DIRECT NORMAL IRRADIANCE FOR RATING C-SYSTEMS

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ABSTRACT: The work describes a method for determining the Direct Normal Irradiance (DNI) for rating PV concentrator systems, best known as C-Systems. It is based on finding the DNI that produces more Direct Normal Energy during the whole year for a specific location, rather than determining an arbitrary or peak DNI value. Since DNI is not normally measured on weather stations, a mathematical method based on stochastically generated DNI hourly values obtained from monthly global horizontal irradiation values proposed by J. Remund et al. is used. The work is enclosed under the C-Rating project founded by the 5th FP of EC.

Keywords: Solar Radiation – 1: Qualification and Testing – 2: Concentrators – 3.

1. INTRODUCTION

The main difficulty found when trying to compare C-Systems is the lack of consensus about test conditions. Flat-plate PV modules are rated using 1000 W/m^2 Global Normal Irradiance (GNI), according to the Standard Test Conditions (STC). A previous work shows that this peak performance condition value is not very appropriate to be used as a standard for DNI and 850 W/m^2 is proposed based on measured DNI when GNI was close to 1000 W/m^2 [1]. Reasons stated for proposing this value are based on the fact that 1000 W/m^2 is not an easily achievable DNI value and scaling the DNI spectrum for 1000 W/m^2 leads to unrealistic spectral distributions [2].

In this work we present a different approach, which is based on real operation conditions instead of peak conditions. This is aimed at determining the DNI that usually delivers more Direct Normal Energy during a whole year. This approach provides a more realistic rating of the system under normal operation conditions and allows a better optimisation of PV concentrators.

2. DESCRIPTION

2.1 Obtaining DNI values

In order to determine the most appropriate DNI value for rating C-Systems at a specific location, historical data collection should be carried out. The data format chosen is hourly DNI values for at least 10-year period.

Since DNI is not a usually recorded data world wide, an alternative model that uses global radiation values has been chosen. This method consist on generating stochastically hourly DNI values from monthly global horizontal irradiation (10-year average) values, using the Aguiar and Collares-Pereira (1988) model for generation of daily values and the Aguiar and Collares-Pereira TAG-model (1992) for the generation of hourly values from the previously calculated daily values [3]. The DNI value is then obtained using the Pérez-models modified by J. Remund et al. A flow diagram of the calculation process is shown in figure 1.

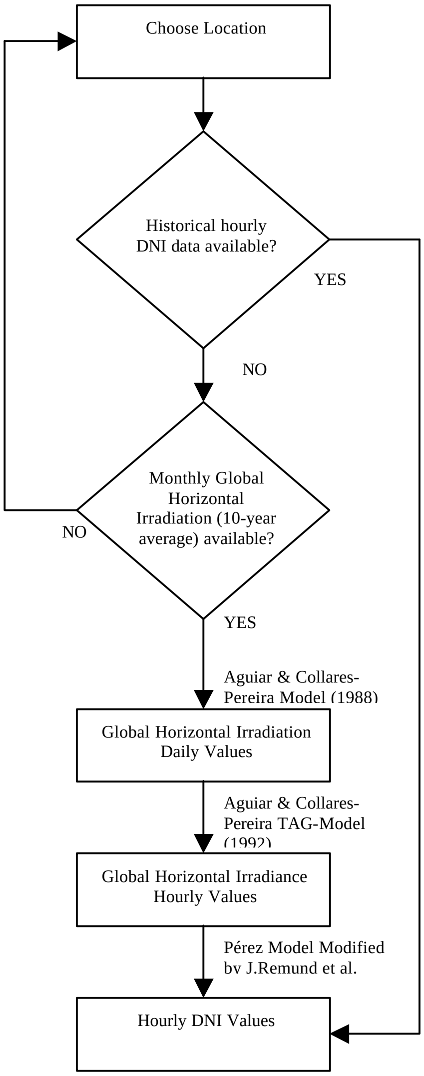

Figure 1: Flow diagram for obtaining hourly DNI data.

