SIMULATION OF THE FEED-IN POWER OF DISTRIBUTED PV SYSTEMS

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Motivation

In Southern Germany a large number of photovoltaic (PV) plants feeds into the grid. New load patterns occur and with them changed grid requirements. Feed-in management is one possibility to maintain grid stability and safety. Nowadays feed-in management measures are carried out in defined steps (typically: 100 %, 60 %, 30 %, 0 % of P_{STC}). As the power produced by PV plants depends on the current irradiance situation, the reduction of the feed-in power according to a predefined level mostly does not lead to the desired effect in the grid. Thus, the network operator needs detailed knowledge of the condition of the grid in order to be able to carry out targeted regulating measures.

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* IQR: interquartile range

Simulation based on Distributed Measurement

In order to characterize the behavior of distributed PV systems and gain thorough knowledge of the grid condition, an investigation area, which is situated in a rural area in Northern Bavaria, is analyzed. Its size amounts to ca. 100 km² and it is characterized by a very high PV penetration (ca. 5.5 kW per house connection). Power quality measurements are carried out and ten spatially distributed ground based measurement devices record global irradiation and temperature.

Figure 1a illustrates the distributed measurement in the area. The acquired highly resolved data is being used to simulate the fleet's power generation and determine the load flow in the investigated grid.

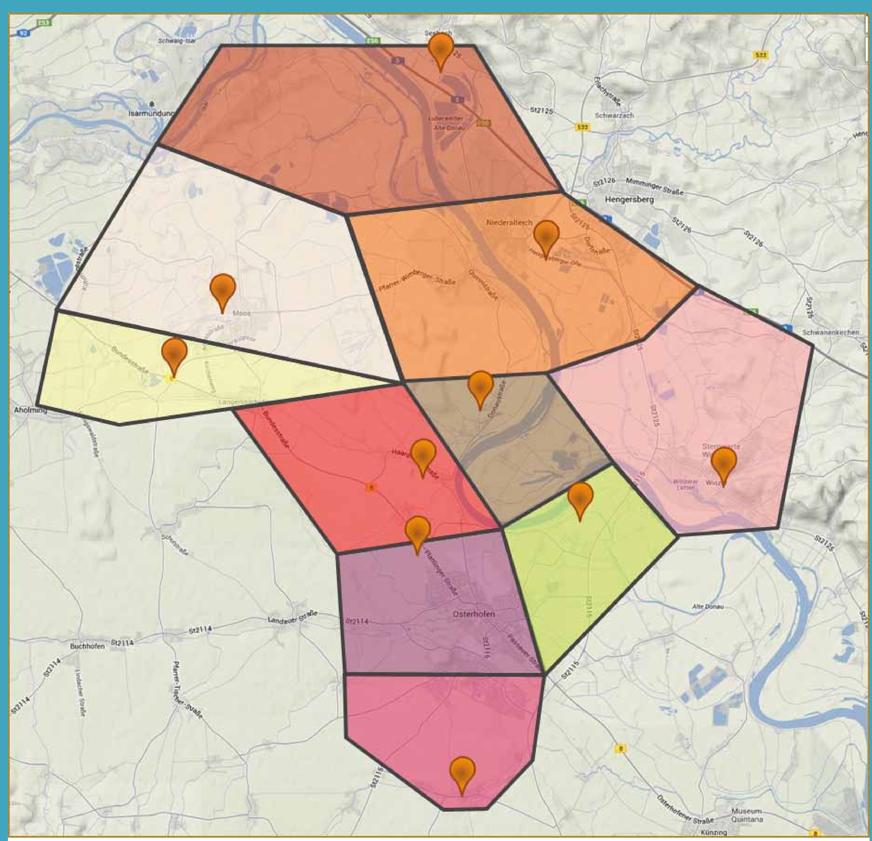

Fig. 1a: Investigation area with the distributed measurement system. Spatial resolution amounts to 10 km² and the measurement interval is 3 seconds. The area is subdivided into ten subareas and simulated separately using the corresponding device's data and the installed PV capacity.

