# Code Corner

# Example Systems: Water Pumping

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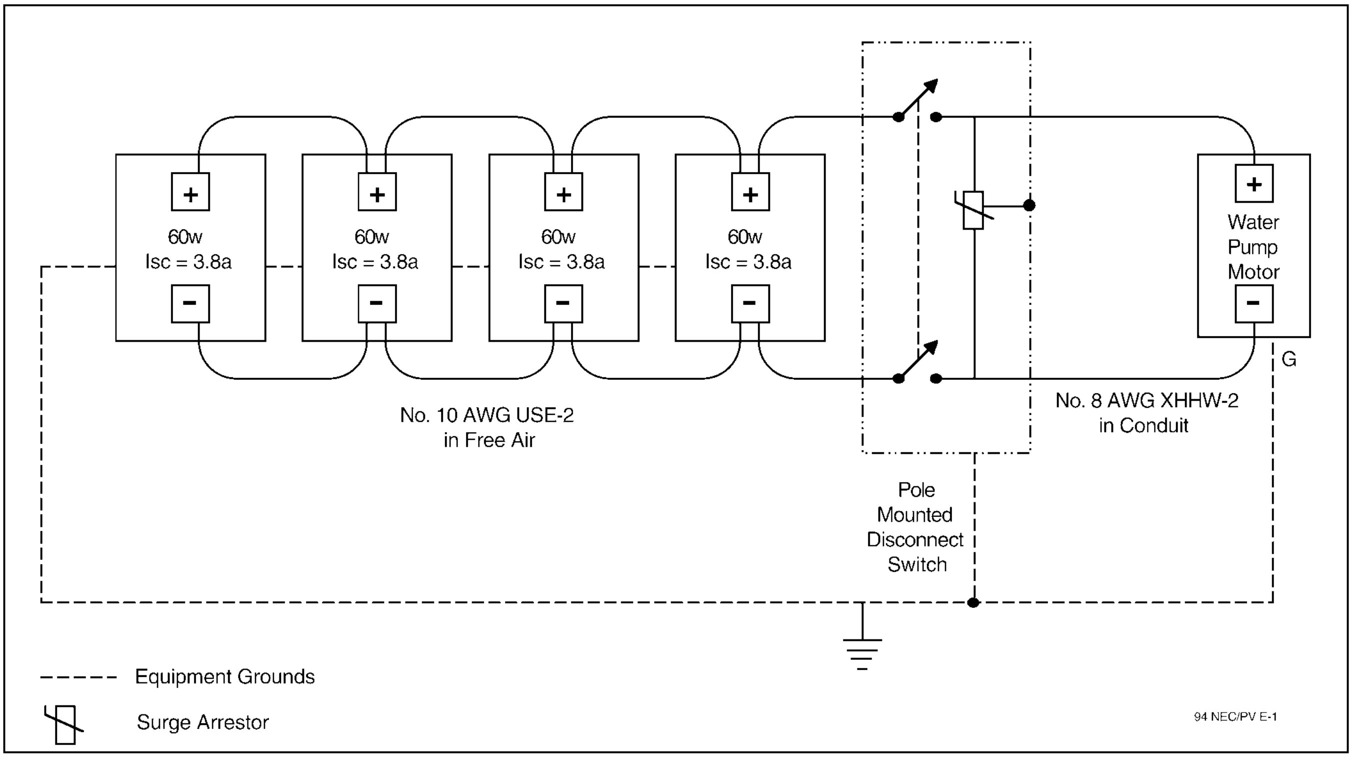
This is the first of a series of examples on the selection of the wiring, overcurrent devices, and disconnects for various types of PV systems. These designs meet National Electrical Code (NEC) requirements. These are examples only and should not be used to define the requirements for any particular system. No information is given on sizing the PV array. The array sizes used and the loads driven are used only for illustration. Calculations for a specific system should use the methods presented in earlier issues of Home Power. The first example is the simplest — a water pumping system. The last example in the series will cover a complex residential hybrid PV system with a backup generator.

**Direct Connected Water Pumping System Example**
Array Size: 4, 12-volt, 60-watt modules Isc = 3.8 amps, Voc = 21.1 volts Load: 12-volt, 10-amp pump motor

**Description**
The modules are mounted on a tracker and connected in parallel. The modules are wired as shown in Figure 1 with number 10 AWG USE-2 single-conductor cable. A large loop is placed in the cable to allow for tracker motion without straining the rather stiff building cable. A jacketed cable, such as SEO W-A, could be used for this connection. The USE-2 cable is run to a disconnect switch in an enclosure mounted on the pole. From this disconnect enclosure, number 8 AWG XHHW-2 (cross-linked polyethylene) cable in electrical non-metallic conduit (gray electrical PVC) is routed to the well head. The conduit is buried 18 inches deep. Number 8 AWG cable is used to minimize voltage drop.



