SOLAR ELECTRICITY FORECAST – APPROACHES AND FIRST RESULTS

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ABSTRACT: Due to the rapidly growing photovoltaic (PV) market in Germany, solar electricity fed in the grid amounts already to a share of approx. 2% of the total grid load during midday summertime. This is already a significant figure for grid operators. For several years a wind power prediction for wind energy is already available. But until now, there has been no operational solar electricity forecast. Therefore, the paper is aimed at providing an approach for a solar electricity forecast system based on the forecasts of the European center of midrange weather forecast ECMWF locally refined by model output statistics MOS with local weather stations. To evaluate the results, they have been compared with measured values of several thousand PV plants in Germany. The results show for daily values an RMSE of 24.5 % for the months July and August 2006, which is of course a satisfying result.
Keywords: Forecasting, Utilities, Grid-connected

1 MOTIVATION

Germany's conventional power plants are traditionally cooled by means of river water. The maximum allowable water temperature is limited by law. Due to the hot summer 2003 and this year, a significant part of conventional base load power plants have to reduce their output power significantly. For instance, nuclear power plants Krümmel und Brunsbüttel had to reduce their output up to 25% and, Isar 1 had to limit its output to 20% [18]. Considering this and the fact that these power plants cover base load, it becomes obvious that during warm summers another technical solution has to be found to substitute traditional base load and, if possible, to reduce the needed peak load, too.

In order to investigate, if PV electricity may help to cover the shortage, the hourly grid load of three typical summer days during the last three years and the measured power of about 4000 PV plants have been taken as basis for this evaluation. The data for grid load are available from the "Union for the Co-ordination of Transmission of Electricity" (UCTE) under [20]. (Please refer to section 5.1 for more information about the data basis of measured PV power).

The characteristics of the grid load of three summer days are very similar to each other. Now we compared these to the feed-in PV power normalized to the total installed PV capacity. The feed-in electricity we took from a typical summer day, the 17th of July 2006. The results are shown in figure 1:

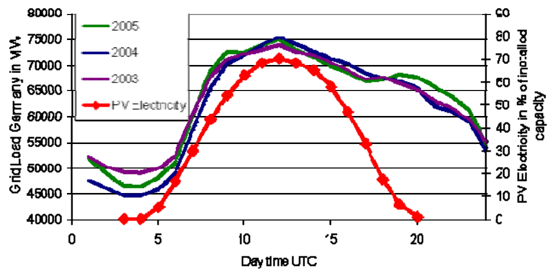

Figure 1: Comparison of the total grid load according to UCTE to the feed-in PV electricity of three typical summer days and PV electricity feed-in the grid on July 17th 2006.

The good correlation of peak load and PV power shows that PV electricity may help to substitute conventional power plants in case of power limitations caused by cooling problems.

In addition, the following conclusion can be drawn out of the given figure 1:

- Assuming an installed capacity of 2 GWp in Germany at summer days PV electricity has already a share of 2,000MWP*0.7/70,000=2% at the midday's peak
- The share of the difference of peak load and base load (approx. 75,000-45,000) constituting the most expensive power, is even at 4,7% which is of significant importance for the utilities

Therefore, solar energy forecast is already needed for grid operation today, but will become more and more important in the future.

2 INTRODUCTION

Today some work has been carried out to predict the solar radiation for hours or days ahead. For example the ECMWF forecast includes the parameter radiation as a direct model output DMO. ECMWF delivers forecast up to 10 days ahead, but in a maximum spatial resolution of approx. 60 km x 60 km, so that regional or even local variations are not included. To solve this shortage e.g. model output statistics or mesoscale models can be employed.

Besides these also weather services predict solar radiation for the next few days, such as the meteomedia AG, Germany's biggest private weather service, which has included it into its MOS (see below).

Furthermore, forecast for up to 6 hours ahead has been realised using motion vectors and smoothing on satellite derived cloud covers [7].

But until now, no solar electricity forecast has been carried out. To close this gap, we have developed the system explained in the next chapter.

