# Code Corner
# Example Systems
# Stand-Alone and Grid-Tied Systems

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This Code Corner will continue the series of examples on the selection of the wiring, overcurrent devices, and disconnects for various types of PV systems. These designs will meet the requirements of the National Electrical Code (NEC). These are examples only and should not be used to define the requirements for any particular system. No information will be presented on sizing the PV array. The array sizes and the loads are used only for illustration. Calculations for a specific system should be accomplished using the methods presented in previous issues of Home Power. The examples in this Code Corner will cover a small residential stand-alone system and a small grid-tied system. The last example in the series will cover a complex residential hybrid PV system with a backup generator.

The systems described below and the calculations shown are presented as examples only. The calculations for conductor sizes and the ratings of overcurrent devices are based on the requirements of the 1993 National Electrical Code (NEC) and on UL Standard 1703 which requires specific instructions in the installation manuals of UL-Listed PV modules. Local codes and site-specific variations in irradiance, temperature, and module mounting as well as other installation particularities dictate that these examples should not be used without further refinement. Tables 310-16 and 310-17 from the NEC provide the ampacity data and temperature derating factors.

**EXAMPLE 1 Stand-Alone Residential System**
Array Size: 10, 12-volt, 51-watt modules Isc = 3.25 amps, Voc = 20.7 volts
Batteries: 800 amp-hours at 12 volts
Loads: 5 amps dc and 500-watt inverter with 90 percent efficiency

**Description**
The PV modules are mounted on the roof. Single conductor cables are used to connect the modules to a roof-mounted junction box. UF two-conductor sheathed cable is used from the roof to the control center. Physical protection (wood barriers or conduit) for the UF cable is used where required. The control center, diagrammed in Figure 1, contains disconnect and overcurrent devices for the PV array, the batteries, the inverter, and the charge-controller.

**Calculations**
The module short-circuit current is 3.25 amps.
UL 125 percent: 1.25 x 3.25 = 4.06 amps
NEC 125 percent: 1.25 x 4.06 = 5.08 amps per module
The module operating temperature is 68°C.
The derating factor for USE-2 cable is 0.58 at 61-70°C.
Number 14 cable has an ampacity at 68°C of 20.3 amps (0.58 x 35) (max fuse is 15 amps).
Number 12 cable has an ampacity at 68°C of 23.2 amps (0.58 x 40) (max fuse is 20 amps).
Number 10 cable has an ampacity at 68°C of 31.9 amps (0.58 x 55) (max fuse is 30 amps).
Number 8 cable has an ampacity at 68°C of 46.4 amps (0.58 x 80).

The array is divided into two five-module subarrays. The modules in each subarray are wired from module junction box to module junction box and then to the array junction box. Number 10 AWG USE-2 is selected for this wiring, because it has an ampacity of 31.9 amps under these conditions, and the requirement for each subarray is 5 x 5.08 = 25.4 amps. Evaluated with 75°C insulation, a number 10 AWG cable has an ampacity of 30.8 amps (35 x 0.88) at 40°F (the J-box temp), which is greater than the actual expected current (125% of Isc) of 20.3 amps (5 x 4.06). In the array junction box on the roof, two 30-amp fuses in pull-out holders are used to provide overcurrent protection for the number 10 AWG conductors.

In this junction box, the two subarrays are combined into an array output. The ampacity requirement for the cable to the control center is 50.8 amps (10 x 5.08). A number 4 AWG UF cable (4-2 w/gnd) is selected for the run to the control box. It operates in an ambient