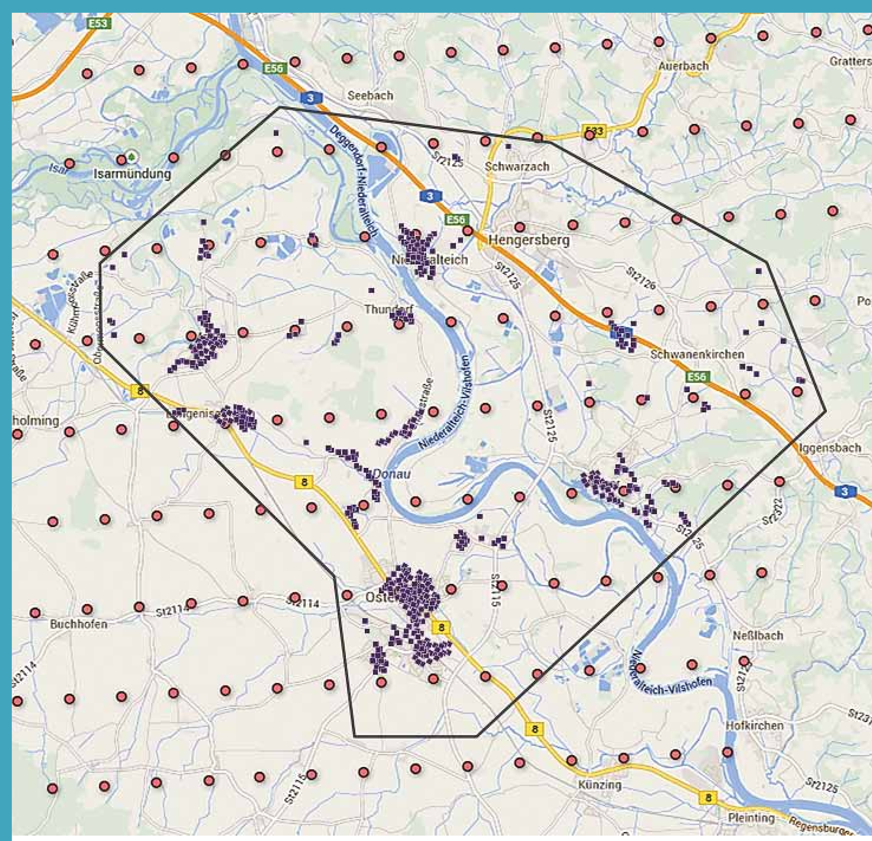

Fig. 1b: Investigation area and measurement points (red) covered by satellite. Data is recorded every 15 minutes in a spatial resolution of ca. 2.6 km². PV systems in the area (blue) are assigned to the single pixels and each pixel is simulated separately with its measured data and the respective PV capacity as input.

Simulation based on Satellite Data

Nowadays satellite data is already used to determine PV feed-in on transmission network level for trade and balancing. The advantage of satellite data is that no measurement system has to be built up and maintained. For this work the satellite method is applied to the investigated medium voltage grid which is a comparatively small area. The raw data is provided by EUMETSAT and recorded by a geostationary MSG satellite in a time resolution of 15 minutes and a spatial resolution of ca. 1.2 x 2.2 km.

The University of Oldenburg uses the Heliosat method to convert raw into cloud and irradiance data which serves as simulation input. Figure 1b shows the investigation area and the contained satellite pixels.