3 PREDICTION SYSTEM

The general design of the forecast system is shown in figure 2 below:

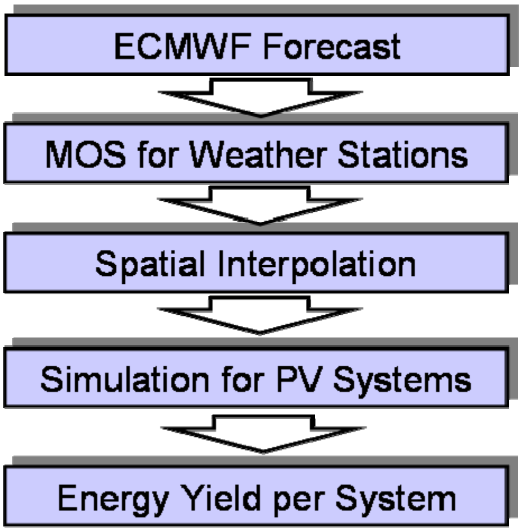

Figure 2: Schematical flow chart of forecasting system

In the next paragraphs the single steps will be described in more detail.

4 SOLAR RADIATION FORECAST

4.1 ECMWF MOS

The forecast of the European Center for Midrange Weather Forecasts (ECMWF [6]) computes weather forecast a 1°x1° arc grid for Europe by means of two diagnostic and four prognostic physical equations of the atmosphere. Due to the course grid the results cannot be used directly for energy meteorology. Different approaches are available either using statistics, mesoscale models or neural networks.

The approach chosen for this paper is based on the statistical method MOS (model output statistics). The MOS version used is developed and employed by meteomedia AG together with meteocontrol GmbH.

A simplified definition of MOS is given by the following symbolic formula:

MOS = Forecast model +
local measurements +
local statistics

The meteomedia MOS is generated using the following steps:

- The basis is a long-term mean seasonal value of the parameter which should be predicted
- Different weather parameters (measured values or values of the ECMWF model) are taken into account
- Furthermore, means of hourly measured values as well as standard deviations, etc. are taken into account
- For each predicted value a certain weight and coefficients are derived by statistical analysis
- Step by step every value is calculated

As basis value the hourly mean per month of the past years is taken. The results are corrected by using step by step multiple regressions. Depending on the predicted value other ECMWF output values are used for this regression.

If Y is the predictant to be predicted and A_0 the long-term mean, then MOS can be described as (see e.g. [8])

$$Y = A_0 + A_1 X_1 + A_2 X_2 + \Lambda + A_n X_n$$

where Ai are coefficients to weight the parameters and Xi are predictors. To summarize it can be stated that most of the Xi are an output of a numerical model, like ECMWF optimized by means of statistical methods. Generally, both parameters Xi and coefficients Ai vary from season to season.

An important issue is the weight of each parameter. It gives an idea of the importance of the parameter. It is calculated by

$$Wgt = 100\% \cdot \frac{Co \cdot Sd}{\sum abs(Co \cdot Sd)}$$

where

Wgt	- Weight
Co	- Regression coefficient
Sd	- Standard deviation

This weight and also the used parameters are different for each season. Other topics of MOS like smoothing will not be further discussed. (Smoothing is used to avoid unrealistic jumps in the prediction).

4.2 Data b asis

Figure 3: Distribution of weather stations used for the MOS. The red as well as the blue dots indicates the weather stations owned by different weather services, but all are considered in meteomedia's MOS

In total the MOS forecasts for about 850 WMO synop weather stations in Germany and near the German border in neighboring countries are used. Their distribution is shown in the figure 3.

Unfortunately only a few of the weather stations are equipped with radiation sensors. Therefore, a “virtual sensor” has been added to the parameter set of each weather station. To do this, satellite derived solar radiation is added as parameter before training the MOS. The radiation data is processed by the Carl-von-Ossietzky university of Oldenburg according to the Heliosat method.

4.3 Interpolation

With the help of the MOS a local refined forecast of temperature as well as solar radiation is given, but it needs to be transferred to the PC system’s location. This is done by means of interpolation

For this first version the interpolation method used is Inverse Distance Weighted (IDW). It is one of simplest interpolation method and its formula is given e.g. in [14].

An advantage of IDW compared to other interpolation methods like splines is its stability and that it is easy to be automated. It is impossible that it undershoots the lowest value of a surrounding weather station neither it can overshoot the highest value. Disadvantages of the method may seen in its very simple approach not considering any statistical measures and other local effects.

5 PV SYSTEM SIMULATION

5.1. Data basis

To get the most reliable forecast, distribution of orientation and tilt of the plants has to be considered as well as their spatial distribution over Germany. The leading and widespread data base of saferSun [5] has been chosen as the appropriate database to get information of different systems all over Germany considering different orientations, different plant layout and different components. Today, over 3500 plants with more than 150 MWp are included in the remote monitoring system. This is about 10% of the installed capacity in Germany.

