Integrated Power Analysis and Battery Justification for Rover System

(Full Drivetrain Calculations + Gripper Analysis)

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September 29, 2025

Abstract

This report merges the drivetrain and battery guidance from the uploaded system report with a detailed Gripper Power Analysis (2×28BYJ-48 steppers + 2×SG90 servos). All key arithmetic is shown explicitly. The document gives per-component power, battery-side draws at the nominal 24 V bus, runtime tables for 24 V 20 Ah and 35 Ah packs across typical driving scenarios, peak current considerations, and procurement recommendations.

Contents

1 Overview

This document contains:

1. Full drivetrain power calculations (digit-by-digit) derived from the original uploaded report.

2. Ancillary electronics and gripper power analyses.
3. Integrated runtime tables for several realistic scenarios: straight driving, turning, climbing, and heavy loads.
4. Peak/stall current treatment and wiring/protection recommendations.
5. A one-page purchase justification summary.

2 Base numbers and assumptions

- System nominal bus voltage: **24** V (from original report).
- Battery candidates: **24 V**, **20 Ah** (480 Wh) and **24 V**, **35 Ah** (840 Wh).
- Drivetrain continuous baseline (from uploaded report): **384 W** combined for 4 wheel motors (used as a baseline).
- Reported typical current ranges (from uploaded report): straight driving $\approx$ 12 A to 15 A, turning $\approx$ 15 A to 18 A, climbing $\approx$ 20 A to 25 A, reported continuous $\approx$ 16.7 A, stall bursts up to $\approx$ 120 A.
- DC–DC (24→5 V) converter efficiency assumed: $\eta = 0.90$.
- Two electronics budgets used for scenario comparison:
  - **Light electronics** (MCU, sensors, telemetry): 30 W (actuator-side) → battery-side $30/0.9 = 33.333\ldots$ W.
  - **Heavy electronics** (Raspberry Pi, camera, heavier payload): 75 W → battery-side $75/0.9 = 83.333\ldots$ W.
- Gripper battery-side draw (from gripper analysis): $P_{gripper,bat} = \dfrac{6.8 \text{ W}}{0.9} = 7.5555555556 \text{ W}$ (see Section 4).

3 Drivetrain detailed calculations

We compute motor power for several currents (digit-by-digit) and add electronics + gripper draws.

3.1 Motor power at 24 V

Power $P = V \times I$. Using $V = 24$ V.

$$
\begin{aligned}
\text{At } I = 12\,\text{A}: &\quad P = 24 \times 12 = 288 \text{ W.}\\
\text{At } I = 15\,\text{A}: &\quad P = 24 \times 15 = 360 \text{ W.}\\
\text{At } I = 16.7\,\text{A}: &\quad P = 24 \times 16.7 = 24 \times 16.7 = 400.8 \text{ W.}\\
\text{At } I = 18\,\text{A}: &\quad P = 24 \times 18 = 432 \text{ W.}\\
\text{At } I = 20\,\text{A}: &\quad P = 24 \times 20 = 480 \text{ W.}\\
\text{At } I = 25\,\text{A}: &\quad P = 24 \times 25 = 600 \text{ W.}\\
\text{At } I = 120\,\text{A (stall)}: &\quad P = 24 \times 120 = 2880 \text{ W.}
\end{aligned}
$$

Notes:

- The original report quoted a combined continuous motor electrical power ≈ 384 W which equates to about 16 A at 24 V; report also quoted ≈ 16.7 A as a typical figure (400.8 W). Both are consistent baselines.
- Stall power is extremely large (2880 W) and only occurs in brief bursts — design wiring and motor drivers to safely handle stall currents; do not expect to sustain stall power for runtime calculations.

3.2 Add electronics + gripper contributions

We add the battery-side electronics and gripper contributions to form total battery-side draw for each scenario.

