INTRODUCING NREL'S BEST PRACTICES HANDBOOK FOR COLLECTION AND USE OF SOLAR RESOURCE DATA FOR CSP

Manajit Sengupta – Manajit.Sengupta@nrel.gov
Thomas Stoffel – Thomas.Stoffel@nrel.gov
David Renne – David.Renne@nrel.gov
Stephen Wilcox – Stephen.Wilcox@nrel.gov
Ray George – Ray.George@nrel.gov
Craig Turchi – Craig.Turchi@nrel.gov
National Renewable Energy Laboratory, 1617 Cole Blvd. Golden, CO 80401, USA

ABSTRACT. *This paper introduces a best practices handbook for resource assessment for Concentrated Solar Power (CSP) projects. A meeting of CSP developers and stakeholders to identify areas in which US Department of Energy's (DOE) CSP program should focus its effort was organized by US DOE in September 2008. One of the most urgent requirements that came out of the meeting was for assistance in developing standards for resource data collection and analysis for site selection and plant performance estimation. Subsequent to the recommendations of the meeting, scientists at the National Renewable Energy Laboratory (NREL) went to work to create a handbook that could provide a roadmap to the CSP industry about the best practices for resource measurement and analysis. This handbook is ultimately a collection of information based on the experience of scientists and engineers from industry, academia and DOE. The content includes identification of sources, quality, and methods for applying solar and meteorological data to CSP projects. The handbook also presents detailed information about solar resource data and the resulting data products needed for each stage of the project, from initial site selection to systems operations. Project developers, engineering procurement construction firms, utility companies, energy suppliers, financial investors, and others involved in CSP plant planning and development will find this handbook a valuable resource for the collection and interpretation of solar resource data.*

***Keywords**: Direct Normal Irradiance, DNI, Solar Resource, Measuring Solar Radiation, Modeling Solar Radiation*

1. INTRODUCTION

The fuel for all solar generating technologies including CSP is sunlight. As with any other fuel it is important to understand the quality and reliability of solar radiation at a location in order to assess performance and financial viability before any development takes place. This assessment requires long-term (order of years) high quality DNI measurement to be able to not only characterize annual output but also inter-annual variability. As taking years of surface measurement is not a viable solution it becomes necessary to develop other options that include use of long-term satellite measurements. These satellite-based DNI estimates are correlated with DNI measured at the surface over a short time period and then used for resource assessment studies.

After a plant is built it becomes important to conduct acceptance testing to demonstrate that design specifications have been met. This testing phase also requires high quality measurements for a short period of time. Again data measured for a few months cannot meet the complete testing requirements such as those requiring an annual production estimate. Again information from satellites may be required to complete the test. Ultimately resource data is an essential part of determining whether a plant is running efficiently and is therefore required for the useful lifetime of the plant. Plant performance needs to be continuously monitored and solar resource information is an essential input. Finally resource information is used to forecast a plant's output and the need for such forecasts is growing as more plants come online. Depending on the time scale the forecast may be used for utility dispatch, maintenance scheduling or seasonal prediction.

As multiple facets of a solar power plant including site assessment, acceptance testing, plant operation and production forecasting depends on accurate measurement and modeling of solar resource it is important to establish commonly agreed upon best practices. This best practice manual is the first attempt at creating such a document that is usable by developers, financiers, bankers and utilities. The handbook has multiple chapters that are introduced in the following sections. This is the first edition of this handbook and will be updated regularly as more experience is gained in solar resource assessment and forecasting.

2. HANDBOOK CHAPTERS

The handbook is divided into seven chapter that provide some level of detailed insight into the physics of solar radiation, measurements, current modeling practices, historical data sources and application of datasets. Needless to say it is impossible to completely present the whole body of knowledge that has been developed over decades. Nevertheless the authors have made the effort to provide sufficient details as necessary as well as copious references for readers wishing to access more information in any specific area. This section is divided into multiple sub-sections to provide a synopsis of the chapters in the handbook.

