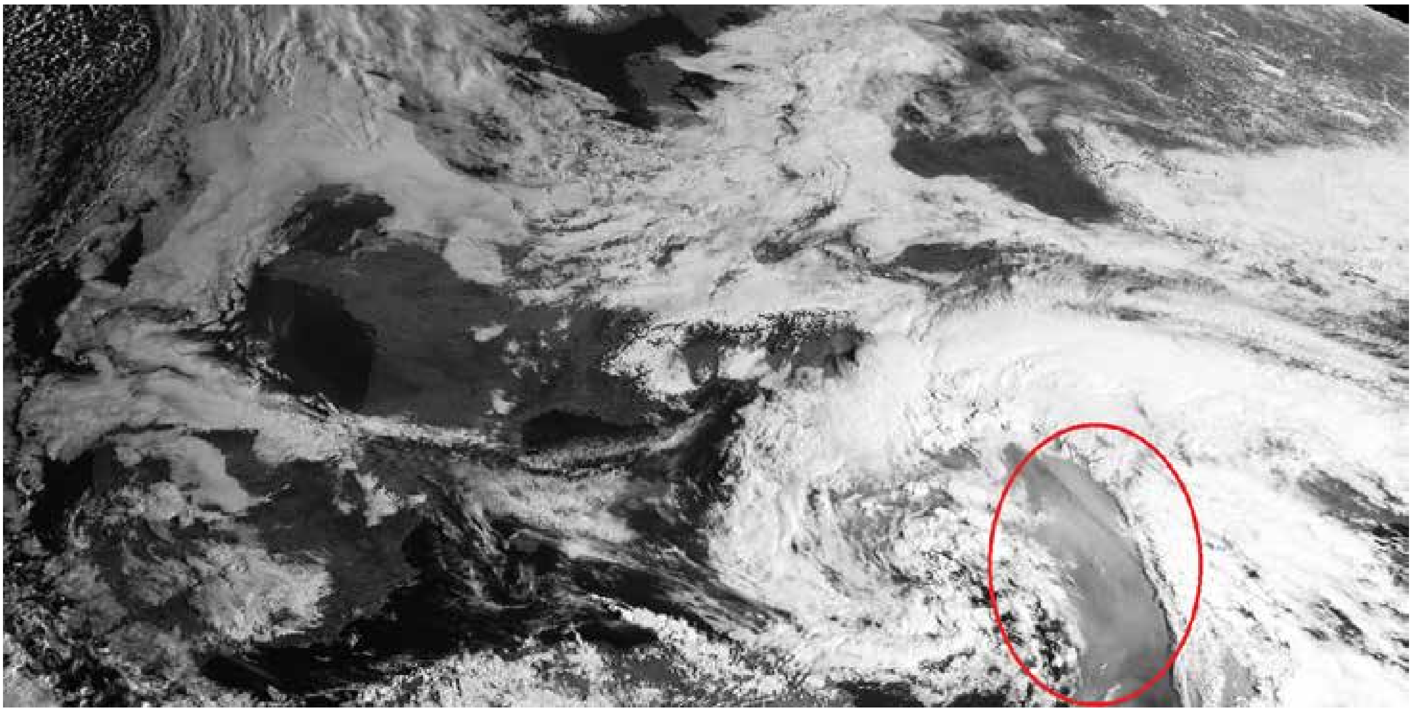
Getting a grip on Saharan dust



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Forecasting | A poor understanding of how European PV arrays perform in Saharan dust outbreaks can have a crippling financial impact on grid operators. Christian Kurz and Lucas Richter of meteocontrol describe a major new research project underway in Germany to improve the forecasting of dust outbreaks and their impact on PV power output

Germany's electricity market is highly affected by volatile renewable energy generators. German policy is seeking to eliminate atomic power, reduce CO2 emissions and also to become more independent of fossil energy sources, as a model for other countries to follow. The aim is to increase the portion of renewables incrementally from approximately 30% now to 35% in 2020, to 50% in 2030 and to 65% in 2040.

Due to the higher proportion of renewables in the energy mix and their volatility because of the variability of weather conditions – and until recently no possibility of electrical storage – renewables can endanger the stability of the grid. If there is too much electricity in the grid either renewables will be curtailed in their power output or the overflow of electricity is delivered to other countries, which are not always pleased by the prospect of having to absorb the additional power in their own grids. Otherwise if there is too little electricity in the grid the deficit has to be compensated for by generation from conventional power stations.

Thus we can see that the integration of renewables does not work all the time. In the case of photovoltaic power stations and their expected aggregated contribution to the electricity grid, tricky situations are mainly a consequence of low stratus cloud, extended convection with cloud building and Saharan dust outbreaks, the latter of which is considered here in more detail. Power forecasts help to maximise the integration of renewables and minimise the costs. On sunny days the contribution of photovoltaic power to the entire energy consumption can reach up to 80%. During Saharan dust outbreaks single PV sites can lose over 80% in comparison to the forecasted power generation of a numerical weather model, and the aggregated sum of regional PV sites can lose up to 50-60%.