Let:

$$P_{elec,light} = \frac{30}{0.9} = 33.333333333333336 \text{ W},$$

$$P_{elec,heavy} = \frac{75}{0.9} = 83.33333333333334 \text{ W},$$

$$P_{gripper,bat} = \frac{6.8}{0.9} = 7.555555555555555 \text{ W}.$$

Therefore for a given motor power P_{motor}:

$$P_{total,light} = P_{motor} + P_{elec,light} + P_{gripper,bat},$$

$$P_{total,heavy} = P_{motor} + P_{elec,heavy} + P_{gripper,bat}.$$

3.3 Runtimes (digit-by-digit) for 20 Ah and 35 Ah

Battery energies:

$$E_{20} = 24 \times 20 = 480 \text{ Wh}, \qquad E_{35} = 24 \times 35 = 840 \text{ Wh}.$$

Compute total draws and runtimes (hours) for representative currents. The arithmetic below is explicit.

Scenario	Motor power (W)	Total (light) (W)	Runtime on 20Ah (h)
Straight (12 A)	$24 \times 12 = 288$	$288 + 33.3333 + 7.5556 = 328.8889$	$480/328.8889 = 1.45946$ h
Straight (15 A)	$24 \times 15 = 360$	$360 + 33.3333 + 7.5556 = 400.8889$	$480/400.8889 = 1.19734$ h
Reported continuous (16.7 A)	$24 \times 16.7 = 400.8$	$400.8 + 33.3333 + 7.5556 = 441.6889$	$480/441.6889 = 1.08674$ h
Turning (18 A)	$24 \times 18 = 432$	$432 + 33.3333 + 7.5556 = 472.8889$	$480/472.8889 = 1.01532$ h
Climbing (20 A)	$24 \times 20 = 480$	$480 + 33.3333 + 7.5556 = 520.8889$	$480/520.8889 = 0.92166$ h
Climbing heavy (25 A)	$24 \times 25 = 600$	$600 + 33.3333 + 7.5556 = 640.8889$	$480/640.8889 = 0.74896$ h

The same table but for **heavy electronics** ($P_{elec,heavy} = 83.3333$ W) — useful when using Raspberry Pi + camera:

Scenario	Motor power (W)	Total (heavy) (W)	Runtime on 20Ah (h)
Straight (12 A)	288	$288 + 83.3333 + 7.5556 = 378.8889$	$480/378.8889 = 1.26686$ h
Straight (15 A)	360	$360 + 83.3333 + 7.5556 = 450.8889$	$480/450.8889 = 1.06456$ h
Reported continuous (16.7 A)	400.8	$400.8 + 83.3333 + 7.5556 = 491.6889$	$480/491.6889 = 0.97623$ h
Turning (18 A)	432	$432 + 83.3333 + 7.5556 = 522.8889$	$480/522.8889 = 0.91828$ h

Scenario	Motor power (W)	Total (heavy) (W)	Runtime on 20Ah (h)
Climbing (20 A)	480	$480 + 83.3333 + 7.5556 = 570.8889$	$480/570.8889 = 0.84099$ h
Climbing heavy (25 A)	600	$600 + 83.3333 + 7.5556 = 690.8889$	$480/690.8889 = 0.69476$ h

3.4 Notes on the tables

- All arithmetic is explicit: motor power computed as $24 \times I$ (W), electronics are scaled by the converter efficiency, and totals are summed before dividing into battery Wh to compute runtime.
- Differences between light and heavy electronics examples show how payloads like a camera/RPi reduce runtime substantially.
- Stall events (e.g., 120 A) are not usable for runtime—they are short bursts that stress wiring and the BMS. Example: stall power $= 24 \times 120 = 2880$ W (instantaneous).

4 Gripper analysis (integrated)

This is the gripper analysis previously computed and now referenced within the integrated runtimes.

4.1 Components and typical currents

- 2 × 28BYJ-48 stepper motors: 5 V, typical active current ≈ 0.48 A per motor.
- 2 × SG90 micro servos: 5 V, moving current ≈ 0.20 A per servo, stall ≈ 1.3 A.

