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Small PV Systems Performance Evaluation at NREL's Outdoor Test Facility Using the PVUSA Power Rating Method

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J. Adelstein and W. Sekulic

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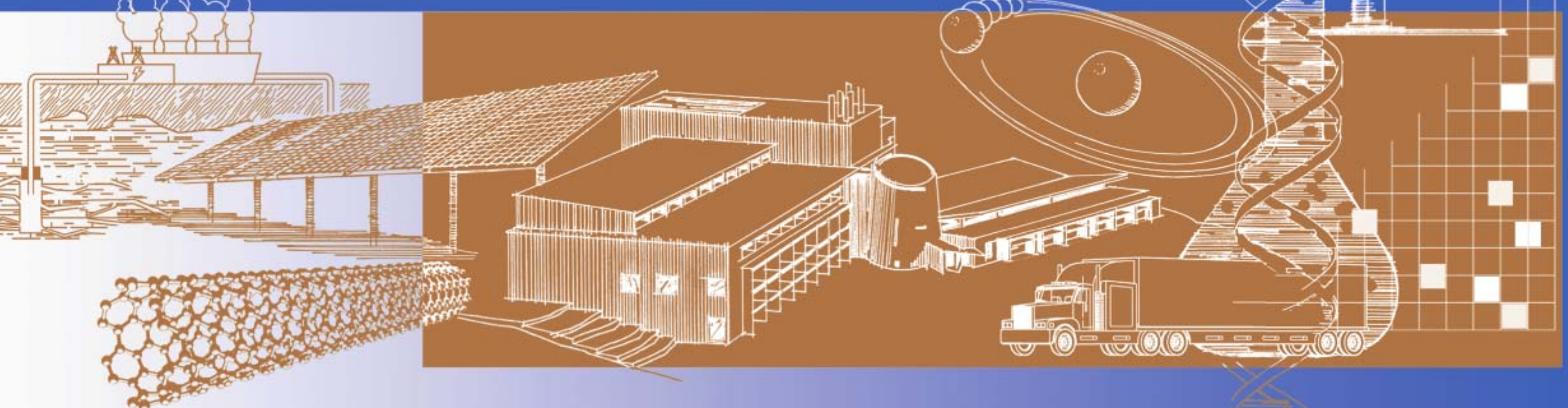

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J. Adelstein and W. Sekulic
National Renewable Energy Laboratory, 1617 Cole Blvd. Golden, CO 80401 jill_adelstein@nrel.gov

ABSTRACT

The PV Systems Performance and Reliability R & D group currently has seven grid-tied 1-2 kilowatt PV systems deployed at NREL's Outdoor Test Facility (OTF) and two 6 kilowatt systems mounted on the roof of NREL's Solar Energy Research Facility (SERF). The systems, which employ several PV module technologies including crystalline silicon (c-Si), amorphous silicon (a-Si), cadmium telluride (CdTe), and copper indium diselenide (CIS), are being monitored to determine the long-term performance and reliability of the modules and arrays under actual field conditions. The length of observation ranges from 2 months for our newest system to 11 years for our oldest systems. The annual degradation and seasonal fluctuation of the systems' power output are calculated using the PV for Utility-Scale Applications (PVUSA) power rating regression model.

1. System Descriptions

A typical 1kW system consists of anywhere between 5 modules for larger and/or high efficiency c-Si modules and 53 for smaller and/or lower efficiency a-Si modules. Strings of series wired modules are combined in parallel and both held at the system maximum power point and connected to the utility grid through an inverter. System voltages range from 35V to ~250V while system currents range from 2.5A to 17A. All of the OTF systems face true south and are mounted at a (latitude) tilt of 40 degrees with the exception of one system, which is mounted at a 30 degree tilt. Mounting systems at the OTF include Uni-Strut rack mounts, pole mounts and a simulated roof mount for an array of combination shingle/modules (see Figure 1).

Fig. 1. Typical OTF rack mounted PV system.

The two SERF systems are mounted on the SERF roof and face 158° (22° east of south) with a tilt angle from the horizontal equal to 45° due to building constraints. Kipp and Zonen CM11 thermopile pyranometers and Campbell Scientific 107 thermistor temperature probe are mounted in the plane-of-array of each system to measure POA irradiance and ambient temperature, respectively.

