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# ADVANCED PARABOLIC TROUGH FIELD TESTING – REAL-TIME DATA COLLECTION, ARCHIVING, AND ANALYSIS FOR THE SOLARGENIX ADVANCED PARABOLIC TROUGH

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## ABSTRACT

Solargenix Energy is currently constructing a 64-MWe parabolic trough solar plant in Eldorado Valley, Nevada, just south of Las Vegas. As part of the preparation for construction and operation of the new utility-scale solar plant, Solargenix has collaborated with UNLV and NREL to build a collector test row. The test row is serving as a platform for field testing advanced parabolic trough components before their large-scale deployment. The test row consists of two Solargenix Solar Collector Assemblies (SCAs); each SCA has 12 collector modules (space frames and mirrors). This facility has been used to field test new Solargenix designs for first and second generation collector space frames, advanced reflectors, advanced local controllers (AdLoCs), a hydraulic-based drive system, receiver support arms, low-cost injection-molded bearings, ball joints and collector support pylons. The test-row facility also has equipment for monitoring the following weather data: direct normal irradiance, dry bulb temperature, relative humidity, wind speed and precipitation. Data logging equipment is used to record and track weather data as well as SCA parameters. Site instrumentation is solar-powered (photovoltaics) and uses cellular technology to transmit data to a web-based data collection system. This paper describes construction of this facility, the installation of the data-collection system and some data collected to date.

## INTRODUCTION

In cooperation with the National Renewable Energy Laboratory and the U.S. Department of Energy, Solargenix has been developing an advanced parabolic trough for utility-scale solar power plants. The first large solar power plant to be constructed by Solargenix will be a 64 MWe plant located in Eldorado Valley near Boulder City, Nevada. This project was initiated to test the advanced components prior to the installation of the 64 MWe plant and for the 1 MWe Arizona Public Service Saguaro Solar Trough Generating Station located in Redrock, Arizona. In collaboration with UNLV and as part of the work at Eldorado Valley, two Solar Collector Assemblies (SCAs) were erected, exclusive of the receiver tubes, so that mechanical testing could be completed, proper fit and function can be demonstrated, and installation methods can be verified and improved. Included in the equipment being tested at the site are Advanced Local Controllers (AdLoCs), which have been newly developed, to control the sun tracking of the parabolic troughs using a new hydraulic-based drive system. Receivers will be added at a later time so that the SCAs can also be tested for thermal performance.

**Figure 1. Artist conception of the 64 $MW_e$ solar trough plant in Eldorado Valley (Graphic from Solargenix).**

As part of the scope of work for the project, data logging instrumentation was needed to measure and record weather, solar irradiance, battery voltages, and tracking parameters of the SCAs. Because of the remote location of the test site and the absence of utilities, the instrumentation is solar powered and uses cellular technology to transmit the data to a web-based data collection system with real time capabilities. A website was developed to give access to the data and the real time displays. The remote monitoring of the AdLoCs and SCAs allows researchers involved in the development of the various components to see their operation in real-time through the Internet and also evaluate their performance through archived data. Analysis of the solar and weather data is required to determine such things as available energy, temperatures, maximum wind speeds and directions, and precipitation for the Eldorado Valley site. This data is important for the characterization of the site as no site-specific data was previously available. Remote monitoring using web cameras, which also display to the website and archive images for later review, was also developed for the site. Lessons learned during the assembly and function of the components can then be used in the construction and operation of future plants.

## LOCATION

The solar test facility is located on Eldorado Valley Drive approximately 2 miles (3.2 km) west of U.S. Highway 95 in Eldorado Valley which is located southwest of Boulder City, Nevada and 40 miles (64.4 km) southeast of Las Vegas, Nevada. Boulder City has designated 6,000 acres of land in Eldorado Valley as a Solar Enterprise Zone for the development of solar energy projects. This zone is excluded from a conservation easement within the valley that is managed for the conservation, protection, restoration, and enhancement of the desert tortoise and its habitat [1].

