A Statistical Approach to Day Ahead Forecasting of Solar Irradiance in a Local Point

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1. Abstract

Today, for the management of energy supply systems forecast information on load and the production of meteorology dependent (wind, solar, hydro) generation is ever rising. Solar irradiance forecasting is given a unique priority as it spans over major applications such as management of grids with a high share of photovoltaic generation and thermal power supply systems relying on solar heat generation. This research addresses the day ahead prediction of the local irradiances intended to be applied for the management of solar assistant systems for heat and hot water supply. The forecast method presented here is based on the statistical analysis of historical data in Kristiansand, Southern Norway. For this, satellite derived irradiance data covering seven years provided by Geomodel Solar, Slovacia (D. Heinemann, 2005) can be used. In this approach, it is assumed that the irradiance sum of today shows a dependence on the irradiance sum of yesterday (B.O. Ngoko, 2014). This day to day dependency is assessed by obtaining conditional probability distributions of irradiance sum on next day for a given status of weather, given here by the irradiance sum on previous day. Based on such probabilistic approach two schemes are introduced to obtain values for the forecasting. The first scheme is based on most probable expected irradiance sum of tomorrow and the second approach is based on the average expected irradiance sum, both extracted from the probability distributions. Having obtained forecasted values for the irradiance, the validity of prediction methods are investigated by

comparing with the actual measured data giving the statistical parameters, relative monthly Bias and relative monthly Root Mean Square Error (RMSE). The comparison reveals that the approach using the average expected irradiance sum, gives more accurate results showing low RMSE. Concerning the application, the irradiance data, both measured and forecasted can be used to analyze the daily energy gain of a solar thermal collector and its forecastability.

Key words: **Day-ahead, Energy, Forecast, Irradiance, RMSE**

2. Introduction and research problem/issue

Today, use of renewable energy is ever increasing. As both wind and solar irradiance are highly variable and uncontrollable, this gives new challenges for the design and control of energy supply systems and calls for tools to as least partly predict these energy flows. Concerning wind power, power prediction systems have already shown their strong economic impact and improve the integration of wind energy into the management of grids with high penetration levels (Lie, 2012),

(Heinemann, 2002). For solar power forecasts come up to the same importance in grids with high PV penetration. For that application, the forecast of the regionally integrated irradiance affecting the PV systems distributed in the respective region is of importance, and scheme for the prediction of the spatially averaged irradiance had been developed yielding good quality (Heinemann, 2002). The prediction of single point irradiance still fights with higher uncertainties. But, as for the control of local systems for solar thermal applications, this single point forecast is the relevant parameter. The research addressed the day ahead prediction of single point irradiances and applied it for domestic and commercial power management systems to achieve of economic benefits.

Objectives:

1. Proposing a method to forecast global irradiance on horizontal and tilted surfaces by means of a probabilistic approach derived from the analysis of historical sets measured irradiance in a local region.
2. Obtaining time series forecasted information for solar irradiance behaviour.
3. Investigation of the quality of forecasts with statistical parameters.

3. Research Methodology

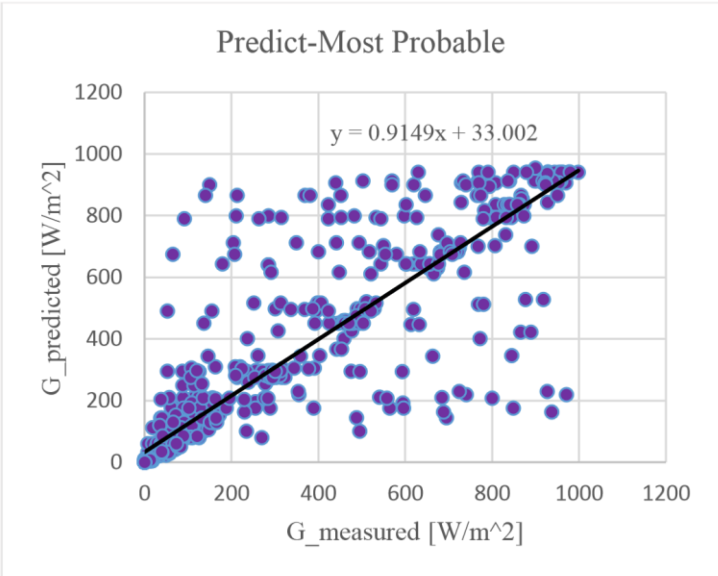
In this research, the basic solar irradiance data are given by satellite derived information supplied by Geomodel Solar (Solar, 2013), Slovacia, SolarGIS database. These data are derived for the location with latitude of 58.15° and a longitude of 8.00° Kristiansand city, Southern Norway. Initially, irradiance and atmospheric data is sorted out in to a simple formats; hourly, daily, and monthly values. As the initial step towards a probabilistic approach of forecasting, daily tilted irradiance sum is obtained. Subsequently, daily irradiance sum is sorted out for individual months. Thereafter, irradiance classes are defined for each month, depending on the minimum and maximum value of irradiance sum. For a single month, the possibility of one-day-ahead daily irradiance sum is investigated based on the irradiance class of the previous day. Such investigation reveals that the expected daily irradiance sum could behave much closer to the irradiance class of the previous day, though certain divergence would be possible. In such a way, it is possible to obtain a most probable irradiance class based on the irradiance sum of previous day. Apart from the most probable behavior, it is also possible to obtain an average outcome for the expected daily irradiance sum as an alternative forecasting scheme. Eventually, success of the research outcome is

