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THE SOUTH AFRICAN REFIT: SOLAR RESOURCE ASSESSMENT OPTIONS FOR SOLAR DEVELOPERS

Adriaan J. Meyer[1]

[1] Mr AJ Meyer, BEng (Electric & Electronic) & MScEng (Mechanical), Research Engineer, Centre for Renewable and Sustainable Energy Studies, Department of Mechanical and Mechatronic Engineering, Stellenbosch University, South Africa. Private Bag x1, Matieland, 7602, South Africa. Telephone: +27 21 808 4945. E-mail: meyer@sun.ac.za.

Abstract

Each solar technology (CSP, PV and CPV) are dependent on a different component of solar irradiance. Therefore different solar instrumentation is required for on-site measurements. This paper discussed the capital cost and the operation and maintenance requirements of each on-site solar measurement station within the South African context, the author's experience and requirements from the REFIT programme. The incorporation of satellite derived data and the accuracy of it compared to on-site measurements is also discussed.

PV developers are not required to have on-site measurements under the REFIT programme. For sites that are located within the areas with high annual solar insolation values, the uncertainty of the long term annual average of satellite derived solar data can be given as: 3.0 – 3.5% for GHI and 4.0 – 4.5% for GTI. If on-site measurements are installed, typically two pyranometers measuring GHI and GTI, the uncertainties can be reduced to 2.0 - 2.5% for GHI and 2.5 – 3.0% for GTI. Although CPV utilises DNI and not GTI, onsite measurements are not required due to the fact that in the REFIT programme CPV falls under PV. CSP developments are required to have on-site DNI measurements of at least one year in the REFIT programme. For sites that are located within the areas with high annual solar insolation values the uncertainty for the long term DNI average is: 7.0 – 9.0% for annual sums and 9.0 – 12.0% for monthly sums. A tracker and pyrheliometer or a RSR are typically used to measure DNI. When measurements of at least one year are combined with high accuracy satellite derived data it will decrease the uncertainty for the long term DNI satellite derived data to up to 5.0 % for annual sums and 7.0 – 8.0% for monthly sums.

Keywords: South Africa, DNI, GTI, LTI, Solar Resource, Solar measurement, REFIT, REBID, pyranometer, pyrheliometer

1. Introduction

The interest of various renewable energy developers were stimulated when the National Energy Regulator of South Africa (NERSA) announced the implementation of renewable energy feed-in tariffs (REFIT) in March 2009 [1] and in October 2009 [2]. Renewable energy developers consequently became eager to construct renewable energy power plants including CSP, PV and CPV-plants in South Africa. For the first time in the history of South Africa, grid connected independent power producers (IPPs) became viable.

In August 2011 the requirements for this bidding process (also referred to as the REBID) was released. The REFIT has different requirements for PV, CPV and CSP plants in terms of solar resource assessment [3]. This paper describes the various solar components required by each solar technology and the solar instrumentation required for measurement. It discusses the capital cost operation and maintenance requirements of each measurement installation within the South African contextand also the incorporation of satellite derived data for each technology.

2. Measuring Solar Irradiance

2.1 Solar Instruments

The most commonly used broadband radiometric instrument is the pyranometer which measures global horizontal irradiance (GHI). This device can be shaded with a shadow band or shadow ball to measure diffuse irradiance. A pyranometer can also be used in a tilted position measuring global tilted irradiance (GTI). GTI is of interest to PV developers when installing PV panels at a fixed tilt angle.

Direct normal irradiance (DNI), also referred to as beam irradiance, is typically measured with a pyrheliometer mounted on a sun-tracker. DNI is of interest to CSP and CPV developers employing technologies that concentrate solar energy. Since two pyranometers are typically also mounted on the tracker, one with a shading ball (recording diffuse irradiance) and one without (recording GHI), the DNI can also be calculated from GHI and fiffuse irradiance. This allows for redundancy in the DNI measurements.

Most radiometers are based on either the thermoelectric, also called a thermopile, sensor or a photoelectric, also referred to as the silicon, sensor. The photoelectric sensor generally provides lower accuracy due to the spectrally selective characteristics of the silicon sensor. The advantage is that it has an instantaneous response and a lower cost thus explaining their wide use in weather stations and agricultural based solar monitoring networks. Thermopile radiometers are generally preferred for the generation of bankable-grade solar data.

Both thermopopile and silicon type pyranometers and pyrheliometers must be calibrated against a reference instrument at regular intervals, typically every 2 years, to minimize their measurement uncertainty.

