Climatic Rating of Photovoltaic Modules: Different Technologies for Various Operating Conditions

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Executive Summary

The photovoltaic (PV) energy rating is related to the energy yield performance of a PV module. Unlike the power rating, which is only related to the performance at a single operating point at 25°C, 1000 W/m2, and AM1.5 spectrum (Standard Test Conditions, STC), the energy rating considers several characteristics of the PV module that affect the amount of energy produced: a) low irradiation behaviour b) temperature behaviour c) spectral response and d) angular response. These characteristics are also a function of climate and location conditions, vary over time, and differ widely from the STC. For the PV industry and its market players, accurate information on how much energy PV modules and systems can generate is crucial, and even more relevant than the power rating. In recent times the photovoltaic industry is moving from thinking about power (watt-peak) to thinking about energy (kWh), giving greater importance to the energy rating. Chapter 1 of this report examines the importance of energy classification in more detail and provides an overview of the state of the art in this area.

The energy rating aims to allow differentiation between PV modules according to their performance for typical locations. To this end, one of the most important international standardization bodies of the photovoltaic industry: The International Electrotechnical Commission (IEC), has designed the IEC 61853 series of standards Photovoltaic (PV) module performance testing and energy rating (Parts 1 to 4). The series provides guidelines and standardized procedures for the indoor and outdoor characterization of PV modules and the calculation of the climate-specific energy rating (CSER). The CSER is equivalent to the annual performance ratio of the PV module for a specific climate.

Part 1 deals with the measurement of PV module performance under variable irradiance and module temperature (G-T or power matrix). Part 2 contains the measurement procedures of the angular response (AR), the spectral response (SR), and the nominal module operating temperature (NMOT) of the PV modules. Part 3 lays down a methodology for the calculation of the CSER value, which uses the results from Parts 1, 2 and 4 (reference climate data sets) as input data. Currently, six climate data sets are available (temperate continental, temperate coastal, tropical humid, subtropical arid, subtropical coastal, high elevation), all of which com-prise a time series of hourly data of meteorological parameters for a complete year.

Part 1 and Part 2 of IEC 61853 series will be discussed in Chapter 2. Specifically, Chapters 2.1 and 2.2 briefly describe the procedures for indoor measurement with a solar simulator, which is the most common practice in the PV industry. Nevertheless, procedures for out-door measurements are also outlined in international standards and, among other advantages, can fully benefit from realistic thermal operating conditions, which is why they are discussed in Chapter 2.3. Here, Section 2.3.1 presents an

approach for characterizing PV modules using two-axis solar trackers at outdoor installations. In Section 2.3.2, the challenges of the continuum cooperating conditions are addressed by extracting the IEC 61853-1 matrix from one-full year outdoor data including periods of non-optimal weather conditions. For practical purposes, Chapter 2.4 gives insights into an online dataset of nine PV modules tested according to IEC 61853 at an accredited laboratory. The new kWh thinking has not only in-creased the role of energy rating but has also opened the market to new technologies, such as bifacial PV modules. With this, new measuring procedures have been developed. Chapter 2.5 provides an overview of the current status of bifacial power output characterization.

It is not possible to talk about energy rating, without addressing climate classification and the efforts to understand the impact of climate on the performance and degradation of PV technologies. Therefore, Chapter 3 covers the energy meteorology in PV technologies. Chapter 3.1 discusses the most popular scheme supporting the PV community, the Köppen-Geiger (KG) climate classification, and presents other approaches to include additional photovoltaic-relevant climate variables (global irradiance, UV irradiance, and wind speed) such as the Photovoltaic Degradation Climate Zones (PVCZ), the Köppen-Geiger-Photovoltaic (KGPV) and a scheme for indoor aging testing (Project Infinity). Besides the irradiance and the temperature, the spectral distribution is one of the main influencing factors on the performance of a given PV technology, since the spectral distribution of a certain location differs from the reference global spectral irradiance defined in IEC 60904-3. Chapter 3.2 discusses this matter. Chapter 3.3 evaluates the data sets proposed by the IEC 61853-4, which contain: hourly values over a year of ambient temperature, wind speed, satellite-retrieved irradiance data of horizontal global and beam broadband irradiance, in-plane global and beam broadband irradiance, and spectrally resolved in-plane global irradiance integrated into 29 spectral bands. To give an overview of the challenges of normalizing particular climatic conditions, the case of the Atacama Desert is presented in Chapter 3.4. The comprehensive characterization required for PV technologies operating in such a harsh climate (i.e. UV radiation), is also discussed.

Chapter 4 constitutes the core of this report, as it not only explains in detail the IEC methodology for the determination of the CSER but also explains the existing approaches and practices established by recognized solar institutes. Chap. 4.1 describes step by step, the calculation of the CSER parameter using the IEC 61853-3 methodology. Even when given the equations and procedures for energy rating, practical implementation could be still challenging. Chapter 4.2 addresses this issue by presenting the results of round robin among ten solar institutes. By using the same PV module laboratory, each institution was asked to calculate the CSER. After several phases of harmonizing methods and excluding outliers, differences in the CSER value were still found amongst participants.

