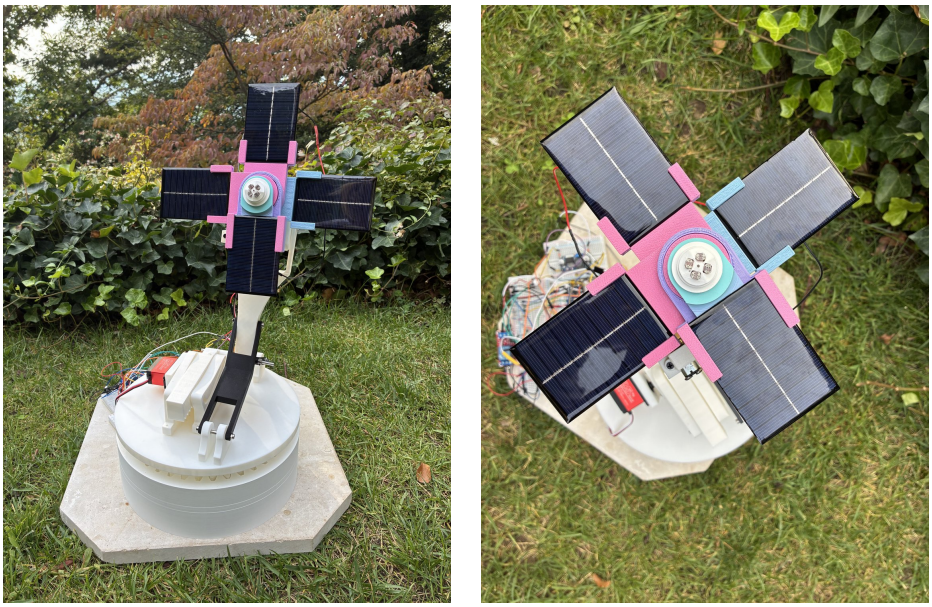
Dual-Axis Solar Tracker

1 Use Case

A portable dual-axis solar tracker that keeps a 2.4 W solar array pointed toward the strongest available sunlight. The array charges an onboard battery, and the battery powers a phone output on one side and the tracker's own electronics on the other. Four LDRs measure light intensity from different directions, and the servos adjust the array when it moves away from the strongest source.



(a) Front view

(b) Top view, with the four LDRs at the center

Figure 1: Tracker deployed.

Energy Model

The four panels are wired 2S2P, producing 12 V, 200 mA, 2.4 W.

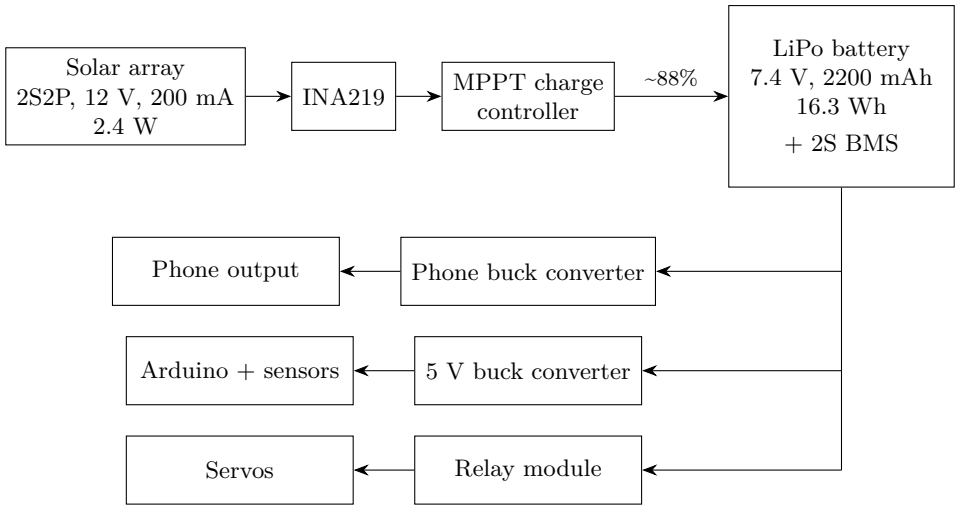
For a fixed panel:

$$P(\theta) = P_{\max} \cos(\theta) \tag{1}$$

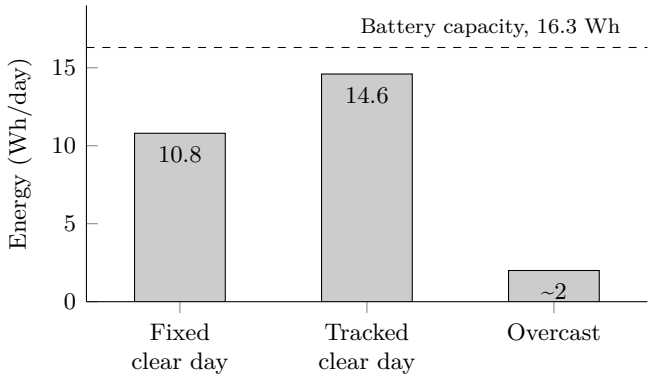
At 45° off-axis, the ideal output falls to 1.70 W. With 4.5 peak-sun-hours, a fixed 2.4 W array can produce about 10.8 Wh/day, compared with 14.6 Wh/day for the tracked system.