Validation of the hourly DNI generation model has been carried out in a previous research (J. Remund et al.,1997) and the data generated with this model seem to be appropriate substitutes of long-term measured data (Gansler et al., 1994).

2.2 Determining the rating DNI value

Once hourly DNI data are available, a histogram representation of Hours per year vs. Direct Normal Irradiance for the desired location is plotted. Figure 2 shows an example for Munich for a stochastically generated year according to the calculation procedure described in the previous section. The figure shows that low DNI values are very frequent during the year. This is normally the profile found in most of the locations studied due to the low direct irradiance at early hours in the morning and late hours in the afternoon, as well as in cloudy days.

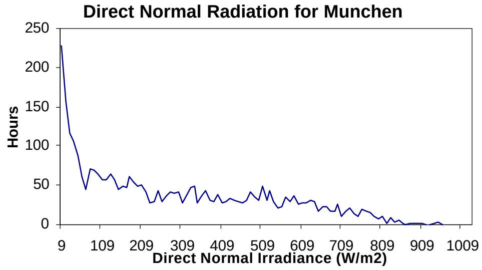

Figure 2: Availability of DNI for Munich.

However, although low DNI values seem to be very frequent for some locations, the energy delivered by these DNI values contribute very little to the Direct Normal Irradiation (energy per normal surface, see figure 3).

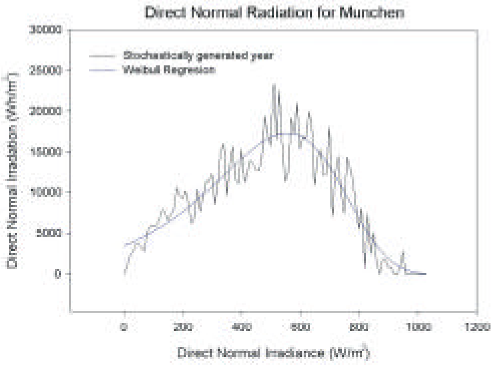

Figure 3: Direct Normal Irradiation vs. Direct Normal Irradiance for a stochastically generated year for Munich. The fit to a Weibull distribution gives a DNI rating value of 556±69 W/m^2 and a correlation coefficient of 92%.

In order to choose the DNI value that produces more energy during the whole year, we should choose the DNI values at the maximum Direct Normal Irradiation. Since the distribution has many local maximums, we have carried out a fitting procedure to find the theoretical distribution that best fits the experimental data. The best results were found using the four parameter Weibull distribution:

$$f = a\left(\frac{c-1}{c}\right)^{\frac{1-c}{c}} g^{c-1} e^{\left(-g^{c}+c-1\right)}$$

where

$$g = \left|\frac{x-x_0}{b} + \left(\frac{c-1}{c}\right)^{\frac{1}{c}}\right|$$

and x_0, a, b and c are four independent parameters.

The correlation coefficient between the distribution and the Weibull function is greater than 90% for all the locations studied so far. Figure 3 shows this curve fitting for stochastically generated DNI data for Munich.

Therefore, the work has focused on obtaining the Weibull function that best fits the distributions for each specific location and on determining the DNI value that provides its maximum irradiation with its associated standard error. Figure 4 shows the flow diagram of the calculation procedure:

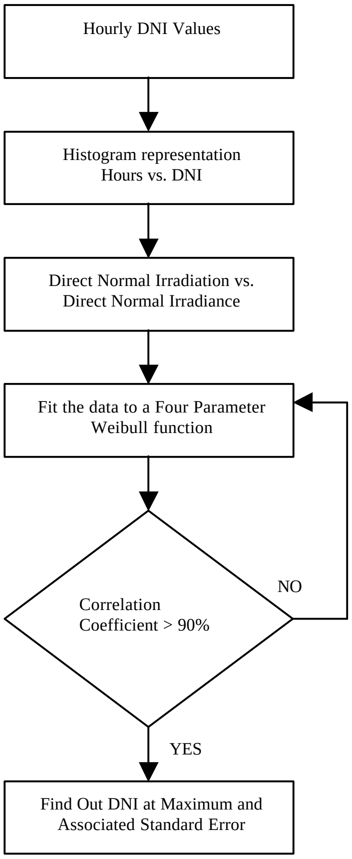

Figure 4: Flow diagram for obtaining DNI rating value.

