Topic 6: PV Applications and Integration
Subtopic 6.1: Grid and Energy System Integration

Forecasting and observability: critical technologies for system operations with high PV penetration

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Summary

Forecasting and monitoring technologies for photovoltaics are required on different spatial and temporal scales by multiple actors, from the owners of PV systems to transmission system operators. In this paper the Grid integration working group of the European Technology and Innovation Platform – Photovoltaics (ETIP PV) reviews the different use cases for these technologies, their current status, and the need for future developments.

Power system operations require a real-time view of PV production for managing power reserves and for feeding short-term forecasts. They also require forecasts on all timescales from the short (for dispatching purposes), where statistical models work best, to the very long (for infrastructure planning), where physics-based models are more accurate. Power system regulations are driving the development of these techniques. This application also provides a good basis for a cost/benefit analysis since the forecasting error can be linked to the prices charged for energy imbalance.

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Purpose

It its review of the challenges and opportunities associated with massive deployment of solar PV generation,[2] the Grid integration working group of the European PV Technology Platform (now ETIP PV) identified forecasting and observability as critical technologies for the planning and operations of the power system with large PV penetration. In this paper we set out to spell out in more details what features are needed from these technologies and, after an assessment of their current status, how they need to be developed.

Approach

Some very good reviews of forecasting techniques have been published in recent years.[3] We have built on these by taking a step back and analysing the different use cases for forecasting in relation to PV, and by linking forecasting to the issue of observability i.e., the ability to evaluate at a given time the status of PV generation. Experts on power systems, PV technologies and forecasting contributed their knowledge of the field as well as first-hand results they have obtained and issues they have observed.

To estimate the economic value of further improvements in forecasting, we linked the effect of forecast errors with the current imbalance settlement prices charges by balancing authorities in Europe. We also analysed the likely regulatory and technical evolutions, such as changes in the structure of the electricity market and the increasing availability of storage technologies.

Main results

Forecasting and observation techniques are relevant to the following stakeholders:

- Owners and operators of PV power plants:
    - Forecasts of annual energy production for investment decision
    - Observation of actual energy production and deviation from forecast for maintenance decisions and warranty calls
    - Time-resolved forecasts of energy production for sale of electricity (bids on wholesale electricity market or other forms of contractual arrangements e.g. with aggregator)
- Distribution system operators:
    - Observation of current production and state of the network for decision on active/reactive power control and management of other network components
    - Forecast of deployment potential and high-resolution representative times series of production data for network planning

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2 P.-J. Alet, F. Baccaro, M. De Felice, V. Efthymiou, C. Mayr, G. Graditi, M. Juel, D. Moser, M. Petitta, S. Tselepis, and G. Yang, "Quantification, challenges and outlook of PV integration in the power system: a review by the European PV Technology Platform," in *31st Eur. PV Sol. Energy Conf. Exhib.*, pp. 2937–2943, WIP Wirtschaft und Infrastruktur GmbH & Co Planungs KG, Hamburg, Germany (2015) [doi:10.4229/EUPVSEC20152015-7EP.1.2]

3 S. Pelland, J. Remund, J. Kleissl, T. Oozeki, and K. De Brabandere, "Photovoltaic and Solar Forecasting: State of the Art," IEA PVPS T14-01:2013, International Energy Agency, Paris (2013), ,E. Lorenz, J. Kühnert, D. Heinemann, K. P. Nielsen, J. Remund, and S. C. Müller, "Comparison of Irradiance Forecasts Based on Numerical Weather Prediction Models with different Spatio-Temporal Resolutions," in *31st Eur. PV Sol. Energy Conf. Exhib.*, pp. 1524–1537, WIP Wirtschaft und Infrastruktur GmbH & Co Planungs KG, Hamburg, Germany (2015) [doi:10.4229/EUPVSEC20152015-5DP.1.3],

- Balance group manager: time-resolved aggregate forecasts of energy production for balancing electricity supply and demand within balance group and optimize trading
- Balancing authority:
    - Time-resolved aggregate forecasts of energy production for balancing electricity supply and demand over system area
    - Observation of current production for activation of reserve in case of deviation
- Transmission system operator:
    - Forecast of deployment potential and high-resolution representative times series of production data for network planning
    - Scenario forecasts for optimal power flow decisions and evaluation of network safety.

More specifically, for power system operations, PV power forecasts could mitigate the effects of high PV penetration on both grid management and the energy market. Short-term forecasts (intra hours) could be used to predict power ramps and voltage flickers as well as to better control operations on the real-time market and dispatching management. Mid-term forecasts (intra-day and day-ahead) can be used, on one hand, for load following to control voltage and frequency, and for transmission scheduling to reduce the secondary reserve. On the other hand, it can be employed for a better match between the intra-day and day-ahead market commitments and the real PV production, reducing the energy unbalance costs. For these reasons, the site and regional day-ahead forecast of the solar power generated by large PV producers and distribution system operators (DSOs) is now mandatory in many European and non-European countries (Italy, Germany, Spain, Romania, USA, Japan etc.) and the required accuracy is increasing.

Forecasting approaches can be split between physics-based models and statistical models (Figure 1). The choice of the approach mainly depends on the time horizon, as well as on the geographical extension.