Campbell Scientific or National Instruments data acquisition systems (DAS) record in-situ data for the PV systems, which are is instrumented with sensors to measure various system parameters (see Figure 2). Parameters measured and recorded for the PV systems include: plane-of-array (POA) irradiance, DC voltage, DC current, AC power, and ambient temperature. DC power is calculated by the DAS by multiplying the DC voltage and DC current. Wind speeds are recorded with a Campbell Scientific DAS from NREL's Reference Meteorological and Irradiance System (RMIS), also located at the OTF, just north of most of the systems. Measurements are made every 5 s and stored as 15-min averages for the PV systems and 1-min averages for the RMIS wind speed data.

Fig. 2. Typical DAS using Campbell Scientific data logger.

2. PVUSA power rating analysis

The annual degradation and seasonal fluctuation of the PV system' power output are calculated using the PVUSA power rating regression model. The PVUSA rating system is based on the assumption that array current primarily depends on irradiance and that array voltage primarily depends on array temperature—which, in turn, depends on irradiance, ambient temperature, and wind speed [2]. Measured data can be used to calculate a best-fit correlation to the following equation:

$P = I_{POA} (a + bI_{POA} + cT_{amb} + dW)$,

where:

P = power (AC or DC), kW
I_{POA} = POA irradiance, W/m^2
T_{amb} = ambient temperature, ^oC
W = wind speed, m/s
a,b,c,d = regression coefficients derived from operational data

One-month blocks of 15-min average system performance and meteorological observations are used to obtain the regression coefficients above. Because the PVUSA model performance is poor at low irradiances, the POA irradiance inputs to the regression equation are restricted to $I_{POA} > 800\ W/m^2$. The measured power is restricted to $P_{DC} > \sim 0.75\ P_{DCmax}$ to eliminate data points where the array may be snow covered while the pyranometer is not.

After determining the regression coefficients, we find the PVUSA power rating for the system for each one month block by normalizing to PVUSA test conditions (PTC), where PTC conditions are defined as 1000 W/m^2 POA irradiance, 20^{o}C ambient temperature, and 1 m/s wind speed.

National Instrument's LabVIEW programs, originally developed at NREL by Keith Emery and modified for this paper, are used to combine the USSC data with the RMIS wind speed data and to perform the linear regression. LabVIEW's general linear-fit function was used to determine the set of linear coefficients using the least chi-square method. Monthly power ratings are then plotted to show the system performance vs. time.

3. Results and Accomplishments

Figure 3 depicts a typical a-Si system plot of PVUSA DC power rating vs. from September 1999 through July 2005 for irradiances greater than 800 W/m^2 and system power greater than 1100 W_{DC}.

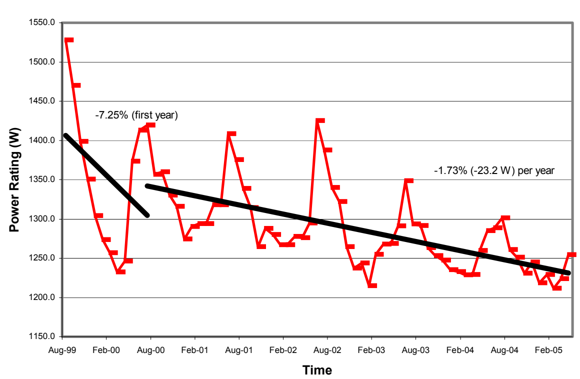

Fig. 3. PVUSA power rating vs. time plot for typical a-Si system.

The analysis clearly shows the initial six months to one year of rapid degradation (-7.25% from September 1999 to August 2000 in this case) characteristic of a-Si modules, followed by the typical seasonal oscillating power output also characteristic of a-Si modules, i.e. higher power output in the warmer summer months. The yearly maximum and minimum power ratings for this system varied by +6.6% and -3.8%, respectively, from the yearly mean power rating. In a paper summarizing performance characterization of a-Si modules from several manufacturers, Sandia National Laboratories found that previously unexposed a-Si modules showed an initial rapid degradation in power over the first 6 months and reached a "stabilized" power level, about 20% below the initial (1st day) power after about one year. Seasonal oscillation is usually ±4% from the "stabilized" level [1].

Through the PVUSA analysis described in this paper, we have observed annual degradations of between 1 and 3 percent per year. The photovoltaic (PV) industry wants a module technology that will last 30 years in the field. A PV module fails to provide service if its power output decreases by more than 30% after 30 years in its use environment.[2] Through careful measurement and analysis by the methods described above, we can identify possible failure mechanisms and help to determine solutions to these problems.

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