Johnson Space Center's Solar and Wind-based Renewable Energy System

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ABSTRACT

The NASA Johnson Space Center (JSC) in Houston, Texas has a Sustainability Partnership team that seeks ways for earth-based sustainability practices to also benefit space exploration research. A renewable energy gathering system was installed in 2007 at the JSC Child Care Center (CCC) which also offers a potential test bed for space exploration power generation and remote monitoring and control concepts. The system comprises: 1) several different types of photovoltaic panels (29 kW), 2) two wind-turbines (3.6 kW total), and 3) one roof-mounted solar thermal water heater and tank. A tie to the JSC local electrical grid was provided to accommodate excess power. The total first year electrical energy production was 53 megawatt-hours. A web-based real-time metering system collects and reports system performance and weather data. Improvements in areas of the CCC that were detected during subsequent energy analyses and some concepts for future efforts are also presented.

Keywords: renewable-energy, solar, photovoltaic, wind-turbine, space-exploration power

1 SYSTEM INSTALLATION

JSC Facility Operation managers and spacecraft engineers worked together to develop requirements for a renewable energy system which would benefit both communities. The JSC CCC includes a 13066 square foot building on an acre of land, and includes classrooms, offices, and a kitchen. It was originally constructed in 2000, and accommodates approximately 130 children and 34 teachers and administrators. The CCC was selected as the site for installation of this renewable energy gathering system for several reasons: 1) the size of the facility allowed for some installation flexibility, 2) the tie-in to the electrical grid was uncomplicated, and 3) it would provide excellent education opportunities. For Engineering, the installation is intended to provide a potential test bed for: 1) space exploration power generation concepts and 2) remote monitoring and control of lunar surface and other planetary-body power generation systems. For Operations, the new power-system will help meet government-wide requirements to increase the use of renewable energy at federal facilities.

The multi-platform renewable energy system consists of: 1) several different types of photovoltaic panels, 2) two wind-turbines, and 3) one solar thermal water heater. The electrical power production available from the system is 32kW peak, and all the power is used directly at the facility or, if excess power is available that the facility cannot use, a tie to the JSC local electrical grid has been provided. The system also includes a roof-mounted solar thermal collector connected to an 80-gallon storage tank that can provide most of the hot water needs of the CCC. A web-based real-time metering system that collects and reports system performance and weather data is included with the system. This renewable energy system installation was completed in September 2007.

2 PHOTOVOLTAIC PANELS

Solar photovoltaic (PV) panels were obtained from three manufacturers with three mounting fixture types. Two of the fixture types provide dual-axis tracking capabilities using a solar tracker as controller. First, an array of eight "large" tracking fixtures was located between the CCC parking lot and the access road to the CCC. Each of these large trackers supports an array of 16 Kyocera Multi-Crystal PV panels (manufacturer's efficiency rating of 16 percent). Second, an array of three "small" tracking fixtures was located to the south of the CCC parking lot. Each of the small trackers supports an array of eight PhotoWatt PW1250 panels (manufacturer's efficiency rating of 16 percent). These three small trackers are also specifically configured to allow for individual position monitoring and control of each fixture. The third fixture type is a stationary, decorative, "lollipop" fixture; three of these were located directly adjacent to the children's playground at the CCC. Seasonal adjustments can be made manually with this fixture type. Each of the three lollipop fixtures supports an array of four Schott ASE-270-DFG/50 panels (manufacturer's efficiency rating of 17 percent). Each of the large photovoltaic fixtures with 16 panels per fixture is connected to its own KACO Blue Planet 3601 xi Grid-Tied inverter. The array of small trackers and the array of lollipop fixtures are each tied to a single KACO Blue Planet 3601 xi Grid-Tied inverter at the array level, for a total of ten KACO Blue Planet 3601 xi Grid-Tied photovoltaic array inverters.

3 WIND TURBINES AND SOLAR WATER HEATER

Two wind turbines were installed in an effort to gage the effectiveness of these devices in a location such as the JSC CCC, located 25 miles inland from the Texas Gulf coast. Two 1.8 kW wind turbines (SkyStream 3.7 Residential Power Appliance) were installed between the large and small tracking photovoltaic arrays. Each of these turbines has a rated capacity of 1.8 kW at about 20mph wind with a peak power output of 2.4 kW. Each of the wind turbines has a cut-in wind speed of 8mph, and is connected to the CCC facility with a Southwest Windpower inverter.