2.2 Ground Station Measurements

In most developing countries high quality solar resource data is obtainable from weather stations operated by government or related agencies. These measurements, typically spanning multiple years, are used in the planning phase of solar developments. High quality, high resolution satellite derived data sets is also available from various suppliers, especially in Europe. When ground measured data is combined with satellite derived data, a bankable solar data set comprising of multiple years of data can be obtained. Similar to other developing countries, South Africa suffers from a lack of high quality ground-based solar monitoring stations. This is mainly due to the cost of acquiring and maintaining instrumentation.

Historically, the South African Weather Service (SAWS) has been the main source of ground irradiation data. The measurement of solar radiation in Southern Africa dates back to 1914 [4]. During the 1950's the Weather Service established a network of global and diffuse (mechanical shadow band) solar radiation measurements at its main "manned" weather offices around the country, including stations in Namibia (formerly South West Africa and part of the Republic of South Africa). The network was deployed with Kipp&Zonen CM2 and CM5 instruments. This also was established at the South Africa National Antarctic Expedition Base - SANAE, and at Marion- and Gough Islands as the Island Meteorological measurement programmes were established. These instruments and points of measurement were complimented by non-SAWS owned station such as Roodeplaatdam and Grootfontein operated by the agricultural community. [4]

During the period (1950-80's) this network functioned well with dedicated staff assigned to the operational maintenance, data processing and archiving of data. Since the 1980's, it was decided that the conventional solar radiation network must gradually be superseded by a network of Automated Weather Stations which is to be equipped with radiation sensors. The current CM2 and CM5 had become old and spare consumables were hard to obtain. Requests for new conventional instruments were invariably vetoed on many occasions and only expenditure on consumables and maintenance items have been approved in recent years [4].
In 1994 the SAWS embarked on the roll-out of an Automated Weather Station (AWS) Network. These stations were equipped with photoelectric pyranometers (Licor LI-200) measuring global radiation only [4,5]. This AWS solar network showed a decline in monitoring capabilities during the 2000 - 2010 period.

In 1999 the SAWS became a member of the Baseline Surface Radiation Network (BSRN) with a fully equipped ground station installed at De Aar. The station ceased operation due to technical difficulties and lack of capacity/ maintenance [5]. The data period available from this station is from January 2000 – January 2005 with a few months of data missing in 2000 and 2001 [6].

SAWS have placed a moratorium on disseminating their solar data due to the high measurement uncertainties in the database, resulting from lack of proper quality control and declining instrument maintenance. Some primary stations have fallen into disuse since the introduction of the AWS equipment and in certain cases the instrumentation has not been calibrated in over a decade. At present, there is only one operational radiometric ground station recording GHI and diffuse irradiance at hourly resolution, Cape Town. Fortunately, the issue of data quality is currently receiving attention from SAWS and personnel are working on restoring their radiometric network so that good quality ground-based irradiation data can be made available. This project has only just started and would be completed over the next two to three years. Historical database recovery and the assessment of the quality are also to be undertaken [4],[5].

There are three other sources of ground measured solar data, namely the South African Agricultural Research Council (ARC), the South African Sugarcane Research Institute (SASRI) and the utility ESKOM. Both ARC and SASRI make use of photoelectric (silicon) pyranometers measuring GHI only [5] while Eskom makes use of pyrheliometers mounted on trackers, with only some of their stations equipped with photoelectric pyranometers. Eskom data was reported to be of low quality due to a lack of regular cleaning [7]. This is due to the remote locations of their stations in the Northern Cape.

2.3 Research Solar Stations

Although ground stations are limited, several Universities have carried out research, or continue to do so, and contribute high quality data free of charge. These include [5]:

- The University of Durban-Westville (UDW) with an operational station from 1996 - 2002. GHI and DNI was recorded.
- The Mangosuthu University of Technology (MUT) in Durban. Measurement started in 2003 and is ongoing. Data includes GHI, diffuse and DNI.
- UKZN's Howard College campus. Measurements started in 2009 and are ongoing. Data include GHI, diffuse and DNI.
- Stellenbosch University started solar measurements in 2010 and is ongoing. Data include GHI, diffuse and DNI, among other weather and solar data being monitored.

2.4 Solar Developers

A number of solar developersare are recording on-site solar irradiance at various locations in South Africa. The author of this paper has installed and is monitoring seven of these stations. Most of the solar developers in South Africa that have on-site measurement stations are CSP or CPV developers, with a limited number of PV developers conducting on-site measurements.

