Shortcomings and developments in PV forecasting

Forecasting | Accurate forecasting is becoming increasingly important as PV penetration grows. Jan Remund of Meteotest looks at some of the recent developments in forecasting science and the work going on to improve this vital aspect of solar's interaction with the grid

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Recent years have seen the fast development of solar forecasting. Today, large scientific communities as well as many private companies are working on enhancing solar forecasts. Meanwhile, the scientific communities dealing with solar resources and with numerical weather prediction (NWP) modelling, for so long separated, have now met and are working together.

The improvements are strongly driven by end users, which are mainly PV producers or grid operators in need of accurate solar forecasts. According to the 2015 International Energy Agency Photovoltaic Power Systems Programme (IEA PVPS) report, 'Trends in Photovoltaic Applications', 13 countries had reached the milestone of 2% of yearly PV penetration in relation to electricity demand in 2014. Two percent seems to be a low value on an annual level (Italy reached 8% in 2014). However with 2% of the yearly energy share, instant PV penetration can rise up to 20% in certain moments. Experience in Europe has shown that above this level accurate solar forecasts are of great importance to run the transmission grid stably and safely. Local solar forecasts – mostly for big PV installations – are also common nowadays. The need to provide forecasts for those installations is mostly based on grid or market regulations and therefore depends on countries' specific legislation.

Improved forecasting is vital to help solar penetration carry on growing.

A short history of solar forecast validation

Today's state-of-the-art solar forecast is based on a mixture of nowcasting models and NWP, adapted to local measurements – based on model output statistics (MOS) or Kalman filters.

Looking back only seven years, predictions have come a long way: in 2009, the results of a first international benchmark were presented [1]. Mostly direct model output (DMO), the raw and unchanged results of different weather models, was compared. The first simple statistical bias corrections had been proposed, but the application of MOS was not common. Uncertainty levels were in the range of 42-50% of relative root mean square error (rmse) for a day-ahead forecast including hourly values, referenced to average radiation and analysed for sites in Germany. The lengthy definition of the validation in the study (measure, forecast horizon, time resolution, reference, region) shows also one major issue of benchmarks in those first years: the results heavily depend on these definitions and make comparisons difficult.

In the IEA PVPS report, 'Photovoltaic and Solar Forecasting: State of the Art' [2], an overview of existing models and validations was given. In this report, different nowcasting methods based on sky cameras and satellites were introduced (Figure 1). All methods show their optimum performance in different forecast horizons as well as in different temporal and spatial resolutions.

Nowcasting based on sky cameras can be produced in half- or one-minute temporal resolution for up to 10-15 minutes ahead with a spatial resolution of tenths or hundreds of meters. Nowcasting based on satellites is available with temporal resolutions of five to 15 minutes and for forecast horizons from 15 minutes to four hours ahead. Spatial resolutions are in the range of two to 10km. NWP output is optimal for forecast horizons of three to 120 hours ahead with a temporal resolution of one hour and a spatial resolution of 10-50km.

For both nowcasting methods – sky cameras and satellites – images are analysed to obtain the current cloud position. Cloud motion vectors are calculated based on multiple images or retrieved from NWP to be able to compute forecasts of cloud movement. Those forecasted layers are used together with clear sky forecasts to produce global and direct radiation predictions.

Nowcasting – defined as forecasts up to six hours ahead – implies the ability to forecast cloud positions accurately, which isn't possible with NWP due to the chaotic behaviour of the atmosphere. This is the

