Interesting Battery Info

Hi all,

There has been a few threads lately on battery/inverter setups, so I decided to just start a new thread for this, as it should answer most questions. Please note that these calculations are not accurate to the last watt, but will get you close enough (either for a runtime estimate, or indication of how much battery energy you need). Because most people will put some kind of varying load on their inverters (with the resulting varying power factor, and varying inverter efficiency), the only way to accurately classify your load characteristics, is to graph it in real-time, or run it through an energy measurement device (working on one at the moment).

Before we get to the calculations, it is important to understand how a battery works, and is destroyed. If you understand it, the calculations, and what values to use, will be common sense.

Math skills required:

- Add, subtract, divide, multiply
- Helps if you can transpose formulas

Some terms you need to know:

- **DOD** = Depth-of-Discharge. The percentage of usable energy discharged (consumed) from a battery.
- **SOC** = State-of-Charge. The percentage of usable energy remaining in a battery.
- **Power** = General term to signify the work being performed, or energy being consumed, and measured in W (watts). Power (P) = voltage (V) x current (I).
- **Real power** = Power, measured in W (watts), taking into account the phase angle between the voltage and current in reactive loads (capacitive or inductive). On a reactive load (anything that is not purely resistive), real power will ALWAYS be less than apparent power. Real power is the actual energy being consumed, per unit of time. The power rating printed on your devices are real power ratings.
- **Apparent power** = Power, measured in VA (volt-amps), WITHOUT taking into account the phase angle between voltage and current in reactive loads. With purely resistive loads, real power is the same as apparent power. On reactive loads, apparent power is ALWAYS more than real power. Apparent power is the power you pay for in ZA. For practical purposes, you can generally assume VA = W in the DC circuit of your inverter setup (technically not true, but there are so many other varying factors involved, that the error would be marginal).
- **Battery Ah (amp-hour) rating** = This is the MAXIMUM current (in amps) x TOTAL runtime (in hours) of energy that a battery can deliver. There is however a catch: this rating is calculated over a 20 hour discharge time, so that for example, a 105Ah battery, should not be loaded more than 5.25A (105Ah / 20 hours = 5.25A) if you want the full 105Ah of energy. This curve derates very quickly as you increase the load current over the 20 hour discharge rating. For most batteries, you lose around 40% of total energy at a full 1C discharge (in our example battery, it means that you only get around 60Ah of energy that you can use, if you discharge it with a 105A load). Check the battery datasheet for the details of your battery. If you keep your load current below the 20 hour discharge rate, you can ignore the derating completely.

What destroys a battery, or shortens it life (whether a car battery, or adeep-cycle battery):

- The greater your DOD, the shorter your battery life.
- The more times you cycle the battery, the shorter your battery life.
- The greater the discharge current, the shorter your battery life.
- The moment you remove your charger from the battery, sulphation starts, and shortens your battery life.
- The moment you put a load on your battery, sulphation starts and shorten your battery life.
- If you let your battery run flat, the battery is damaged.
- If you leave your battery in a discharged state for more than an hour, the battery is damaged.
- Battery cells exposed to air (not enough electrolyte) damages your battery.
- ...and the list goes on...

What is important to remember is: ANY action, other than leaving a lead-acid battery on float charge (with no load), is a link in the chain that destroys the battery. Looks grim, doesn't it?

So what can we do to maximize the battery life we do have?

First, let's look at how a battery functions. A lead-acid battery is comprised of lead plates (Pb), lead-dioxide plates (PbO_2), and sulphuric acid (H_2SO_4). Unless you expose it to very high temperatures, or very low pressures (way more than a human can withstand), sulphuric acid is a very stable solution, and will not evaporate. Now, as you start discharging the battery, the chemical reaction will form lead-sulphate ($PbSO_4$) on the anode and cathode plates, as well as water (H_2O). As you recharge the battery, the lead-sulphate will decompose again, and with the water, turn back into sulphuric acid. So in a partial (or fully) discharged state, a lead-acid battery has pure water in it. What do we know about water that is not in an airtight container? It evaporates, so right there we lose some of our chemicals that make up the sulphuric acid. Next is the lead-sulphate: if left in that form, it will start to crystallize (this process starts in less than an hour). Clearly, we want to keep the discharged state as short as possible to begin with.

OK, so how far do we discharge? For deep-cycle batteries, no more than 50% max. Preferably no more than 20-30%. Even on deep-cycle batteries, the lifespan drops significantly after 20% DOD. Here is an example from an American manufactured battery datasheet:

From 20% DOD, to 50% DOD halves your battery life!

