Solar Panel Array Wiring: Series, Parallel & Series-Parallel

Engineering Quick-Reference: Voltage, Current, Conductor Sizing, and Resistive Power-Loss Dynamics

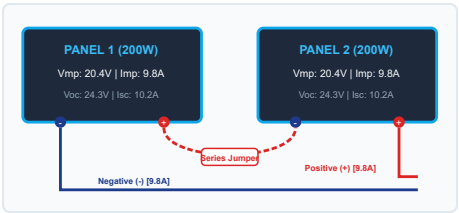
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Full Interactive Guide: calcmypower.com

1. PRIMARY PHOTOVOLTAIC ARRAY WIRING CONFIGURATIONS

BENCHMARK: 200W MONOCRYSTALLINE MODULE (VOC=24.3V, VMP=20.4V, ISC=10.2A, IMP=9.8A)

Series Connection (2S)

Voltages Add

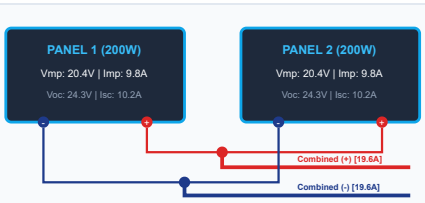


TOTAL ARRAY: 400W
Vmp: 40.8V (Doubled) | Imp: 9.80A (Same)
Voc: 48.6V | Isc: 10.20A

- **Physics:** V_total = V1 + V2; I_total = I1 = I2.
- **Copper Efficiency:** Doubles voltage, cutting current in half; reduces line power loss (I^2R) by 75%.
- **Wire Sizing:** Allows smaller conductors (10-12 AWG) on long runs (50-100 ft).
- **Shading Impact:** Shading on one cell drops current through the entire string.
- **Controller:** Requires an MPPT solar charge controller.

Parallel Connection (2P)

Current Adds



TOTAL ARRAY: 400W
Vmp: 20.4V (Same) | Imp: 19.60A (Doubled)
Voc: 24.3V | Isc: 20.40A

- **Physics:** V_total = V1 = V2; I_total = I1 + I2.
- **High Current:** Amperage doubles, multiplying resistive voltage drop unless wire gauge is increased.
- **Wire Sizing:** Demands heavy 8 AWG or 6 AWG copper cables even over short runs.
- **Shading Impact:** Shaded panel does not pull down current of parallel neighbor.
- **Controller:** Compatible with both PWM and MPPT charge controllers.

Series-Parallel (2S2P)

Balanced Array



TOTAL ARRAY: 800W
Vmp: 40.8V (Doubled) | Imp: 19.60A (Doubled)
Voc: 48.6V | Isc: 20.40A

- **Physics:** Two series strings connected in parallel.
- **Balanced Limits:** Keeps voltage within MPPT 100-150V limits while keeping current within 20A branch limits.
- **Wire Sizing:** Standard 10 AWG solar PV wire handles home-run transmission.
- **Scale:** The standard layout for residential and cabin arrays with 4 or more panels.
- **Controller:** Requires an MPPT solar charge controller.