The lost output from PV power plants during a Saharan dust outbreak can have a detrimental effect on grid stability

For such situations the grid operators have to hold back special energy in the form of gas power stations, which is demanded instantaneously and which is very expensive. So Saharan dust outbreaks can lead to economic damage for the German grid operators – around a high two-digit million amount in euros per year, figures supplied by the grid operators suggest. There are

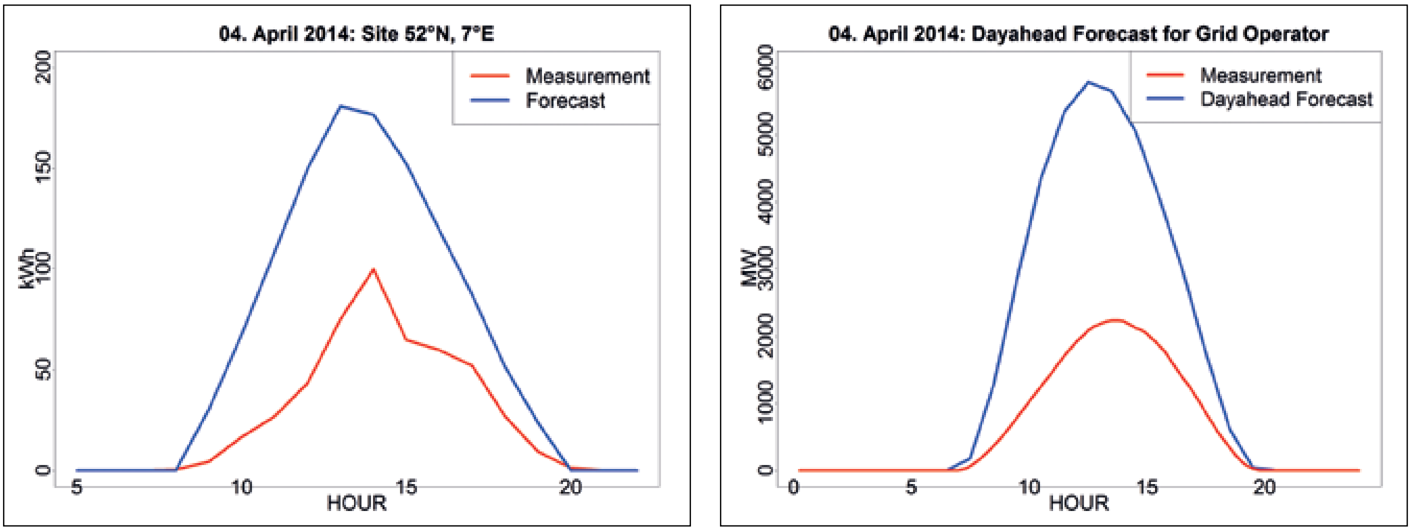

Figure 1. The difference between forecast and actual production during a Saharan dust outbreak for a single site (left) and at a grid level

four grid operators in Germany. Each of them has a certain level of electricity demand dependent on the time of day, day of the week and also day of the year due to holidays. As a result they all have to plan the energy generation from conventional power stations to react to the forecasted power generated by the renewables and to ensure grid stability. During Saharan dust outbreaks this procedure can be very difficult.

The Saharan dust problem

Over 50% of the tropospheric aerosol content consists of mineral dust particles of which over half originate from desert regions. For the transport of Saharan dust to Middle Europe there have to be special weather conditions and a certain circulation pattern over North Africa and Europe. At first the dust has to be blown up into the air by turbulence and high wind speed to rise high up in the atmosphere. If the dust gets into the stratosphere it can remain there for several weeks until it sediments on the ground or falls back into the troposphere and is washed out by precipitation.

For the dust to be carried from the Sahara to Europe requires a strong longwave upper-level trough in the west of Europe, equivalent to a low pressure area. Because of an anticlock-wise rotation of low pressure systems in the northern hemisphere, Saharan air mass is moved by a great southern wind current to Europe. The frequency and intensity of such an event is different from year to year, but it occurs mostly in spring and early summer in the cycle of the year. The content of aerosol in the atmosphere can be twenty times higher than usual and in mean there are five to 15 events per year with an aggregated duration of 10 to 60 days.

In terms of solar radiation and PV power output levels, Saharan dust can have various different effects. Firstly aerosols can reflect solar radiation directly or indirectly by tuning the development of clouds: cloud development requires a surface on which water vapour can condense; if there are more dust particles there, more droplets and thus more clouds will be formed. Otherwise photovoltaic power output is reduced by deposition of dust on the module surface. Furthermore the occurrence of Saharan dust in the atmosphere leads to less precipitation and this leads also to a longer pollution of the PV module.