Comparison of the Two Methods

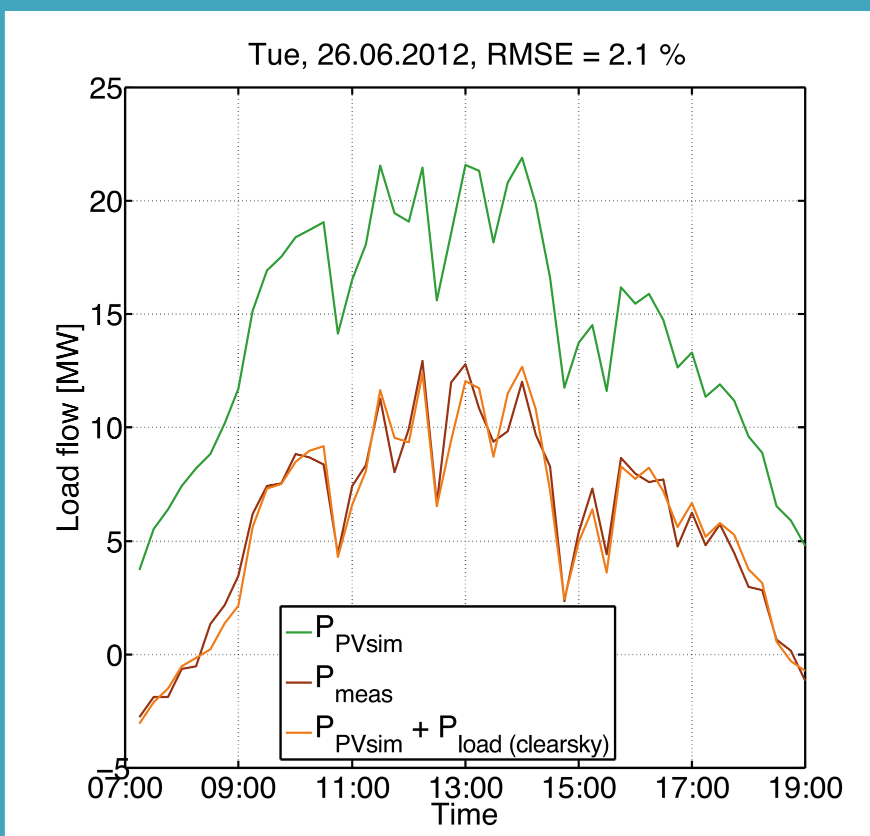

Figure 2a: Simulation on the basis of ten distributed measurement devices. In order to quantify simulation accuracy, the root mean squared error (rmse) is applied. Rmse is only 2.1 %. Spatial smoothing of the distributed PV fleet is modeled properly.