**Figure 2. Installation of the Solar Collector Assemblies at the test site (Photo from Solargenix)**

Three existing 500-kV substations are within a few miles of the Solar Enterprise Zone in Eldorado Valley: Southern California Edison's Eldorado Substation, Los Angeles Department of Water and Power's McCullough Substation, and the Marketplace Switching Station. These substations connect the transmission systems of California, southern Nevada, and Arizona. Also located two miles (3.2 km) further to the west of the site, on Eldorado Valley Drive, is the El Dorado Energy 480 MW combined-cycle gas turbine power plant owned in a partnership between Reliant Energy and Sempra Generation. A 100 kW photovoltaic plant was installed adjacent to the plant when the 480 MW El Dorado plant was built. A second 600 MW power plant, called Copper Mountain Power generating station, has been proposed for construction adjacent to the El Dorado plant and has received all key permits [2].

Two major Southwest Gas natural gas pipelines transect Eldorado Valley. One pipeline is immediately adjacent to U.S. Highway 95, and the other pipeline is approximately 1 mile (2 km) west of the highway and runs adjacent to the test site and the proposed Solar Enterprise Zone facility. Both pipelines are main supply lines for the Las Vegas area.

The proximity of the substations and natural gas pipelines are important for the development of the future plant in that it will provide access to the power grid and also provide a natural gas source for supplemental boilers used to maintain heat transfer fluid temperatures during periods of low solar flux.

## DESIGN

Solargenix Energy has developed an advanced-generation trough concentrator that uses an all aluminum space frame [3]. This design is patterned after the size and operational characteristics of the Luz LS-2 collector which is a proven design with years of field operation at the Kramer Junction Facility in California. The new design is superior to the LS-2 collector in terms of structural properties, weight, manufacturing simplicity, corrosion resistance, manufacturing costs, and installation ease. Finite element models of the LS-2 and the new space frame design were developed to assess both structures accurately and show that the new space frame matches the LS-2's torsional stiffness and is superior to the LS-2 in terms of beam stiffness. Detailed and comprehensive wind tunnel testing was also conducted as part of the structural analysis. In addition the design emphasizes simplicity in fabrication and a minimum number of required parts [3].

## INSTALLATION

As part of the work, two Solar Collector Assemblies (SCAs), exclusive of receiver tubes and only partially outfitted with parabolic mirrors, were erected (Figure 2). This included the construction of 23 concrete pier foundations and the installation of 25 support pylons. Twenty-four prefabricated space frame modules, 12 for each SCA, were then assembled in the field and erected onto the support pylons. These were connected to the two prototype Solargenix hydraulic drive units previously installed atop the support pylons.

The collector design utilizes a new low-cost injection-molded two-piece bearing with the bearing shaft assembly that supports the ends of the space frames [4]. The receiver arm support is also a new design, although it is based on those used on the LS-2 collector. These receiver supports are designed to accommodate the larger angular swing of the hinged connection at the base of the receiver support, which is necessary because of the longer SCA length of the Solargenix design. The new design also uses the same support arm for the different locations on the collector to gain economy in manufacturing by limiting the number of different parts needed. New ball joint assemblies were also installed. These are different than the ball joint assemblies used on the LS-2 collectors in that they must accommodate twice the thermal expansion of the receivers since twelve modules are used per SCA and not just six as used with the LS-2 collector design. After the modules were erected, parabolic-shaped glass mirrors were installed onto the space frames. The Solargenix trough module has a 5-meter (16.4 ft) aperture width and spans four separate glass panels, two inner panels and two outer panels installed symmetrically relative to the trough vertex. Five sets of these mirror columns comprise one collector module, and twelve modules comprise one SCA.