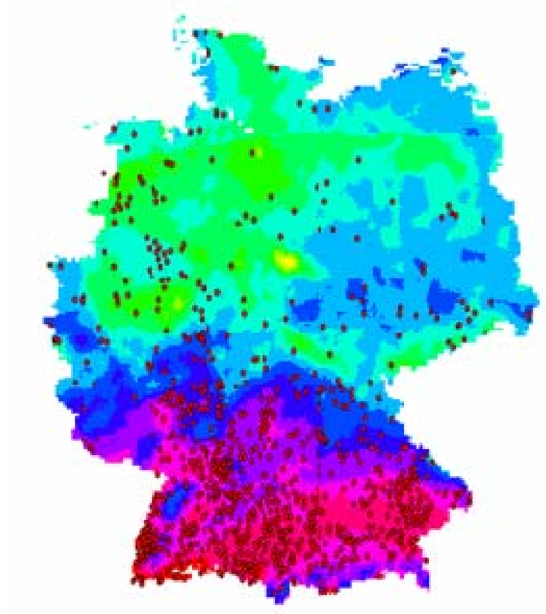

Figure 4: Distribution of PV systems in Germany included in the safer’Sun data base. Every red dot indicates one of more than 3500 PV systems.

Due to this fact, the plants included in safer‘Sun are an adequate sample for both, the distribution, orientation and configuration of PV systems and validation of the results of the solar electricity prediction.

Tracked systems are not considered in the simulation at this project stage, but it is an option to include them into the project in future.

First, the horizontal radiation has to be converted into radiation on the tilted plane. Afterwards, the simulation of the electrical system PV module, cabling, and inverter has to be provided.

5.2. Models for radiation transformation

For each system of safer’Sun a simulation is provided considering site, plant layout and orientation. In order to get these results, the common steps for time-step simulation are taken:

- Calculation of sun position according to the DIN algorithm [4]
- Splitting global radiation into diffuse and direct fraction using the model of [16]
- Transformation of horizontal radiation to the module orientation for diffuse radiation using the model of Klucher [12]

5.3. Electrical modelling

The electrical model consists basically of two components, the inverter and the modules. Other influences like cabling are considered in a linear reduction factor at the appropriate stage of simulation.

As PV panel model the simple efficiency model of Beyer is used [1]. It is given by the formula:

$$\eta_{MPP}(G, T_{module}) = [a_1 + a_2 \cdot G + a_3 \cdot \ln(G)] \cdot \left[(T_{module} - 25°C) * \alpha_{P_{MPP}}\right]$$

where a1-a3 are empirical parameters, alpha is the temperature coefficient of the module power at MPP.

The decision to use the HGB simulation model for the simulation is caused by the following reasons:

- High accuracy (see e.g. [1])
- Due to calculating directly MPP efficiency the model equations are solved analytically leading to high calculation performance and computing time reduction

The inverter is simulated using a common method according to Schmidt and Sauer [19] and [17].

6 SYSTEM OUTPUT

Outputs from the solar electricity forecast are both, time series in hourly resolution and a graphical user interface. These are shown in the following two figures.

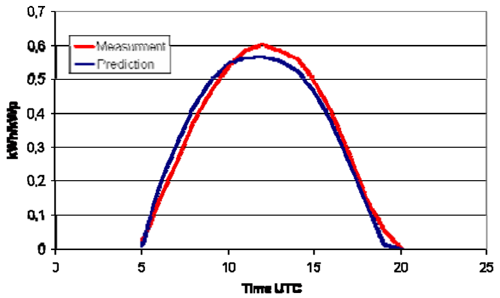

Figure 5: Example for forecasted and measured data as hourly time series for the 17th of July. The graph shows the accumulated values of all German PV systems.

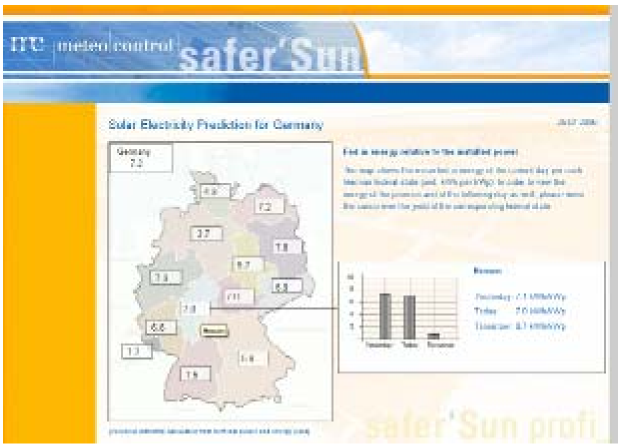

Figure 6: Screenshot of the web-based graphical user interface showing daily sums of PV electricity production normalized to the total installed capacity for each German federal state and the whole country.

