Battery Discharge Analysis

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I sampled the discharge rates of different batteries. My goal: Predict remaining times for battery powered mesh network nodes given rapidly varying discharge rates. I describe the batteries, experiments and preliminary results.

I experimented with 3 battery types:

1. $LiFePOo_4$ batteries rated at nominal 12 volt outputs with capacities from 4 Ah to 20 Ah.

2. Ryobi power tool lithium cells at nominal 18 volts with capacities from 2 Ah to 6 Ah.

3. Lead acid batteries, nominal 12 volts output.

Some of these were brand new, others had many charge/discharge cycles.

Battery	**Chemistry**	**Voltage**	**Capacity**	**Weight**
Ryobi P107[1]	Lithium Ion	18 V	1.5 Ah	.452 kg
Ryobi P108[1]	Lithium Ion	18 V	2.6 Ah	.664 kg
Ryobi P193	Lithium Ion	18 V	6 Ah[1]	.92 kg
DC House	$LiFePO_4$	12.8 V	6 Ah	.768 kg
Deep Cycle	$LiFePO_4$	12.8 V	8 Ah	1.098 kg
Botku	$LiFePO_4$	12.8 V	10 Ah	1.228 kg
Eco-Worth	$LiFePO_4$	12.8 V	20 Ah	2.55 kg
Genesys	Lead Acid	12 V	4 Ah	1.620 kg
Magna Power	Lead Acid	12 V	?	6.848 kg

Table 1: Sampled Batteries

Figure 1: The test batteries

The test conditions and charging were conducted at a nominal 65 degrees Fahrenheit. Ryobi batteries were charged with a standard Intelliport Ryobi charger. Others were charged by a NEXPEAK portable battery charger NC202.

1 Test Setup

Test and recording equipment consists of:

Raspberry PI Using USB to serial port for data collection.

Arduino with OLED display and an I^2C connection to INA3221 and serial port to Raspberry PI.

INA3221 devboard A 3 channel 13 bit analog to digital converter with I^2C interface returns both voltage and amperage.

Buck-Boost Converter Set to generate approximately 19 volts from 5 to 35 volts input.

Resistors 50 watt, low ohm resistors for providing a static load.

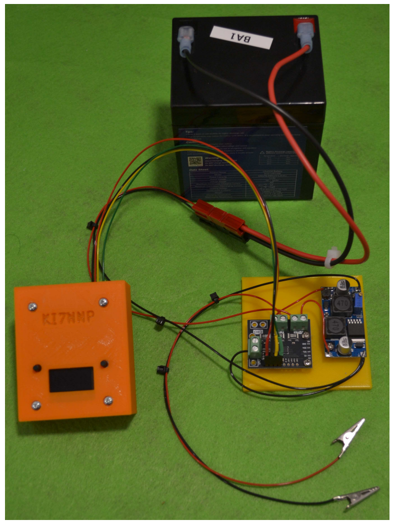

Figure 2: Arduino with OLED, INA3221 and buck-boost, battery.

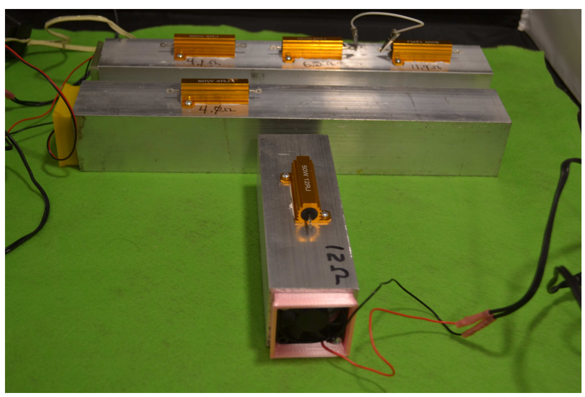

Figure 3: 50 watt, low ohmage resistors, heat sinks, fans.

2 Start Voltage vs Duration

You never may quite know the charge state of a battery. It may have sat on the shelf for some time, been used on a previous outing or may just be sulking. We attempt to use the starting battery voltage as a prediction of remaining power.

