PV-FORECAST
REGIONALISED FORECASTING OF ENERGY PRODUCTION FROM PHOTOVOLTAIC AND THEIR DYNAMICS


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A model based solution for PV production forecasting

Objective:
• Better integration of PV into energy system / market
• Assure grid stability

Challenge:
• Reach adequate accuracy at small regional scale / increase spatial resolution

122 [MW\textsubscript{p}] PV installed
app. 207 [W\textsubscript{p} / Inhabitant]
(End 2016)

In collaboration with
PV-Power Forecasting

Solar irradiation forecasts (ECMWF)

Processing irradiance forecasts on inclined surf.

Reference-systems

Statistical PV-systems model

Photovoltaic power predictions

Monitoring data & system profiles

Regionalised power predictions on different time scales

About 80 systems visited, evaluated & charact.

23 chosen and integrated (8 + 15)
INDIVIDUAL FORECASTS FOR THE REFERENCE SYSTEMS

Global irradiance on inclined surface ($G_\psi$)

Reflection losses (IAM factor)

Degradation losses = $f$(age)

Mismatch losses

DC wiring losses = $f$ (cabling scheme)

$\eta_{\text{module}} = f(T_{\text{module}}, \eta_{\text{MPP}}, G_\psi)$

$T_{\text{module}} = T_{\text{amb}} + \gamma G_\psi$

$T_{\text{module}} = \text{module temperature}$

$T_{\text{amb}} = \text{ambient temperature}$

$\gamma = 0.020$ for free standing PV systems

$\gamma = 0.056$ for building integrated PV systems

$G_\psi = \text{global irradiance in plane [W/m2]}$

2.5 %

0.5 % / a (following years)

$\eta_{\text{inv}} = f(\eta_{\text{partload}}, \eta_{\text{euro}}, P_{\text{PV arrays}})$

$P_{\text{sys inv}}$

AC wiring losses = $f$ (cabling scheme)
Reference systems

- 8 technically detailed reference systems (red)
- 15 synthetic reference systems (orange)

A total of 23 reference systems currently in use for the forecasting algorithm
Example of an hourly forecast curve

Example: 1st of July 2014, reference system Nr. 0067, showing the correlation of the three forecast horizons (0-24h in red line / 24-48h in orange, dashed line / 48-72h in yellow, dotted line) and the measured values (grey line)
Boxplot of the normalized error $\varepsilon$ of the hourly forecast for reference system Nr. 0067 for July ’14 Example: six days in July 2014, showing the correlation of the three forecast horizons (0-24h in red line / 24-48h in orange, dashed line / 48-72h in yellow, dotted line) and the measured values (grey line)
Boxplot of the normalized error of the hourly forecast for reference system Nr. 0067 for July 2014
Evaluation criteria of the performance of the forecasting model

- **Mean power – mean P**
  mean value of the power in a certain time range, normalized to nominal power

- **Bias**
  mean value of the error, normalized to nominal power

\[
\text{bias} = \frac{1}{N} \sum_{t=1}^{N} \varepsilon(t)
\]

- **Root mean square error**
  Gives higher weighting to larger deviations from the real value, suitable to power applications, where large error are disproportionally problematic (normalized to nominal power)

\[
\text{RMSE} = \frac{1}{\sqrt{N}} \sqrt{\sum_{t=1}^{N} \varepsilon(t)^2}
\]

- **Day time values only – Suffix \( dt \)**
  Only forecast values different from 0 are considered, not to bias the evaluation criteria by trivial night time forecasts

- Performance can only be evaluated on individual PV system level – not country level
performance of the forecasting model for all reference systems over 2 years

Mean daily RMSE = 7.4% / RMSE_{dt} = 10%
Mean daily bias = 1.1% / bias_{dt} = 2.2%

mean evaluation criteria over 2 years (2014 & 2015) for the reference systems
Forecast adaptations – two approaches tested

Adapting the short term forecasts based on measured deviations

1. Error persistence
   Assuming that the deviations occurring at $t_n$ would persist at time step $t_{n+i}$

2. Error movement vectors
   Assuming that the deviations occurring at $t_n$, caused by improper forecasts of cloud movements, would propagate over the forecast region at time step $t_{n+i}$, with constant direction and time
Forecast adaptations – Correction by error persistence

Example: 1st of May 2014, reference system Nr. 0067, showing the adaptation of the forecasts (red line), based on previously measured deviations (1 hour into the future (blue) / 2 hours into the future (green)) and the deviations from the measured values (grey line)
Correction by error persistence

Evaluation criteria on forecast accuracy for system Nr. 0080 in 2015 without correction based on error persistence (top), based on 1h error persistence (middle) and 2h error persistence (bottom)
Forecasted PV power [kWp] for 03.07.2014 12:00, aggregated per commune.
Hourly forecasted PV power (one day)

Sequence of hourly maps, illustrating the regionalized forecast of expected PV power, aggregated on communal level
Lessons learned / barriers to deployment

- Photovoltaic power forecasting model for Luxemburg (combining NWP & performance model) → good performance at evaluation on single sites
- Characterisation & Modelling of photovoltaic installations successful
  - on site characterisation – good results
  - Virtual characterisation of existing PV installations (satellite images, …) => Simplified model with **synthetic system profiles** – works also well
- Adaptation of system profiles and use of calibration factors improved forecast
- two approaches to establish a feedback-loop in the forecast tested
  - **Error persistence** – improves forecast, but only on short term forecast horizon (1-2h), systemic deviations (e.g. snow cover) can be effectively reduced
  - **Error movement vectors** – improvement with current time resolution not possible.
- Established a very representative statistical matrix, representing PV in Lux.
- **Upscaling procedure allows aggregation on different levels** (currently communes); barrier for more detailed aggregation: knowledge on PV Systems characteristics
- **Implementation of the model currently in discussion** (shift from top-down to bottom-up model)
Future improvements / implementation

- The **smart metering data** available are not available close to “real time” — currently best case: the data for day x are available day x+1
- deployment of the „smart meters“ started, but still ongoing
- **National data protection aspects** hinder the implementation
- Research project => provides algorithm development and validation — no „plug and play“ solution – further automation necessary
- PV data set (nominal power / location) needs to be adapted to operator
- Further development of the “error movement vector” method possible, if resolution (temporal & spatial) of NWP models increase
- **attribution of single PV systems to its transformers / distribution grid lines** easily feasible – orientation and inclination necessary
- Shift **from point forecasting to probability forecasting** envisaged
Thank you for your attention!

Questions? Do not hesitate to contact me: daniel.koster@list.lu