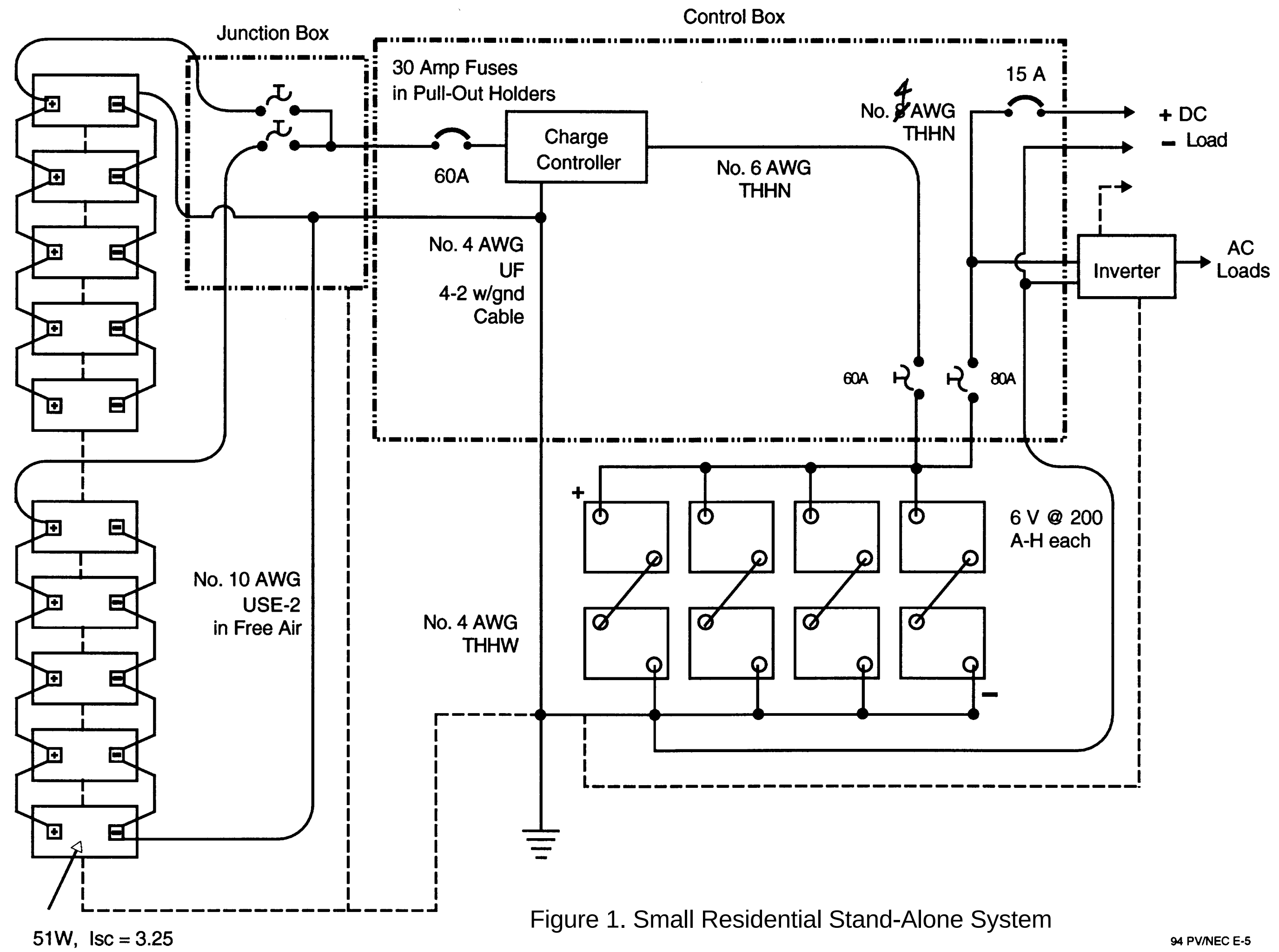


Figure 1. Small Residential Stand-Alone System

temperature of 40°C and has an ampacity of 57.4 amps (70 x 0.82). This is a 60°C cable with 90°C conductors. Care must be used when connecting to fuses that are rated for use only with 75°C conductors.

A 60-amp circuit breaker in the control box serves as the PV disconnect switch and overcurrent protection for the UF cable. The NEC allows the next larger size; in this case, 60 amps, which is over the 57 amps ampacity of the cable. Two single-pole, pull-out fuse holders are used for the battery disconnect. The charge circuit fuse is a 60-amp RK-5 type.