When it comes to measurements, whether in the laboratory or outdoors, some factors play an important role in decision making from a practical point of view: cost, time and accuracy. The reduction of measurements for the G-T matrix and the impact on the accuracy of the rating are discussed in Chapter 4.3. This reduction is not only a cost mitigation alternative but also a solution when the testing equipment does not allow measurement of the full matrix due to limitations in irradiance or temperature settings.

The need for an energy rating has caused different procedures to be developed independently by solar research institutes. Some of them are discussed in this section. Chapter 4.4 presents the Sandia Array Performance Model, which is a semi-empirical set of four principal equations that, when appropriately calibrated, reduces outdoor data into a set of coefficients that represent module performance at STC, which can be used to translate outdoor data to the IEC 61853-1 G-T matrix and be coupled with tabular weather data to perform energy pre-dictions or ratings. Chapter 4.5 presents the approach of Fraunhofer ISE (Dirnberger et al. method), which relies on available historical data and technical datasheets of the PV module, instead of the extended laboratory measurements.

Chapter 4.6 presents the Linear Performance Loss Analysis (LPLA) from TÜV Rheinland. This approach relies on the measurements of Part 1 and Part 2 of the IEC 61853, climate datasets obtained from real measurements at outdoor locations, and equations to calculate the module performance ratio as a linear superposition of various meteorological factors. The scope of the IEC energy rating covers monofacial and single-junction PV devices, but its application cannot be easily extended to bifacial devices. These challenges and the proposal of two bifacial Standard Mounting Conditions (SMC) are discussed in Chapter 4.7.

Chapter 5 discusses issues that also need to be addressed, such as the application of energy rating to other promising PV solutions, for instance, Building-Integrated Photovoltaic (BIPV) and coloured modules. Throughout this report, the analysis has been maintained at the module level rather than the system level. Recognising how important this is, the last two sub-chapters discuss PV systems issues. Chapter 5.1 shows the results of a round robin test ac-cording to BIPV IEC 61853 with nine participating institutes from seven countries, which was carried out within the framework of the IEA PVPS Task 15.1 and in which globally identical modules, the same laboratory characterisation and a globally agreed methodology were used. Chapter 5.2 presents the results of a one-year study conducted by SUPSI PVLab, in which seven prototype modules of different colours were evaluated to understand the different technology and climatic factors impacting their real-world performance. Like any model, the IEC 61853 energy rating also has uncertainties from systematic and random errors, coming from the input data and the applied models. The main sources of uncertainties are discussed in Chapter 5.3.

The performance of photovoltaics depends on static metadata (i.e azimuth, tilt) and dynamic weather data. When it comes to obtaining global regional system performance data, Chapter 5.4 shows that, rather than finding annual performance data, a better approach is to obtain PV system metadata (module tilt and azimuth, installed capacity), and use representative, regionally resolved distributions to calculate specific annual performance distributions based on annually varying weather information. This approach could improve how national energy plans are established, installations are optimized, and give specific information about common regional installation practices. One of the biggest questions is what kind of information the energy rating has for the long-term run of PV modules and systems. To this end, it is important to understand the differences between energy rating, energy yield, and long-term performance assessment. This is discussed in Chapter 5.5. This chapter explores the long-term degradation of PV modules through a case study in Thailand.

As a whole, this report is a compendium of the current status of energy rating, ranging from input data on technologies (whether measured in the laboratory or outdoors) and on climate, to the description and evaluation of existing methods (IEC 61853 and from other solar re-search institutes). It also opens the discussion on the application of these methods in new technologies such as bifacial modules, BIPV and coloured PV, competitions on method uncertainties and evaluation at system level.

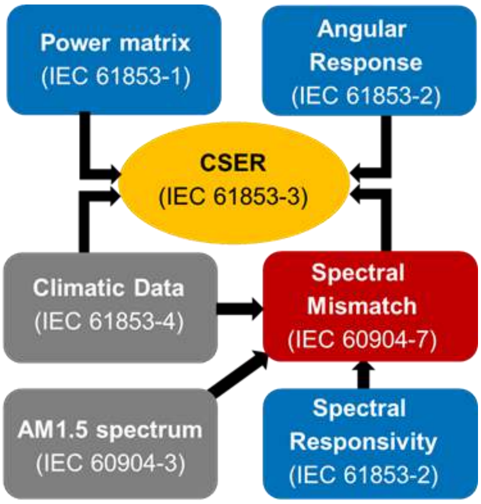

Figure 1: Methodology of IEC 61853 series for climate specific energy rating (Source: TÜV Rheinland Group).

The Technical Report is available for download from the IEA-PVPS website www.iea-pvps.org.

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