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New and improved methods to estimate day-ahead quantity and quality of solar irradiance

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HIGHLIGHTS

- Quality parameter used efficiently represents daily solar irradiance quality.
- NWS sky cover forecast needs to be adjusted based on the type of day.
- Relationship between cloud observation and surface solar irradiance established.
- A new method to estimate day-ahead solar irradiance quality proposed.
- Improved methods to estimate day-ahead solar irradiance quantity proposed.

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ABSTRACT

This paper proposes methodologies to estimate day-ahead quantity and quality of solar irradiance using the National Weather Service (NWS) sky cover forecast. The proposed methods use two parameters, the daily sky clearness index (K_D) for quantity and the daily probability of persistence (POP–K_D) for quality. POP–K_D efficiently represents quality of daily solar irradiance. In addition, POP–K_D can be applicable to indicate that solar irradiance variability is within ramp rates of common generators in power systems at a certain photovoltaic (PV) penetration level. For model development, this paper splits up a direct estimation process from cloud forecast to solar irradiance into two stages: forecast verification and cloud-to-irradiance conversion. Verification of the sky cover forecast shows an overestimation bias of approximately 20% on days with a high irradiance level. Thus, the NWS sky cover forecast needs to be adjusted based on the type of day. This paper also proposes new equations that provide accurate conversion from cloud observation to surface solar irradiance. Finally, this paper proposes a method for estimating day-ahead POP–K_D and three methods for estimating day-ahead K_D based on the NWS sky cover forecast. The proposed methods incorporate different schemes for dealing with the bias discovered in the cloud forecast. Estimation results demonstrate the effectiveness of the proposed methods at different irradiance levels.

1. Introduction

As increasing amounts of solar power are being used to satisfy electric demands, prediction of solar irradiance becomes important for reliable power operations. In addition, the predicted information is also of interest in other fields, including agricultural and environmental applications [1–4]. Due to the variability of solar resources, the solar industry needs more accurate prediction results [5].

Recently, fluctuation (quality) of daily solar irradiance has become a main focus for a constant power delivery to the grid and a guide for deciding the power storage size of back-up facilities in a solar-based generation system [6–8]. Accurate prediction results of daily solar fluctuation will enable power operators to make better scheduling decisions for solar-based power generation and to avoid excessive backup facilities. Different approaches have been used to analyze solar irradiance fluctuation. These approaches include the statistical method with signal processed fluctuation [9], wavelet-based spectral analyses [6,10], the stability observation for increments of the fluctuation [11], and signal processing of ramp rates of the fluctuation [12]. A recent study [13] proposed a probability of persistence (POP), stochastic observation for persistency of the solar irradiance during a day. This study used the POP for quality analysis of daily solar irradiance in order to characterize and classify daily sky conditions along with the quantity analysis.

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Cloud forecast information is a valuable source for estimating day-ahead solar irradiance since the solar irradiance received at ground level is directly affected by the extent of cloud coverage. The National Weather Service (NWS) provides free and publicly available gridded forecasts of sky cover, the forecast percentage of cloud coverage in the atmosphere, for various uses including solar irradiance estimation for different sectors of the economy. The NWS sky cover forecast combines inputs from human experts and automated measurements from NWS offices at various locations [14–16]. A pioneering study [14] introduced a direct conversion from the NWS sky cover forecast to solar irradiance for estimating day-ahead quantity of solar irradiance. This conversion was modified by adjusting fit results with the hourly interpolated time horizon [15]. Some studies [17–19] also tested this methodology with other numerical weather prediction (NWP)-based forecasting models for day-ahead estimation capability. However, these studies focused only on the quantity estimation.

Information of the NWS sky cover forecast can be used to estimate not only the day-ahead solar irradiance quantity but also the day-ahead solar quality. Thus, this paper proposes new methodologies for estimating day-ahead quantity and quality of solar irradiance based on the NWS sky cover forecast. The daily sky clearness index (K_D) is for the quantity and the daily POP value (POP–K_D) is used for the quality. POP–K_D was evaluated an efficient parameter for the quality analysis. Further details about K_D and POP–K_D are provided in Section 2. Fig. 1 shows the multi-year relationship between K_D and POP–K_D at a specific location. As shown in Fig. 1, different ranges of K_D exist for each value of POP–K_D. These ranges between K_D and POP–K_D can be enclosed by a specific polygon boundary as proposed in [13]. The sky condition is correlated with this statistic. This indicates that the estimation of K_D and the estimation of POP–K_D are independent although they utilize the same data.

Fig. 2 shows a block diagram of the proposed methods. The data processed from the sky cover forecast in Stage 1 were individually adjusted for the quantity estimation (Stage 2A) and normalized for the quality estimation (Stage 2B). Then, multi-year data from the Solar Radiation Research Laboratory Baseline Measurement System (SRRL BMS) were used for method development and result verification.