The inverter has a continuous rating of 500 watts at 10.75 volts and an efficiency of 90 percent at this power level. The ampacity requirement of the input circuit is 64.6 amps ((500 / 10.75 / 0.90) x 1.25).

The cables from the battery to the control center must meet the inverter requirements of 64.6 amps plus the dc load requirements of 6.25 amps (1.25 x 5). A number 4 AWG THHN has an ampacity of 85 amps when placed in conduit and evaluated with 75°C insulation at 30°C. This exceeds the requirements of 71 amps (64.6 + 6.25). This cable can be used in the custom power center and be run from the batteries to the inverter.

The discharge-circuit fuse must be rated at least 71 amps. An 80-amp fuse should be used, which is less than the cable ampacity.

The dc-load circuit is wired with number 10 AWG NM cable (ampacity of 30 amps) and protected with a 15-amp circuit breaker.

The grounding electrode conductor is number 4 AWG and is sized to match the largest conductor in the system, which is the array-to-control center wiring and the battery-to-inverter wiring.

Equipment grounding conductors for the array and the charge circuit can be number 10 AWG based on the 60-amp overcurrent devices [Table 250-95]. The equipment ground for the inverter must be a number 8 AWG conductor.

All components should have at least a dc voltage rating of 1.25 x 20.7 = 26 volts.

**EXAMPLE 2 Roof-Top Grid-Connected System**
Array Size: 24, 50-volt, 240-watt modules, Isc = 5.6, Voc = 62

Inverter: 200-volt dc input, 240-volt ac output at 5000 watts with an efficiency of 0.95.

**Description**
The roof-top array consists of six parallel-connected strings of four modules each. A junction box is mounted at the end of each string which contains a surge arrestor, a blocking diode, and a fuse. All wiring is THHN in conduit. The inverter is located adjacent to the service entrance load center where PV power is fed to the grid through a back-fed circuit breaker. Figure 2 shows the system diagram.

**Calculations**
The string short-circuit current is 5.6 amps.

UL 125 percent: 1.25 x 5.6 = 7 amps
NEC 125 percent: 1.27 x 7 = 8.75 amps

The array short-circuit current is 33.6 amps (6 x 5.6).
UL 125 percent: 1.25 x 33.6 = 42 amps
NEC 125 percent: 1.25 x 42 = 52.5 amps

The modules in each string are connected in series. The conductors operate at 63°C. The temperature derating factor for THHN at this temperature is 0.58. The required 30°C ampacity for this cable is 15.1 amps (8.75 / 0.58). Number 14 AWG cable has an ampacity of 25 amps with 90°C insulation and 20 amps with 75°C insulation so there is no problem with the end of the cable connected to the fuse since the 7 amps (the expected maximum current) is below either ampacity.

This cable is protected with a 9-amp fuse.

The cable from the string J-Boxes to the main PV disconnect operates at 40°C. The temperature derating factor for THHN with 90°C insulation is 0.91. This yields a 30°C ampacity requirement of 58 amps (52.5 / 0.91). Number 6 AWG meets this requirement with an ampacity of 75 amps (90°C insulation), and a number 6

