

How to Size Wiring for Your System

Properly sized wire can make the difference between inadequate and full charging of a battery system, between dim and bright lights, and between feeble and full performance of tools and appliances. Designers of low voltage power circuits are often unaware of the implications of voltage drop and wire size.

In conventional home electrical systems (120/240 volts ac), wire is sized primarily for safe amperage carrying capacity (ampacity). The overriding concern is fire safety. In low voltage systems (12, 24, 48VDC) the overriding concern is power loss. Wire must not be sized merely for the ampacity, because there is less tolerance for voltage drop (except for very short runs). For example, at a constant wattage load, a 1V drop from 12V causes 10 times the power loss of a 1V drop from 120V.

Universal Wire Sizing Chart A 2-Step Process

This chart works for any voltage or voltage drop, American (AWG) or metric (mm²) sizing. It applies to typical DC circuits and to some simple AC circuits (single-phase AC with resistive loads, not motor loads, power factor = 1.0, line reactance negligible).

STEP 1: Calculate the Following:

$$\text{VDI} = (\text{AMPS} \times \text{FEET}) / (\% \text{VOLT DROP} \times \text{VOLTAGE})$$

VDI = Voltage Drop Index (a reference number based on resistance of wire)

FEET = ONE-WAY wiring distance (1 meter = 3.28 feet)

% VOLT DROP = Your choice of acceptable voltage drop (example: use 3 for 3%)

STEP 2: Determine Appropriate Wire Size from Chart

Compare your calculated VDI with the VDI in the chart to determine the closest wire size. Amps must not exceed the AMPACITY indicated for the wire size.

Wire Size AWG	Area mm ²	COPPER		ALUMINUM	
		VDI	Ampacity	VDI	Ampacity
16	1.31	1	10	Not Recommended	
14	2.08	2	15		
12	3.31	3	20		
10	5.26	5	30		
8	8.37	8	55		
6	13.3	12	75		

4	21.1	20	95		
2	33.6	31	130	20	100
0	53.5	49	170	31	132
00	67.4	62	195	39	150
000	85.0	78	225	49	175
0000	107	99	260	62	205

Metric Size by cross-sectional area	COPPER (VDI x 1.1 = mm ²)	ALUMINUM (VDI x 1.7 = mm ²)
Available Sizes: 1 1.5 2.5 4 6 10 16 25 35 50 70 95 120 mm ²		

EXAMPLE:

20 Amp load at 24V over a distance of 100 feet with 3% max. voltage drop

$VDI = (20 \times 100) / (3 \times 24) = 27.78$	For copper wire, the nearest VDI=31. <i>This indicates #2 AWG wire or 35mm²</i>
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NOTES: AWG=American Wire Gauge. Ampacity is based on the National Electrical Code (USA) for 30 degrees C (85 degrees F) ambient air temperature, for no more than three insulated conductors in raceway in free air of cable types AC, NM, NMC and SE; and conductor insulation types TA, TBS, SA, AVB, SIS, RHH, THHN and XHHW. For other conditions, refer to National Electric Code or an engineering handbook.

Use the following chart as your primary tool in solving wire sizing problems. It replaces many pages of older sizing charts. You can apply it to any working voltage, at any percent voltage drop.

Determining tolerable voltage drop for various electrical loads

A general rule is to size the wire for approximately 2 or 3% drop at typical load. When that turns out to be very expensive, consider some of the following advice. Different electrical circuits have different tolerances for voltage drop.

LIGHTING CIRCUITS, INCANDESCENT AND QUARTZ HALOGEN (QH): Don't cheat on these! A 5% voltage drop causes an approximate 10% loss in light output. This is because the bulb not only receives less power, but the cooler filament drops from white-hot towards red-hot, emitting much less visible light.

LIGHTING CIRCUITS, FLUORESCENT: Voltage drop causes a nearly proportional drop in light output. Fluorescents use 1/2 to 1/3 the current of incandescent or QH bulbs for the same light output, so they can use smaller wire. We advocate use of quality fluorescent lights. Buzz, flicker and poor color rendition are eliminated in most of today's compact fluorescents, electronic ballasts and warm or full spectrum tubes.

DC MOTORS may be used in renewable energy systems, especially for water pumps. They operate at 10-50% higher efficiencies than AC motors, and eliminate the costs and losses associated with inverters. DC motors do NOT have excessive power surge demands when starting, unlike AC induction motors. Voltage drop during the starting surge simply results in a "soft start".

AC INDUCTION MOTORS are commonly found in large power tools, appliances and well pumps. They exhibit very high surge demands when starting. Significant voltage drop in these circuits may cause failure to start and possible motor damage. Follow the National Electrical Code. In the case of a well pump, follow the manufacturer's instructions.

PV-DIRECT SOLAR WATER PUMP circuits should be sized not for the nominal voltage (ie. 24V) but for the actual working voltage (in that case approximately 34V). Without a battery to hold the voltage down, the working voltage will be around the peak power point voltage of the PV array.

PV BATTERY CHARGING CIRCUITS are critical because voltage drop can cause a disproportionate loss of charge current. To charge a battery, a generating device must apply a higher voltage than already exists within the battery. That's why most PV modules are made for 16-18V peak power point. A voltage drop greater than 5% will reduce this necessary voltage difference, and can reduce charge current to the battery by a much greater percentage. Our general recommendation here is to size for a 2-3% voltage drop. If you think that the PV array may be expanded in the future, size the wire for future expansion. Your customer will appreciate that when it comes time to add to the array.

WIND GENERATOR CIRCUITS: At most locations, a wind generator produces its full rated current only during occasional windstorms or gusts. If wire sized for low loss is large and very expensive, you may consider sizing for a voltage drop as high as 10% at the rated current. That loss will only occur occasionally, when energy is most abundant. Consult the wind system's instruction manual.

More techniques for cost reduction

ALUMINUM WIRE may be more economical than copper for some main lines. Power companies use it because it is cheaper than copper and lighter in weight, even though a larger size must be used. It is safe when installed to code with AL-rated terminals. You may wish to consider it for long, expensive runs of #2 or larger. The cost difference

fluctuates with the metals market. It is stiff and hard to bend, and not rated for submersible pumps.

HIGH VOLTAGE PV MODULES: Consider using higher voltage modules and a MPPT solar charge controller to down convert to the system voltage (e.g. 12, 24 and 48V) to compensate for excessive voltage drop. In some cases of long distance, the increased module cost may be lower than the cost of larger wire.

SOLAR TRACKING: Use a solar tracker (e.g. Zomeworks or Unirac) so that a smaller array can be used, particularly in high summer-use situations (tracking gains the most energy in summer when the sun takes the longest arc through the sky). The smaller PV array will require smaller wire.

WATER WELL PUMPS: Consider a slow-pumping, low power system with a storage tank to accumulate water. This reduces both wire and pipe sizes where long lifts or runs are involved. A PV array-direct pumping system may eliminate a long wire run by using a separate PV array located close to the pump. Many of our solar water pumps are highly efficient DC pumps that are available up to 48V. We also make AC versions and converters to allow use of AC transmitted over great distances. These pumps draw less running current, and far less starting current than conventional AC pumps, thus greatly reducing wire size requirements.