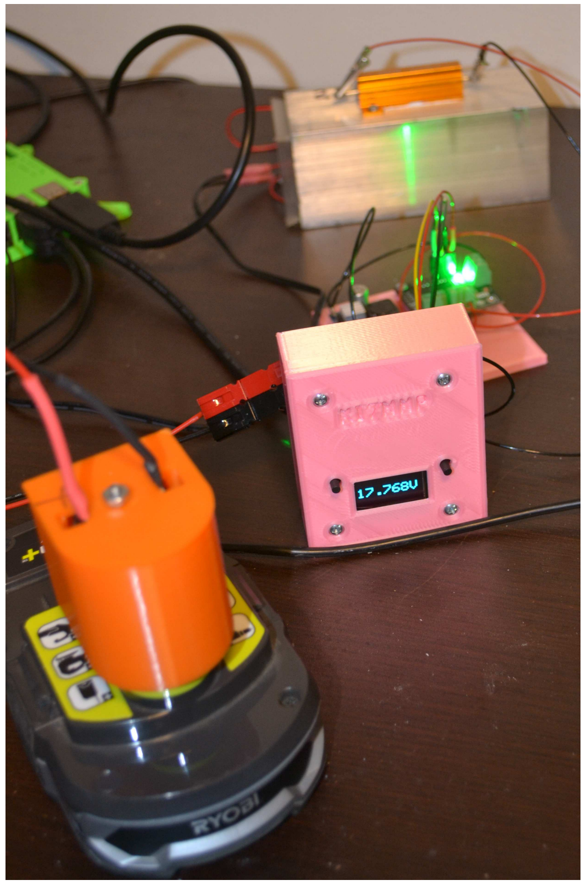

Figure 4: Data collection in progress

In this experiment, I first fully charge a battery, use it to run near 19 volts into a static 25.1 ohm load. The load is attached to a large aluminum heat sink cooled by a small fan, I then charge the battery for various minutes to simulate prior usage. I sample every two seconds and record:

- Battery voltage to the buck-boost converter.
- Amperage taken by the converter.
- “Regulated” output voltage.
- Output current.

2.1 8 Ah $LiFePO_4$

The 8 Ah DeepCycle battery converter is operating as a boost regulator. As you near full charge, the starting voltage changes less and less. For poorly charged batteries start voltage is a good duration predictor, at higher levels, it becomes less reliable.

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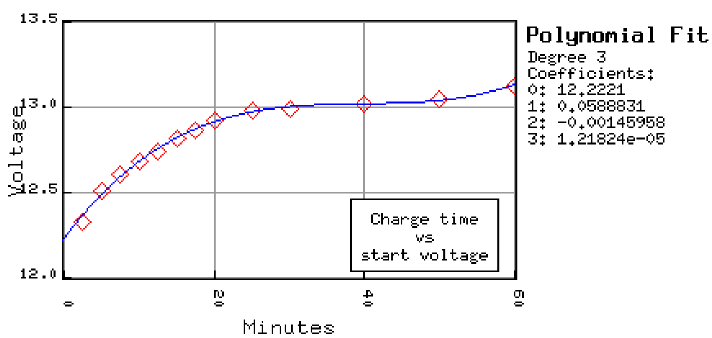

Figure 5: Charge time vs starting voltage, 8Ah $LiFePO_4$ battery

The charge time is related to the duration through the resistive load by the square of the charge time as shown in Figure 6.

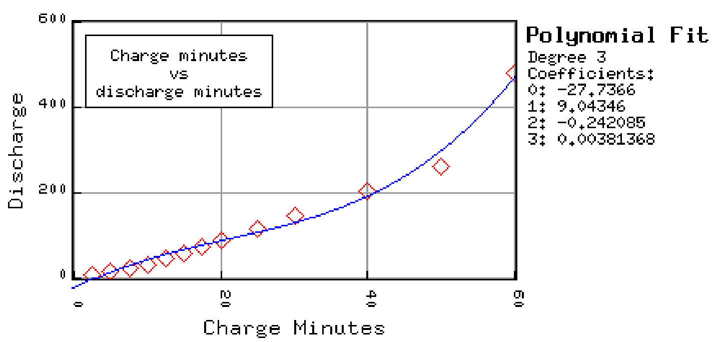

Figure 6: Charge time vs duration, 8Ah $LiFePO_4$ battery

Finally, compare time to battery voltage buck-boost input. We use this data to establish which of the three discharge phases we're in.