Clear day: 14.6 Wh/day **Overcast:** ~2 Wh/day

The system uses a 7.4 V, 2200 mAh LiPo battery (16.3 Wh) for storage. All solar power goes into the battery through an MPPT charge controller, and the battery then supplies every load: the phone output on one side, and the controller, sensors and servos on the other. Because the battery acts as a buffer between generation and use, the phone can be charged in the evening or under cloud, not only while the sun is up.



(a) Power flow. All solar energy is stored in the battery before it reaches any load.



(b) Calculated daily energy

Figure 2: Energy budget and power flow.

2 Mechanical Design

The tracker uses geared actuation to achieve the required range while keeping motor torque manageable.

- **Azimuth:** planetary gearbox
- **Elevation:** rack-and-pinion
- **Deployment:** N20 gearmotor + self-locking worm drive

The worm drive opens the solar panels and holds them without continuous motor power. The tracking servos only move during corrections and are operated one at a time to limit peak power.

The linkage was sized around the servo torque available at the minimum battery voltage, rather than the maximum datasheet rating.

[IMAGE — CAD: FULL ASSEMBLY + GEARBOX / LINKAGE CLOSE-UP]



(a) Planetary gearbox (azimuth)



(b) Folded



(c) Elevation extended, panels stowed

Figure 3: Mechanical assembly.

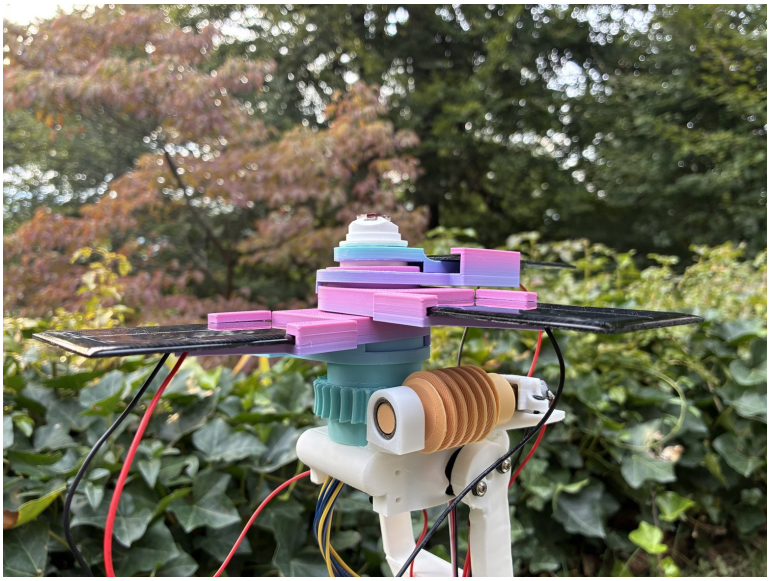


Figure 4: Self-locking worm drive (N20 gearmotor) for panel deployment.

3 Electrical Design

The electrical architecture was designed around the same energy constraint as the mechanical system. The battery sits at the center: the array charges it, and every load draws from it.

Solar array → INA219 → MPPT charge controller → battery
Battery → phone buck converter → phone output
Battery → 5 V buck converter → Arduino + sensors
Battery → relay module → servos

Schottky diodes (1N5822) on each panel string and at the charger output stop current flowing backwards into the panels when they are shaded or dark.

