SOLAR IRRADIANCE FORECASTING, BENCHMARKING of DIFFERENT TECHNIQUES and APPLICATIONS of ENERGY METEOROLOGY

Wolfgang Traunmüller[1]* and Gerald Steinmaurer[2]

[1] BLUE SKY Wetteranalysen , 4800 Attnang-Puchheim, Austria,
+43 / 7674-206-60; E-Mail: Wolfgang.traunmueller@blueskywetter.at

[2] ASiC – Austria Solar Innovation Center, Roseggerstraße 12, 4600 Wels, Austria,
+43 / 7242 / 9396 5560; E-Mail: Steinmaurer.gerald@asic.at

Abstract

The forecasts of solar irradiance, wind speed, ambient temperatures and other meteorological parameters play an important role in the field of energy meteorology. This paper is addressed to the forecast of solar irradiance, the comparison of different forecast methods and the use of this irradiance prediction in applications.

Solar irradiance forecast can be accomplished with completely different methods, ranging from Fuzzy-Logic-models to synoptic cloud cover forecasts of meteorologists. In the first part of the paper the basic principles of different methods and a comparison of achievable results will be presented.

Forecast of meteorological conditions should not practice as an end in itself, but can be used for energy-relevant applications. In this paper the use of solar irradiance and weather forecasts to control the heating and cooling of an office building as well as the energy efficient implementation of a solar thermal power plant into an existing district heating grid is demonstrated.

1. Introduction

An energy efficient use of fluctuating power sources requires reliable forecast information for management and operation strategies. Due to the strong increase of solar power generation the prediction of solar yields becomes more and more important. As a consequence, in the last years various research institutes and companies have been developing different methods to forecast irradiance as a basis for respective power forecasts. For the user of these forecasts it is important that standardized methodology is used when presenting results on the accuracy of a prediction model in order to get a clear idea on the advantages of a specific approach.

In this paper methods of solar forecasting are described for a forecast period for more than 3 hours. For shorter periods so called "nowcasting methods" are delivering the best results using methods based on remote sensing and satellite data.

2. From global meteorological models to local solar irradiance forecasts

Solar irradiance forecasts can be either base on direct model outputs of meteorological forecast models, different post processing methods of these results or of synoptic cloud cover forecasts of meteorologists.

2.1. Global Meteorolocial Forecast Models

Global horizontal irradiance (GHI) is one of more than 50 forecast parameters beside of temperature, air pressure, precipitation, etc. which are predicted as direct model output values (DMO) of global meteorological forecast models. Currently 14 global meteorological models are calculated daily by operational services. The providers of these models are National Weather Services (NWS), mainly located in Europe and Northern America. The most common models in Central Europe are the models of the European Center for Mediom Range Weather Forcast in Reading/Gbr (ECMWF), the DWD GME - model (Offenbach, Germany), the UKMO model (Bracknell, Gbr), the ALADIN model (Toulouse, France) and the GFS-model (NOAA, USA). The solar irradiance data in these models is computed directly (GHI, downward longwave irradiance flux, downward shortwave irradiance flux) or indirectly (cloud cover index).

Due to different policy and economic interests the access to this DMO-data is free or limited, depending on different service providers.

The intial value and startpoint of all thes models are worldwide meteorological observastions at the surface (synops, metars of about 10 000 meteorological stations and airports worldwide) and observations of the lower and higher atmosphere (soundings of more then 100 meteorolical ballons worlwide) as well as satellite data, precipitation radar data, lightnig data and oceanographic data, mostly at 00 and 12 UTC (UTC..Universal Time Coordinated), some models start their model runs additionaly at 6 and 18 UTC.

Most of these models are grid based. That means, that the observational values are concentrated to a 3-dimensional grid worldwide (Figure 1). The distance of these gridpoints is horizontally mostly about 40 to 90 kilometers and vertically the atmosphere is mostly parted in 30 to 50 altitude horizons.

From the initial state the forecasts are computed in timesteps (about 1-10 minutes) to the future using dynamic meteorological and physical equations, hydrostatic equation, thermodynamic equations and different parametric functions. The end of each time step is the initial state for the next computing period.

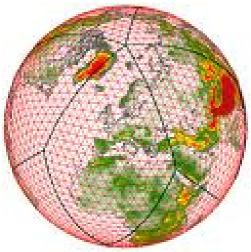

Fig. 1: Example of a global meteorological grid (source: DWD, GME)

In operational service the final model results are available for the most important meteorological parameters (including GHI or radiation flux) in time steps of 3 to 12 hours for a time range up to 180 to 360 hours for all gridpoints worlwide.

2.2. Postprocessing – local solar irradiance forecast

"Postprocessing" is the term that describes the procedure to gain reliable local solar irradiance forecasts from global meteorological forecast models. Different methods exit to regard the individual climatological and orographic characters of a location. To achieve the best results for local forecasts different methods and techniques are currently used, appending to the different demands of forecasting quality and availability in practise.