**Figure 3. NREL researcher conducting VSHOT testing of the SCA modules (Photo from NREL).**

**Figure 4. Instrumentation test shed located at the test site with camera box, weather station, Normal Incidence Pyrheliometer, and photovoltaic panels located on the roof.**

Solargenix engineers participated in the assembly process with particular interest in seeking ways to speed the process for larger installations. Prior to erection, the rotational straightness of each of the modules was checked using a precision inclinometer at each end of each module [5]. These measurements showed that the amount of "twist" along each module was well within specified tolerance. Several ways of speeding the assembly process were devised during the course of assembling the space frames, and these improvements were incorporated into those space frames used on the 1-MWe solar plant in Arizona. Changes were also made to support pylon spacing and module design from lessons learned during the SCA assembly.

After the installation of the mirrors, NREL researchers used the Video Scanning Hartmann Optical Test system (VSHOT) to characterize the optical quality of the new SCA design (Figure 3). Vertical VSHOT data profiles spanning the aperture were made for two randomly selected locations on each module including some repeat scans taken after some module alignment adjustments were made. VSHOT software was then used to analyze this data to determine overall optical rms slope errors relative to an ideal parabolic contour, providing information on the shape and tilt of the individual panels. The value of the optical accuracy of the concentrators was found to satisfy the Solargenix design specification [5].

Two newly designed Advanced Local Controllers (AdLoCs) were installed to control the sun tracking and operation of the two SCAs. The AdLoCs were wired into a central laptop computer that serves as a Field Controller Supervisor (FCS). The hydraulic drive units, AdLoCs, and Field Controller Supervisor computer are all powered with a 500 W photovoltaic system with battery storage and a 110 V inverter. The photovoltaic system and FCS computer are located in an instrumentation shed located at the site as seen in Figure 4.

## INSTRUMENTATION

Data logging instrumentation was installed to measure and record weather, solar irradiance, battery voltages, and tracking parameters of the SCAs. Because of the remote location of the test site and the absence of utilities, the instrumentation is solar powered and uses cellular technology to transmit the data to a web-based data collection system with real time capabilities.

The data collection system uses a Campbell Scientific Incorporated (CSI) CR23X Micrologger for data acquisition. The data logger is connected to an AirLink Communications Raven CDMA C3210 cellular modem. The system is powered by a 12 V, 75 A-hr deep cycle lead acid battery which is recharged by a CSI model MSX64R regulated solar panel. The dry bulb temperature and relative humidity are measured using a CSI model HMP45C temperature and relative humidity probe. Wind speed and direction are measured using a CSI Met One 034B-L windset. Precipitation is measured with a CSI model TE525 Tipping Bucket Rain Gage. Tracking data from the Field Controller Supervisor (FCS) computer for the AdLoCs is sent through a serial cable to the datalogger.

The direct normal irradiance (DNI) is measured with an Eppley Normal Incidence Pyrheliometer (NIP) mounted on a Li-Cor model LI-2020 Automatic Solar Tracker. This is powered by the 110-V AC power supply from the photovoltaic solar array. Back-up power is provided by the 12-V battery through a 12 to 18 V DC power converter.

Data is transmitted using CDMA cellular to a local cell site where it is ultimately connected to the Internet. The data is accessed from the Internet using Transmission Control Protocol/Internet Protocol (TCP/IP), the suite of communications protocols used to connect hosts on the Internet. TCP/IP is built into the UNIX operating system, is used by the Internet, and is the standard for transmitting data over networks. The data are collected for archiving and analysis at the University of Las Vegas, Nevada Center for Energy Research using CSI Loggernet software. CSI's Baler software is used to bundle the data for archiving and Real-Time Data Monitoring Software (RTDM) is used to provide real-time plots for display on the web pages.

Remote monitoring of the site using web cameras, which also display to the website and archive images, was also developed for the site. The system uses four Silent Witness SWC20 Series CCTV cameras. These are connected to an Axis Communications model 2400+ Video Server. The video server is connected to an AirLink Communications Raven CDMA C3210 cellular modem. Additional remote color images are taken using an Axis Communications model 2100 Network Camera that can also be connected to the Raven modem. The system is powered from the 110-volt AC power supply.