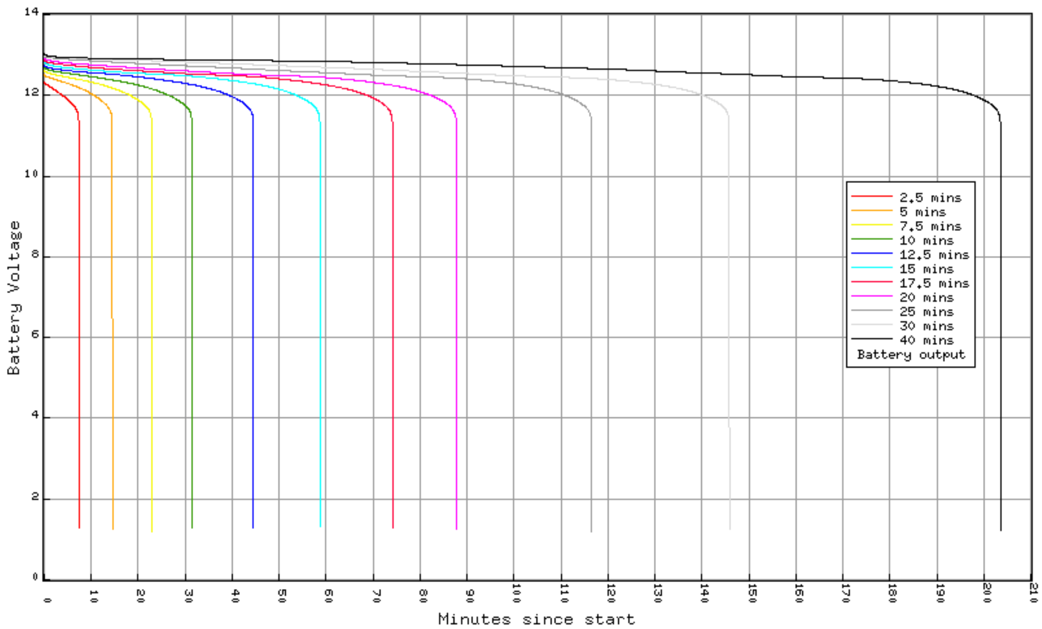

Figure 7: Time vs battery voltage, 8Ah $LiFePO_4$ battery

2.2 Ryobi 2 Ah 18 volt

The test was repeated with an 18 volt Ryobi 2 Ah tool battery. In this case, the converter is operating as a buck converter until the input voltage drops below 18 then switches over to boost. The 8 Ah Lithium was always operating in boost mode.

The starting voltage is a reasonable predictor of charge time though the third degree polynomial has a rough time near the edges.

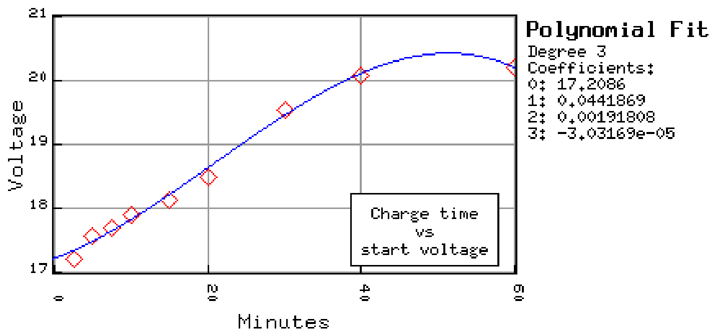

Figure 8: Charge time vs starting voltage for a Ryobi 2 Ah battery

The charge time is a good predictor of static load duration.

