Short-term Machine-learning-based Forecasting of Distributed Solar Energy Production

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Overview

• The challenge and potential benefits
• Project objective
• Context
• Tasks and timeline
• Status and direction
• Challenges and connections to the PV industry
The Challenge

• Millions of distributed PV systems → GWs to tens of GWs of generation capacity worldwide
  – Some “behind the meter” or “off-grid”
  – Regulation varies widely across jurisdictions

• How to
  – integrate high penetration levels on the grid?
  – monitor, control, and/or forecast collective output (or reduced demand!) at relevant spatial and temporal scales with meaningful uncertainties?
Solar Energy in Australia

• Over 1 million PV systems in Australia

• 2+ GW cumulative, some forecast 7+ GW by 2017

• Utilities do not generally monitor output in real-time

– Average size 2-3 kW rooftop system

– So electric utilities do not know the contribution of these systems to the grid
Some Potential Benefits

• Much higher uptake of small-scale PV
  – Transformation of electricity markets
  – Transition to more sustainable, low carbon economy
• 2x – 5x increase in “standard” potential market for PV systems
• Other business opportunities – development of new markets
What’s Needed

• Information from and about installed distributed PV systems (throughout product lifetime)
• Forecasts (with uncertainty estimates) of collective output from distributed PV systems
• Forecasts of output from large-scale solar plants
• Time-shifting of supply and/or demand (eg, via storage)
• Dynamic control over direction and magnitude of dispatch of electricity
ANU-NICTA Project Objective

• Develop prototype hardware and software to demonstrate the viability of machine-learning-based solar energy production forecasts
  – at 5-minute to 1-hour ahead time horizons
  – for a city-wide distribution of household-size PV systems

• System must be cost-effective, easy to deploy and maintain, scalable and capable of using data from many different sources
Applications and customers

• Electricity generators
• Electricity transmission and distribution firms
• Solar hot water generation systems
• Building management systems
• PV industry
Major Solar Energy Forecasting Efforts

USA
- NCAR
- IBM
- UCSD

Europe
- Oldenburg Uni (Germany)
- Meteo France
- Fraunhofer Institute (Germany)

Asia-Pacific
- SERIS (Singapore)
- CSIRO (Australia)
- Australian National University
ANU-NICTA Project

• Leads:
  – Australian National University
  – NICTA (Australia’s ICT Centre of Excellence)

• USA Partners:
  – UC San Diego, University of Central Florida, SEMATECH PVMC

• Australian Partners:
  – Armada Solar, Laros Technologies, ActewAGL
Project Concept

• Use installed base of distributed PV systems as primary data source
• Supplement with real-time sky camera images analyzed via computer vision techniques
• Merge and analyze via machine-learning (eg, artificial intelligence) techniques
• Create self-improving adaptable forecast system that is economically scalable for large-area use
Key Project Tasks

• Develop prototype lower-cost sky camera and cloud image analysis and forecast system
• Develop prototype lower-cost remote data logger to report PV system and sky camera data
• Develop prototype solar energy production forecast algorithm(s)
• Devise appropriate performance metrics
Test Area – Canberra, Australia

- Monitor 200-300 PV systems (out of 12,000+)
- Supplement with half-dozen sky cameras
- Use PV system registry from local distributor
- Goal: Short-term forecasts at city and suburb spatial scales

Figure: PV site data in Canberra (814km²) from public and private sources
Project Timeline

• Jan 2013: Project initiated
• Jun 2013: Baseline algorithm and metrics
• Feb 2014: Hardware design reviews
• Late 2014: Algorithm and metric evaluation
• May 2015: Conclusion of project
Near-term Implementation Challenge – Scalable, Low-cost, Wide-area Data Collection

- Proprietary data encoding by inverter manufacturers and lack of standardization
- Collection of data from PV systems with permission from but without active cooperation from system owner
- Remote control of and data collection from low-cost commercial cameras to monitor sky conditions and forecast cloud evolution/motion
Consequently ...

- Initial forecasting efforts based on publicly-available data from websites like pvoutput.org
Initial Forecasting Results

• First novel experiments:
  – Explore value of including surrounding PV sites as features in machine-learning forecasts

• Linear Predictor

\[ \hat{y} = w^T x \]

• Support Vector Machine (SVM) Learner

\[ \text{minimize}_w \frac{1}{2} \|w\|^2 + C \sum_k (w^T x_k - y_k)^2 \]
Initial Forecasting Results

60 Minute Data

Persistence
1 site
17 sites
Initial Forecasting Results

10 Minute Data

- Mean Absolute Error (\%)
- Root Mean Square Error (\%)
- Coefficient of Determination

Forecast Horizon (minutes)

N. A. Engerer ICEM 2013  [http://solarnick.info]
Incorporating Cloud Tracking
Far-term Implementation Challenge – Incorporating into Business Operations

• Improve confidence in and utilization of variable generation by electric utilities and businesses
  – Technical integration and forecast reliability
  – Financial “derivatives” to hedge risks
  – Full-scale advanced technology demonstrations

• Quantify costs and benefits vs alternatives
  – Multiple stakeholder audiences
  – Economic: deferred augmentation, “behind meter”
  – Social: community development and participation
  – Environmental: sustainable, “clean”
How PV system developers can help

• Standardize data reporting software interface

• Release information from existing databases

• Integrate monitoring into balance of systems

• Partner with communities and research groups
  – beyond materials and manufacturing research
  – system level integration is now a critical bottleneck
Anticipated benefits to the PV industry

• Specific
  – Low-cost, ongoing monitoring and comparative assessment of performance and degradation

• Generic
  – Integrated services that enhance customer value
  – Increased market for PV systems and ancillary services
  – New business opportunities

• Additionally
  – Rapid real-world testing in broad range of carefully monitored environmental conditions
Further Information


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