Images are sent via the cellular modem to the Internet using File Transfer Protocol (FTP) to the web server at the university where they are archived for later review. A Perl script in the web page directory is used to select the most recent images in the archive and post them to the website allowing remote viewing of the current site images. Streaming video to the university from the video server is possible but it can use excessive bandwidth. Changes to the image download rates are made remotely from the university.

## DATA

The two groups of data that are monitored are Real Time Data and Slow Data. Real Time Data are measured and recorded in two second increments and includes the date, time, AdLoC tracking data including the calculated sun angle, the collectors tracking angles, and sun sensor voltages that can be used in real time display for remote monitoring and detailed evaluation of the tracking parameters. The Slow Data, which are recorded in one minute increments, also includes the date, time, and 72 of the AdLoC tracking parameters. They also include the air temperature, relative humidity, wind speed and direction, precipitation, DNI, and the two photovoltaic systems battery voltages. The Slow Data are used to monitor long term tracking variables, calculate available energy, and used in characterizing the weather parameters for the site. Slow Data for the site are archived monthly and are available on the website as comma delimited text files.

The current data for the site can be viewed on the website in continuously updated 12 hour data plots (Figure 5). Real time displays of the current values are also available. The remote monitoring of the AdLoCs and SCAs allows the researchers involved in the development of the various components to see their operation in real-time through the internet and also evaluate their performance through archived data.

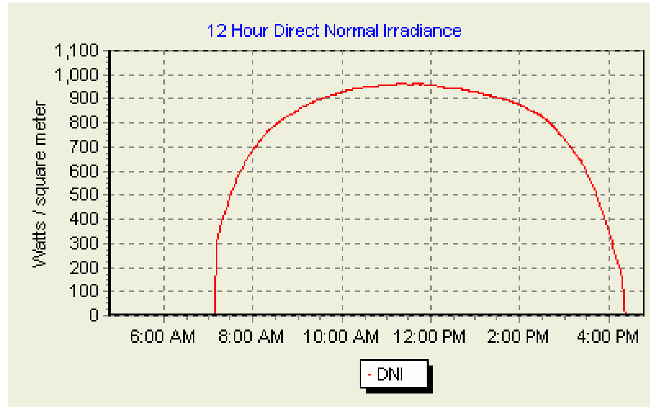


**Figure 5. Example of continuously updating data plots available on the web page. Plot is from January 10, 2005.**

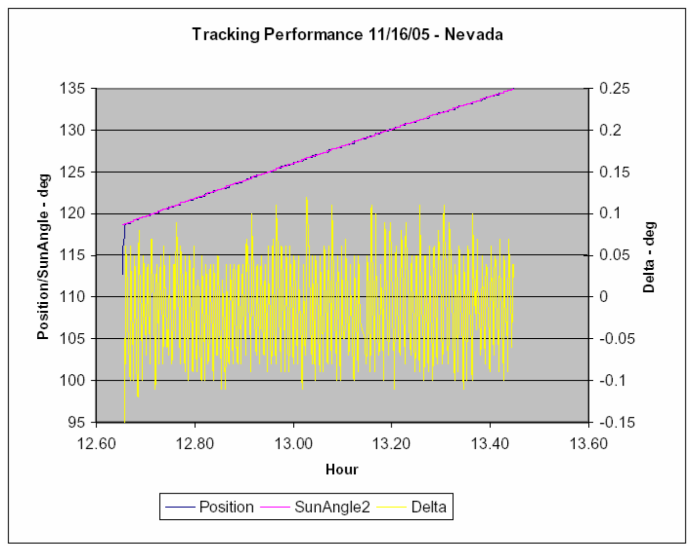


**Figure 6. Plot of Solar Collector Assembly tracking data during virtual tracking. The "Position" represents the position of the collector based on the inclinometer reading and the "SunAngle2" is the calculated sun angle. "Delta" represents the difference between the "Position" and "SunAngle2" [5].**

Various data download rates to the server through the modem have been tested including continuous download. Several months of continuous download has been tested without interruption. Setting the download rates is accomplished remotely at the UNLV server using the Loggernet software.

