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The Photovoltaic Power System for the NCSU Solar House

About the NCSU Solar House

The North Carolina State University Solar House was built in 1981 in order to evaluate and demonstrate solar design and construction techniques and energy efficient technologies. It incorporates passive solar features such as a sunspace, trombe walls, and earth-berm insulation. The house also uses compact fluorescent lighting, a ground-coupled heat pump, and has both active solar water heating and photovoltaic (PV) systems.

The Solar House was resided in for three years after construction as a research project. It now serves as an educational and demonstration facility for the North Carolina Solar Center, which was established in 1988 to educate the public about solar energy and energy efficiency technologies.

The Solar House Photovoltaic System

One of the most interesting features of the Solar House is the photovoltaic (PV) power system. This system converts sunlight into electricity which can be used by appliances in the house and/or sold back to the utility company. The system is comprised of the major components described below and depicted in *Figure 2*.

The Photovoltaic Array converts sunlight into direct current (DC) electricity. The array converts about 8.5 % of the sunlight into DC electricity. PV modules available today can convert up to 14.5% of the sunlight into DC electricity. The PV array is made up of eighty 40 Watt PV modules with a total power rating of 3,200 Watts DC (3.2 kW) in full sun. The array is wired in a nominal 48 volt configuration. This is accomplished by wiring four 12 volt modules in series, which results in 20 parallel circuits at 48 volts. The photovoltaic modules are roof-mounted several inches above and parallel to the roof. A 4 inch air space beneath the modules allows free air circulation for improved module cooling and performance.

Figure 1. The south side of the NCSU Solar House.

The DC Combiner Box is an electrical junction box in the attic where the 20 parallel circuits from the PV array are brought together to form two output circuits that are routed to the inverter. The combiner box contains fuses for each of the 20 circuits and lightning surge arrestors for both of the output circuits.

The Charge Controllers regulate the charging current from the PV array to the battery bank. The controllers use pulse width modulation to precisely charge the batteries – preventing the batteries from being damaged from overcharge. Because the system is broken up into east and west arrays, this system uses two charge controllers.

The Inverter converts DC electricity produced by the PV array to alternating current (AC) electricity required by household appliances. It can convert up to 4,000 Watts (4 kW) of electricity continuously, and can handle surges up to 9 kW for a few seconds. The inverter is connected to the utility grid between the meter and the main service panel and is programmed to buy or sell electricity based on the PV array output and the Solar House's needs. The inverter is programmed to maintain the batteries at full charge until a utility outage occurs. In response to a utility outage, the inverter automatically disconnects from the

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utility line. However, the inverter continues to operate and provides power to dedicated circuits in the Solar House from the PV array and the energy stored in the system's batteries.

The Battery Bank stores electricity produced by the solar array. This energy is used to power dedicated emergency circuits in case of a utility failure. The battery bank is usually kept fully charged by the PV array. It is only discharged when utility power is not available to power the dedicated circuits in the house. The battery bank is composed of eight 12-volt sealed lead acid (also called absorbed glass mat) batteries. The batteries are arranged in two parallel strings of four batteries in series. Each of the strings are 48 volts. The battery bank is configured this way to match the voltage of the PV array.

The Battery Monitor keeps track of energy in and out of the battery and displays the state of charge of the battery bank. It is a fuel gauge to let the user know how much of their battery energy is remaining during utility outages.

The Ground Fault Protection Unit (GFP) ensures that there are no electrical faults or shorts in the PV array wiring. If faults are detected, the unit disconnects the PV array from the charge controllers and indicates a fault. The device is for fire protection.

The Power Module is a commercially available enclosure that houses the charge controllers, the inverter, the battery bank, and all of the code required AC and DC circuit breakers. It protects individuals from live electrical terminals and provides an attractive enclosure for these components.

The Uninterruptible Power Supply (UPS) Panel supplies power to five dedicated circuits in the house. These circuits are considered important in the case of a power outage. The inverter supplies power to the UPS panel from the PV array, batteries and the utility. In the event of a utility power outage, the inverter continues to power the UPS panel from the PV array and batteries. All other circuits in the house are connected to the main service panel and are not powered during a utility outage.

The Dual Meter Base is used to separately register electrical energy entering and leaving the Solar House. The two meters are connected in series with one meter being wired in the opposite direction of the other. Both meters have a ratchet mechanism that only allows them to rotate in one direction. One meter registers the energy imported from the utility and the other registers the energy exported to the utility.