A roof-mounted, solar hot water panel (HELIODYNE Gobi Solar Collector) and an 80-gallon Bradford-White storage tank were the final components of this renewable energy installation project. Water-glycol is used as the heat transfer fluid.

4 PHOTOVOLTAIC ANALYSES

System efficiency analyses focused on each solar array's efficiency measurement based upon the real-time data collected within the integrated system. The solar array panel manufacturers provided expected efficiencies of 16, 16, and 17 percent as mentioned above. Due to the proprietary nature of the manufacturer's processes, algorithms used by each manufacturer to assess the differences in efficiency analysis were not available.

The system sensors at the JSC CCC provide, among many other data points, the real-time irradiance measured at the panels. Additionally, the power output of each array system is also collected and stored. Maximum power, minimum power, and average power output is reported. These sensors report out readings over a 15 minute interval during a 24 hour period; consequently, the maximum power reading over the interval is the highest power reading, the lowest power reading, and the average power reading over the 15 minute interval.

A derivation of the solar cell energy conversion efficiency is used to determine the array power output efficiency over time. In this equation, the real-time irradiance measures are used in lieu of the Standard Test Condition (STC) irradiance. The resulting equation is:

$$\acute{\eta} = P_m / E \times A_c \quad (1)$$

where:

$\acute{\eta}$ = percentage of power converted and collected
P_m = maximum power point
E = irradiance
A_c = total surface area of the solar cell(s)

Currently the data is downloaded into a Microsoft Excel Workbook on a monthly basis. The next phase of analysis will focus on transitioning the data into MatLab for a more robust 'post-processing' of the data. Figure 1 provides an example of the early springtime (March 2008) efficiency analysis of all three solar array sets on a sunny day.

Clear differences can be seen in the performance of the articulating array sets versus the fixed array set (blue line). "Operational efficiency" is presented, which includes the effect of sun angle. Thus, the fixed array has much lower efficiency in the early morning and late afternoon due to poor incidence angles. The efficiency spikes at either end need further investigation, but are expected to be the result of combined sensor anomalies in the maximum power reading and of the irradiance reading not being correlated correctly.

5 WIND TURBINES AND SOLAR WATER HEATER PERFORMANCE

Total power production from the two wind turbines for the year 2008 was 2400 kWh. Except for low wind speeds at certain times of the year, the turbines have operated most of the time. Monthly total energy production from the wind turbines is shown in Figure 2, and the data strongly suggests that the wind resource is seasonal.

An effort is underway to add flow and temperature sensors to the solar hot water system so that performance measurements can be made. From observations that can be made currently, the solar water heater appears to be functioning as expected, supplying a substantial portion of the hot water needs of the CCC, with the balance supplied by the natural-gas-fueled backup heater.

