Hybrid short-term forecasting of PV and load power for predictive control applications

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Work based on the CyDER project (DE-EE00031266)
Partners: LBNL, LLNL, PG&E, SolarCity (BP1-BP2), ChargePoint (BP1-BP2)

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CyDER: A cyber-physical co-simulation platform for distributed energy resources in smart grids

- Increasing complexity in power systems (DERs, T&D interaction, etc.).
- CyDER platform: open-source, modular and easy to use co-simulation.
- Based on the **Functional Mock-up Interface (FMI)** standard as an API between various simulators and/or models.
Model Predictive Control (MPC)

Optimal battery control (local objective)

- Forecast FMU
- PV / load forecasts
- MPC FMU
- Battery setpoint
- Battery SOC
- Delay FMU

Optimize Volt/Var/Watt setpoints

- Forecasting module
  - PV + battery module 1
  - PV + battery module i
  - PV + battery module N
  - Grid module

Hardware-in-the-Loop testing of MPC and forecasting algorithms at FLEXGRID

FLEXGRID

- Tesla Battery 3.3 kW
- Solar Edge Inverter 22.8 kVA
- REC PV array 14.6 kW

FLEXLAB

Opal-RT Real-time Simulator

Ametek Load Simulator

Ametek MX-30 Grid Emulator

μPMU

Weather data, PV / load measurements
Hybrid Model for Short-Term Power Forecasting

- Seasonal Autoregressive Moving Average (SARIMA) + Artificial Neural Network (ANN) + weighting factor vector \( w \) obtained with constrained least squares.
- Practical advantages: modular, reliable (due to parallel architecture), self-adapting (adjusts \( w \) depending on relative accuracy of SARIMA and ANN).

**Diagram:**

- Forecasting modules
  - PV power of previous day
  - ANN
    - \( P_{\text{ann}} \)
  - SARIMA
    - \( P_{\text{sar}} \)
  - Weighting factors
    - \( P_{\text{comb,k}} = w_k \cdot P_{\text{sar,k}} + (1-w_k) \cdot P_{\text{ann,k}} \)

- Periodic and/or event-based retraining
  - Retrain ANN
  - Re-compute weighting factors
  - Retrain SARIMA

- Post-processing
  - Regression or persistence model
  - Additional simple logic
  - Final forecast \( P_f \)
SARIMA and ANN model structure and training

Best SARIMA model for PV power: $(1,0,0) \times (0,1,2)_{96}$

- ANN inputs for PV power
  - Clear sky irradiance (S1-S5)
  - Cloud cover (S1-S5)
  - Ambient temperature (S2-S5)
  - PV power of previous day (S3,S5)
  - Time step in prediction horizon (S4,S5)

- Two ANN architectures
  - Scalar (single time step prediction)
  - Vector (whole prediction horizon)
Results for PV power forecasting

- Normalized RMSE in the range 5-10%.
- Hybrid model improves performance by up to 10% on periods with increased PV volatility.
- Hybrid model is able to detect and take advantage of performance patterns.
Results for load power forecasting

Load data from Building 90 at LBNL campus

Day Ahead forecasts using SARIMA, ANN and hybrid model

- **RMSE SARIMA**: 27.6 kW
- **RMSE ANN**: 30.2 kW
- **RMSE Hybrid**: 27.7 kW

- Optimize SARIMA architecture (currently dominated by daily seasonality)
- Optimize ANN architecture (current results indicate overfitting issues)
- New ANN inputs (time-of-day, day-of-week)
- Weighting factors re-tuning
Next step: plug forecasts into the MPC

- Use PV and load power as input to the MPC for battery dispatch optimization.
- Perform HIL tests using FMI standard to integrate the models, forecasting unit, and MPC controller.

**Preliminary experimental results on battery dispatch optimization**

- **Goal:** minimize electricity bill
- **Demand charge**
- **Peak, part-peak, off-peak TOU tariff**
Outlook and Challenges

- Related to forecasting
  - Overfitting issues with the ANN model.
  - Alternatives to the weighting factors based approach for switching among models (e.g., exponential smoothing).
  - Strategy to update the weighting factors (periodically or event based, length of historical measurement window).
  - Current implementation is memory intensive $\rightarrow$ modifications might be needed for a low-footprint implementation (e.g., Raspberry Pi).

- General in CyDER
  - Maintaining platform, following version changes (e.g., Modelica), and getting other people to use it.
  - Lack of visibility in third-party simulators/models masked behind the FMI-interface might make results interpretation tricky sometimes.
  - Scaling up co-simulations by running FMI-interfaced simulators across different machines.
Thank you for your attention!

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**More information**