3. Photovoltaic (PV)

3.1. Satellite derived data

PV developers are not required to have on-site measurements under the REFIT programme [3]. Without on-site measurements or publically available data from a nearby station, developers are to rely on satellite derived data only. The uncertainty of satellite derived data for the long term annual average is to 3.0 – 3.5% for GHI and 4.0 – 4.5% for GTI [8] for sites located within the Northern Cape with fairly stable weather conditions. It should be noted that not all satellite derived suppliers have these low uncertainties. On-site solar measurements are highly recommended by the author, especially if tracking PV is considered.

3.2. On-site Measurements

The minimum recommended set of instrument of an on-site measurement station consist of two ISO secondary *standard* (thermopile) pyranometers (e.g. Kipp&Zonen CMP11, EKO MS-802 or Eppley PSP) - one mounted horizontally to measure GHI and the other tilted to measure GTI. The ISO secondary standard instruments have an expected daily uncertainty of ±2%. Care should be taken not to select an ISO second *class* instrument (e.g. the Kipp&Zonen CMP 3, EKO MS-602) with an expected daily uncertainty of ±10%.

In addition to solar irradiation ambient temperature and wind speed and direction at 2 m should be recorded. Such a system is quick to install and cost about R 85 000 [9], excluding installation and security fencing. The system can also be rented for a minimum period of 1 year for R 50 000 [9], excluding installation and security fencing. Data from the system is downloaded via a GSM network. A different variant of this setup (with a single pyrometer and including a rain gauge) is shown in figure 1.

Fig. 1: Minimum on-site solar measurement system for PV plants [9]

For larger PV plants a system consisting of the following is recommended: two ISO secondary standard pyranometers, wind speed and direction at 10 m above ground, ambient temperature and relative humidity, barometric pressure and rain. Such a system costs about R 162 000 [9] excluding installation and security fencing.

When combining on-site measurements of at least one year with satellite derived data the uncertainty for the long term annual average will decrease to 2.0 - 2.5% for GHI and 2.5 – 3.0% for GTI [8].
Regular maintenance on such a system involves cleaning the pyranometer dome, changing the desiccant of the instruments and ensure the rain gauge is free of leaves or other objects. Some sources recommend to clean the pyranometer dome every week [10] while others state that every two weeks is sufficient [11]. The author recommends cleaning at least every week. The desiccant of each pyranometer requires change every 3 – 6 months, depending on the humidity of the climate [12]. For sites located in the Northen Cape the author experience show that the desiccant needs replacement about every 4 months. More regular changing might be required for more humid regions.

4. Concentrating Photovoltaics (CPV)

4.1. Satellite derived data

In the REFIT programme CPV falls under PV therefore no on-site measurements are required. However, CPV utilises DNI and not GTI. It is highly recommended that CPV developers measure the DNI on site since, in general, the uncertainty of satellite derived DNI is much higher than GHI and GTI. The uncertainty of the long term average can be given as: 7.0 - 9.0% for annual sums and 9.0 - 12.0% for monthly sums [8] for sites located within the Northern Cape with fairly stable weather conditions. These figures are based on data from the SolarGIS data base. In the authors experience DNI has higher uncertainties compared to GHI and GTI, some data basis has an annual DNI uncertainty up to 15%.

4.2. Measuring

The minimum instruments of an on-site station consist of an ISO first class pyrheliometer (e.g. Kipp&Zonen CHP1, EKO MS-56 or Eppley NIP) mounted on a solar tracker and one ISO secondary standard (thermopile) pyranometer mounted horizontally to measure GHI. In addition to this, ambient temperature, wind speed and wind direction at 2 m should be recorded. Such a system is easy to install and cost about R 296 000 [9], figure 2, excluding installation and security fencing. Data from the system is downloaded via a GSM network.

Fig. 2: DNI measuring station (wind and temperature sensor not shown)

A system consisting of the following is recommended for large CPV plants: pyrheliometer and solar tracker with a shading ball assembly , two ISO secondary standard pyranometers (measuring GHI and Diffuse), wind speed and direction at 10 m above ground, ambient temperature and relative humidity, barometric pressure and rain. Such a system costs about R 380 000 [9] excluding installation and security fencing. Wind speed measurements are important for CPV developers in order to assess the wind loads on their CPV arrays. Temperature measurements are important to assess the temperature of the PV cells.