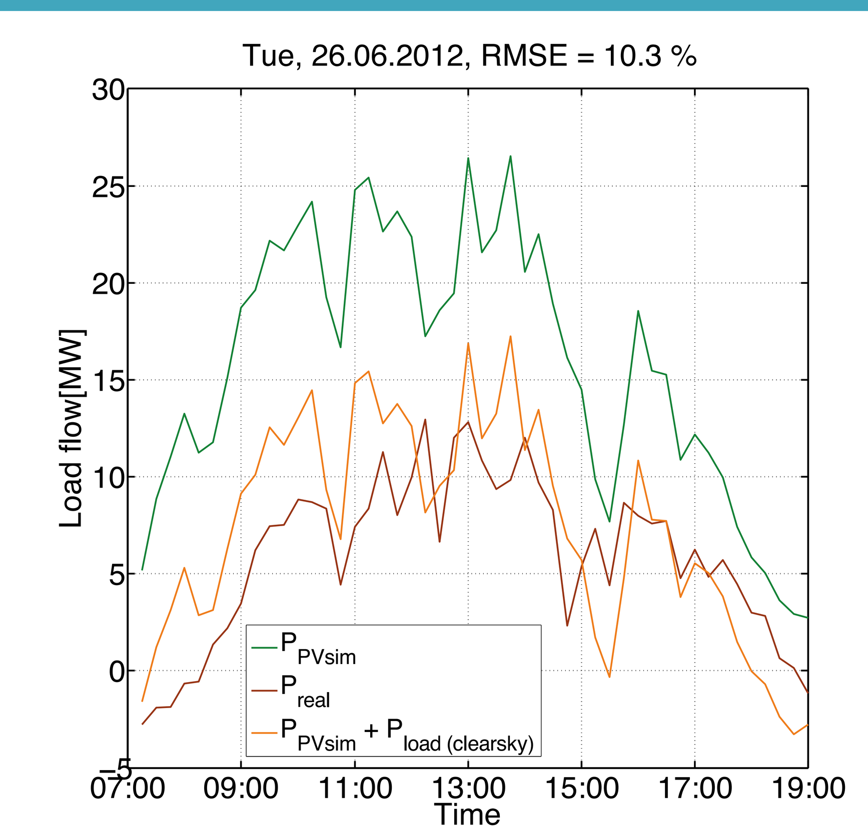

Figure 2b: Simulation based on just one measurement sensor. One sensor is not sufficient to model the spatial smoothing of the feed-in power of the distributed PV systems and hence the grid condition on a fluctuating day. The rmse is significantly high with 10.3 %.

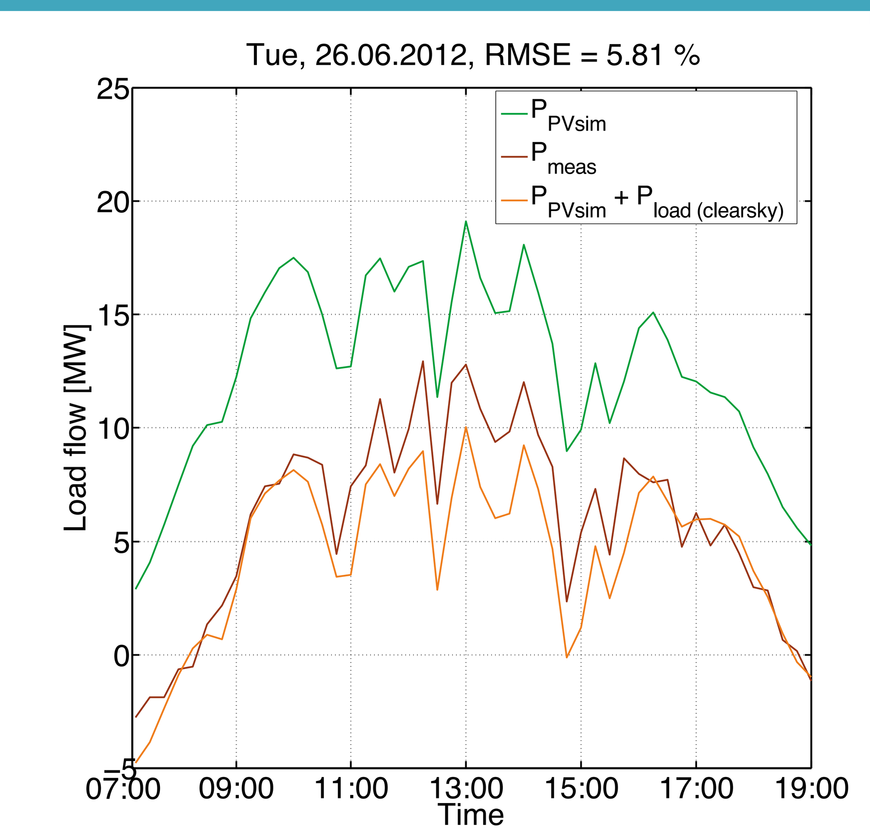

Figure 2c: Simulation on the basis of satellite data. Simulated and measured load flow match rather well. The rmse amounts to 5.81 %. Simulated power is slightly lower than the measured curve and the rather high smoothing effect is modeled well.

Figure 2a-c: Simulated PV power (green), measured (brown) and simulated (orange) cumulated power flow of the area on 26 June 2012. Time resolution amounts to 15 minutes. On the basis of the simulated feed-in power and the cumulated power of the area measured over the 110 kV substation, a reference load can be calculated. The load curve is calculated for a clear sky day and serves as reference for the simulation of further days. By subtracting it from the simulated PV power, simulated cumulated power arises.

