SMART SOLAR RESOURCE ASSESSMENTS

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June 2010

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1. INTRODUCTION

The solar market continues to advance at a rapid pace, from the development of new technologies and materials to the production capacity of installed projects. Characterizing the available solar resource and local meteorological attributes is an important first step to begin any solar energy project. While residential and small commercial solar projects may require only a cursory assessment of the potential solar resource, larger utility scale projects necessitate a much more thorough evaluation. For the purposes of this paper, larger distributed generation (DG) projects (>500 kW) and utility scale projects (>5 MW) will be the primary focus.

When exploring the elements of a smart solar resource review and assessment for large DG and utility scale solar projects, two overarching goals influence the analysis methods: 1) Characterize the site to evaluate the risk associated with power purchase agreements (PPA) or off-taker requirements and 2) Build a case to financial institutions to make the project appealing for investment potential.

The framework of this paper provides an overview of why solar resource assessments are conducted, what are the best practices for desktop studies, on-site monitoring programs, and field activities. While the primary focus of the paper is on solar resource analysis, significant influences on energy assessment and conversion calculations are noted.

2. WHY CONDUCT SOLAR RESOURCE ASSESSMENTS?

The initial steps of any solar resource review or assessment includes setting goals and understanding overall project needs. These preliminary steps will aid in establishing the appropriate level of review and assessment consistent with the level of risk associated with the project. Although the solar resource is generally considered more stable and in many cases less complicated to assess than the wind resource, project size and location will influence the level of review necessary for the proposed project. With increasing project size, uncertainty in the solar resource has an escalating effect on overall energy production and plant design.

A review by an experienced independent solar resource analyst will help mitigate a portion of this risk. Simple tools and publicly available data sources are available for the U.S. on a limited basis through sources such as the National Renewable Energy Laboratory (NREL) and system integrators with energy and sizing calculation programs. While analyses utilizing these resources can provide a preliminary estimate of a project's potential, large systems require a more detailed analysis to help evaluate the solar and energy characteristics, and ultimately quantify any applicable uncertainties.

The principal data set for most solar resource assessments performed by an experienced meteorologist or analyst, the Typical Meteorological Year (TMY), is used as an input to energy production simulation models. The output of these energy production models is essential information to evaluate PPA and financial risk. The TMY is composed of hourly solar radiation and applicable meteorological elements for a one year period. These data sets, while based on actual monthly data for different periods of record, represent the typical conditions for a specific site and not the extreme weather conditions also required for project design (1). Publicly available TMY data sets can be used to support site prospecting or to compare the relative performance of various technologies for a potential project location and size. They are not intended for real time system validation, performance verification, or weather prediction.

One common source for TMY data sets in the U.S. is the National Solar Radiation Data Base (NSRDB), developed by NREL. Over 1,400 locations in the United States and its territories are represented in the NSRDB. However almost all of these were assembled using satellite modeled irradiation data and only a small percentage of sites incorporate on-site measurements. For more information regarding data access and the development of the NSRDB, refer to the NSRDB Users Manual (2).

Although TMY data sets have been used extensively in the industry, seasonal biases have been identified in the satellite models when comparing concurrent on-site with modeled data for the same location (3). These biases are most likely attributed to the high ground reflection of desert and snow-covered regions and the model's reduced accuracy at higher latitudes. Potential biases and higher uncertainty in modeled data over ground-based measurements help reinforce the case for additional resource assessment techniques.

While important, project size may not be the sole factor in deciding when a detailed assessment of a potential project is necessary. Although the requirements for resource and energy reports are well established in the wind industry, the utility scale solar industry is still emerging and the needs of the financial institutions are evolving in parallel. In a recent publication by Standard & Poor's (4), it is recommended that an independent review be completed by a solar consultant to address the applicability and integrity of data sources.

3. BEST PRACTICES IN DESKTOP STUDIES

3.1 Overview

Solar resource assessment and review can range from simple to complex. A simple desktop review may consist of evaluating publicly available data at a high level for site prospecting, ranking candidate sites, or for estimating approximate power potential. A complex review may include a combination of data from multiple sources such as long-term reference stations, satellite modeled data, and on-site measurements. This type of assessment helps to understand the long-term solar resource, assess its predicted variability and conduct an in-depth uncertainty analysis to aid in project financing.

The first step in any desktop study is securing solar and meteorological data that best represents the project site. Ideally, instrumentation has been installed at the project site and has acquired several years of high-quality, reliable, consistent data. However, data of this nature is rare due to the emerging state of the solar industry and the smaller scale of antecedent projects where securing external project financing was not dependent upon rigorous data analysis. Since it can be cost and schedule prohibitive to collect several years of data, a relatively short period of record of on-site data can be combined with a longer term reference data source to characterize the long-term solar climate at the area of interest. This allows a more feasible on-site resource assessment campaign that facilitates long term projections with lower uncertainty.

