Code Corner

Example Systems Stand-Alone Hybrid System

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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 example in this Code Corner will cover a complex residential hybrid PV system with a backup generator.

The system 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 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.

Medium Sized Residential Hybrid System

Array Size: 40, 12-volt, 53-watt modules
Isc = 3.4 amps, Voc = 21.7 volts
Batteries: 1000 amp-hours at 24 volts
Generator: 6 kW, 240-volt ac
Loads: 15 amps DC and 4000-watt inverter, efficiency = .85

Description

The 40 modules (2120 watts) are mounted on the roof in subarrays consisting of eight modules mounted on a custom single-axis tracker. The eight modules are wired in series and parallel for this 24-volt system. Five source circuits are routed to a custom power center. Single-conductor cables are used from the modules to roof-mounted junction boxes for each source circuit. From the junction boxes, UF sheathed cable is run to the main power center.

Blocking diodes are not used to minimize voltage drops in the system.

A prototype array ground-fault detector /array disabler provides experimental compliance with the requirements of NEC Section 690-5.

The charge controller is a relay type. Diversion loads are used to keep the batteries operating below 90% state of charge. The batteries are fully charged once a week.

DC loads consist of a refrigerator, a freezer, several telephone devices, and two fluorescent lamps. Peak current is 15 amps.

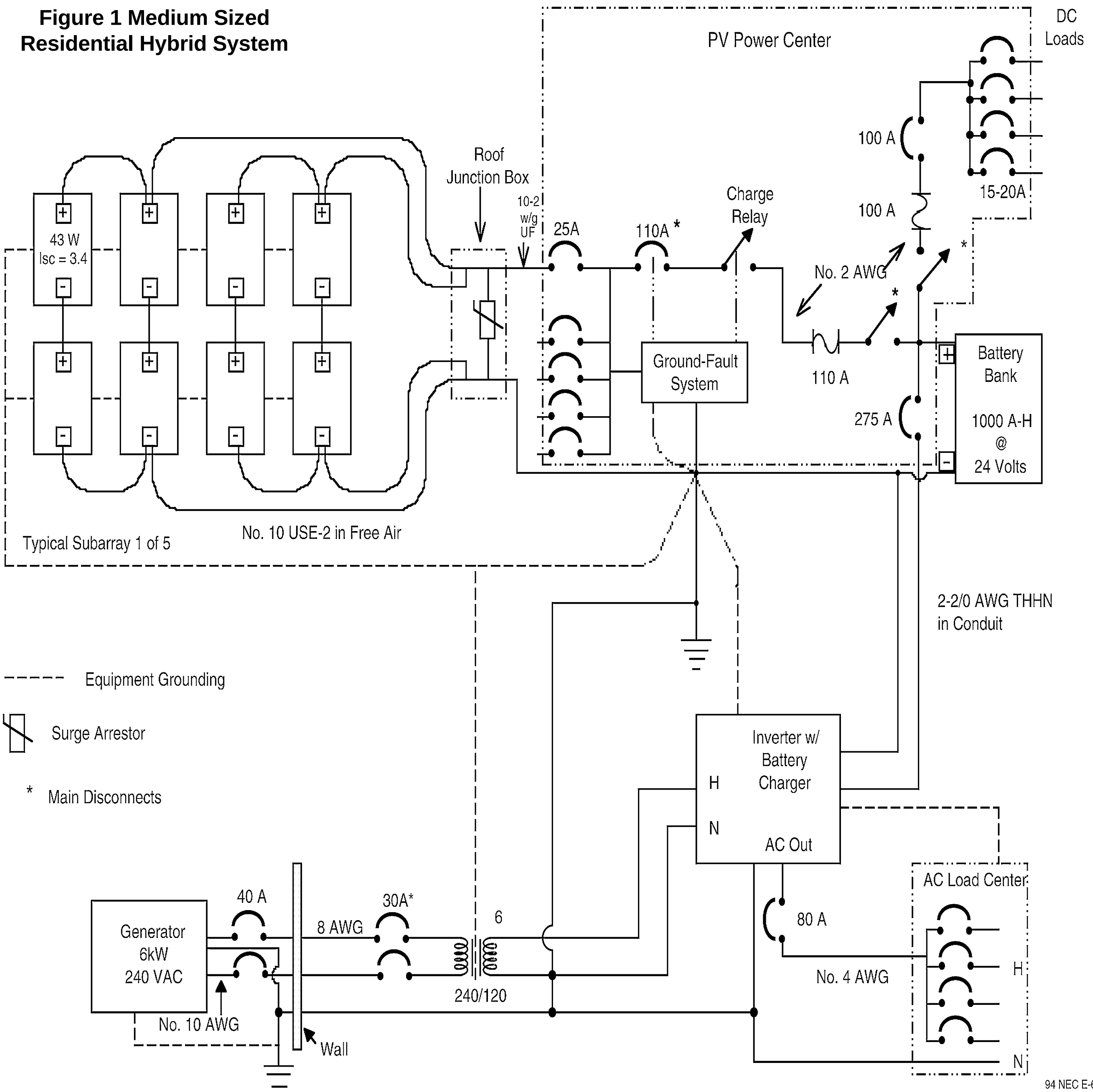
The 4000-watt sine-wave inverter supplies the rest of the house.