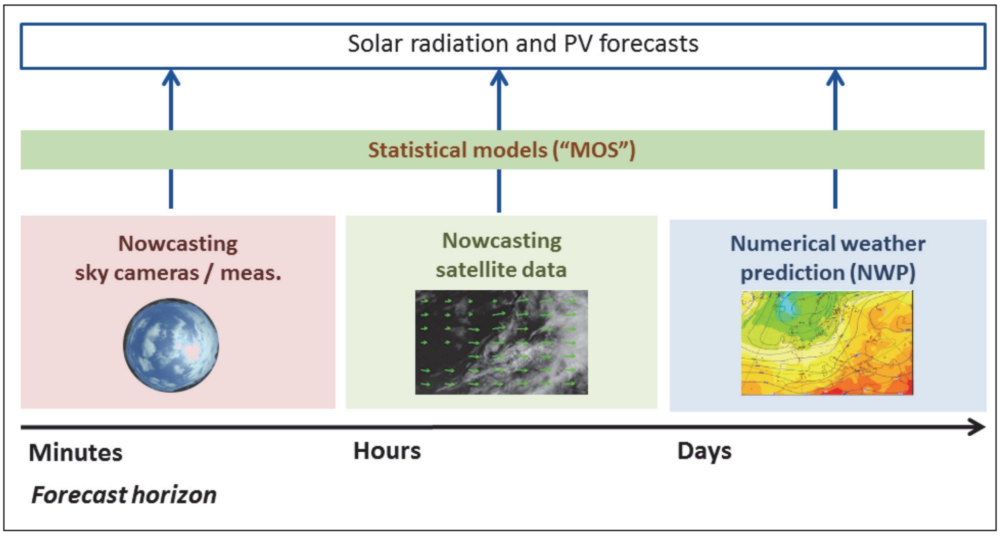


Figure 1: Three different forecast methods and their forecast horizons. Statistical models include model output statistics (MOS) like multiple linear regressions, neural networks or Kalman filter.

biggest advantage of nowcasting methods with satellites and sky cameras. However cloud formations are not stable over a long time. At least after four to six hours the cloud forms have generally changed, dissipated or new clouds have formed. All current validations show that for longer timescales NWP delivers more accurate results than nowcasting methods. Since 2012 many scientific groups have been working on forecasts with the help of sky cameras. However uncertainty levels are still high, forecast horizons short (10 minutes) and commercial applications still rare.

In the PVPS report of 2013 the validations for day-ahead forecasts showed relative rmse levels of 18-64%. The main differences are not based on the forecasting technique – but on the local climate. For sunny climates the forecast accuracy is much higher than for cloudy climates as the biggest source of uncertainty comes from the positioning and optical density of the clouds.

Also in 2013, the second benchmark of IEA Solar Heating and Cooling programme Task 46 was published [3]. This paper included four different benchmarks in the USA, Canada, Central Europe and Spain. Again, mostly DMO data was compared. The relative rmse was between 32% (USA, global models) and 52% (Central Europe, regional models). The uncertainty levels had only marginally lowered since the first benchmark in 2009.

The weather research and forecasting model (WRF) of the US National Center for Atmospheric Research (NCAR) and the integrated forecast system (IFS) of the European Center for Medium Range Weather Forecast (ECMWF) were applied to all areas. In all of them IFS showed the lowest uncertainties – together with Canada's weather model, GEMS (for Canadian sites). It could be shown that averaging of models lowers uncertainty. The global forecast system (GFS) of the US National Weather Service produced higher levels of uncertainties than IFS. WRF – together with other regional models – showed clearly higher uncertainty. Overall the IFS model was the state of the art in those days. In contradiction to the experience from other meteorological parameters – that using nested models with higher spatial resolution enhance the quality of predictions – this wasn't the case for global radiation. Further, below we will see one of the reasons for this behaviour.

In 2016 a new benchmark paper will be published within the framework of IEA SHC Task 46 [4]. This paper will include the latest results of the benchmarks for Central Europe and includes nowcasting methods based on satellite images and output of NWP – or a mixture of both. The benchmark was done for 18 sites in Germany for the period of March 2013 to February 2014 (Figure 2) and additionally for Switzerland, Austria and Denmark, which are not covered here.

Results of ECMWF$_{IFS}$, the COSMO model of the German weather service the Deutscher Wetterndiest, (DWD$_{COSMO,EU}$) and the HIRLAM (high-resolution limited area model) of the Danish Meteorological Institute (DMI$_{HIRLAM,SKA}$) are based on direct model output. IFS has a temporal resolution of three hours, the two others one hour. Meteotest's MT$_{GFS\text{-}MOS}$ is a MOS based on GFS including ongoing hourly updates of meteorological stations provided by. UOL$_{Combi}$ is a combination of DWD and ECMWF model provided by the University of Oldenburg. Both are based on hourly data.