Car lead-acid batteries?
Don't even think about anything more than 5%, as your battery will not see 6 months of life. Lead-calcium and silver-calcium batteries are "supposedly" more rugged, but after having used them exclusively in my cars since 1995, I can tell you, compared to flooded lead-acid, there is only ONE difference. Although damaged in the process, they will survive one, maybe 2 full discharges (flat down to zero volt), and you will still be able to recharge them. Don't however, expect them to retain even close to their original capacity after that. They will die completely within a few months. Picking standard car lead-acid batteries for a standby application, will cost you a lot of money in the long run. In our current load-shedding scenario, you'll be lucky to get 6 months from them. Stick to proper deep-cycle lead-acid.

Lithium based batteries?
They have similar problems like the anodes or cathodes being plated while fully charged (how many of you can show a cellphone older than 2 years, with the original battery still having usable life?). They are not the saviour they're being made out to be, and they are VERY dangerous (ask your insurer for a revised quote on your house insurance with you having a 1kW+ Lithium battery anywhere on your property...).

Charging a battery, is a fairly well-known process, so just follow the manufacturers recommendations. This generally starts with a bulk charge at a specified constant current, followed by a top-up charge at constant voltage (generally around 14.4V for a 12V battery), followed by a float charge. A float charge should be under 13.8V (the gassing voltage for a lead-acid based battery). The closer you go to 13.8V, obviously the more energy you store in the battery, however, as batteries age, the cells in the battery start charging and discharging at different rates, leading to some cells going over their gassing voltage, while other cells are still charging while you float the battery. To mitigate this a bit, float your battery between 13.2 and 13.5V (recommended by most manufacturers), to make sure you don't have cells that gas. These not fully charged cells, are also now undergoing sulphate crystallization because they are not fully charged. To mitigate against this, you use an equalization charge. Again, this is a double edged sword, as you are raising the charge voltage considerably (0.05V in battery state is significant), meaning a lot of gassing while you equalize. In general, it does more good than bad, so an equalization charge once a month is a good thing. Consult the battery datasheet, but equalization charge is generally 15 to 16V. When selecting a bi-directional inverter or stand-alone charger for your setup, look for one that allows you to float and equalize, AS WELL as allowing you to SET those voltages, because they are not exactly the same between battery types.

OK...now that we know a bit more about how a battery works, and what can destroy it, on to the calculations.

For the first one I'm going to use Ian as an example, with a 72Ah battery. This is a "I have this battery...how long can I run it without damage". I've added the damage part, because as radio amateurs, we prefer to get the longest life out of our gear. Of course, you can put whatever load you want on your batteries, what I'm doing is showing you how MUCH load you SHOULD put on your batteries, to make them last as long as possible (lifespan and running time during load-shedding). With this example, we start with a know capacity battery, and try to figure out how much load we can drive, and for how long. Even though I recommend 20-30% DOD, I'll do this example as a 50% DOD worst case.

First, we calculate how **much usable energy we have in the battery**:

72Ah / 20 hours = 3.6A (that is the max current we can draw out of the battery to get the full 72Ah)

if we times this by 12V, to get power, in theory we can supply 43.2W (actually VA, as we're ignoring reactive loads for now) of energy for 20 hours:

3.6A x 12V = 43.2W

...however, 20 hours will get us to 100% DOD, and we only want to do 50% DOD, so we take 50% of our time, and multiply with our power to get a power-time rating:

(20 hours x 0.5) x 43.2W = 432Wh

OK, so now we know that we can supply 43.2W of energy, for 10 hours (432Wh / 10 = 43.2W), or we can supply 86.4W of energy for 5 hours (432Wh / 5 hours = 86.4W), to get to 50% DOD of our battery. However, the 43.2W rating was calculated at a current draw of 3.6A (our 20 hour discharge rating) that will give us our full 72Ah, but the current draw at 86.4W is double, so we are not going to get our full 72Ah, and henceforth total 432Wh of energy out of this battery. Because our current draw is more than the 20 hour discharge rating, we have to de-rate the total energy with a factor. This we can only get in the datasheets, but for the calculation I'll de-rate to 85% for double the current. We can either de-rate the Ah, or we can de-rate the Wh, it doesn't really matter...answer will be the same in either case. I'll de-rate the Wh...

...so for 432Wh de-rated by 15% (to 85%) we get:

432Wh * 0.85 = 367Wh (this is how much energy we can consume out of the battery, using double the 20 hour current rating, to get to a 50% DOD).

OK, so now we know how much total energy we can consume from the battery before reaching 50% DOD. The point here is, if you draw more current from the battery than the 20 hour rating, you have to de-rate the battery capacity.

Cool, let's say, we are not sure yet of whether we want the 43.2W load, or the 86.4W load, so leave that till later, and continue our calculation.