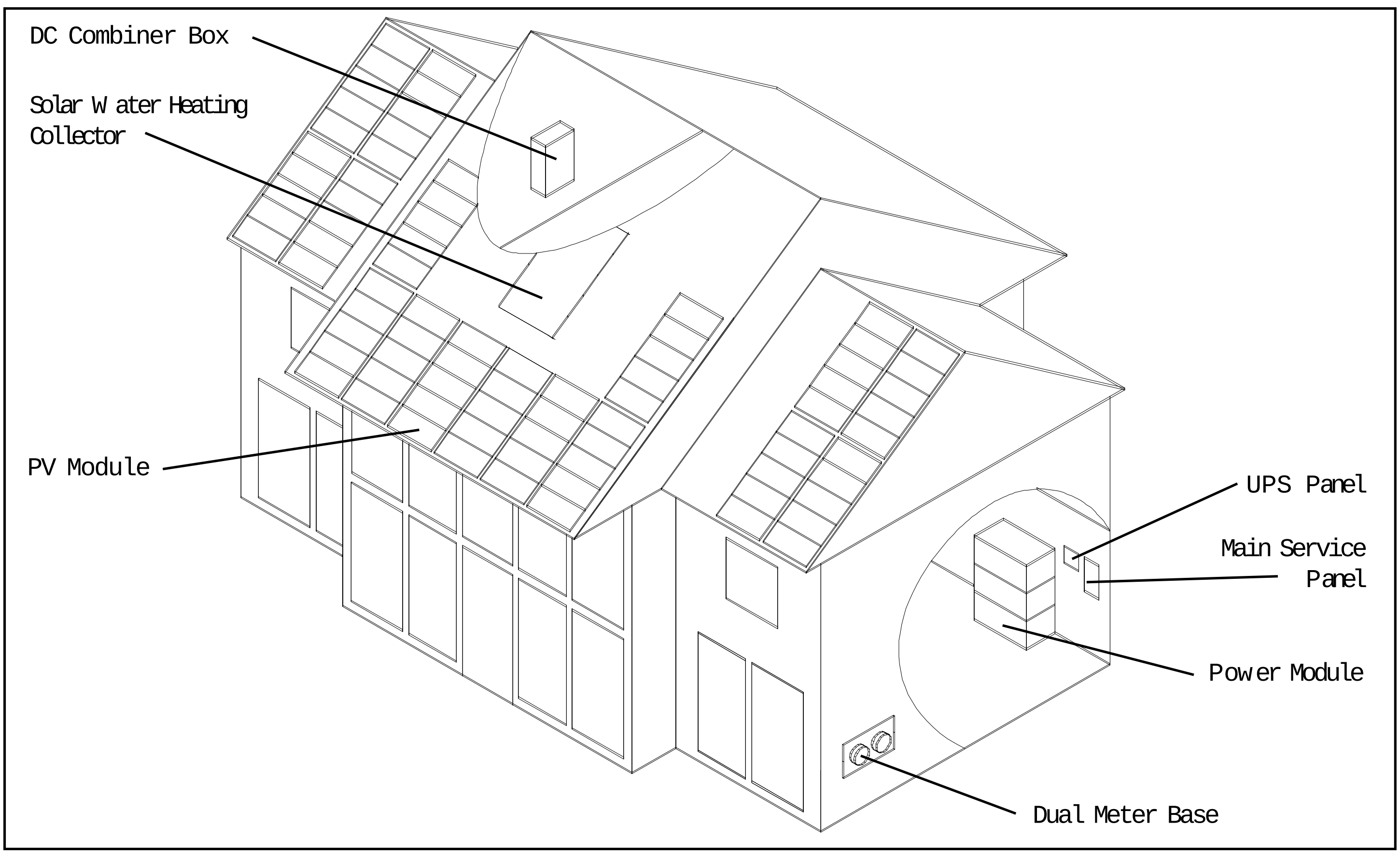

Figure 2. The NCSU Solar House PV System.

Monthly Energy Generation

The PV system's electrical generation is proportional to the sunlight available. *Figure 3* shows the solar energy available each month in Raleigh and the associated electrical energy generation capability of the Solar House's PV system. The average solar energy available for each day is presented in equivalent full sun hours.