The following paragraphs address important considerations for measured data from nearby reference stations, and modeled data sets. On-site measurement campaigns are discussed in more detail in the next section.

3.2 Solar Resource Data Sets

Solar resource and meteorological data sets are available for thousands of locations around the country through a variety of public and private measurement networks. Although the periods of record vary for these stations, most include data up to the present day with some observation records extending back to the mid-1970's. More widely known networks include the National Oceanic and Atmospheric Administration's (NOAA) Integrated Surface Irradiance Study (ISIS) and Surface Radiation (SURFRAD) networks, and NREL's Measurement and Instrumentation Data Center (MIDC).

While these networks provide high-quality data over a long period of record, there are only about 40 such stations available throughout the entire country. Developing a potential project near one of these stations is rare. For this reason, acquisition of other sources of private and publicly available data is needed, including regional and state-wide meteorological networks. While this data may not be as high-quality as the data provided through NOAA and NREL, these networks typically measure the solar resource with reasonable accuracy , and depending on their proximity to the target station, are more likely to have a high correlation with on-site measurements. An evaluation of these reference data sets are important, including a review of the proximity to the project site, period of record, data quality, accuracy of measurement equipment, and operations and maintenance protocols.

3.3 Measured Data Considerations

The types of measurements necessary for a solar resource analysis are dictated by the type of technology for the proposed project. The three most common measurements of solar radiation are Global Horizontal Irradiance (GHI), Diffuse Horizontal Irradiance (DHI), and Direct Normal Irradiance (DNI). Photovoltaic projects utilize both direct and diffuse radiation in the project's plane of the array, while concentrating solar thermal projects rely solely on the direct component. Other meteorological parameters that are typically collected with the irradiance values include temperature, precipitation, relative humidity, wind speed, wind direction and barometric pressure.

Regardless of project type, an examination of reference data sets for accuracy and validity is needed before their employment in assessing the solar resource at a given project site. The need to utilize data from a variety of sources increases the possibility of invalid or poorly measured data being used to understand a site's resource. To prevent this, several factors need to be considered when using long-term reference station data: proximity to project site, period of record, and station maintenance.

Proximity to Project Site

The solar and meteorological resource can vary widely from region to region, and in some cases varies between nearby locations due to micro climate effects and terrain-induced phenomenon. When combined with seasonal changes and interannual variability in the resource, a high spatial variability may exist between the project site and the closest long-term reference stations. For these reasons, it is important to acquire historical data that are most representative of the site. While this is not always possible, examining several data sources as proximate to the project site is recommended and preferred.

Period of Record

Reference stations having long periods of record allow for a better understanding of the variability in the solar resource and the representativeness of the long-term projections. Having multiple years of data allows for an analysis of annual and seasonal trends that may indicate inconsistencies in the data record resulting from circumstances such as sensor modifications or changes in the surrounding environmental conditions. While a longer period of record is preferred, eight to ten years of valid solar radiation data is more pragmatic given the dearth of long-term irradiance measurement networks in the U.S.

Station Maintenance

An important attribute of measured data sets is the frequency and quality of operations and maintenance activities. While proximity to project site and period of record are key considerations, if the measurement equipment has not been regularly calibrated per manufacturer's specifications and maintenance protocols have not been followed to ensure the operational integrity of the equipment, the data set may be suspect. Regular site maintenance programs include sensor leveling and cleaning, examination of site characteristics, documentation of site conditions, and notation of meteorological conditions.

3.4 Modeled Data Considerations

The common use of numerical and satellite-modeled irradiation data in the current solar industry warrants a brief discussion of its availability and characteristics. As part of the NSRDB, the SUNY (5) 10-km gridded data set covers the period of 1998 through 2005 and provides hourly estimations of GHI, DNI, and DHI. This model uses Geostationary Operational Environmental Satellite visible-channel imagery to estimate solar radiation. Spatial coverage includes the entire United States, a small portion of southern Canada, and northern Mexico. Additional modeled data sets are available through various private sources.

NREL has created TMY data files for over 1,000 locations in the U.S. using modeled data sets from the 1961-1990 and 1991-2005 NSRDB archives. The most recent version of the database are the TMY3 data. These data provide hourly solar and meteorological data for a complete 1-year period and are widely used for basic resource and energy assessment in the industry. The sites are broken into three classes, labeled Class I, Class II, and Class III. Class 1 sites have a complete period of record and the highest quality modeled data. Class II sites have a complete period of record, but have lower quality input data for the solar models. The period of record has some gaps for Class III sites, but at least three years of data that may be useful for certain applications. While the modeled TMY3 data is useful for preliminary solar resource assessment applications, a more robust analysis method is recommended to accurately characterize the local solar resource and climatology.