4.2 Actuator-side power (explicit)

$$P_{\text{stepper,per}} = 5.0 \times 0.48 = 2.4 \text{ W}.$$

$$P_{\text{servo,per}} = 5.0 \times 0.20 = 1.0 \text{ W}.$$

Total actuator-side moving power:

$$P_{act} = 2 \times 2.4 + 2 \times 1.0 = 6.8 \text{ W}.$$

Battery-side (24 V bus) with $\eta = 0.9$:

$$P_{bat} = \frac{6.8}{0.9} = 7.5555555556 \text{ W}.$$

Battery-side current at 24 V:

$$I_{bat} = \frac{7.5555555556}{24} = 0.3148148148 \text{ A} \approx 0.315 \text{ A}.$$

4.3 Energy per grip (2 s)

$$t = \frac{2}{3600} = 0.0005555555556 \text{ h}.$$

$$E_{op} = 7.5555555556 \times 0.0005555555556 = 0.0041975308642 \text{ Wh}.$$

This energy is negligible relative to battery capacity (see runtime tables).

4.4 Peak/stall sizing for the gripper

Worst-case actuator-side peak (both servos stalled, steppers active):

$$P_{act,peak} = 2 \times (5.0 \times 0.48) + 2 \times (5.0 \times 1.3) = 4.8 + 13.0 = 17.8 \text{ W},$$

$$P_{bat,peak} = \frac{17.8}{0.9} = 19.7777777778 \text{ W},$$

$$I_{bat,peak} = \frac{19.7777777778}{24} = 0.8240740741 \text{ A} \approx 0.82 \text{ A}.$$

5 Sizing & procurement recommendations (full)

5.1 Battery selection

- For 1–2 hour operation under typical cruising loads, a 24 V, 35 Ah pack (840 Wh) is recommended.
- For ≈4 hours at cruising load, required energy is:

  $$E_{\text{req}} = P_{cruise} \times 4 \approx 417.33 \times 4 = 1669.32 \text{ Wh},$$

  $$\text{Ah}_{req} = \frac{1669.32}{24} \approx 69.56 \text{ Ah}.$$

  So choose ≈70–80 Ah @ 24 V (e.g., two matched 35 Ah packs in parallel, or one 70–80 Ah pack).
- Batteries must be rated to supply brief stall bursts (up to the reported 120 A). Choose pack with appropriate C-rating or parallel cells to support short high-current delivery.

5.2 DC–DC and 5 V rail

- 5 V buck converter: $\geq$ **3 A (15 W)** recommended to handle servo stalls and steppers margin.
- 5 V rail fuse: **4 A slow-blow** recommended.
- Local decoupling: 470–1000 µF low ESR electrolytic + 0.1 µF ceramic near servos.

5.3 Wiring, fuses and protection

- Main fuse: sized above expected continuous draw but below wiring limit; a practical main fuse of **100 A slow-blow** is suggested given stall risk (tune after final motor-driver selection).
- Per-motor fuses (or current-limited motor drivers): **30 A** or per-motor rating as recommended by motor driver datasheets.
- Use XT90 / Anderson connectors for high-current battery connections; AWG sized wiring for continuous and peak currents.
- BMS with balancing and cell monitoring; if paralleling packs, ensure safe paralleling procedure and compatible BMS.

6 Summary

System battery needs: Drivetrain continuous draw 384 W (16 17A at 24 V). For 1–2 hours operation a 24 V, 35 Ah pack (840 Wh) is recommended. For ≈4 hours at cruising load choose 70 Ah (e.g., two 35 Ah packs in parallel). Battery must support short stall bursts up to reported 120 A.

Gripper: 2×28BYJ-48 steppers + 2×SG90 servos draw 6.8 W actuator-side; battery-side 7.56 W. One grip (2 s) uses 0.0042 Wh. Impact on main pack runtime is negligible; design local 5 V rail (≥ 3 A buck, 4 A fuse, decoupling caps) and wiring for servo stall currents.

Other procurement: 5 V buck (≥ 3 A), main fuse 100 A slow-blow (verify), per-motor fuses (per driver spec), XT90/Anderson connectors, AWG correct wiring, BMS with balancing, motor drivers rated for continuous and peak currents.