2.3. Local mesoscale models

The local mesoscale models (LM) rely on global models. These models run for a bounded area, in general up to a geograhpic area of 1000 x 1000 km or closer. The intial values for the points of the borders of the model area are delievered by global models. The advantage of the local model is the possibility to compute the meteorological parameters on a high resolution orography, mostly based on GIS-technology. The local model computes the meteorological forecasts in spacial steps depending on the model from 1 up to 7 kilometers and in timesteps from a few seconds up to some minutes. Some examples of local models are COSMO-LM (DWD), WRF or MM5.

2.4. Statistical methods

Statistical forecast models take the DMOs of global and local meteorological models as their inputs and calculate a forecast for a particular location. Such statistical models are trained in order to minimize the forecast error. This training is based on historical data, both for DMOs and observed meteorological data. For example the method of Model Output Statistics (MOS) uses multivariate linear regression to get an optimized model for mapping the DMOs into a local forecast. However, one is not limited using linear methods but any suitable machine learning method like neural networks, fuzzy logic based approaches or kernel methods like support vector machines and Gaussian process regression can be used. The advantage of this forecasting approach is that average forecasting errors are minimized. On the other hand maximum and minimum values are often cut and MOS-methods can be only used, if observation data near the forecast location is available.

2.5. Synoptic methods by meteorologists

The synoptic method (MET) is the traditional way of forecasting solar irradiance. Meteorologists in the operational weather service use the results of one or often more meteorological forecast models and combine these with their meteorological knowledge and forecasting experience. The result is a cloud cover forecast, for example in 1 hour resolution for a forecast period of 48 or 72 hours. With an equation including the cloud cover coefficient and the clear sky irradiance the solar irradiance is computed. This method has the advantage to deliver very good results for local weather phenomenons like fog or orographical effects, but it is restricted to areas which are well known by meteorologists.

3. Benchmarking of different forecasting approaches, state of the art

The quality of different forecast approaches was examined during a benchmarking campaign of the IEA SHC-Task 36 [1], where the rmse-deviation to ground data (hourly values) according to equation (1) can be seen in Figure 2.

$$rmse = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(I_{forecast,i} - I_{ground,i}\right)^2}$$

The different approaches were examined regarding the root mean square error (rmse), the relative RMSE (rRMSE) normalized to the average of observed daytime data of solar irradiance during the benchmarking period and the mean absolute error (MAE) [1]. For simplicity, in this paper only the rRMSE is regarded as benchmark pattern.

The benchmarking campaign of the IEA SHC-Task 36 last one year from July 2007 to June 2008 [1]. In this period hourly forecasts up to 3 days of each participating member were compared for 3 locations in Germany, 16 locations in Switzerland, 2 locations in Austria and 3 locations in Spain.

The approaches of the members of the IEA-Task used different techniques of forecasting ranging from DMOs of local models, statistic methods and synoptic methods by meteorologists. Beside of these approaches a reference model was run using the effect of "persistance". The persistance model compute the observed values of GHI of the actual day as forecast values for the next 3 days. The goal of all meteorological forecast models is to be better than this persistance "model" and acts as a quality criteria.

The participating members were the University of Oldenburg and Meteocontrol (both Germany, statistic methods), Meteotest (Switzerland, LM methods), Blue Sky (Austria, statistic and meteorological methods) and CIEMAT, CENER and Universiy of Jaen (all three Spain with LM methods).

They delivered forecasts with different methods (LM, STAT, MET) for the following regions and forecast days can be seen in Table 1. The results of the different benchmarking regions, based on rRMSE can be seen in Table 2, 3, 4 and 5 (in brackets: the number of the participating members).

Table 1. Participants, Forecast regions (forecast days).
LM…Local model, STAT…statistic model, MET…meteorologists

Member/Forecast region	Germany	Switzerland	Austria	Spain
University Oldenburg (GER)	STAT (3)	STAT (3)	STAT (3)	STAT (3)
Meteocontrol (GER)	STAT (3)	STAT (3)	--	--
Meoteotest (SUI)	LM (3)	LM (3)	LM (3)	--
Blue Sky (AUT)	STAT (3)	STAT (3)	STAT(3), MET(2)	--
CIEMAT (ESP)	--	--	--	LM (3)
University Jaen (ESP)	--	--	--	LM (3)
CENER (ESP)	LM (2)	--	LM (2)	LM (2)

Table 2. Germany, rRMSE, 3 locations

Method/Forecast Day	DAY 1	DAY 2	DAY 3
STAT	40,3-43,5 % (3)	41,6-45,1 % (3)	44,9-46,8 % (3)
LM	49,9-51,8 % (2)	52,9-54,9 % (2)	60,6 % (1)
persistence	63,5 %	70,2 %	73,3 %