## DATA ANALYSIS

Tracking data collected at the site have been used to check the performance of the newly developed AdLoCs and the operating characteristics of the hydraulic drive units, and monitoring of the real time data has allowed researchers to check the systems performance while operating in different tracking modes. Figure 6 shows tracking data taken over a three hour period while the system operated in a virtual tracking mode, that is following a sun position calculated by the AdLoCs, and measuring the collector position with an inclinometer. The figure also shows the user set dead band, in this case 0.1 degrees, to check the collector operation around the dead band setting.

Other tests monitored by researchers include checking the voltages of sun sensors during virtual and sun sensor tracking to test the performance of each type of tracking. This testing is currently ongoing. The data monitoring allows researchers to also check the performance of different sun tracking algorithms that can be used in the AdLoCs.

Analysis of the Direct Normal Irradiance (DNI) data recorded allows the calculation of the total available energy measured at the test site. Currently the only DNI data available for the area are from stations located in Las Vegas. Because of different weather conditions caused by Las Vegas' location relative to the Spring Mountain Range and local conditions such as dust caused by construction in Las Vegas and vehicle pollution, the available data do not accurately reflect the conditions in Eldorado Valley. Measurements taken at the site give a better representation of the current conditions and are important as a database for future modeling. Comparison of measurements taken in Las Vegas and Eldorado Valley provide a better understanding of the climatic differences, as shown in Figure 7. Plots of the irradiance distribution, such as Figure 8, are also developed to evaluate the available resource.

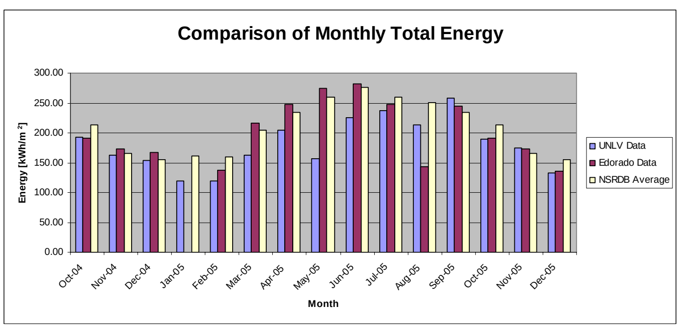


**Figure 7. Plot comparing monthly total energy from 1 minute data for the UNLV Solar Site, the Eldorado Valley Site, and the National Solar Radiation Database average monthly Direct Beam Solar Radiation for Concentrating Collectors data for a 2 axis tracker. Note: January is omitted for the Eldorado Site and July data does not include data for the 8th thru the 11th**

It should be noted that during the monitoring period over the past 15 months, Las Vegas and the surrounding areas have had record rainfall with over two inches (69.1 mm) of rain measured at the site during the month of August 2005 with over an inch (25.9 mm) of rain falling in one day (Figure 9).

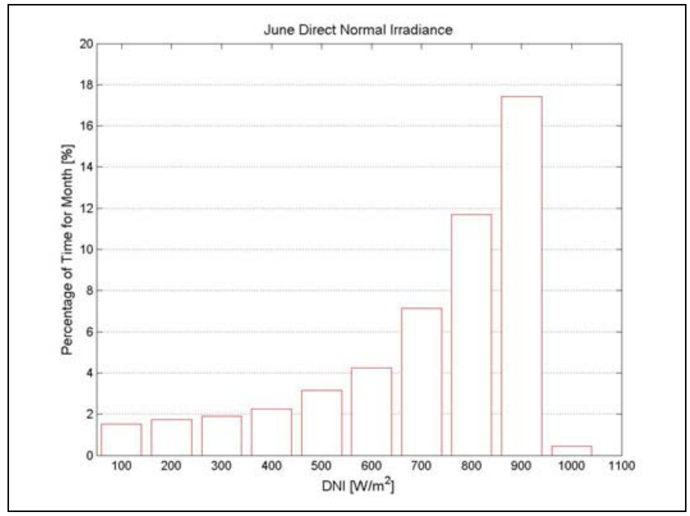


**Figure 8. Plot showing the distribution of measured Direct Normal Irradiance (DNI) for the month of June 2005 from one minute data.**