This paper provides several contributions. Firstly, this paper shows that POP–K_D efficiently represents the quality of daily solar irradiance. Higher POP–K_D levels show higher certainty and sharper peakedness in the distribution of the per-minute changes in daily solar irradiance. Thus, the distributional pattern can be represented by a single value of POP–K_D. In addition, POP–K_D can be applicable to indicate that solar irradiance variability is within the ramp rates of common generators in power systems. Secondly, this paper demonstrates the need to adjust the NWS sky cover forecasts. The previously introduced direct conversion from cloud forecast to solar irradiance was spilt up into two stages: forecast verification and cloud-to-irradiance conversion. Verification of the sky cover forecast reveals an overall overestimated bias. This bias is stronger at high irradiance levels. Thus, the estimation methods need to adaptively handle this bias at different irradiance levels. Thirdly, this paper describes the conversion from cloud information to surface solar irradiance with new equations. These equations were developed based on the multi-year relationship between the sky imager-based cloud observation and the measured solar irradiance. Fourthly, this paper proposes a day-ahead POP–K_D estimation method based on fluctuation information provided by the NWS sky cover forecast. This method uses a normalization approach to relate fluctuation of cloud forecast and fluctuation of cloud observation. Lastly, this paper proposes three different day-ahead K_D estimation methods based on the quantity information from the NWS sky cover forecast. These methods incorporate different schemes for dealing with the aforementioned bias of the cloud forecast.

The rest of this paper is organized as follows. Section 2 presents POP–K_D as a parameter relating to the daily solar irradiance quality

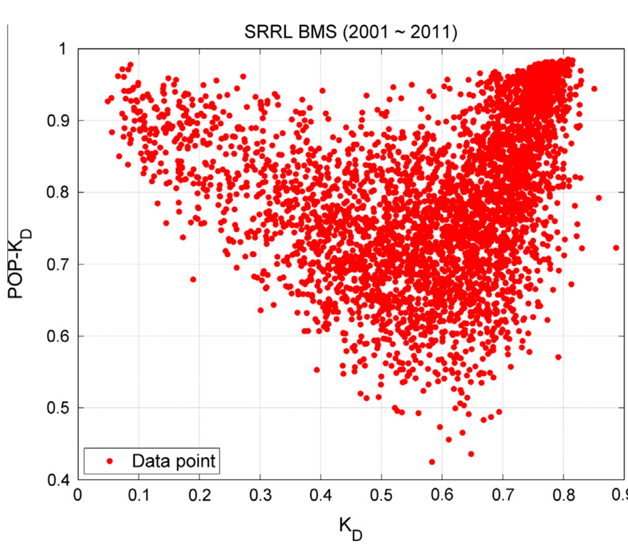

Fig. 1. Relationship between K_D and POP–K_D at SRRL BMS for 11 years (2001–2011).

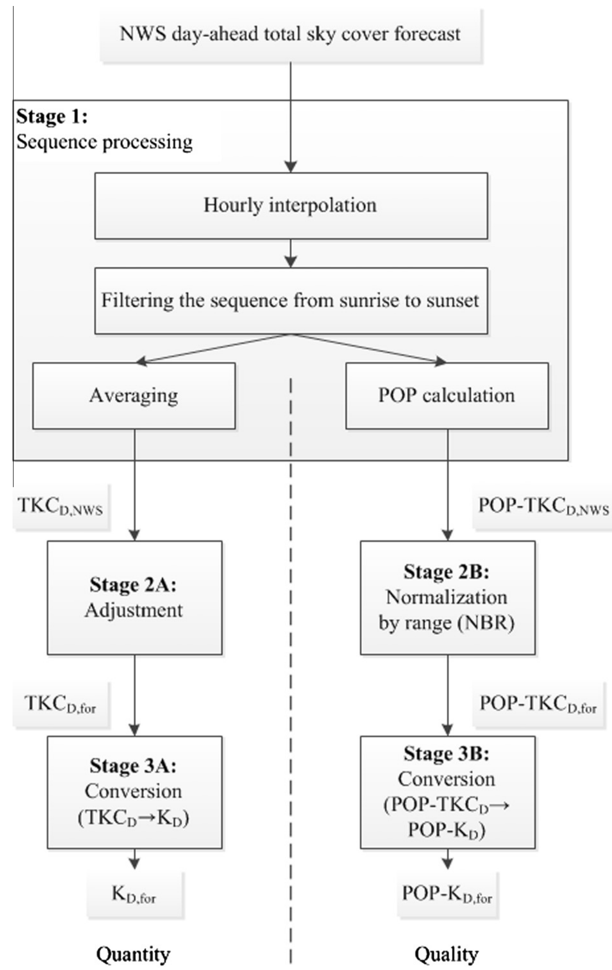

Fig. 2. Overall sequence of the proposed estimation method for quantity ($K_{D,for}$) and quality (POP–$K_{D,for}$) of daily solar irradiance.