2. ELECTRICAL CIRCUIT MATRIX & OPERATING CHARACTERISTICS

STC: 1,000 W/M², 25°C CELL TEMP, AM 1.5

PARAMETER	SERIES (2S)	PARALLEL (2P)	SERIES-PARALLEL (2S2P)	CIRCUIT FORMULA & ENGINEERING RATIONALE
Operating Voltage (Vmp)	40.8 V	20.4 V	40.8 V	Series: V_total = V1 + V2. Parallel: V_total = V_module.
Operating Current (Imp)	9.80 A	19.60 A	19.60 A	Series: I_total = I_module. Parallel: I_total = I1 + I2.
Open-Circuit Voltage (Voc)	48.6 V	24.3 V	48.6 V	Voc adds per series module. Critical for MPPT max voltage check.
Short-Circuit Current (Isc)	10.20 A	20.40 A	20.40 A	Isc adds per parallel branch. Determines minimum wire ampacity.
Total Rated Power	400 W	400 W	800 W	P = Vmp × Imp. Uniform irradiance delivers identical power per panel count.
Conductor Size & Drop	10 AWG to 12 AWG (Low Drop)	8 AWG to 6 AWG (High Drop)	10 AWG (Balanced)	Higher voltage lowers line current, preventing heavy copper costs.
Partial Shading Response	String current restricted	Independent branch output	Isolated to shaded string	Bypass diodes bypass shaded cells; parallel isolates unaffected strings.
Charge Controller Type	MPPT Required	PWM or MPPT	MPPT Required	PWM drops array voltage to battery voltage; MPPT steps down V to gain Amps.

3. CONDUCTOR RESISTANCE & VOLTAGE-DROP ENGINEERING BENCHMARK

NEC CH. 9, TABLE 8 STRANDED UNCOATED COPPER @ 75°C CONDUCTOR OPERATING TEMP

AWG SIZE	DC RESISTANCE (Ω / 1,000 FT)	SERIES 2S DROP (40.8V, 9.8A, 50 FT)	SERIES 2S % DROP	PARALLEL 2P DROP (20.4V, 19.6A, 50 FT)	PARALLEL 2P % DROP	COMPLIANCE ASSESSMENT (3% TARGET)
12 AWG	1.98 Ω	1.94 V	4.75%	3.88 V	19.02%	Unacceptable for parallel; exceeds recommended 3% threshold.
10 AWG	1.24 Ω	1.22 V	2.98%	2.43 V	11.91%	**Optimal for Series 2S** (<3%). Unacceptable for Parallel 2P.
8 AWG	0.778 Ω	0.76 V	1.87%	1.52 V	7.47%	Excellent for Series. Borderline for Parallel (exceeds 3% limit).
6 AWG	0.491 Ω	0.48 V	1.18%	0.96 V	4.72%	Required for Parallel home-runs to control line losses below 5%.

ENGINEERING CAVEAT & NATIONAL ELECTRICAL CODE NOTICE

Voltage drop formula: *V_drop = 2 × L × R × I ÷ 1000* (where L = 50 ft one-way, 100 ft total loop). While voltage drop optimization prevents power loss, code compliance mandates conductor sizing based on **NEC 690.8** minimum circuit ampacity: *I_max = Isc × 1.25 (continuous load) × 1.25 (irradiance reflection) = 1.56 × Isc*, plus ambient temperature derating (NEC 310.15(B)(1)) and conduit fill adjustments (NEC 310.15(C)(1)).

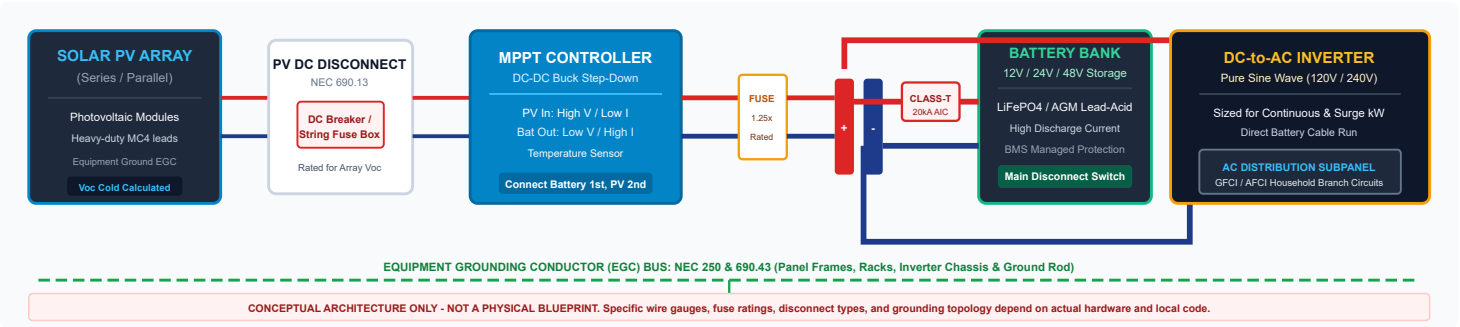
Complete Off-Grid Solar Electrical System Architecture