Table 3. Switzerland, rRMSE, 16 locations

Method/Forecast Day	DAY 1	DAY 2	DAY 3
STAT	39,6-45,0 % (3)	41,8-46,3 % (3)	42,7-48,1 % (3)
LM	44,2 % (1)	46,2 % (1)	50,5 % (1)
persistence	58,4 %	64,0 %	66,8 %

Table 4. Austria, rRMSE, 2 locations

Method/Forecast Day	DAY 1	DAY 2	DAY 3
STAT	44,6-45,6% (2)	45,2-47,4 % (2)	48,1-50,5 % (2)
LM	55,4-58,1% (2)	58,5-59,5 % (2)	62,9 % (1)
MET	50,4 % (1)	49,3 % (1)	--
persistence	64,3 %	70,2 %	71,7 %

Table 5. Spain, rRMSE, 3 locations

Method/Forecast Day	DAY 1	DAY 2	DAY 3
STAT	20,8 % (1)	21,3 % (1)	22,4 % (1)
LM	22,9-31,7 % (3)	24,4-36,8 % (3)	26,9-40,9 % (2)
persistence	32,1 %	35,8 %	37,0 %

In all forecast regions the trends and results are similar for the forecast days 1 to 3. In Central Europe the methods of statistical forecasting achieve a rRMSE of 40-46 % for the first forecast day, the local models about 44-58 % rRMSE and the synoptic cloud cover forecast about 50 % rRMSE. In the southern regions of Europe (Spain) the results are better due to more consistant weather situations. The error for all methods and forecast days varies between 20 and 41 % rRMSE.

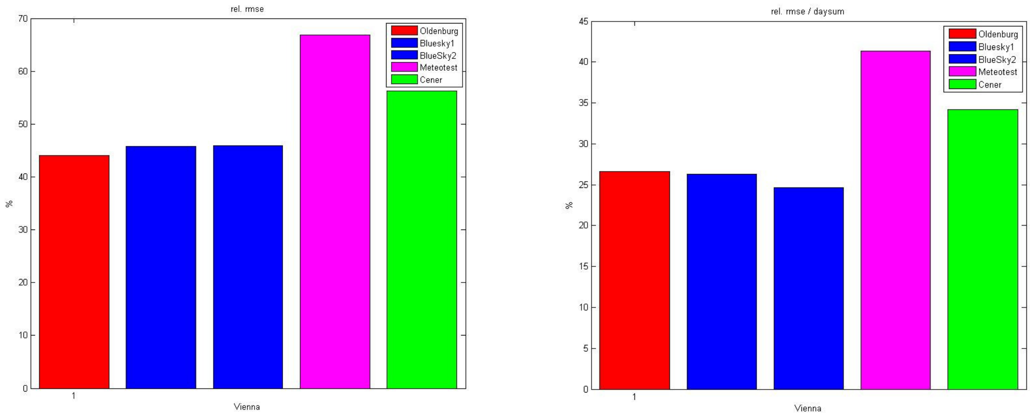

Figure 2: Results (rRMSE) of different forecast methods in Austria, examples for day 2 for Vienna hourly values (left) and daysum values (right) [1]

3. Applications

Reliable solar irradiance forecasts are used as initial values for forecast models for solar power generation (PV and CSP), solar thermal power plants, load forecasts and the heating and cooling control of buildings to optimize the management and operation strategies. In the following two applications and the use of forecast models in the energy management are adumbrated. The objects are an office building and a solar thermal assisted district heating grid.

3.1. Office building

The forecast of solar irradiation and of the ambient temperature is used to support the building control of an office building in Linz, Austria. The control can influence the heating and cooling devices, the ventilation system but also the external blind system.

A forecast file (for 48h) will be sent every afternoon to the central building control system, where this building management system can change set points, based on expected weather conditions. The set point of e.g. a room temperature can be reduced to a “comfort limit” (2K below desired room temperature), when solar radiation is predicted in the next 2 hours. It is important to mention, that also the user has the possibility to change this set points.

The overall management system consists of an enormous number of linguistic rules, for example

• If the predicted ambient temperature in the night is 5K lower than the room temperatures, then the night ventilation system is activated.

Measurement results of e.g. night ventilation can be seen in Figure 3.