Next up in line: our **inverter**. For this example we'll use a 12V inverter, but if say you are using a 24V inverter, in the step above where we calculated the power by multiplying by 12V, you just multiply by 24V (or whatever your inverter DC voltage is) to get total power. All the other calculations stay the same. Note on series/parallel batteries:

- When calculating power with multiple batteries connected in series, you keep the amps the same as for a single battery, and use the total voltage for all batteries in series (example for 2 x 72Ah in series is 3.6A x (12V x 2) = 86.4W);

- When calculating power with multiple batteries connected in parallel, you keep the voltage the same as for a single battery, and add up all the currents (example for 2 x 72Ah in parallel is 12V x (3.6A x 2) = 86.4W);

- As can be seen from the previous 2 points, to total energy stays the same, whether series or parallel, so a quick way is to calculate for 1 battery as we did above, and just multiply by the amount of batteries you are using (all batteries must be identical)...

OK, our inverter is say a 2kVA inverter, running from a 12V 72Ah battery. Now there are 2 things that is going to affect how much of that 432W or 367W we can shove through to the 220V side of the inverter.

They are:

- Inverter efficiency;
- Power factor.

Inverter efficiency is stated in the datasheet, but that efficiency is almost guaranteed to be no-load. I've seen 1000VA inverters that can drive no more than 400W loads before overloading, because of efficiency. For a good converter you can expect 90%+ for efficiency, but if you run a no-name inverter, with no datasheet available, using 80% will get you close enough (+- 15 min variance on runtime for small systems).

Power factor...remember real and apparent power above? Power factor is the real power, divided by the apparent power (always less than 1 in practice). Think of this as the difference in power supplied, and power used....with the power supplied always being more (not an analogy that is technically 100% correct, I know). Here there is a lot of variance, from 0.4 for cheap switchmode supplies, all the way up to 0.99 for stuff with linear supplies. Unless you measure PF (power factor) for a specific device, under specific load conditions, this becomes a guess. My recommendation...ignore it and see how far you get. You will most probably swap equipment at some point during load-shedding, so it makes an initial calculation pointless. Once you've purchased your batteries, you're generally stuck with them. Just be mindful of PF, as it can make a difference to your runtime (especially if you run only one battery).

First thing: whether you decide to go for 43.2W at 10 hours, or 86.4W at 5 hours, you need to make sure that your instantaneous max power load (the 2 values mentioned earlier), before derating for efficiency, is within the inverter rating. In our example, both 43.2W and 86.4W is well within the 2kVA inverter rating. One recommendation here, don't push your inverter over 80% power utilization (the VA rating).

Our no-name inverter is 80% efficient (guessing), so we multiply our max load power by 0.8:

86.4W x 0.8 = 69.12W (having decided to go with the higher power delivery at 5 hours)

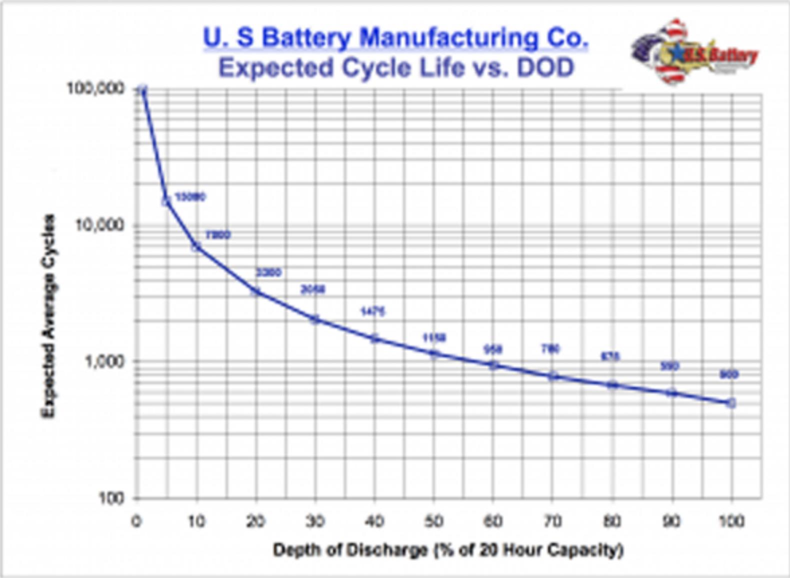
69.12W is the maximum load we can drive from the inverter.

...however, remember at the higher current, we derated the max total energy delivered above, so we are not going to get 5 hours without dropping below 50% DOD. We calculated this at 367Wh, and because this is the power actually consumed from the battery, we use the 86.4W to calculate how long we can maintain that power:

367Wh / 86.4W = 4.2 hours

So, a single 72Ah 12V battery, supplying a 69.12W load, can run for 4.2 hours from our inverter, before the battery DOD drops below 50%. Easy peasy...

The best way to do this exercise is to start at the loads that you require, and then work through the calculations in reverse to figure out how many batteries you need. If you do this and run 24V or 48V, just remember to round up at the end to the next set of batteries (2 for 24V, or 4 for 48V).



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