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Variability of measured Global Horizontal Irradiation throughout Qatar

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Abstract

This paper presents a study of up to six years of ground measurements of Global Horizontal Irradiation (GHI), the total solar radiation arriving on a horizontal surface, collected by 12 automatic weather stations throughout Qatar. The year-to-year and monthly variations of daily GHI are calculated for each station; the average found is 5.80 kWh/m^2/day, a total of 2116 kWh/m^2/year. Spatially, the monthly averages through the country vary with a relative standard deviation of up to 4% with respect to the country averages; in general, higher GHI is found in the south and north regions of Qatar, except at the northern tip of the country, and lower values are found mainly in the central latitudes, close to the industrial areas. Frequency distributions of daily GHI present two peaks, which are found to correspond to two distinct periods of the year: one from March to September, with most frequent GHI values around 7 kWh/m^2/day, and one from October to February, centred around 4.5 kWh/m^2/day. A similar study can be advisable for other areas with comparable climate or topographies, since these two solar seasons might also be present and, if found, should be considered in the design and implementation of photovoltaic-based systems. Finally, the monthly clearness index (ratio of ground-level GHI to top-of-the-atmosphere GHI) is presented for each location and for Qatar as a whole from ground measurements and compared to longer-term satellite-based values. The annual average of clearness index for Qatar from ground measurements is 0.64, indicative of clear-sky conditions most of the year. GHI is the fuel of photovoltaic systems, so its study is fundamental for such applications, and also provides a reference for the derivation of solar radiation data from models or satellite observations.

Keywords: Solar resource assessment; Clearness index; Seasonal solar variation; Frequency distribution

1. Introduction

Energy needs in Qatar are currently covered by using its large resources of oil and natural gas. However, in line with its National Vision 2030, Qatar has started thinking for the long term and planning ahead for the reduction of its dependency on fossil fuels and for the adoption of energy conservation measures. Indeed, the country intends to invest large amounts of money in the renewable energy sectors and is heavily supporting research and development in this field (QNV2030, 2015). In particular, Qatar plans to deploy photovoltaic (PV) technologies for electricity production. PV panels convert into electricity any solar radiation (in their wavelength acceptance range) reaching their surface, either coming directly from the line to the sun (called the *direct component*), or diffused by the atmosphere or reflected by any surface (called *diffuse component*). The Global Horizontal Irradiation (GHI) is a measure of the

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total incoming radiation on a horizontal surface, and its knowledge is therefore vital in order to be able to plan and execute any project or application of PV technologies.

Being geographically positioned in the so-called Sun Belt region of the world, Qatar has long sunshine duration per day with an average of 9.2 h during the whole year (Abdalla and Baghdady, 1985) and high solar radiation intensity, with a satellite-estimated GHI of 2134 kWh/m^2/year (Beták et al., 2012); therefore, Qatar is well located to exploit solar energy and to make from it a major source of energy in the country. For this reason and as mentioned above, the accurate knowledge of the available solar resource in the country is an essential prerequisite. When solar radiation data are not available, it is necessary to develop models to estimate it through other available data, usually weather data. A number of empirical or semi-empirical models have been developed; for instance, the difference between maximum and minimum air temperatures was used, with saturation vapour pressures, to derive GHI in Almorox et al. (2011), while only temperature was used in Pan et al. (2013), and in Janjai et al. (2011) solar radiation was derived from clear-sky radiation measurements combined with the Ångström turbidity coefficient, the Ångström wavelength exponent, precipitable water and total-column ozone. Neural network techniques have also been employed; for example, several combinations of meteorological variables were used in Behrang et al. (2010); temperature and vegetation index were used in Qin et al. (2011); sunshine duration, temperature, relative humidity and day of the year were used in Benghanem et al. (2009); and sunshine duration, maximum temperature, cloud cover and location parameters were used in Mubiru and Banda (2008). Solar irradiation can be derived from satellite images, and is currently provided by paid services such as SolarGIS (GeoModel, 2015), HelioClim (HelioClim, 2015), SOLEMI (SOLEMI, 2015) and IrSOLaV (IRSOLAV, 2015), or for free, e.g., NASA-SSE (2015a) and PVGIS (2015). Although satellites provide long-term data for most of the world, the derivation of ground-level solar radiation from their (spaceborne) measurements depends on the model and the input parameters used, in addition to inherent problems such as parallax, for instance; more information on the complexities of deriving solar radiation from satellite observations, and validation procedures, can be found in Perez et al. (2013). Due to their nature, being direct measurements taken on-site and not derived, good quality ground measurements provide the most accurate on-site information, and indeed, validation and calibration of satellite-derived radiation are done with ground measurements; however, since ground measurements are rarely available for all sites and for extended periods of time, they are usually combined with long-term satellite-derived information to provide the most complete assessment and characterisation of solar climate at any given site.

Ground measurements are usually limited because of the costs and problematics involved in maintaining monitoring stations, including frequent cleaning, routine checks, repairs, calibration, etc. Some of the problematics are compounded at particularly harsh environments, as is the case of most of the Middle East, with high contents of aerosols (desert dust and industrial) and, in some areas, water vapour in the atmosphere. Nevertheless, a number of studies on global solar radiation based on ground measurements have been carried out in previous years in the Arab region. Solar resource availability has been studied in North-East Saudi Arabia (Sahin et al., 1999; Aksakal and Rehman, 1999); GHI and clearness index have been studied in Abu Dhabi (Islam et al., 2009), in Amman (Hamdan, 1994) and in several locations in Oman (Al-Hinai and Al-Alawi, 1995). In Qatar, to the authors' knowledge and until very recently, the only published study on solar resources with ground measurements was made for Doha, in 1985 (Abdalla and Baghdady, 1985); a more recent study of GHI for Doha was published by the authors (Bachour and Perez-Astudillo, 2014b). Currently available solar maps and averages for the whole country, such as the average given in Beták et al. (2012), are satellite-derived, and have not been validated with ground measurements in Qatar and therefore their reliability cannot be determined at the levels needed for bankability. A well-known case in the Arabian Gulf region is the overestimation of the solar resource in the United Arab Emirates, which was obtained only from satellite-derived data, when planning the Shams 1 Concentrated Solar Power (CSP) plant (SHAMS1, 2010); examples like this stress the importance of why models used to derive irradiation from satellite, as well as other models, as listed above, need ground measurements for calibration. The study presented here contributes to such needed information, assisting in the understanding of deriving solar irradiation from images and other measurements.

The objective of this work is to study the available solar resources in Qatar through an analysis of ground measurements of GHI covering a 6-year period, from 2007 to 2012. The variations of daily GHI measurements taken at different locations in Qatar are presented here. Year-to-year and monthly variations are shown and analysed. The clearness index is also examined and compared with values from three open-access satellite-derived databases. Seasonal variations of the global solar radiation throughout the year are studied across the country in order to highlight the average amount of solar radiation available on the horizontal surface during summer and winter months, and provide an in-depth view of the temporal and spatial variations of solar radiation, which are vital in the considerations of implementing photovoltaic (PV) technologies, since these variations may cause noticeable changes in the resulting effectiveness and productivity; the relation between solar variability and PV output variability is shown in Stein (2010) and Šùri et al. (2007) studied how the variability of GHI affects the uncertainties on the predicted electricity yield of PV systems around the Mediterranean and Black seas.