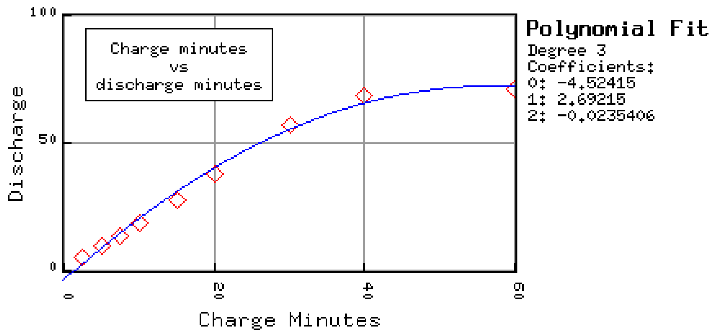

Figure 9: Charge time vs duration, Ryobi 2 Ah battery

The Ryobi battery has a sharp cutoff when 16.5 volts is reached probably due to some internal circuitry but the curve matches the 12.8v $LiFePO_4$ curve relatively closely.

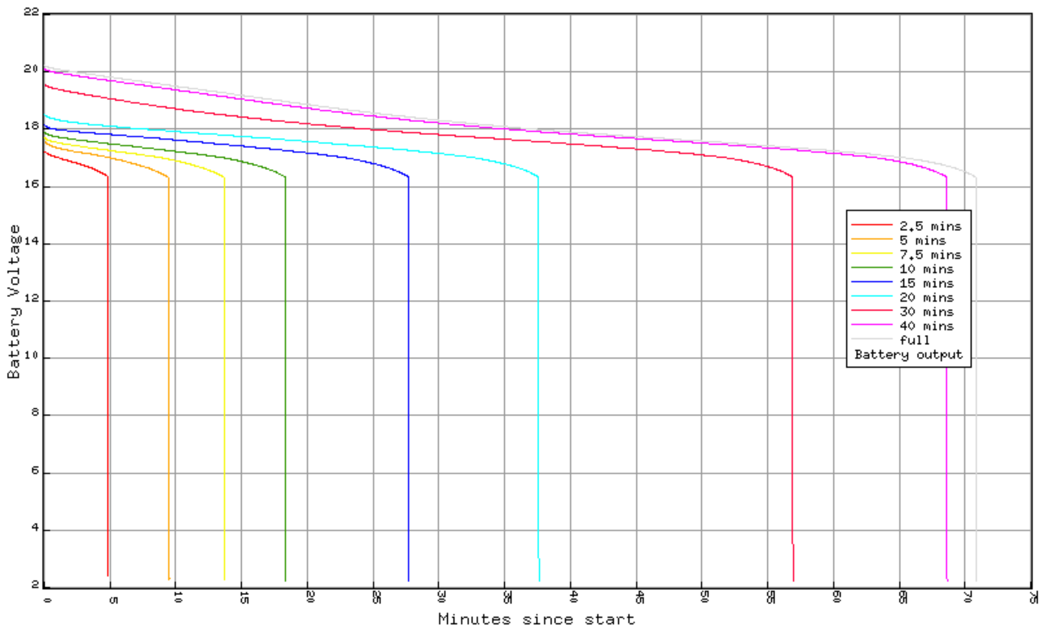

Figure 10: Time vs battery voltage, 2Ah Ryobi battery

2.3 Sealed Lead Acid 4 Ah

The sealed lead-acid cell has no internal electronics so its discharge curve has no abrupt cutoff. Rather, it keeps supplying voltage below the boost converter cutoff. Consequently, we stop data collection when the output falls below three volts. However, if the battery continues supplying minimal power before being recharged, the charge time will no longer be a reliable prediction.

It appears that charge time is not a good predictor of start voltage except at low charge levels.