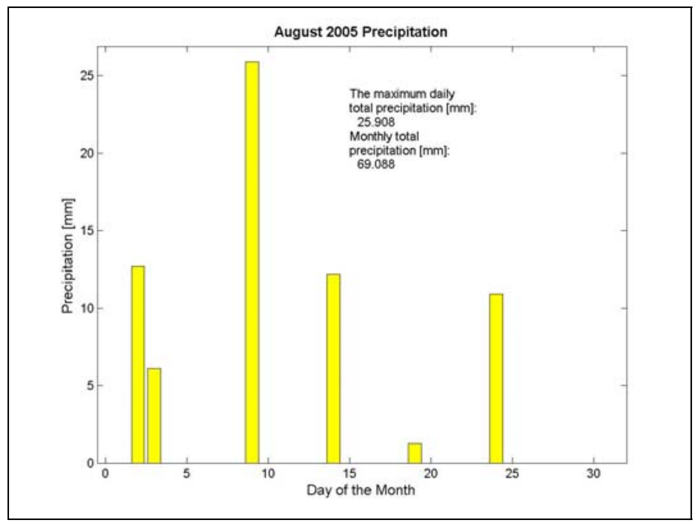


**Figure 9. Precipitation measured at the site for the month of August 2005.**

Historical weather data for Eldorado Valley also do not exist; the closest weather data location is Boulder City, which is in the foothills to the north. Measurement of wind speed and direction help to predict wind patterns at the site and allows monitoring the effects of the wind on the tracking collectors. During the monitoring period to date it has been noted that the highest winds tend to be trending from the north or south at the site which has the least effect on the north-to-south oriented collectors. Values for the maximum wind speed and the corresponding directions, which are closely monitored, can be compared to values used for the wind tunnel testing of the SCAs.

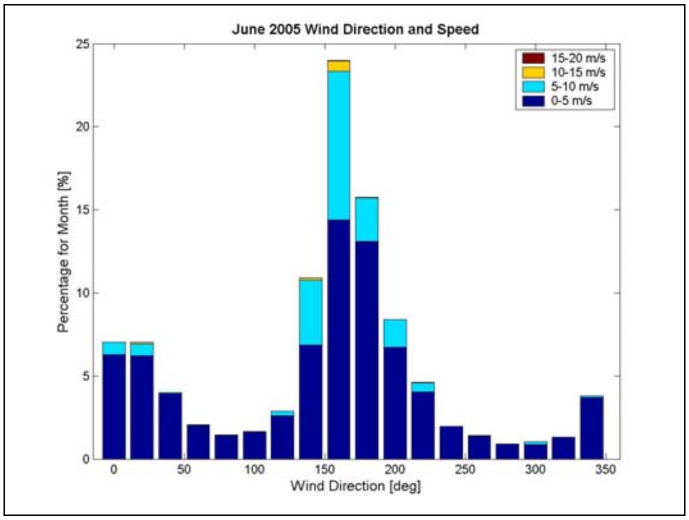


**Figure 10. Example of a plot of wind speed and direction for June 2005 for the Eldorado test site.**

## CONCLUSIONS

Assembly of the components used in the SCA's at the Eldorado test site has provided Solargenix engineers opportunities to test the form and fit of the new designs. Improvements to the designs will be used in the future 64 MWe plant, which is now under construction. Testing of the components is ongoing and part of the next phase of testing will include the installation of receiver tubes and a heat transfer loop. This will allow thermal performance testing of the new design on the test row, independent of the large adjacent 64-MW solar field. Remote monitoring of the Advanced Local Controllers, Solar Collector Assemblies, weather, and solar irradiance will continue to provide valuable information.

## ACKNOWLEDGMENTS

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