Results and findings

The forecasting is achieved under two different forecasting approaches. The first one is based on the most probable behavior of the irradiance classes and the second scheme is based on calculated average value of the irradiance over the probability distribution. Finally the accuracy of the forecast is investigated by applying some quality tests. For this, most recently measured values are compared with the forecasted values. Figure 1 compares the measured irradiance with the forecasted irradiance for the most probable forecasting scheme and Figure 2 shows the same comparison for average forecasting scheme. It becomes clear that, Figure

1 shows more scatter leading to less accurate forecasting, whereas Figure 2 shows less scatter leading to high accurate forecasting.

It is proved that the average scheme is a better choice for obtaining more accurate forecasted values.



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2012 under Most Probable Forecasting Scheme

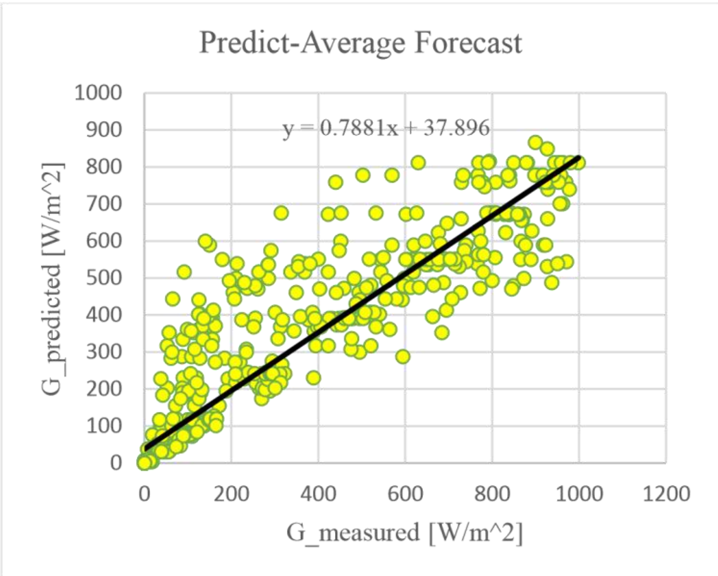

Figure 2. Forecasted Irradiance vs. Measured Irradiance for the Month-May, 2012 under Average Forecasting Scheme

The quality of the forecast can also be investigated by calculating the Monthly Bias and Root Mean Square Error (RMSE) which is normalized to the monthly mean.

Relative Monthly Bias for the daily irradiance can be defined as,

$$Relative\ Monthly\ Bias = \frac{\frac{1}{N}\sum_{i=1}^{N}(Measured\ Irradiance(i) - Forecasted\ Irradiance(i))}{Monthly\ Mean\ of\ the\ Measured\ Irradiance} \quad (1)$$

Relative Monthly RMSE for the daily irradiance can be defined as,

$$Relative\ Monthly\ RMSE = \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}(Measured\ Irradiance(i) - Forecasted\ Irradiance(i))^2}}{Monthly\ Mean\ of\ the\ Measured\ Irradiance} \quad (2)$$

Irradiance in a single day spans over 24 hours, thus for a typical month, 724 (24x30) amount of measured and forecasted irradiance data has to be included to obtain monthly bias and monthly RMSE. Equation (1) and (2) can be applied to assess the quality of adopted two forecasting schemes. Further they can be applied to differentiate proposed forecasting scheme with a very basis persistent forecasting scheme. In the persistent forecasting, it is assumed that tomorrow's behavior is exactly similar to today's behavior. Table 1 depicts the comparison of all three forecasting schemes for the month of May.

Table 1. Quality Comparison for Different Forecasting Schemes

Forecasting Scheme	**Relative Monthly Bias for Daily Irradiance Pattern**	**Relative Monthly RMSE for Daily Irradiance Pattern**

Persistent forecasting	0.030	0.58
Most probable forecasting	-0.051	0.601
Average forecasting	0.055	0.481

The least RMSE is recorded for average forecasting scheme. A high RMSE is recorded for the persistent scheme. It is proved that probabilistic approach of forecasting stands taller as far as concerning the accuracy of the output. We can say, probabilistic approach really offers better information than the naïve forecast.

Figure 3 and Figure 4 compare the daily time series on predicted irradiance and measured irradiance with respect to different approaches of forecasting during a single month. The curves display the variations between measured and forecasting values. By observing the behavior of curves, it can be concluded that average forecasting scheme offers better results with less divergences.