Characteristics to consider when using modeled solar radiation data include spatial and temporal resolution, variability between grid cells, representativeness of the long-term solar climate, and potential gaps in satellite data.

3.5 Long-term Resource Projection

As solar energy plants are anticipated to be in operation for 25 years or longer, an understanding of the long-term solar resource is helpful in projecting plant production through the complete operating life. This can be accomplished through several methods, all of which involve combining available on-site measured data with data having a longer period of record from the networks and sources referenced above. There are many advanced techniques that a resource analyst may use to generate a long-term resource projection that will help in project bankability.

3.6 Uncertainty Analysis

While long-term projections are helpful in estimating average conditions at a project site, the estimate is acquired with a level of uncertainty. Further analysis is required to address the associated uncertainties in both the solar resource and the energy production estimates. The level of uncertainty is higher for estimates yielded solely from modeled or nearby reference data where on-site data is not available. Quantifying these uncertainties and evaluating the associated probability confidence intervals will present a more complete statistical representation of the resource and energy production for the long-term. By characterizing the resource at several confidence intervals, the resource and energy risk contributions can be integrated into the financial institution's analysis of the project.

3.7 Desktop Studies Summary

Many public and private data sets are available to characterize the solar resource and energy production potential at project sites. For larger projects, more in-depth analysis is needed to understand the site specific meteorological and climatological conditions for both the short and long-term. An experienced independent resource analyst can provide a valuable service in mining the available data and providing long-term projections while considering the most up-to-date methods and industry standards and minimizing project uncertainty.

4. BEST PRACTICES IN ON-SITE MONITORING PROGRAMS

On-site monitoring of applicable solar and meteorological parameters can provide significant value to assessing a project's potential, translating to higher confidence in energy estimates and decreased project uncertainty. For larger projects, this type of campaign may be critical in providing the site-specific data that may be necessary to secure external financing. In the event of a nearby reference station being in close proximity to the project site, a desktop review to examine the reference station and its data can determine if an on-site monitoring program is recommended. Similar to a desktop resource analysis, this review would examine the equipment used at the station, maintenance and calibration information, site photographs, and other applicable documentation. In most cases, for larger projects, a properly designed and executed monitoring campaign will be recommended. The following sections highlight major components of these campaigns to be considered for effectively reducing uncertainty in the project's solar resource.

4.1 Program Design

Monitoring program design requires careful planning and coordination, constrained by budget and schedule limitations. Clear objectives are needed so the best approach is taken to obtain desired results. The success of the campaign relies heavily on proper equipment siting, a sound measurement plan, consideration of technical and current industry standards, trained maintenance staff, quality equipment, and thorough data analysis techniques.

4.2 Measurement Plan

Common to all monitoring programs is ensure that the measurement and monitoring program provide the data needed to meet the program objectives. A comprehensive plan includes:

- Measurement parameters: irradiance, temperature, precipitation, relative humidity, wind speed, wind direction and barometric pressure
- Equipment type, quality, and cost

- Equipment orientation and positioning (e.g. no shading or obstructions and access for maintenance or repair)
- Site requirements (e.g. permitting and security)
- Data sampling and recording intervals
- Parties responsible for equipment procurement, installation, maintenance, data validation and reporting
- Data transmission, screening and processing procedures
- Quality control measures
- Data reporting intervals and formats
- Communication and data acquisition procedures
- Troubleshooting expectations/plan

The recommended minimum duration of solar resource monitoring is one year, to capture the full seasonal characteristics of the site. A data recovery target for the program greater than 90% will assist in keeping any data gaps to a minimum.

4.3 Installation

One of the first steps in the process is to identify and procure the equipment which meets the measurement plan goals. Prior to deploying equipment in the field, acceptance testing and inspection of each measurement device will ensure all inventory is accounted for and in proper condition for field deployment. During this inspection, broken or missing parts can be identified and components that do not meet technical specifications can be returned to the manufacturer for prompt replacement.

Advanced field preparation will save time and reduce the risk of problems requiring a costly return visit. Data logger programming, communications protocol and checks, modem programming, properly packaged equipment and tools as well as a detailed installation plan will pave the way for a successful deployment and mobilization of the equipment.

For solar monitoring programs, field verification of the irradiance measurement equipment provides a means to identify a baseline relationship with high-quality measurement equipment. Assuming the reference instrumentation follows industry calibration standards, this verification provides increased confidence that the sensors were deployed correctly and will measure the solar resource as expected. Re-examining the initial relationship, performed during the campaign or decommissioning, may be useful in identifying any sensor degradation or drift in the measurements. Awareness of these issues can then be integrated into the data analysis phases of the program.

During installation, it is important to document all aspects of the work. Site information logs and field commissioning forms will provide documentation to support the measurement plan goals and aid in future data analysis. Detailed site descriptions and photos, equipment listings which include the manufacturer, model and serial number of each sensor, telecommunications information and contact information are all key elements of good documentation.