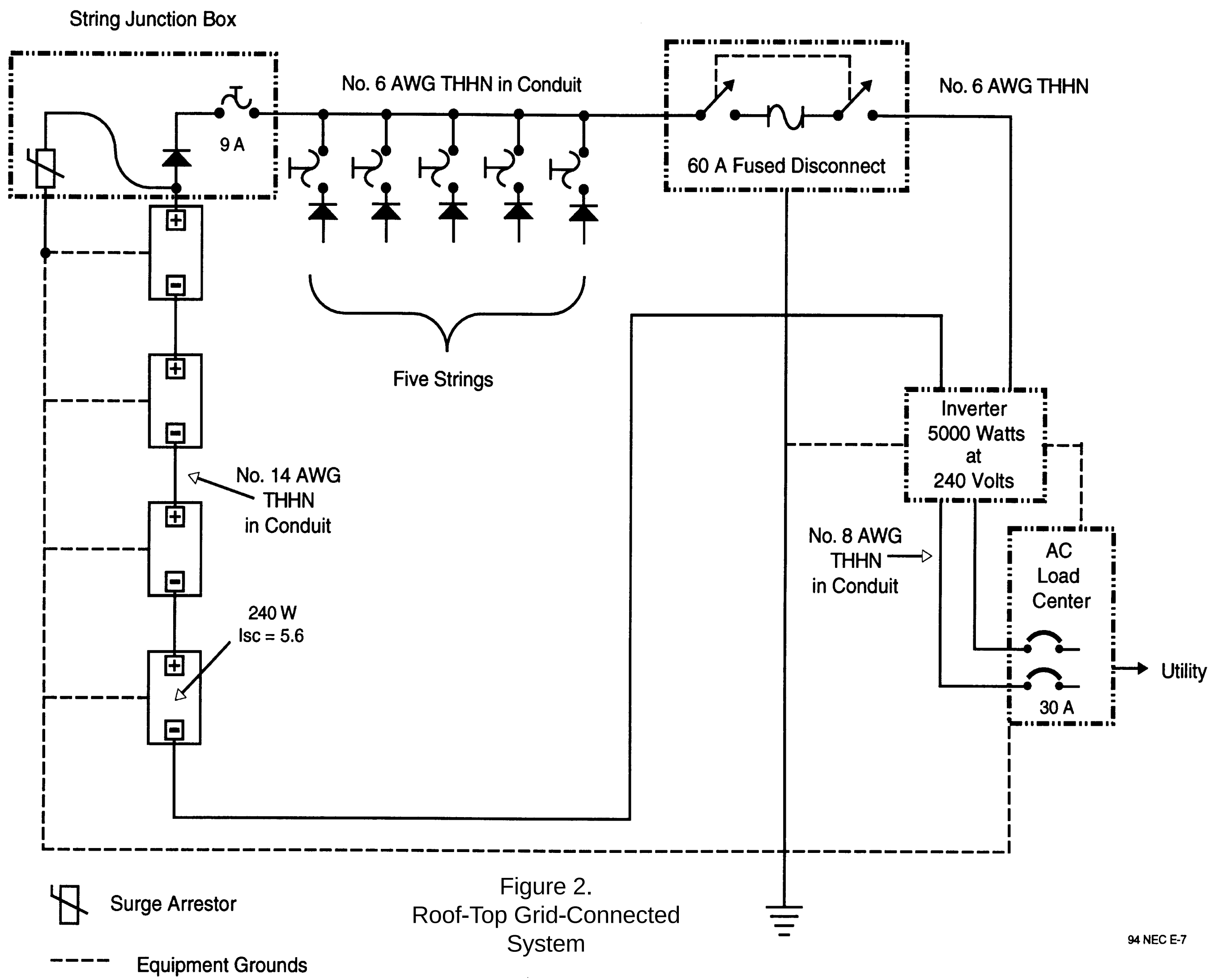


Figure 2.
Roof-Top Grid-Connected System

AWG cable with 75°C insulation has an ampacity of 65 amps, which also exceeds the 48 amp (42 / 0.88) expected current requirement.

Overcurrent protection is provided with a 60-amp fused disconnect. Since the negative dc conductor of the array is grounded, only a single-pole disconnect is needed.

The inverter output current is 21 amps (5000 / 240).

NEC 125 percent: 1.25 x 21 = 26 amps.

The cable from the inverter to the load center operates at 30°C. Number 8 AWG THHN (evaluated with 75°C insulation) has an ampacity of 50 amps.

A back-fed 30-amp, two-pole circuit breaker provides an ac disconnect and overcurrent protection in the load center.

The equipment grounding conductors for this system should be at least number 10 AWG conductors. The system grounding electrode conductor should be a number 6 AWG conductor.

All dc circuits should have a voltage rating of at least 310 volts (1.25 x 4 x 62).

**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. Oversizing the cables will lower voltage drop and increase performance, particularly where long cable runs are involved.

**Access**

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