Component Sequencing, Overcurrent Protection Boundaries, Disconnect Placement & Commissioning Protocol

Document ID: CMP-REF-SOLAR-02
Electrical Safety: Life Safety Notice
Tools: calcmypower.com

1. COMPLETE SYSTEM ELECTRICAL TOPOLOGY (CONCEPTUAL SCHEMATIC)

CONCEPTUAL DIAGRAM: NOT A UNIVERSAL INSTALLATION BLUEPRINT



OVERCURRENT PROTECTION & NEC REQUIREMENTS

- [x] **String Fusing (NEC 690.9):** 1S and 2P configurations generally do not require branch string fuses if conductors are sized to 1.56 × Isc. When 3 or more strings are wired in parallel, each string requires an individual fuse to prevent combined backfeed current into a faulted panel.
- [x] **Cold-Weather Voc (NEC 690.7):** Open-circuit voltage rises sharply below 25°C: *Voc_cold = Voc_STC × [1 + (α_Voc ÷ 100 × (T_min - 25°C))]*. Never exceed the controller maximum input voltage rating; overvoltage causes catastrophic hardware failure.
- [x] **Class-T Battery Fuses (NEC 706):** Lithium (LiFePO4) battery banks possess massive short-circuit current capabilities. Use a high-interrupting Class-T fuse (20,000A AIC rating) within 7 inches of the positive battery terminal to prevent electrical fires.
- [x] **Continuous Load Factor (NEC 690.8):** Solar circuits generate continuous current (3+ hours). All conductors and overcurrent devices must be rated for at least 125% of maximum circuit current.

COMMISSIONING & FIELD SAFETY CHECKLIST

- [x] **Multimeter Verification:** Test array polarity (+ / -) and open-circuit voltage (Voc) with a digital multimeter before connecting to the charge controller or closing circuit breakers.
- [x] **Sequential Commissioning:** Always connect the Battery to the Charge Controller FIRST so the unit detects system voltage. Connect the Solar Array SECOND. (When decommissioning, reverse order: disconnect PV first, then Battery).
- [x] **Never Disconnect Under Load:** DC arcs do not self-extinguish at zero crossings like AC power. Never unplug MC4 connectors while current is flowing; open the DC disconnect switch first.
- [x] **Calibrated Terminal Torque:** Torque all electrical lugs, busbar bolts, and terminal blocks to manufacturer-specified inch-pounds using a calibrated torque wrench. Loose connections cause high-resistance fires.
- [x] **Equipment Grounding:** Bond all solar panel aluminum frames, racking rails, controller chassis, and inverter ground lugs to the system grounding electrode per NEC 250.

2. AUTHORITATIVE US ENGINEERING STANDARDS & VERIFIED CITATIONS

OFFICIAL TECHNICAL REFERENCE DOCUMENTS

1. **NFPA 70: National Electrical Code (NEC):** Articles 690 (Solar PV), 705 (Interconnected Sources), 706 (Energy Storage) • nfpa.org
2. **IEEE Standard 1547:** Standard for Interconnection and Interoperability of Distributed Energy Resources • standards.ieee.org
3. **UL 1741:** Inverters, Converters, Controllers and Interconnection System Equipment for Distributed Energy • ul.com
4. **NREL Photovoltaic Guidelines:** National Renewable Energy Laboratory Design Best Practices • nrel.gov

Online Interactive Calculators:
calcmypower.com/solar-panels-series-vs-parallel

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