The GFS-MOS with online updates results in the lowest uncertainties for short periods (relative rmse of 30%). The combination of COSMO and IFS is best for the time range of 12 to 38 hours. Regional models of DMI and DWD show somewhat higher uncertainties. The 24-hour forecast shows uncertainties of 40-48% relative rmse. These results show that the general level of forecast uncertainty could be lowered by 10% – from 40 to 30% relative rmse – between 2009 and 2016. Regional models still can't beat the global models, but the differences are getting smaller (especially for mountain areas). Multi-model combinations and MOS are delivering nowadays the best results.

Regional aggregation results in clearly lower uncertainties as the errors, because of inaccurate positioning of clouds, are smoothed out. For the comparison of benchmarks of regional aggregation it is important to keep the referencing value in mind. In this text average radiation is used. Using installed capacity would result in clearly lower values (about 50%). The rank of the models for regional aggregation is the same. However the differences between the multi-model combination and MOS to the DMO results are bigger than for single site forecasts. Best forecast models (GFS–MOS, multi-model approaches) reach 11% for three-hour forecasts and 16% for 24-hour forecasts.

Nowcasting forecasts based on satellite images and cloud motion vector (CMV)

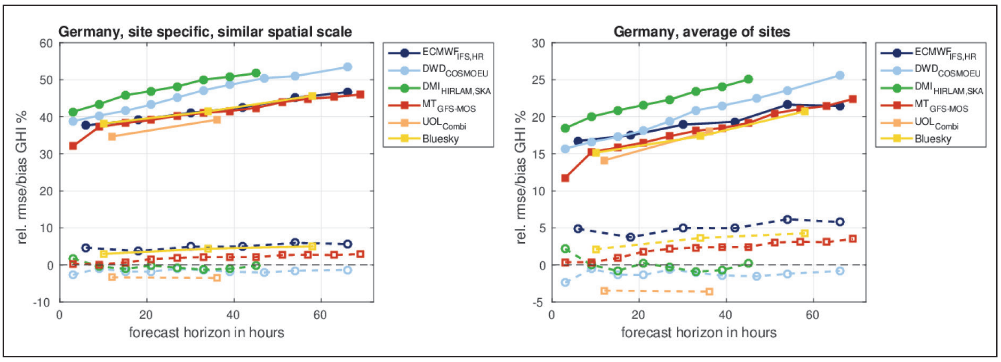


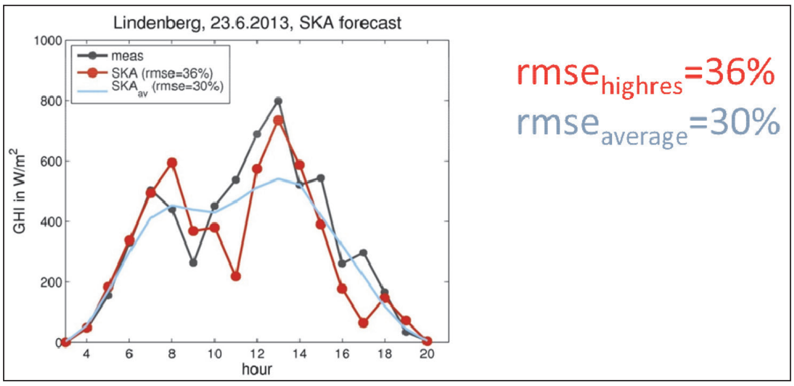
Figure 2: Relative rmse and bias in dependence of forecast horizon for site specific (left) and regional aggregation (right).

result in lower uncertainties for the first two to three hours (Figure 3) compared to NWP. The forecast for 15 minutes shows the uncertainty of the estimation of solar radiation based on satellite data (15-20% depending on region). After three hours the uncertainty level of NWP is reached (30%).