When combining the measurements of at least one year with high accuracy satellite derived data, the uncertainty for the long term annual DNI satellite derived data will decrease to up to 5.0 % for annual sums and 7.0 – 8.0% for monthly sums [8].

Regular maintenance on such a system involves cleaning the pyrheliometer glass and pyranometer dome, change the desiccant and ensure the rain gauge is free of leaves or other objects. Some sources recommended to clean the pyrheliometer daily or every second day [13] while others state that every two weeks is sufficient [11]. The author recommends cleaning it twice a week. The desiccant of the pyrheliometer requires change every 3 – 6 months, depending on the humidity of the climate [12].]. For sites located in the Northen Cape the author experience show that the desiccant needs replacement about every 4 months. More regular changing might be required for more humid regions.

5. Concentrating Solar Power (CSP)

5.1. Satellite derived data

In the REFIT programme CSP developments are required to have on-site measurements of at least one year. CSP plants utilises DNI and not GHI/GTI. Satellite DNI data is useful for finding a suitable CSP site and for initial plant modelling.

5.2. Measuring

Since CSP plants are generally larger than PV and CPV plants, a system consisting of the following is recommended: ISO first class pyrheliometer and solar tracker with shading ball assembly, two ISO secondary standard pyranometers (measuring GHI and diffuse and able to calculate DNI), wind speed and direction at 10 m above ground, ambient temperature and relative humidity, barometric pressure and rain. Such a system costs about R 380 000 [9] excluding installation and security fencing.

Wind measurements are important for CSP developers in order to assess the wind loads on the mirrors and receivers. Wind, temperature and humidity data is an important factor to design the condenser of a CSP plant, especially an air (dry) cooled condenser [14]. Similar solar measurement instruments are installed by PV developers employing tracking (either single axis or dual axis).

6. Alternative DNI measurements

A RSR (Rotating shadow band radiometer) can be used to calculate DNI as an alternative to using a pyrheliometer to measure DNI. The RSR measures GHI and diffuse irradiance and calculates DNI. Both GHI and diffuse are measured with the same silicon pyranometer. A rotating shadow band is used to shade the pyranometer every 2 minutes (typically). The fast response of the silicon pyranometer (about 10 µs) allows for diffuse measurements with a rotating shadow band while thermopile pyranometers requires a stationary shadow band.

These systems are aimed to provide a lower cost alternative for autonomous operation in remote locations. Development of this instrument took place during the times when solar trackers were less reliable (e.g. the onboard clocks experience time drifts) and had relatively high power consumption. Modern day solar trackers, e.g. the Kipp&Zonen Solys 2, have low power consumption and the clock is updated from an on-board GPS. The tracker can also be remotely controlled (e.g. to download status/log files and perform a reset) via the same GSM link from which data is download.

DNI measured from a pyrheliometer requires no post processing. DNI data are, however, quality checked with calculated DNI from GHI and diffuse from the same station, if available. This results in a data time series with low uncertainties. A RSR requires calibration against a pyrheliometer (typically for a few months and ideally in an area with similar weather conditions of the deployment location) in order to better understand the spectral response of the silicon pyranometer. Post processing of data is normally required and quality checks are limited since no additional sensors are usually employed with these devices. This results in a higher uncertainties in the DNI time series when compared to that of a pyrheliometer based station [13].

Even with the mentioned limitations, RSR devices are widely used for solar prospecting, e.g. by CSP developers. The cost of a RSR, including a full weather station with wind measurements on 10 m, ranges from R 210 000 (Irradiance) [9] to R 280 000 (Solar Millennium) [15] to R 320 000 (YesInc.) [16].

7. Plant Monitoring

It is recommended that on-site monitoring continues after a solar project has successfully been constructed. Plant monitoring on a PV plant requires pyranometers mounted at the same angle as the PV panels, Figure 3. On large PV farms multiple sensors are recommended. This will allow for accurate plant performance modeling. Satellite derived data can also be used to perform load forecasts and plant monitoring.

Fig. 3: Tilted pyranometers used for plant performance modelling on a PV plant

8. Conclusion and Recommendations

On-site solar measurements are important to develop successful solar project in South Africa, due to the general lack of high quality solar measurements. ISO secondary standard thermopile pyranometers are recommended for measurements in PV applications. ISO first class pyrheliometers mounted on a solar tracker form the core of a measurement station for CSP of CPV projects. Solar instruments should be cleaned while on site and should be calibrated at recommended intervals. On-site measurements should continue in order to assist on plant performance modeling.

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