6 VALIDATION

For validation different forecast stages forecast have been evaluated including both, radiation forecast and forecasted solar electricity. The results of these evaluations are given in the following subsections.

6.1 Solar radiation forecast quality

According to [21] the forecast for the period 2003 to 2005 has been analysed. It shows a bias of -3.87 Wh/m²d for 24h forecast to -8.88 Wh/m²d for the 120 h forecast. Analysing the RMSE of daily values it ends up with 58.8 Wh/m² (24h forecast) and 76.8 Wh/m² (120 h forecast).

6.2 Accuracy of simulated energy output

The accuracy of fed-in electricity has been determined for the months July and August by calculating the RMSE between the forecasted and the measured values of each system. Regarding hourly values that leads to an RMSE of 34.7% and 24.5% for daily values.

Systems showing obvious failures or wrong plant configuration have been sorted out.

7 INVESTIGATIONS OF MINIMUM REQUIRED PREDICTION SITES

In order to estimate the minimum required number of systems to be forecasted, the average of all plant has been calculated first. Then, this value has been compared with the values of one plant by calculating the RMSE of these two hourly time series per day. After that, this procedure has been repeated for every possible number of plants. The plants have been chosen by random. The resulting RMSE values have been drawn against the number of stations in the following example, showing the results for the southern Bavaria on the 31st of July.

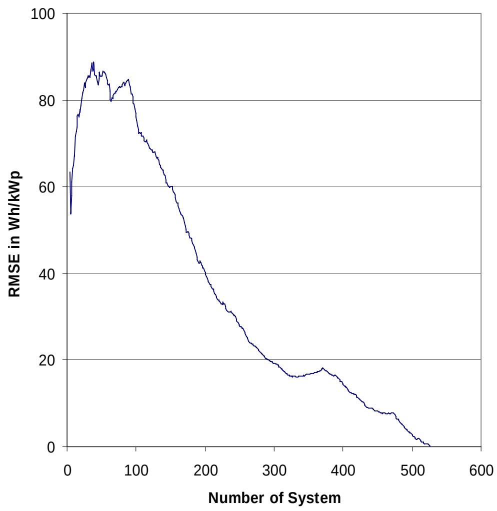

Figure 7: Deviation between the mean of a different number of PV systems and the mean of all systems of the 31st of July 2006 for southern Bavaria

This calculation has been done for different regions and days. The next graph shows the results for total Germany and the complete month July.

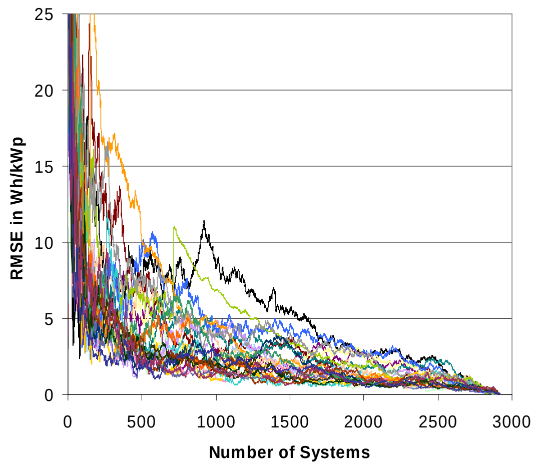

Figure 8: Deviation between the mean of a different number of PV systems and the mean of all systems for each day in July 2006 for whole Germany

Both graphs show no clear saturation of the curve, although this would be expected. Therefore, all systems have been included in the solar electricity forecast.

This evaluation has been done with measured values.

9. CONCLUSION

It has been demonstrated that solar electricity forecast will become essential for a reliable grid operation in future. Furthermore, we have presented an approach for solar electricity forecasting with satisfying results.

10. OUTLOOK

We will keep working on this topic, therefore, we are planning the following actions:

- Evaluation of the results for at least one complete year
- Replacing IDW interpolation by Kriging
- Further investigation on spatial variation
- Including more countries (e.g. Spain) into the model

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