Aside from the already well-understood comparison based on relative rmse (or mean absolute error) a new measure based on the variability index is being introduced. Rmse does not show the whole picture. Smoothing of models lowers the rmse as even small errors in the timing of peaks and valleys results in a double penalty. Figure 3 shows an example of this effect. The smoothed model (blue line) results in a lower rmse value than the original unsmoothed model (red) as the forecasted peak and minimum is slightly delayed in contradiction to the human eye.

Therefore another measure based on variability is introduced to calculate the ability of the models to forecast the correct variability (Figure 4).

Figure 3: Comparison of a smoothed and unsmoothed regional weather model (Hirlam-SKA) and the resulting rmse values for an example day in Lindenberg (Germany).



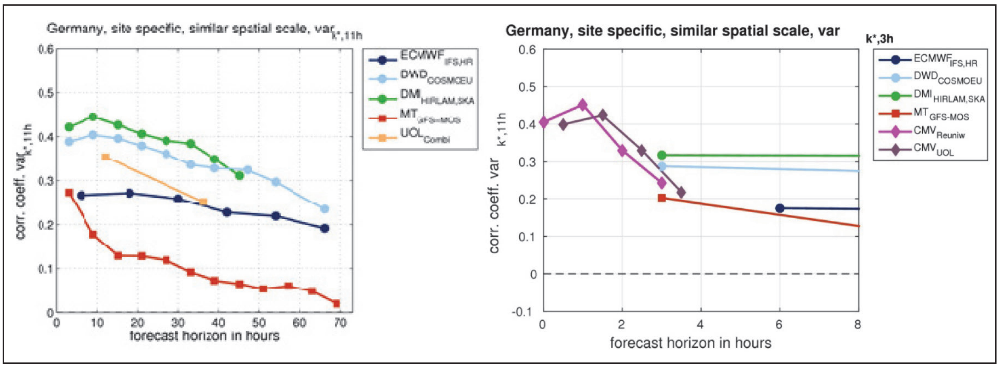


Figure 4: Correlation coefficient of the variability forecast in Germany. NWP models (left) and nowcasting and NWP models (right).

The rank of variability and rmse measures are inversed. The best models concerning rmse ($MT_{GFS-MOS}$, $ECMWF_{IFS,HR}$) are the worst in variability forecasts and vice versa. Regional models and especially nowcasting methods are showing the best results.

Experience of the variability measure has to be gained yet. However we can advise today the user to weight the measures, depending on the usefulness and adequacy for their application. For example, rmse is a good measure for forecasts of PV production for electricity markets because in many cases the correct timing of the production is important and producers get financial penalties for deviations. In other cases, like forecasts of the probability of ramps, the smoothed models are not useful and the variability index measure is more adequate.

Outlook

As shown the forecasts have seen a rapid development in the last years resulting in clearly better products. In the next years this development will go on as the importance of accurate forecasts will grow with growing penetration levels, and many groups and companies are working on improving the models. Here are some of the most important issues in progress:

- Enhanced forecast models: e.g. a special WRF version for solar is being introduced. The improvements include parametrisation of aerosol data, improved aerosol-clouds interactions and shallow convection schemes. The updated model will be accessible for all WRF users;
- Updated aerosol data. Aerosols are the biggest source of uncertainty especially for direct normal irradiance and for sunny periods and climates. The change from using climate averages of aerosols to ongoing forecasts (e.g. ECMWF MACC) is a first step. Additionally MACC and other satellite-based sources also have to be enhanced in the future to eliminate especially high bias in certain (dry) regions like western USA;
- Optimised combination of NWP with nowcasting methods;
- The use of probabilistic predictions and variability forecasting (up to now not yet very common for solar energy);
- Enhanced forecasts of sky cameras, which allow forecasting of the next 15 minutes in very high temporal resolution (30 seconds to one minute);
- New forecast schemes based on ground measurements: forecasts based on networks of ground data – e.g. the fleet of PV installations – is another newly proposed way for nowcasting solar. This "big data" approach will evolve in future.

However we have to keep in mind that miracles won't be possible and uncertainty will never reach zero due to the chaotic nature of the atmosphere. ■

Author

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