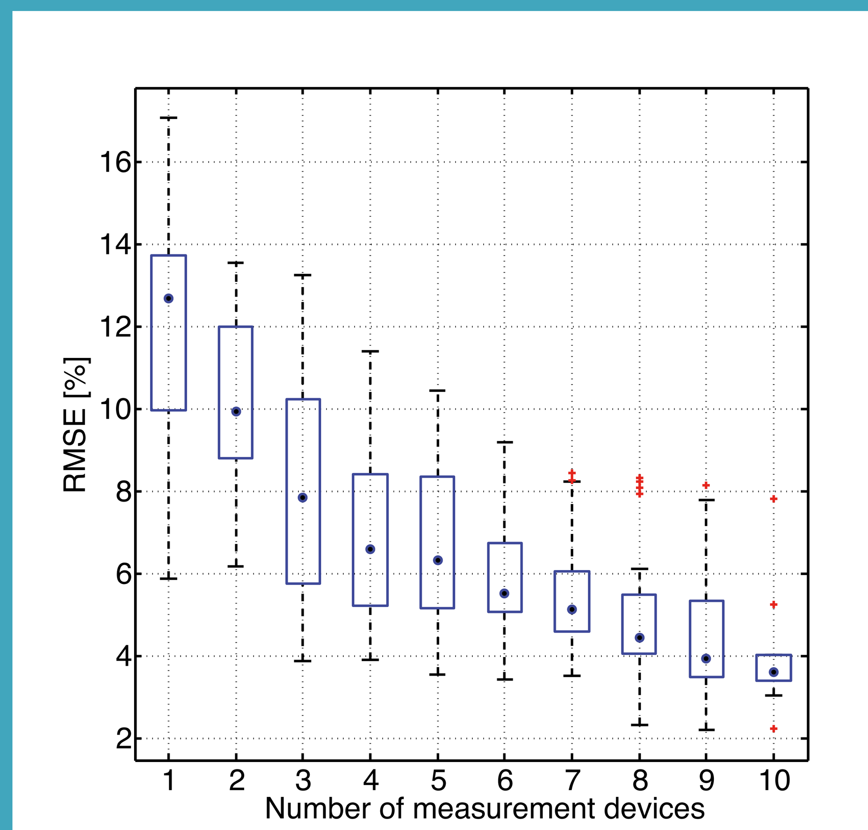

Figure 3: Simulation accuracy of the distributed measurement in dependency of the number of measurement devices in a time resolution of 3 seconds. 20 mostly variable days are analyzed. 50 % of the values are in the box. The whisker's length is maximum 1.5 x IQR*. Outliers are plotted red. Obviously, rmse decreases with increasing number of measurement points. The evaluation of the same 20 days simulated with satellite data leads to an average rmse of 5.6 %. This corresponds to the rmse of a simulation with 6 distributed devices in a time resolution of 3 seconds.

Conclusion

The ground based distributed measurement system features a spatial resolution of ca. 10 km² and a time resolution of 3 seconds. The method enables to characterize the load flow of the medium voltage grid with a high accuracy of averaged 3 % and offers the network operator detailed knowledge of the grid condition. The spatial resolution of the satellite data is higher than the measurement system's and amounts to 1.2 x 2.2 km in Germany. Its time resolution is limited to 15 minutes. For applications regarding power engineering this fact represents not necessarily a disadvantage as many applications work in this time intervals. Improvement potential exists in the precise assignment of cloud shadows to satellite pixels. Simulation accuracy amounts in average to 5.6 % on the 20 mostly variable days.

Satellite data represents a reliable, always available and low maintenance source of irradiance data. A distributed measurement system offers an individually adaptable measurement regarding spatial and time resolution, but it also involves workload and expense. Anyway, both methods provide high accuracy and detailed knowledge to the network operator and can be transferred to any grid area with high PV penetration.