The NEC requires the disconnect switch. PV modules are current limited and all conductors have an ampacity greater than the maximum output of the PV modules. No overcurrent device is required, but some inspectors might require one. The disconnect could also provide some lightning protection. A DC-rated disconnect switch or a DC-rated circuit breaker must be used. Since the system is ungrounded, a two-pole switch must be used. All module frames, the disconnect enclosure, and the pump housing must be grounded whether the system is grounded or not.

If the pump motor is submersible, plastic insulated cables should not be used. Where moisture is present plastic (PVC, e.g. Type TW) cables, in DC applications, have had the insulation melt off the wire. The case of any pump motor, submersible or not, must be grounded. This means three conductor cables will be required down the well.

**Calculations**
The array short-circuit current is 15.2 amps (4 x 3.8).
UL 125%: 1.25 x 15.2 = 19 amps Required by the module instructions.
NEC 125%: 1.25 x 19 = 23.75 amps
The ampacity of 10 AWG USE-2 at 30°C is 55 amps in free air.
The ampacity at 61-70°C is 31.9 amps (0.58 x 55) which is more than the 23.75 amp requirement.
The equipment grounding conductors should be number 10 AWG.
The voltage rating of all components should be at least 26 volts (1.25 x 21.1).

**Water Pumping System with Current Booster**
Array Size: 10, 12-volt, 53-watt UL-Listed modules Isc = 3.4 amps, Voc = 21.7 volts
Current Booster Output: 90 amps maximum, 40 amps steady state
Load: 12-volt, 40-amp motor

**Description**
This system has a current booster connected between the PV array and the water pump. It has more modules than the previous example. Initially number 8 AWG USE-2 cable was chosen for the array connections, but this cable had inadequate ampacity. As the figure and calculations below show, the array was split into two subarrays. There is the possibility of a malfunction in the current booster, but it does not seem possible that excess current can be fed back into the array wiring since there is no other source of energy in the system. These conductors would not need overcurrent devices if they were sized for the entire array current. Since the number 8 AWG conductors had insufficient ampacity for the entire array short-circuit currents, smaller conductors are used in each subarray and overcurrent devices are needed.

Even though the array is broken into two subarrays, the maximum short-circuit current available in the wiring of either subarray is equal to the total array short-circuit current under fault conditions. Overcurrent devices are needed to protect the subarray conductors under these conditions.

A grounded system is selected and only one-pole disconnects and overcurrent devices are required. Equipment grounding and system grounding conductors are shown in Figure 2.

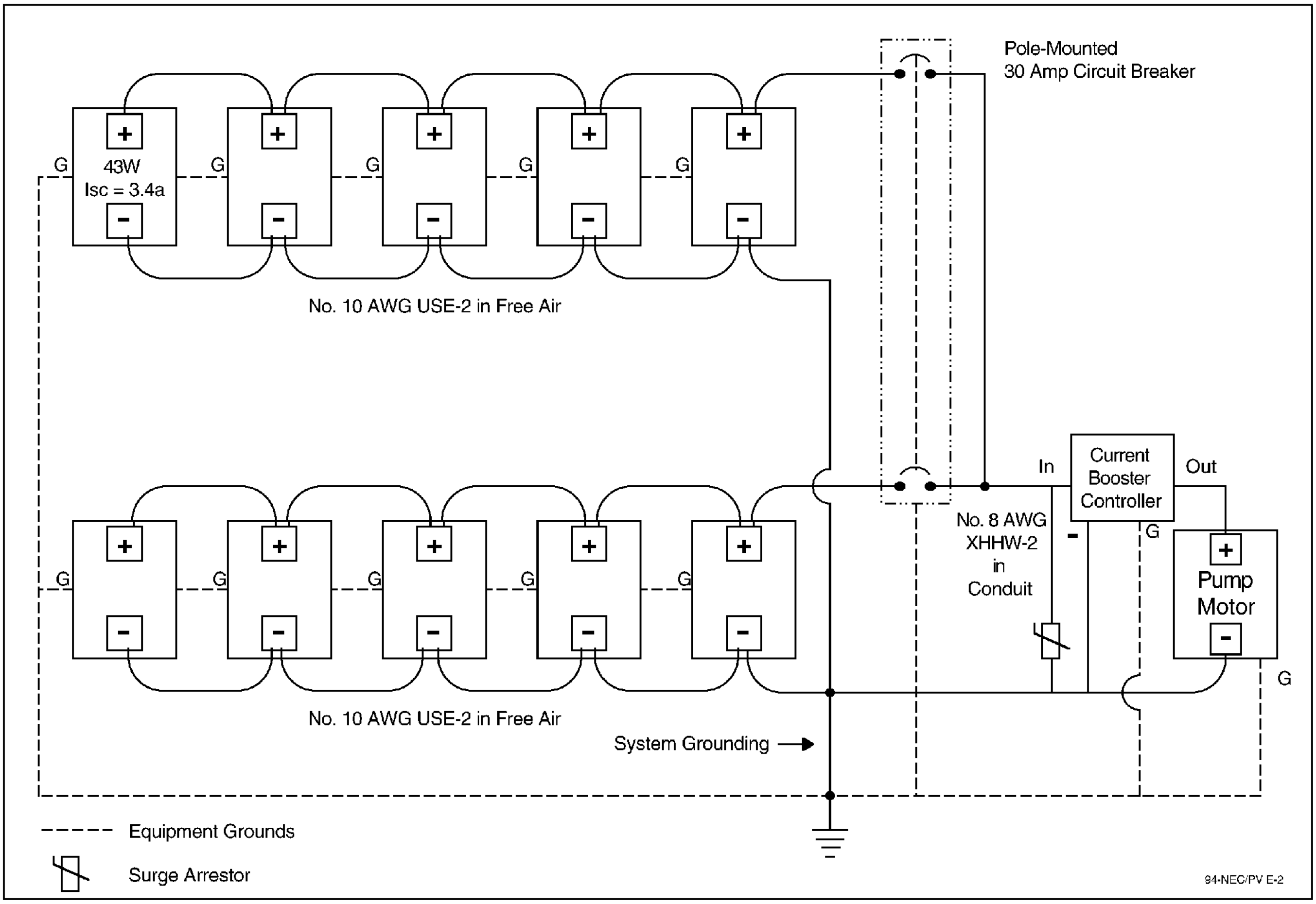
If the current booster output conductors are sized to carry the maximum current of the booster, then overcurrent devices are not necessary, but again, some inspectors may require them.