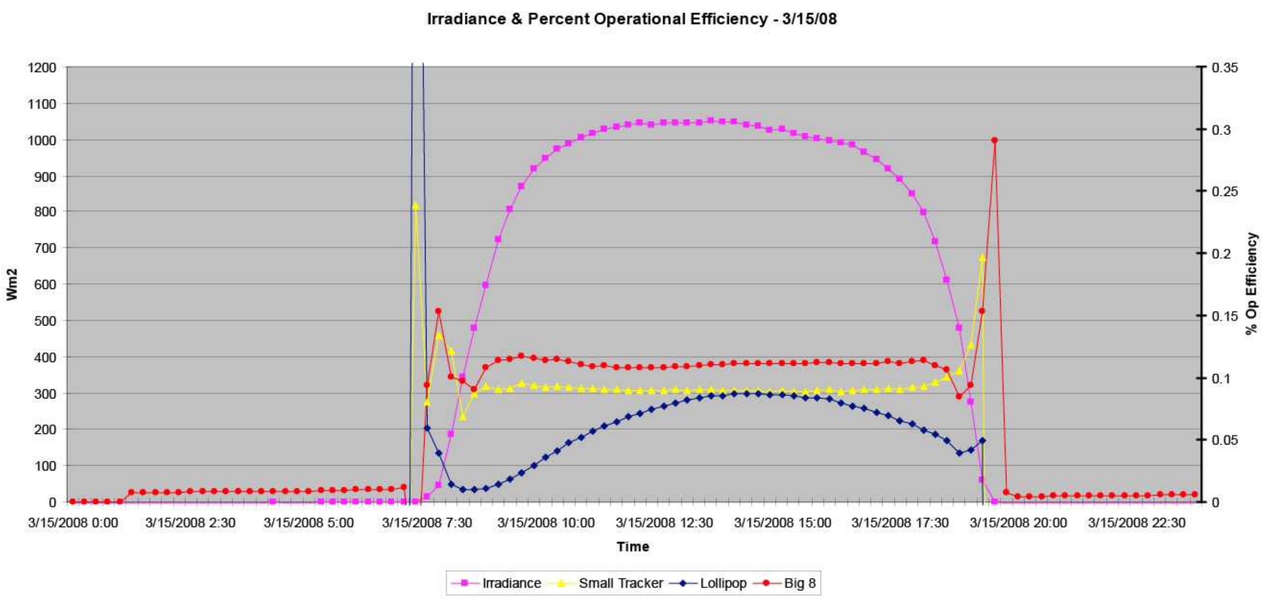

Figure 1: Array efficiency analysis for March 15, 2008

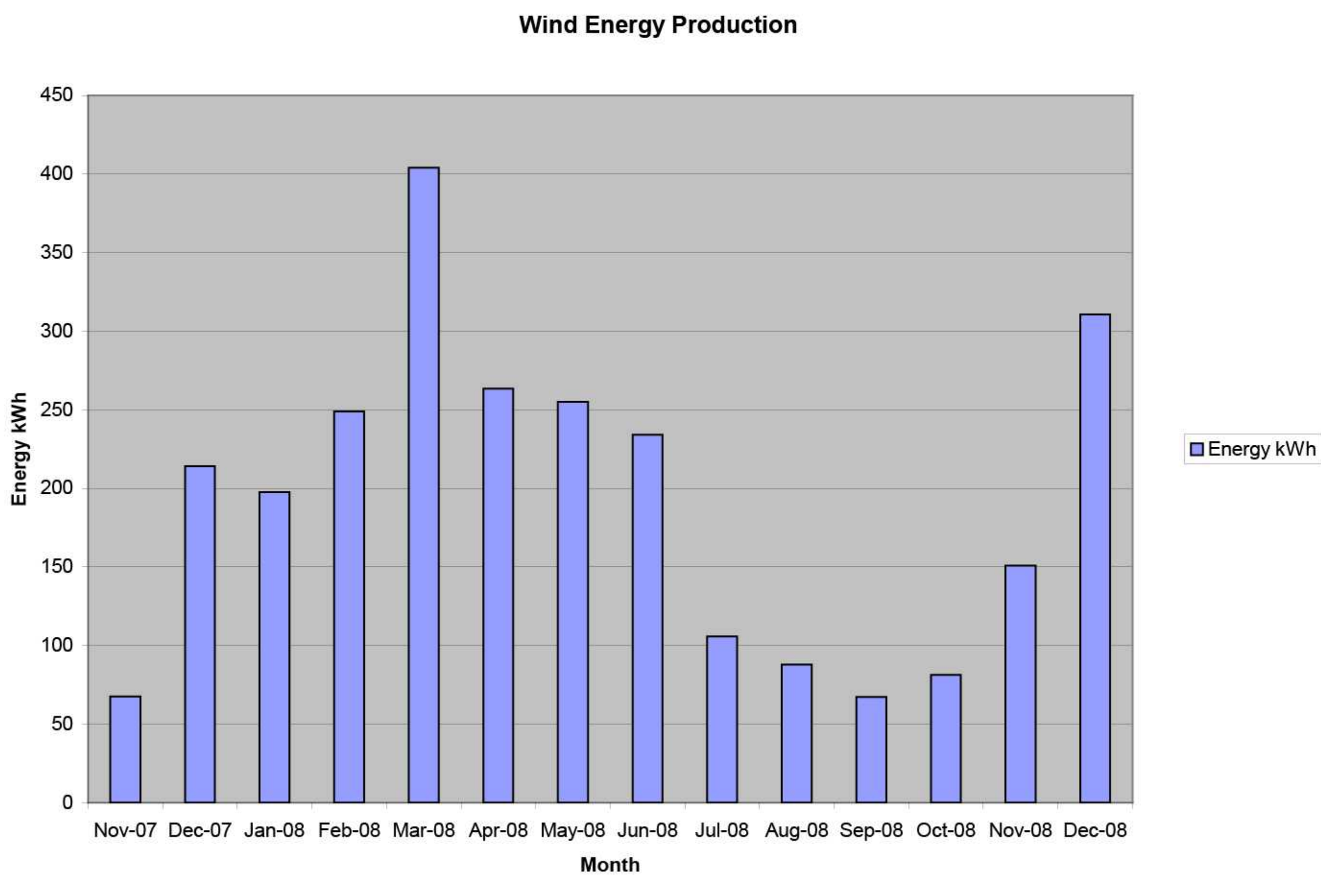

Figure 2: Monthly Wind Energy Production

6 ADDITIONAL ENERGY EFFICIENCY IMPROVEMENTS

The CCC renewable energy gathering system is equipped with instrumentation to gather data from the system's components to process performance results for: 1) the CCC overall energy usage, 2) the energy provided by the renewable energy gathering system just described, and 3) the weather and solar data at the CCC site. The data is sent by cell-modem from the CCC to Fat Spaniel's server in near real-time. This data is currently available for storage and download at Fat Spaniel's web-site as a web-based display with both simple and detail view formats. The web pages can be viewed by the general public from Fat Spaniel's web site under Sacred Power, the installer of the system.

Following the initial installation and operation of the CCC renewable energy gathering system in 2007, additional energy efficiency improvements were identified and pursued. Programmable thermostats were installed to reduce air conditioning power during periods of CCC non-use, such as weekends. Solar shades and attic ventilation fans were added to the windows and roof. A high efficiency washer/dryer set replaced the original units. An Energy-Star refrigerator, freezer, and ice-maker, and a pilot-less natural gas stove, replaced the original units. The condenser and evaporator of the walk-in refrigerator where upgraded to Energy Star units, and the condenser was remounted in the CCC attic to provide a significant improvement in CCC overall building energy efficiency. A study is under way examining the potential performance improvements that a ground-coupled-cooling system addition to the CCC's air-conditioning system could offer. These efficiency improvements have resulted in measurable reductions in total building energy use and thus an increase in the renewable energy percentage for the CCC.

7 POTENTIAL FUTURE SPACE EXPLORATION STUDIES

The final design of the solar power tracking system of the small-tracker photovoltaic array included control and instrumentation features mounted on the three support and tracking fixtures which are envisioned to allow for the future study of control methodologies similar to those that might be used for lunar (or other extra-terrestrial) power systems. As the final design was developed, it became apparent that the web-based monitoring and reporting system provided by Fat Spaniel would be sufficient to cover the near term needs of the power system installation. The three trackers are currently controlled with sun-trackers, similar to the large tracker photovoltaic panels.