2.1 Chapter1: Why Solar Resource Data are Important to Concentrating Solar Power

This chapter introduces the rest of the handbook and provides the background for why solar resource information is required. The rationale for the rest of the chapters is also laid out in this introductory chapter.

2.2 Chapter 2: Overview of Solar Radiation Resource Concepts

Describing the relevant concepts and applying a consistent terminology is important to the usefulness of any handbook. This chapter uses a standard palette of terms to provide an overview of the key characteristics of solar radiation, the fuel source for CSP technologies. Beginning with the sun as the source, we present an overview of the effects of the Earth's orbit and atmosphere on the types and amounts of solar radiation available for energy conversion. An introduction to the concepts of measuring and modeling solar radiation is intended to prepare the reader for the more in-depth treatment in Chapters 3 and 4. The overview concludes with an important discussion of the estimated uncertainties associated with solar resource data based on measurements and modeling methods used to produce the data.

2.3 Chapter 3: Measuring Solar Radiation

Accurate measurements of DNI are essential to CSP project design and implementation. Because DNI data are relatively complex, and therefore expensive compared with other meteorological measurements, they are available for only a limited number of locations. Increasingly, developers are in need of DNI data for site resource analysis, system design, and plant operation. DNI measurements are also used to develop and test models for estimating DNI and other solar irradiance components based on available surface meteorological observations or satellite remote sensing techniques. DNI measurements will also play an important role in developing solar resource forecasting techniques. This chapter focuses on the instrument selection, installation, and the design, and operation and maintenance (O&M) of measurement systems suitable for collecting DNI resource measurements.

2.4 Chapter 4: Modeling Solar Radiation-Current Practices

High-quality solar resource assessment accelerates technology deployment by providing a positive impact on decision making and reducing uncertainty in investment decisions. GHI and DNI are the two quantities of interest for resource assessment and characterization at a particular location. GHI is defined as the total energy from sunlight, both direct and diffuse, that reaches unit area horizontal to the surface of the Earth. DNI is the amount of energy from direct sunlight that reaches unit area normal to the sun. Surface based measurements of DNI and GHI are best measured using well calibrated pyrheliometers and pyranometers, but such measurements can only be made on a sparse network given the costs of operation and maintenance. For example, currently there are only seven National Oceanic and Atmospheric Administration (NOAA) measurement sites under the SURFRAD (Surface Radiation) Network (Augustine et al. 2000). Nevertheless, observations from ground networks have been used in conjunction with models to create maps of surface solar radiation. Another option is to use information from geostationary satellites to estimate GHI and DNI at the surface (e.g., Perez et al. 2002; Pinker et al. 1992). As geostationary satellite coverage is available at regular intervals on a fixed grid surface, radiation can be available for the entire globe at temporal and spatial resolution representative of the particular satellite. This chapter contains a summary of available ground-based techniques, discussions of satellite-based methods, currently operational models that have surface radiation data available for current or recent periods, a summary of two radiative transfer models used in the operational models, and a discussion of uncertainty in solar-based resource assessment.

2.5 Chapter 5: Historical Solar Resource Datasets

Understanding the long-term spatial and temporal variability of available solar resources is fundamental to any assessment of CSP potential. Information derived from historical solar resource data can be used to make energy policy decisions, select optimum energy conversion technologies, design systems for specific locations, and operate and maintain installed solar energy conversion systems. Historical solar resource data can be the result of insitu measurement programs, satellite-remote sensing methods, or meteorological model outputs. As described in the previous chapters, each type of data has different information content and applicability.

This chapter summarizes historical solar resource data available for the United States and selected international locations. It is an inventory of representative sources of solar radiation data and provides a summary of important data characteristics associated with each data source (e.g., period of record, temporal and spatial resolutions, available data elements, and estimated uncertainties).

