, when “Capacity” of a battery is specified, it is usually specified for a specific discharge rate, in amps. For example, it might have 100 amp hours at a 20 hour rate, (meaning an “amps” discharge rate of 100÷20, or 5 amps) but 80 amp-hour at a 5 hour rate (16 amps). This effect becomes less important, however at the lower discharge rates typical of off grid power systems.

Peukert’s relation describes how the capacity is related to the total time to discharge the battery to 10.5 volts.

The relationship is often written thus:

$$I^{\acute{\eta}}\, t = C$$

C= Capacity of battery (Amp hour) for a constant load of I amperes.
$\acute{\eta}$= Peukert’s constant-
t = total time required to discharge battery.

Simply put, the reason you get less amp hours out when the amps are higher is that the higher amps drag down the volts more than a lower amp load, so the 10.5 volts endpoint is reached sooner. It is not because some of the electrons in the battery get lost or wasted when you draw current out faster. So if just before getting down to 10.5 volts you were to reduce the load, the volts would recover somewhat to a higher value, and you would get somewhat more current out before you reached 10.5 volts. (Reference: Handbook of Batteries, Linden and Reddy, McGraw-Hill, Third addition, Figure 3.3).

In the past there has been a misunderstanding of Peukert’s relation. In the 1980’s someone in the battery monitoring business claimed publicly and rather vehemently that if you removed current (amps) out of a battery faster that somehow that wasted some of the battery electrons, so they wouldn’t be available anymore until the battery was recharged. He said that an "amp hours" measurement could not be made by simply multiplying amps times time to get a measurement of charge taken out of a battery, and he claimed that to do it correctly you would need to do a Peukert's compensation to increase the amps beyond the actual amount, and multiply that by time. So if you discharged a battery down to its endpoint voltage at a high rate of discharge, then reduced the rate of discharge, according to his description you still would have an empty battery, with no ability to deliver further energy at a lower rate.

This is not true. The next paragraph is a little complicated, but it tries to explain this.

Suppose you have a battery that is supposed to be discharged after 5 hours if you discharge it at a 20 amp rate. So you start to discharge it at that rate, but after 4.9 hours you reduce the load to only 1 amp. If you had let the load go on longer at 20 amps you would have gotten only 0.1 hours times 20 amps, or 2 amp hours more from the battery. The person who was confused about the meaning of Peukert's relation would have expected that even though the load was now only a 1 amp load that it still would have only 2 amp hours to go, or only 2 hours. But because the load was reduced the voltage would bounce up—and you would be able to quite a bit more than 2 amp hours before the voltage would drop below the "discharged" point. The electrons didn't go missing, it was just the voltage that was dragged down by the higher load—which can be mostly reversed by reducing the load. Technically, this effect is caused by the internal resistance of the batteries, and also by what is called "polarization" of the electrolyte in the battery, which causes the voltage to be dragged down when the load current is higher.

Here's another example: If someone did use Peukert's relation to figure amp hours, or "% battery full" on their meter this is what could happen: Suppose you decided to use your microwave. First, while the microwave is off it could show that you have, say, 20% power left in your batteries. So you say "oh, I have enough power left to run my microwave". But then when you turn on the microwave, because of Peukert's compensation the percentage will suddenly jump down and tell you have only 2% left-- not enough to run your microwave. But you found out too late! Including the Peukert's compensation gave a value that was misleadingly high before you turned on the microwave. What you should have done is set the <u>original assumed</u> "amp hour capacity" in the TriMetric using Peukert's relation, such that it <u>assumed</u> such that the worst case situation with the microwave is already accommodated, so that before you turn your microwave on it says 2% of your energy is left. (At least you wouldn't be surprised by a big jump down when you turn it on.) Then if you don't need to run the microwave, but only some low load lights, you'll actually have more left than 2 %. But I haven't figured out how to make a meter smart enough to know that it could predict *in the future you intend* to turn on a large load such as your microwave, and base the % full on that knowledge. If I did, then it would be reasonable to compensate the "percent full" using Peukert's compensation according to your intended future use.

I would respond similarly to others who have asked whether the battery "% full" reading should take into account the temperature, since it is well known that batteries have less energy at lower temperature. The problem with that is that if the temperature is varying, what will the temperature be at the time you are really low on power? If you live in a place where the battery temperature goes from pretty hot to cold you should put a value of capacity that represents the capacity at the coldest temperature that you expect while using the batteries. Otherwise your meter could tell you that plenty of energy is left at the end of the day, but by the time a cold night happens you find out (too late) when you need the energy in the night that the meter before was too optimistic. Again, to overcome this problem the meter would have to anticipate what your coldest temperature was going to be—difficult to put into a battery monitor, but not so difficult for a human to anticipate. Therefore you should put the value of capacity (amp-hours) in the TriMetric that takes into account the coldest temperature that you expect.

I have heard (but haven't personally verified) that the "E meter" (originally made by Cruising Equipment Co, and then Trace Engineering) did use Peukert's compensation, but only did it for the "time remaining" function which their meter had. The "time remaining" of course is based on the assumption that the present loads are not going to change in the future. Hopefully the users of this function would be smart enough to realize this; and in this case it could be sensible to use Peukert's compensation to compute the time remaining. But I always thought this "time remaining" display was of rather marginal use, because the assumption of a constant load is a somewhat unrealistic assumption in most cases when they are used for powering appliances and lights in a home.

Finally, the other issue about using Perkert's relation, although theoretically interesting, is that it's rather difficult to get an equation that reliably reproduces the performance of an actual battery. And unless it is used in applications where the loads vary a lot, it probably wouldn't give very useful or accurate results—again keeping in mind that it should be used only in a situation where "time remaining" (implied at a fixed present load) were displayed—which the TriMetric or PentaMetric does not have.