For grid operators, the Saharan dust phenomenon is problematic because at the moment the variability of aerosol content in the atmosphere is not included in numerical weather models. They use a climatology of aerosol content, which only gives its average.

To solve this problem, further work is required to better understand and predict performance of PV systems during different levels of pollution by Saharan dust. Real PV measurements have to be investigated to create an appropriate algorithm which approximates the photovoltaic output to the higher aerosol content, its duration, the occurrence of precipitation and at last the assumed module surface pollution.

Subhead

With this in mind, a consortium of DWD – the German Weather Service – the Karlsruher Institute of Technology (KIT) and weather services company meteocontrol earlier this year launched a joint research project, PerduS, to examine how dust affects the output of PV systems. The aim of the project is to expand DWD's numerical forecast with an improved dispersion forecast for desert dust; this enhanced modelling will offer insights into the likely reduction of sunlight by simulated dust distribution. Meteocontrol is in close contact with grid operators and other users, and as such recognises the urgency of this issue. As a PV power forecast provider meteocontrol is mainly a user of the radiation forecast of DWD; it is highly interested in the improvement of the numerical weather models and sees much potential in this research. It uses the radiation forecast in its own PV power forecast model and hopes to enhance regional and single site photovoltaic power forecast quality during Saharan dust outbreaks. The expected soiling of photovoltaic systems by the deposited Saharan dust will also be estimated, and how soon the dust will be washed off by rain later on.

The key step forward offered by the PerduS project is that the current aerosol content is included in the numerical weather models. As well as improving radiation forecasts, this new modelling approach should find application in numerical weather models to advance weather forecasting more generally. In summary the main motivation of this project is to get a reliable radiation and module pollution forecast during Saharan dust outbreaks. Ultimately this should offer an economic benefit to grid operators trying to maintain grid stability and also to electricity consumers.

In the first step of the project, the shift of the particle content distribution has to be modelled and to be compared with real measurements in respect of the great weather circulation, its wind speed, temperature, humidity and the origin of the air mass. The parameterisation of the particle model is then found by a sensitivity study, which will be carried out by KIT and simulate parameters such as the aerosol content, density and distribution as it moves from the Sahara to Europe.

In the next step, DWD will examine the interaction between the particle size distribution and cloud micro physics. The higher the aerosol content, the smaller and lighter the cloud droplet is. In consequence the cloud lifetime is longer than clouds with the usual aerosol content. This is because with fewer particles in the atmosphere, the entire water vapour condenses on this number of particles. In consequence the cloud droplet will be greater and heavier than cloud droplets where water vapour condenses on many more particles – as in a dust outbreak. Thus the radiation retrieval algorithm out of the numerical weather model has to be adapted to this special case.

After the correction of the radiation algorithm, the photovoltaic module pollution has to be approximated with an appropriate model, which will be developed by KIT and meteocontrol. This can be done by comparing the simulated PV power output based on real radiation measurements with the help of real photovoltaic power measurements. The KIT has a test field with PV plants of different orientations and meteocontrol monitors over 40,000 photovoltaic sites with a high temporal and spatial resolution. Most likely there is a significant dependence of the module pollution on the real aerosol content in the atmosphere. At this point you have to be careful with the duration of pollution considering precipitation and in consequence the washout of particles on the photovoltaic module.

After finding a good approximation to reality several case studies can be investigated. For example, each of the four German grid operators has recorded days in history when a Saharan dust outbreak and poor day-ahead solar power forecast have coincided. The new algorithm can now be used to recalculate historical forecasts and then compare them with real photovoltaic power feed-in. The three project partners DWD, KIT and meteocontrol, hope to reduce the forecast error by more than a half. Especially for future scenarios when there is an even higher photovoltaic penetration in the German energy market, the new model will offer numerous advantages. For example if there is one and a half times greater installed photovoltaic capacity, the forecast error would scale linearly with recent numerical weather models. So this new model adapted to Saharan dust would help promote an extension of PV power in the German grid.

The new model could also be used to simulate PV power output for other regions, in general for desert regions. Following the UN climate conferences in Paris last year and in Marrakesh, Morocco this year, the majority of the countries have ratified the new global agreement to reduce greenhouse gas emissions significantly and finally to limit the increase in global temperatures. For this the expansion of renewable energies is necessary. Due to the climate in desert regions there is much potential in solar energy, but also great effort in forecasting module pollution and finally solar energy during sand storms.

With support from Germany's ministry of economy and energy, the PerduS project is expected to be complete by the end of 2019. ■

Authors

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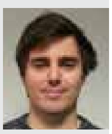

Lucas Richter studied atmospheric physics at Frankfurt University. His master's thesis was about the variability of solar radiation in Europe. Now works in the department of quality services at meteocontrol, where he is responsible for the validation and improvement of forecast quality.