NREL and other agencies have made every effort to make data products that are as useful, robust, and as representative as possible; however, the responsibility for applying the data correctly resides with the user. A thorough understanding of the data sources, how they are created, and their limitations is vital to proper application of the resource data to analyses and subsequent decision-making. Discussion and examples of the use of several of these datasets for CSP applications are presented here. Users are encouraged to read the sections of this chapter before applying solar resource and meteorological data.

Measured solar irradiance data can provide detailed temporal information for a specific site. Because solar radiation measurement stations are challenging to operate and the data collected are not used for routine weather forecasts, they are few in number and have limited data collection records. The largest national measurement network for obtaining hourly solar resource data in the United States was the 39-station NOAA Network, which operated from 1977 through 1980. Currently, measured solar irradiance of some form is available from over 3,000 sites in the United States that are operated by various interests producing data with a wide range of data quality.

Satellite-based observations and mesoscale meteorological models address the needs for understanding the spatial variability of solar radiation resources over a range of distances. Present state-of-the-art models provide estimates for GHI and DNI at spatial resolutions of 10 km or less for the United States. The rapidly growing needs for more accurate solar resource information over shorter temporal and smaller spatial scales require the user to fully appreciate the characteristics of all available data, especially those from historical sources.

2.6 Chapter 6: Applying Solar Resource Data to Concentrating Solar Power Projects

This chapter provides a summary of the tools and techniques for evaluating specific CSP sites based on all available information, as well as guidance on steps to improve the on-site determination of the solar resource relevant to the type of CSP technology that is being considered. The overall goal is to help the project developer and investor obtain the best estimates of the solar resource and weather information to address four stages of a CSP project evaluation and operation, namely (a) pre-feasibility, (b) feasibility, (c) due diligence and (d) project acceptance and systems operation.

Ideally, a potential CSP site will have several years of high-quality on-site data, using the measurement and metrology procedures described in Chapter 4, in formats directly relevant to the type of technology being considered. However, in the current CSP market, such data are not usually available, and project developers must rely on a number of techniques to provide the most accurate determination of site resource characteristics based on any available information sources. In the United States, these data sources might include some limited on-site measurements of varying quality, access to nearby measurements that may or may not be precisely applicable to the site because of spatial and temporal variability, access to satellite derived DNI estimates, or access to nearby modeled ground stations, such as found in the National Solar Radiation Database (NSRDB). In the latter case, both hourly statistics over the entire length of the NSRDB period, and Typical Meteorological Year (TMY) data representing either 15 or 30 years of solar resource data modeled from ground observations, might be available. Most ground stations in the NSRDB provide modeled estimates of the solar resource based on cloud cover and other weather observations obtained at the station, and not on actual solar measurements.

We assume that during the site-screening and prefeasibility stages, no high-quality on-site data are available, and that annual energy estimates must be derived from historical datasets such as the Perez SUNY satellite data and the NSRDB. During feasibility assessments, including engineering analysis and due diligence, some period of high-quality measurements are assumed to be available at the site; however, these relative short-term measurements must be extrapolated to long-term records that capture seasonal trends and the interannual variability of solar resources for the site. During the system acceptance and site operation stages, reliance should be on high-quality ground-based measurements, perhaps supplemented to some extent by ongoing satellite-derived measurements for the region.

2.7 Chapter 7: Future Work

Advancing renewable energy technologies will require improvements to our understanding of solar radiation resources. This chapter briefly describes the areas of R&D identified by NREL as emerging technology needs.

3. CONCLUSIONS

The authors hope that this handbook will provide a useful reference to all readers. Our goal was to collect and summarize the vast body of information about solar resource for the CSP industry. The authors would appreciate any feedback which will ultimately enable them to improve and enhance the relevance of future version of this handbook. We would like to thank all our reviewers who have spent their valuable time to provide us with useful comments which we feel has enhance the value of this handbook.

4. REFERENCES

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