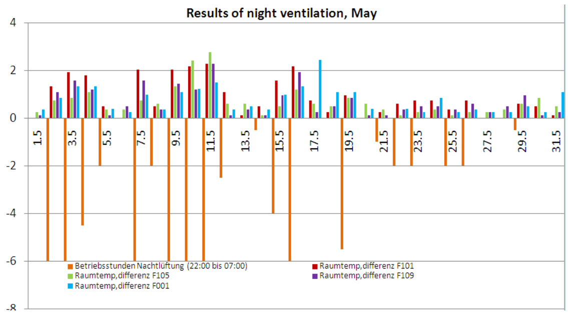

Figure 3: Night ventilation controlled by solar irradiation forecast

3.2 Load forecasts

For cities and communal energy power agencies energy meteorology forecasts are essential for economic and ecological reasons. The energy consumption of a community like a large city strongly depends on meteorological conditions. The most important meteorological parameters regarding to this are temperature and GHI. The day to day fluctuation of these values strongly influences the energy balance and for economical reasons the knowledge of these parameters offers advantages. In practise, hourly forecasts up to 10 days of temperature and GHI are delivered to power agencies. These meteorological inputs are used as initial values for energy consumptions models and the results are used for economic decision processes.

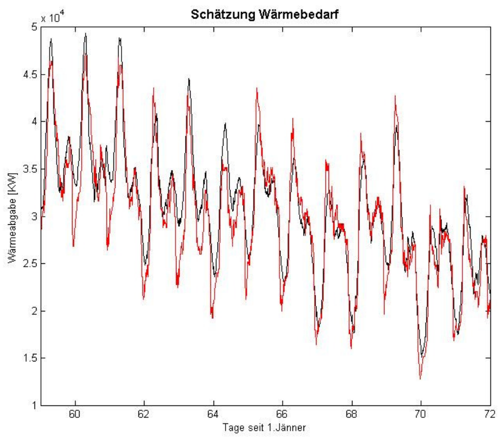

Figure 4: Measured (red) and predicted (black) heat demand

One application with solar radiation forecast and the forecast of ambient temperature is the solar thermal assisted district heating grid in Wels/Austria. These forecast data are an important input to the overall energy management. This system has to decide, if thermal energy (from a solar system and a cogeneration plant) is used to cover the heat demand or can be used to load a thermal energy store. More details can be found in [2].

An other realized project within this application is the prediction of the electric power and heat demand of a city in Austria (Linz). With mathematical identification procedures and predicted meteorological parameters a good estimation of the actual load forecast can be reached (Figure 5).

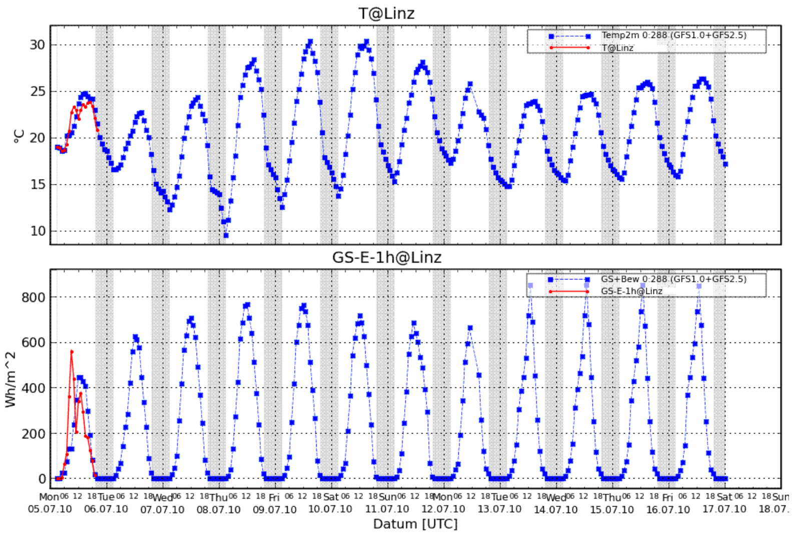

Fig 5: Forecasted (blue) and observed (red) values of temperatur (T) and GHI (GS-E-1h), from a 12 day ahead forecast for Linz/Austria.

4. Conclusion

Forecasts of meteorological conditions in operational service can be used for energy-relevant applications for wind, precipitation, temperature and solar radiation. Both, the production of renewable energy and the consumption (heating and cooling) of energy depend strongly on meteorological conditions. In this paper the state of the art and the advantages are shown, regarding detailed forecasts of GHI (global horizontal irradiance) for individual locations. The quality of these forecasts offers the possibility to predict the energy demand of cities, buildings, ... and the production of fluctuating renewable energy sources for up to 10 days in future. This information can be seriously used by energy agencies and energy production units to gain economical and ecological benefits.

References

[1] E. Lorenz, W. Traunmüller, G. Steinmaurer, et. al. “Benchmarking of different approaches to forecast solar irradiance“, 24th European Photovoltaic Solar Energy Conference, 21-25 September 2009, Hamburg, Germany.

[2] G. Steinmaurer: “The development of the simulation environment for the energy management of the solar assisted district heating grid in Wels”, Eurosun 2008, Lisboa, Portugal.