Month	Full Sun Hours/day	Electrical Energy
Jan	3.8	239
Feb	4.5	256
Mar	5.2	327
Apr	5.7	347
May	5.7	359
Jun	5.7	347
Jul	5.6	352
Aug	5.5	346
Sep	5.2	317
Oct	4.9	308
Nov	4.1	250
Dec	3.6	227

Figure 3. Monthly Energy Production

The average household in North Carolina uses 12,000 kWh of electrical energy each year. A newly constructed energy efficient home would only consume about half as much electrical energy, or about 6,000 kWh. The Solar House's PV system produces approximately 3,600 kWh per year. Such a PV system could produce 30% of the electrical energy required by an average existing household and 60% of the energy required by a newly constructed energy efficient house.

System Costs

The cost of photovoltaics has decreased greatly over the past twenty years. In 1980, the installed cost of a residential scale PV system was about $30 per Watt of capacity. The current cost of a residential photovoltaic system similar to the one at the NCSU Solar House is between $8 and $12 per Watt of capacity (including all equipment and installation). This cost depends on a number of factors, such as the system's size, the installer's experience, and the amount of battery storage. Using an average system cost of $10 per Watt, the Solar House's system would cost $32,000 to install today.

Emergency Backup Power

A very attractive aspect of the Solar House's PV system is its ability to provide emergency backup power in the event of a utility power outage. Almost every year, North Carolina experiences extended power outages caused by hurricanes or ice storms. The Solar House continues to be comfortable in these situations because of its design. Critical circuits in the house, which include an outlet for the refrigerator and several other lighting and receptacle circuits, are all supplied by the PV system. In the event of a power outage, the Solar House's PV system will continue to power these dedicated circuits.

The Solar House batteries have enough energy storage to provide power for the refrigerator and moderate use (a few hours per day) of a radio, a computer, a television and several compact fluorescent light fixtures, for two entire days without sun. With only average winter sunshine, the system produces enough energy to keep the batteries charged and power the emergency circuits indefinitely.

This situation occurred in the fall of 1999, when Hurricane Floyd disrupted utility service. The inverter was able to power the dedicated circuits within the house using the batteries – namely the refrigerator, a computer, and some lights – through the night of the storm and well into the next day. When utility service was finally restored, the inverter automatically reconnected to the utility grid and the batteries were again allowed to fully recharge to be ready for the next power outage.

Figure 4. The Power Module (with covers removed) houses the inverter, batteries, charge controllers, and circuit breakers.

Maintenance and Reliability

The Solar House PV system is nearly maintenance-free. The weakest link in most PV systems are flooded lead acid batteries which require periodic watering to make up for water lost during heavy charging periods. The Solar House system uses sealed lead acid batteries which contain a gelled electrolyte that does not escape from the battery unless the battery is severely stressed – a condition that is avoided by using an appropriate charge controller. In addition, this system only relies on the batteries for emergency power and, therefore, will rarely cycle the batteries very deeply. In a stand-alone PV system where the batteries are repeatedly charged and discharged, batteries typically last only five years; however, as part of a backup system, the batteries at the Solar House should last at least 10 years.

Photovoltaic modules manufactured today typically come with at least a 20-year warranty. Expected module lifetimes are greater than 25 years. Module integrity can easily be checked every few years by measuring individual string currents and voltages in the DC combiner box conveniently mounted in the attic.

The inverter is a high quality unit that has been on the market and field tested for over five years. An inverter failure is not expected. If a failure does occur, it will easily be evident because the dedicated circuits will no longer be energized. The system includes an inverter bypass switch that can be used to transfer the dedicated circuits from the PV system to the utility. This allows the inverter to be removed and repaired without losing power to the dedicated circuits.

History

The photovoltaic system was originally donated to the North Carolina Solar Center by the Advanced Energy Corporation in 1992. The PV modules were manufactured by Solarex Corporation in 1983 and first used as a research project of Advanced Energy and Carolina Power and Light at CP&L's test site in New Hill, North Carolina. They were later moved to the Solar House with support from the Energy Division of the N.C. Department of Commerce and the Advanced Energy Corporation.

The original PV system on the house used ninety 40 Watt modules and had an operating array voltage of 225 volts DC. In 1999, the array was reconfigured to work as a 48 volt DC system to allow the addition of batteries. This was accomplished to demonstrate a system with backup power capability.

For more information

The North Carolina Solar Center also has the following fact sheets on photovoltaics available:

Photovoltaics: Electricity from the Sun (FS 108)

Photovoltaic Applications (FS 124)

Siting of Active Solar Collectors and Photovoltaic Modules (FS 112)

Photovoltaics: A Question and Answer Primer

Consumer's Guide to Buying Photovoltaics

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