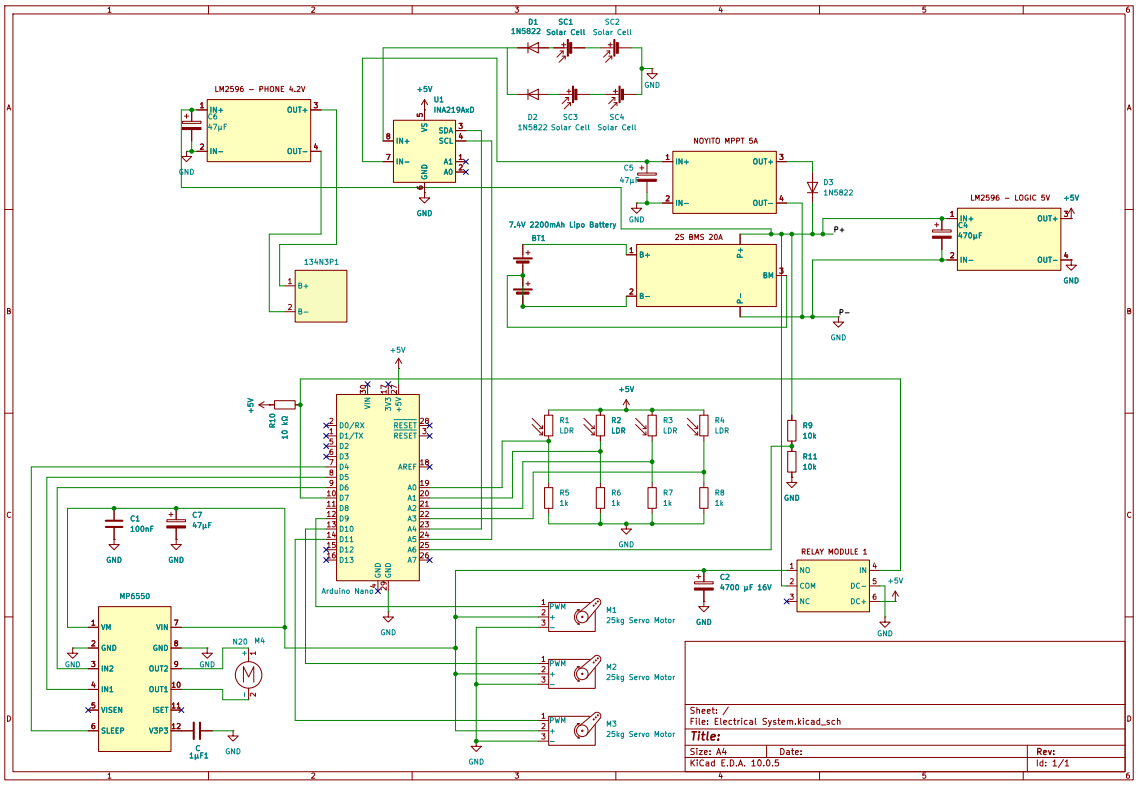


Figure 5: Electrical schematic.

Main Components

Solar	4 × 6 V, 100 mA panels, 2S2P
Storage	7.4 V, 2200 mAh LiPo + 2S BMS
Charging	NOYITO 5 A MPPT charge controller
Control	Arduino Nano + 4 × LDRs
Sensing	INA219 current/voltage sensor
Actuation	3 × 25 kg servos + N20 gearmotor (MP6550 driver)
Switching	relay module (servo supply)
Regulation	2 × LM2596 buck converters (5 V logic, phone)

The charger is an MPPT controller rather than a plain constant-voltage converter. A solar panel can supply a limited current, and pulling harder past that point only drops its voltage. A constant-voltage converter facing a flat battery keeps raising its duty cycle to reach the target, asks for more current than the panels can give, and drags the array down its I-V curve until it produces almost nothing. The MPPT controller instead adjusts how much it draws so the array stays at its maximum power point, delivering as much power as the light allows.

Compared with wiring all four panels in series (4S, 24 V), the 2S2P configuration halves the array voltage to 12 V, which reduces the voltage conversion the charger has to perform. This raises calculated charging efficiency from approximately 80% to 88%. The 2S2P layout also isolates shading between panel pairs.

Panel wiring	Array voltage	Battery charging
4S (all four in series)	24 V	~80%
2S2P (used)	12 V	~88%

Because the phone is now powered from the battery, the panel wiring no longer affects the phone output: its converter always steps down from the battery voltage. Energy reaching the phone passes through two conversions, the charger and then the phone converter, so overall solar-to-phone efficiency is lower than feeding the phone straight from the array. In exchange, phone charging no longer depends on the weather or the time of day, and the array never has to be shared between two loads.

4 Control & Power Dispatch

The Arduino continuously monitors the battery and solar input.

As the battery voltage falls, the loads the controller switches are removed in sequence:

$$\text{Tracking} \rightarrow \text{stow} \rightarrow \text{servo power off}$$

The cutoff is set at 7.2 V, above the 6.5 V dropout of the 5 V converter and well above the 5–6 V at which the BMS disconnects. If shedding were left to the BMS, the controller would already have lost power with the servos still connected and the structure still deployed. The phone output is wired directly to the battery, so it is not switched by the controller and stays available until the BMS disconnects.

The main design constraint was the energy balance: holding the servos continuously could consume more than the 2.4 W generated by the array, so the tracker only moves when a correction is required.