4.4 Site Commissioning

Proper site commissioning includes on-site testing of all measurement equipment, confirming successful remote communications, and completing field verification. Commissioning tests include ensuring that all sensors are reporting reasonable values, verifying data logger programming inputs, verify data retrieval process and ensure the data logger is properly operating. Compiling final documentation of field commissioning forms and site commissioning information provides thorough documentation and traceability through the monitoring period and prevent loss of valuable campaign knowledge.

4.5 Station Operation and Maintenance

The integrity of all system components need to be maintained and documented to ensure smooth and continuous data collection through the monitoring period. Some instruments will need periodic calibration while other instruments need to be maintained on a more regular basis. To achieve this, a simple but thorough operation and maintenance plan that incorporates various quality assurance measures and provides procedural guidelines for all program personnel needs to be developed and implemented.

Key elements of the plan include scheduled visits, inspection parameters, checklists and documentation logs, calibration, sensor integrity checks, training of maintenance staff, and spare parts inventories. Quality maintenance visits are conducted on a regular schedule and incorporate methods to document the cleanliness and operation of all sensors, provide feedback on weather conditions during the visit, and verify site security. Due to the high frequency of site visits, up to eight times per month, creative cost effective solutions can be pursued to manage the program's budget and quality.

4.6 Monitoring, Validation and Reporting

Monitoring

The main objective of the data reporting and monitoring process is to protect the quality of the monitoring campaign by ensuring minimal data loss and identify any sensor anomaly or failure as promptly as possible. A practice of weekly or bi-weekly monitoring of communications and data completeness aids will help achieve this goal.

Validation

Upon collection of measurements, data validation assesses the quality of the data. Data validation involves the inspection of data for completeness and reasonableness while applying a method to detect and flag bad (invalid or suspect) values in the data record without rejecting falsely identified valid data. While a number of methods can be used for data validation, no data-validation procedure is likely to discover every bad record and at times, good data may be wrongly rejected. Data validation is akin to any statistical decision process subject to both false positive and false negative errors. A good data-validation procedure seeks to minimize both types of error.

Reporting

Reporting the results of a measurement campaign on a regular basis allows the sponsor and/or stakeholders in a monitoring program regular access to validated data and operational updates. Transfer of post-processed data to a standard reporting template on a monthly or quarterly basis allows campaign and sponsoring managers to view measurement statistics (averages, maximum, and minimum values) that can be used to characterize the site.

Upon completion of the monitoring program, a summary report for the year provides a more complete record of results and the measured data can then be used to estimate to the long-term solar resource and energy production.

4.7 On-site Monitoring Program Summary

A quality on-site monitoring program goes beyond merely placing measuring equipment on a site then reviewing the data upon completion of data collection. A program based on structured field practices and documentation, data validation and reporting, and regular operations and maintenance protocols should be provided by an experienced, independent consultant. If done properly, the diligence maintained through the entire process will lead to a higher quality program, producing a more accurate characterization of the project site that can be used to support long-term resource and energy estimates.

5. ADVANCED STUDIES

While desktop and on-site monitoring campaigns can play a valuable role in the project development process, other advanced studies may be beneficial. Advanced studies that consider ramp effects on energy production is another area that can provide benefit to project and infrastructure studies. Field and modeling studies are being conducted to better understand the impact of cloud-induced ramp rates on areas with a high penetration of solar projects. The need for this research is driven by the effects of cloud passage on the output from larger scale solar power production plants, which can have negative consequences for the overall grid. As solar power purchase or off-take agreements may rely on peak power and thereby peak load benefits, the effect of clouds and their associated ramp affects are best understood if their probability of occurrence is known.

Operational solar power forecasts are another important area to ensure effective grid operations. These forecasts (minute, hour, and day ahead) benefit from on-site monitoring, allowing a feedback loop between on-site meteorological conditions and concurrent plant output. Forecasting and other grid integration studies will increase the understanding of these effects to further mitigate risk and characterize the project site.

6. SUMMARY

Resource assessment is an important component of any solar energy project. It can be range from a basic desktop analysis of modeled and historic reference station data to an extensive full on-site measurement campaign that incorporates all representative information. For larger distributed or utility-scale projects that require more significant funding and less associate risk, the latter is especially valuable. Although some aspects of solar resource assessment is generally considered less complicated than wind, the need is still present for a thorough, independent review of the site-specific solar resource, including a long-term estimate and the associated uncertainties. An independent analyst with experience in the solar industry can identify available data sources, design efficient, and high quality on-site monitoring campaigns, there providing bankable reports to support project characterization, long-term resource and energy projections, and a robust uncertainty analysis. The benefit of a thorough analysis results in a better characterization of a project site and more confidence in the data used to represent the project potential.

7. REFERENCES

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