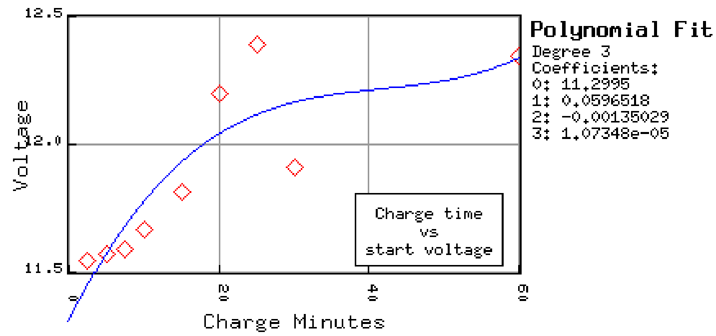

Figure 11: Charge time vs starting voltage for 4 Ah Lead-acid cell

However, it is a better predictor of duration to a static load.

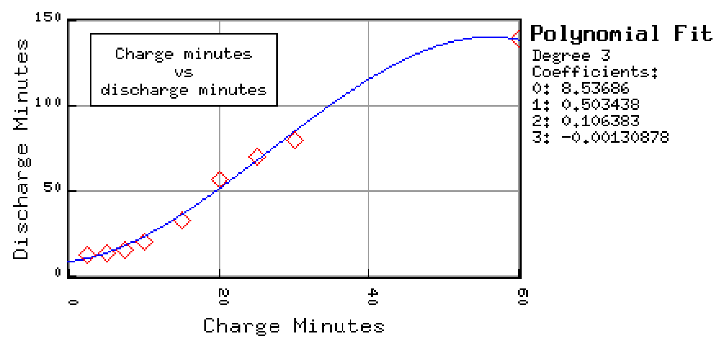

Figure 12: Charge time vs duration, 4 Ah Lead-acid cell

The voltage discharge curve is differs from the $LiFePO_4$. The initial discharge drop is not as sharp, the extended discharge slope is steeper, and as the battery has no swhutoff electronics, the descent from 10 to 3 volts is not as sharp.

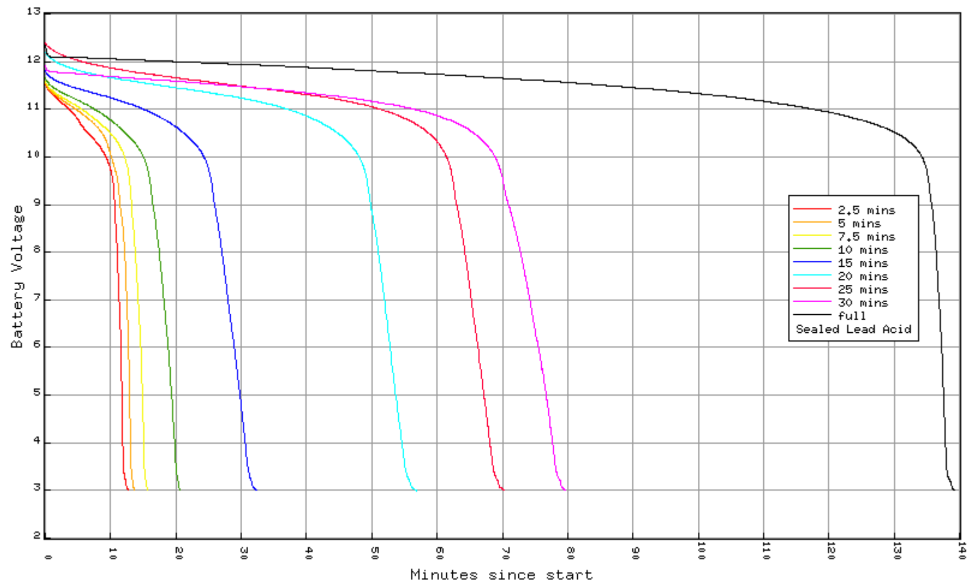

Figure 13: Battery output vs time, different charge times, 4 Ah Lead-acid cell

References

[1] Techtronic Industries GmbH. Safety Data Sheet Ryobi Lithium ion batteries. Technical report, June 2018.