**Calculations**
The array short-circuit current is 34 amps (10 x 3.4).
UL 125%: 1.25 x 34 = 42.5 amps Required by the module instructions
NEC 125%: 1.25 x 42.5 = 53.1 amps
The ampacity of 8 AWG USE-2 cable at 30°C, in free air, is 80 amps.
The ampacity at 61-70°C is 46.4 amps (0.58 x 80) is less than the 53.1 amp requirement. Number 8 AWG is the largest conductor that can be connected to the modules. Therefore, the array is split into two subarrays. Each is wired with number 10 AWG USE-2 conductors.
The subarray short-circuit current is 17 amps (5 x 3.4).
UL 125%: 1.25 x 17 = 21.3 amps
NEC 125%: 1.25 x 21.25 = 26.6 amps
The ampacity of number 10 AWG USE-2 at 30°C, in free air, is 55 amps.

The ampacity at 61-70°C is 31.9 amps (0.58 x 55) is more than the 26.6 amp requirement. Since this cable will be connected to an overcurrent device with terminals rated at 75°C, the ampacity of the cable must be evaluated with 75°C insulation. Number 10 AWG 75°C cable operating at 40°C (the disconnect operating temperature) has an ampacity of 30.8 amps (0.88 x 35) which is more than the 21.3 amps requirement. Thirty amp circuit breakers are used to protect the number 10 AWG subarray conductors.

The current booster maximum current is 90 amps.
The current booster average long-term ( 3-hours or longer) current is 40 amps.
NEC 125%: 1.25 x 40 = 50 amps

The ampacity of number 8 AWG XHHW-2 at 30°C in conduit is 55 amps. The ampacity at 36-40°C is 50 amps (0.91 x 55) which meets the requirements, but




may not meet the overcurrent device connection requirements when such a device is used in the current booster output circuit.

The number 8 AWG conductors would be connected to the terminals of the overcurrent device. There is the possibility that heating of the breaker or fuse may occur. It is good practice to calculate device overheating. The ampacity of a number 8 AWG conductor with 75°C insulation (the maximum temperature of the terminals on the overcurrent device) at 40°C is 44 amps (50 x 0.88). This is greater than the maximum 40 amp current in the circuit. It means that the overcurrent device, if installed, would not be subjected to overheating when the number 8 AWG conductor carries 40 amps.

All equipment grounding conductors should be number 10 AWG. The grounding electrode conductor should be number 8 AWG or larger.

The voltage rating of all components should be at least: 1.25 x 21.1 = 26 volts

**Summary**

The calculations used in these examples are based on UL and NEC requirements. While there is some leeway in the selection of cable types, overcurrent devices, and disconnects, only DC-rated devices should be used. Over sizing the cables will lower voltage drop and increase performance, particularly where long cable runs are involved.

**Access**

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