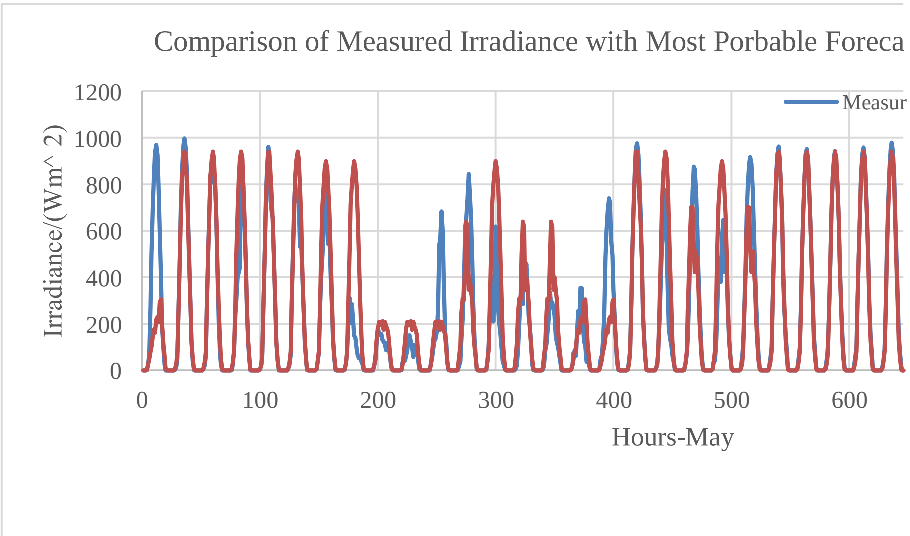

Figure 3: Daily Time Series for Measured and Forecasted Irradiance May, 2012 under **Most Probable** Forecasting Scheme

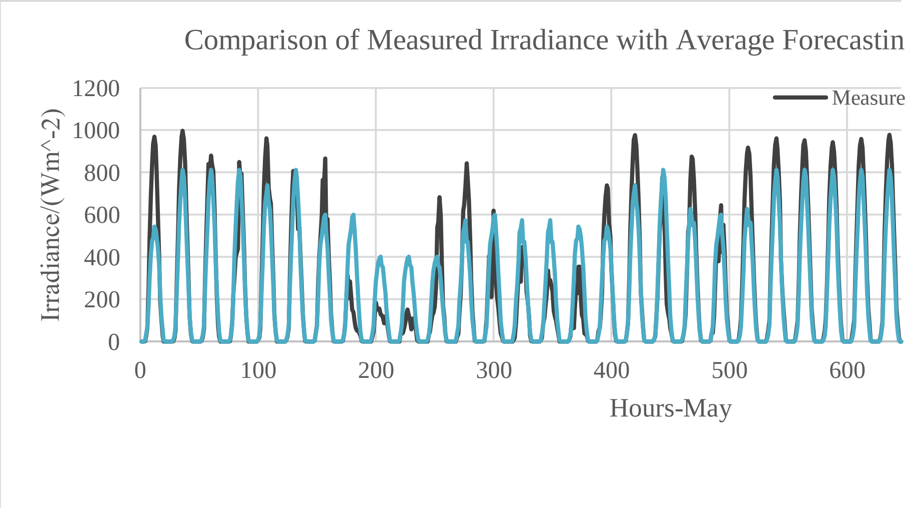

Figure 4: Daily Time Series for Measured and Forecasted Irradiance May, 2012 under Average Forecasting Scheme

5. Conclusions, implications and significance

The method is developed by analyzing historical data in a local region. Such short time forecasting approach can be of its importance to apply for the control of local solar thermal applications. Control systems can be integrated with energy management systems to enhance the efficiency by way of harvesting optimum amount of energy out of available solar power. This single point forecast information can be used as an input variable to such control system. A solar thermal collector can be employed as a simple power management system in domestic level. When we have forecasted information, we can plan the use of available energy. As a results, such scheme will help cut down the energy bill.

Analyzes of the generated schemes reveal that the forecasting is more accurate for the days which have similar weather sequence. When there is a substantial difference between today's weather and tomorrow's weather, the drawback emerges in both proposed forecasting schemes.
Further to explain, if today shows a bad weather, as long as tomorrow also will show a bad weather with little variation, the forecast approach works quite well. Conversely, if today shows a bad weather and then tomorrow

will show a sudden variation, possibly from bad weather to fine weather, the forecast will not accurately work due to the fact that, the probability of such huge variations are very low. Concisely, extreme changes in the weather, disturbs the stability of proposed predicting schemes. It opens a new area for researching, i.e. introducing a sophisticated method to cope up with these sudden changes by analyzing historical data. One option may be given by a link to routine weather forecasts that may feed warnings on sudden changes to the scheme.

6. References (Selected)

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