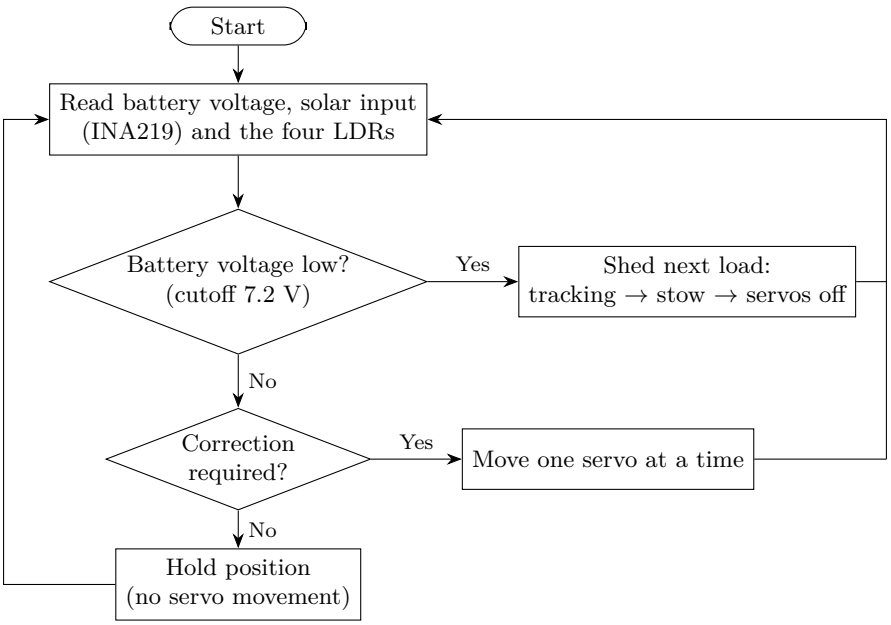


Figure 6: Control logic.

5 Scaling to Industry

The prototype faces the same problem as grid-scale solar:

$$\text{Capture} \rightarrow \text{Store} \rightarrow \text{Dispatch}$$

Solar peaks at midday; demand runs into the evening. In Texas during the 2024 summer peak, demand hit roughly 86 GW in the late afternoon, but the net peak — demand not met by wind or solar — came later, once solar output had dropped to near zero. Grid batteries close that gap, charging through the excess-generation window and discharging as demand rises. The prototype now works the same way: everything the array captures is stored first, and the phone and electronics draw from storage.

At larger scale, the architecture would move from small LiPo batteries, relays, and LDR feedback toward inverter-level MPPT, high-power converters, thermal management, advanced BMS, and modular long-duration storage. DOE defines long-duration energy storage as systems capable of delivering power for 10 hours or more.

At larger scales, single-axis tracking is often preferred because it provides much of the energy gain with less mechanical complexity. Dual-axis tracking becomes more useful when maximising energy from a limited area is more important than minimising system complexity.

The same tradeoff appears at this project's scale. Larger actuators can support larger panels but use more power. Stronger structures handle higher loads but add weight. The goal is to increase solar energy without letting the tracking system consume too much of it.

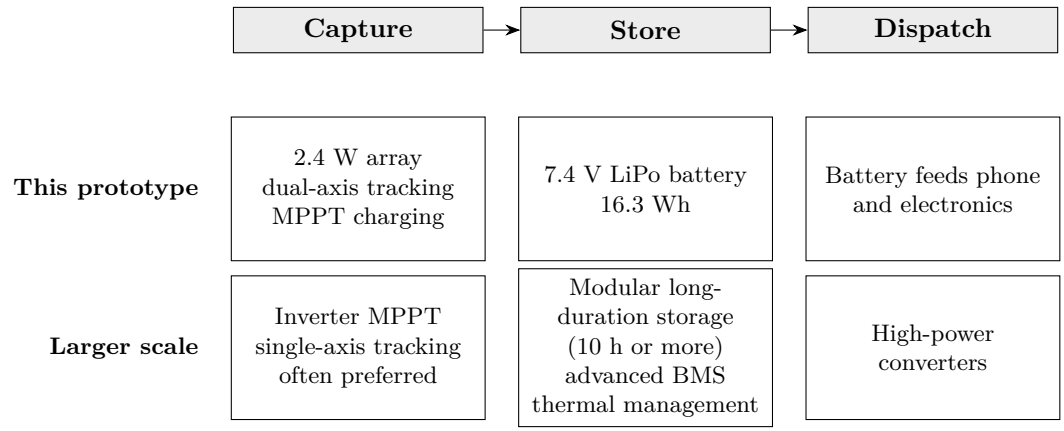


Figure 7: Scaling the same architecture.