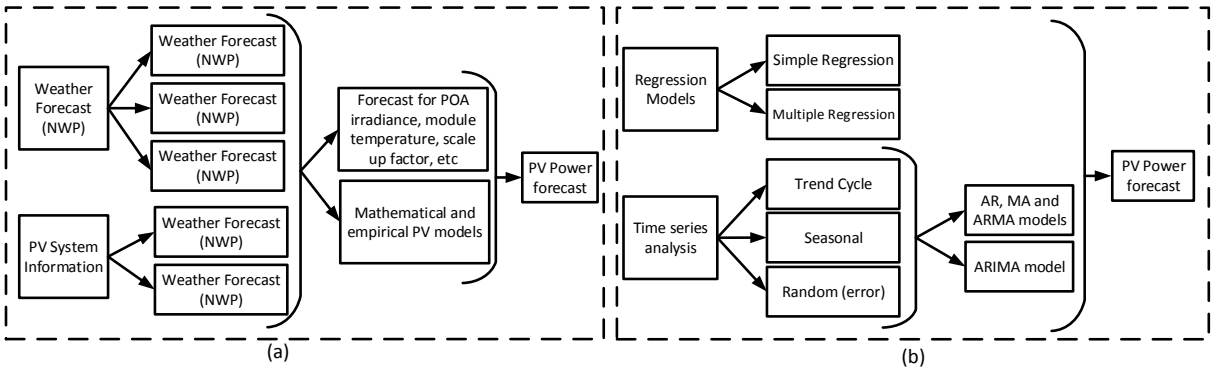

Figure 1: Classification of physics-based models (left) and statistical models (right) for PV power forecasting

In general:

- for time horizons of 6 h or more, physics-based (PB) models are used
- for 2 h to 6 h time horizons, observations, satellite images with cloud optical depth and cloud-motion vector information and predictions of clouds through numerical weather prediction (NWP) models are combined

- for short time horizons (less than 2 h), forecasting applications rely on statistical approaches, such as autoregressive integrated moving average (ARIMA) and artificial neural network (ANN) modeling
- for very short time horizons (less than 30 min), several techniques based on ground-to-sky imagers have been developed for both GHI and DNI by converting the cloud-positioning information into deterministic models.

Accurately assessing the current status of PV production in the power system is important both to feed short-term forecasts based on statistical methods and to actively manage unexpected fluctuations in power generation. The challenge for system operators is to find the right tradeoff between accuracy and the data flows from PV generators. To address this challenge, a sampling system has been put in place in Cyprus, where real-time data are collected from weather stations and smart meters spread over the country, and correlated with statistics of PV system connections to estimate the current PV production. As shown on Figure 2, this system is integrated with intra-day and day-ahead forecasting.

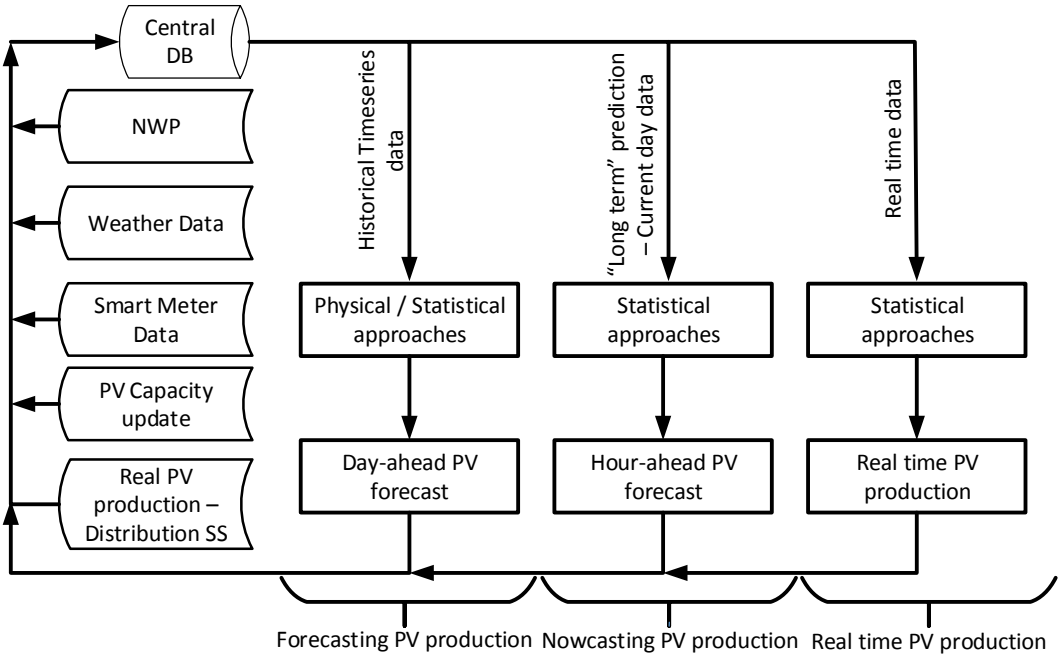

Figure 2: Integrated observation and forecasting system for PV production in Cyprus