The 6-kW natural gas fueled, engine-driven generator provides back-up power and battery charging through the inverter. The 120/240-volt output of the generator is fed through a 6 kVA isolation transformer to step it down to 120 volts to deliver full power to the inverter and the house. Figure 1 presents the details.

Calculations

The subarray short-circuit current is 13.6 amps (4 x 3.4).
UL 125 percent: 1.25 x 13.6 = 17 amps
NEC 125 percent: 1.25 x 17 = 21.25 amps
The temperature derating factor for USE-2 cable at 61-70°C is 0.58.
The ampacity of number 10 AWG USE-2 cable in free air at 70°C is 31.9 amps (55 x 0.58).

Figure 1 Medium Sized Residential Hybrid System



The temperature derating factor for UF cable at 36-40°C is 0.82.

The ampacity of number 10-2 w/gnd UF cable at 40°C is 24.6 amps (30 x 0.82). Since the UF cable insulation is rated at 60°C, no further temperature calculations are required when this cable is connected to circuit breakers rated for use with 75°C conductors.

The source-circuit circuit breakers are rated at 25 amps.

The PV array short-circuit current is 68 amps (5 x 13.6).
UL 125 percent: 1.25 x 68 = 85 amps
NEC 125 percent: 1.25 x 85 = 106 amps

A 110-amp circuit breaker is used for the main PV disconnect after the five source circuits are combined.

A 110-amp RK-5 current-limiting fuse is used in the charge circuits of the power center, which are wired with number 2 AWG THHN (170 amps with 75°C insulation) conductors.

The DC-load circuits are wired with number 10-2 w/gnd NM cable (30 amps) and are protected with 20- or 30-amp circuit breakers. A 100-amp RK-5 fuse protects these discharge circuits from excess current from short circuits involving the batteries.

Inverter
The inverter can produce 4000 watts ac at 22 volts with an efficiency of 85 percent.

The inverter input current ampacity requirements are 267 amps ((4000 / 22 / 0.85) x 1.25).

Two 2/0 AWG USE-2 cables are paralleled in conduit between the inverter and the batteries. The ampacity of this cable (rated with 75°C insulation) at 30°C is 280 amps (175 x 2 x 0.80). The 0.80 derating factor is required because there are four cables in the conduit.

A 275-amp circuit breaker with a 25,000-amp interrupt rating is used between the battery and the inverter. Current-limiting fusing is not required in this circuit because there are no circuit elements that need protection from high short-circuit currents.

The output of the inverter can deliver 4000 watts ac (33 amps) in the inverting mode. It can also pass up to 60 amps through the inverter from the generator while in the battery charging mode.

Ampacity requirements, ac output: 60 x 1.25 = 75 amps This reflects the NEC requirement that all circuits not be operated continuously at more than 80% of rating.

The inverter is connected to the ac load center with number 4 AWG THHN cable in conduit, which has an ampacity of 85 amps when used at 30°C with 75°C overcurrent devices. An 80-amp circuit breaker is used near the inverter to provide a disconnect function and the overcurrent protection for this cable.

Generator
The 6-kW, 240-volt generator has internal circuit breakers rated at 27 amps (6500-watt peak rating). The NEC requires that the output conductors between the generator and the first field-installed overcurrent device be rated at least 115 percent of the nameplate rating ((6000 / 240) x 1.15 = 28.75 amps). Since the generator is connected through a receptacle outlet, a number 10-4 AWG SOW portable cord (30 amps) is run to a NEMA 3R exterior circuit breaker housing. This circuit breaker is rated at 40 amps and provides overcurrent protection for the number 8 AWG THHN conductors to the transformer. These conductors have an ampacity of 44 amps (50 x 0.88) at 40°C (75°C insulation rating). The circuit breaker also provides an exterior disconnect for the generator. Since the isolation transformer isolates the generator conductors from the system electrical ground, the neutral of the generator is grounded at the exterior disconnect.

A 30-amp circuit breaker is mounted near the PV power center in the ac line between the generator and the transformer. This circuit breaker serves as the ac disconnect for the generator and is grouped with the other disconnects in the system.

The output of the transformer is 120 volts. Using the rating of the generator, the ampacity of this cable must be 62.5 amps ((6000 / 120) x 1.25). A number 6 AWG THHN conductor was used, which has an ampacity of 65 amps at 30°C (75°C insulation rating).

Grounding
The module and DC-load equipment grounds must be number 10 AWG conductors. Additional lightning protection will be afforded if a number 6 AWG or larger conductor is run from the array frames to ground. The inverter equipment ground must be a number 4 AWG conductor. This size is based on the 275-300 amp overcurrent device between the battery and the inverter. The grounding electrode conductor must be 2-2/0 AWG or a 500 kcmil conductor.

The system uses two ground rods to provide additional surge protection and to minimize radio frequency interference. The ground rods are spaced ten feet apart and are bonded together with a number 2/0 USE cable.

DC Voltage Ratings
All DC circuits should have a voltage rating of at least 55 volts (1.25 x 2 x 22).

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.

In Home Power Magazine Number 49, the changes in the 1996 National Electrical Code will be discussed and how they impact the installation of PV systems.

Access
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