Advanced space exploration power systems development is an application area envisioned to also benefit from this installation. The photovoltaic panels could be configured so that their direct current electrical power output could be used to provide operating power for a regenerative fuel cell power system, whereby a water electrolysis unit (hydrogen generator) would split water into its constituent gases, with the hydrogen either stored for future use, or delivered directly to another process. The hydrogen storage and a fuel cell power plant combined with the photovoltaic panels and hydrogen generator would provide the building block components of a regenerative fuel cell system, similar to those envisioned for extra-terrestrial surface mobility power systems or stationary continuous power systems. Figure 3 shows a simple layout of a regenerative fuel cell system.

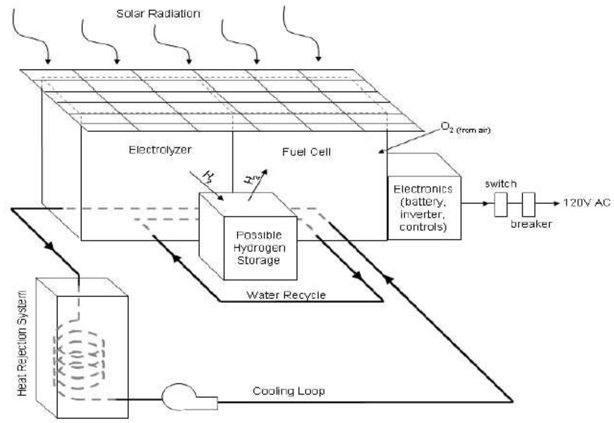

Figure 3: Regenerative Fuel Cell System Concept

8 CONCLUSION

The power system building blocks that exist currently, as well as others that could be added to support future studies, provide meaningful results supporting renewable energy developments.

The total first year renewable energy production from the JSC Child Care Center was 53 megawatt-hours. The additional improvements in the building's energy efficiency have resulted in an approximate 20 percent reduction in the total energy needs of the JSC CCC. This estimate is based on data available from the months of November 2007 and November 2008, which were the first two months separated by a year's time for which CCC energy data was available. Between these two months, the bulk of the energy efficiency improvements outlined in Section 6 of this document were installed.

This system has also offered less tangible benefits in that it is visible to the children attending the JSC CCC, and it has the potential to instill seeds of innovation and understanding, and to inspire both the young and older that witness its capabilities.

REFERENCES

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