Once the regression has been performed, the four parameters of the Weibull function (x_0, a, b and c) and their corresponding errors (Δx_0, Δa, Δb and Δc) are determined. The rating DNI value is then calculated according to the following expression:

$$DNI_{max} = b\left(\left(\frac{c-1}{c}\right)^{-\frac{1}{2(c-2)(c-1)}} - \left(\left(\frac{c-1}{c}\right)^{\frac{1}{c}}\right)\right) + x_0$$

and the associated error:

$$DNI_{error} = \frac{\partial DNI_{max}}{\partial b}\Delta b + \frac{\partial DNI_{max}}{\partial c}\Delta c + \frac{\partial DNI_{max}}{\partial x_0}\Delta x_0$$

3. RESULTS

The method described has been applied to 228 European weather stations where 10-year average monthly global horizontal irradiation data is available. In table I, we present the results for some representative cities.

Some work has been done validating the proposed model by comparing the DNI_{max} obtained from real DNI data with the DNI_{max} obtained from stochastically generated DNI data. The first results show that DNI_{max} seems to be slightly underestimated when generated stochastically but more data needs to be processed in order to figure out a final conclusion.

Table I: DNI value that produces the maximum direct normal energy during the whole year for some locations in Europe.

Location	Latitude	DNI_{max} (W/m^2)	DNI_{error} (W/m^2)	Correlation Coefficient (%)
Ajaccio	41,55	668	76	94
Alghero	40,38	742	83	95
Amendola	41,32	685	69	95
Ankara	39,57	741	92	94
Bar	42,06	668	70	95
Bari	41,07	810	70	95
Beograd	44,48	569	79	93
Bitola	41,03	670	79	94
Bologna	44,32	555	71	90
Bourdeaux	44,5	548	83	93
Borlaenge	60,26	552	83	93
Braganca	41,49	713	70	95
Cagliari	39,15	655	71	95
Cambridge	52,13	493	104	90
Coimbra	40,12	613	68	94
Munchen	48,22	556	69	92
Madrid	40,27	701	51	93
Umea	63,49	611	37	90

4. FUTURE WORK

The proposed model needs to be validated for larger amount of real DNI data. Slight modifications of the model will be carried out if required as a consequence of the validation process, although no big differences are expected according to the results of previous works on the issue.

The main idea behind this work is to define a set of parameters for testing or rating PV concentrators similar to the STC used for flat-plate PV modules. In this sense, a closer study taking into account other test condition parameters such us ambient temperature (Ta), spectrum (through the air mass - AM) and wind velocity (wv) and direction (wd) will be carried out as a continuation of this one.

The objective is to define a complete standardised set of parameters (DNI, Ta, AM, wv, wd) for testing and rating C-Systems outdoors. An initial idea of the method used to define these parameters is to find out the mean value of Ta, AM and wv when DNI is between DNI_{max}-DNI_{error} and DNI_{max}+DNI_{error}.

Next step is to classify these standards for different climatic areas World-wide in case big differences are found.

5. CONCLUSIONS

The proposed method seems to give a very appropriate way of characterising the DNI value that provides more direct normal irradiation for a specific location. Although the work is still in progress, the first results show that the 850 W/m^2 DNI value proposed is too high for most of Central Europe locations, but still reachable. For instance, this value could be kept as a peak performance value, but better results would be obtained if a lower site-characterised value is used.

Once a larger amount of locations are studied, grouping of the resulting DNI standards obtained will be performed, according to climatic area and location.