ADVANCEMENTS IN SOLAR ENERGY AND FORECASTING

The sun produces 3.846×10^{26} W a second. It’s time to cleanly put that to use.

ADVANCEMENT IN SOLAR ENERGY IN THE LAST DECADE

- Solar panel expenses have rapidly declined
  - Si-based solar panels <30% cost of full electric system
- Advancements in grid-scale storage to accommodate for changing weather conditions
- R&D in creating fuel from solar energy
  - Artificial photosynthesis
  - Improving thermal storage would be top priority

MAJOR AREAS OF RESEARCH AND DEVELOPMENT

- Developing cost-effective persistent grid-scale storage to compensate when sun doesn’t shine as bright
  - Liquid fuels, H_2, methane, compressed air
  - Flow batteries
- Regarding artificial photosynthesis…
  - Develop materials that can absorb and convert sunlight efficiently
  - Integrate materials seamlessly with catalysts that promote fuel creation

CONSTRAINTS DICTATING COST EFFECTIVENESS OF PHOTOVOLTAICS (PVS)

1. Materials have to be inexpensive
   - Panels have to cover large areas to capture most sunlight, generate the most Watts
2. Intermittency of sunlight means energy storage needs to exist
   - Backup for when optimal conditions for solar energy have not been met.

PHOTOACTIVE MATERIALS

- Solar cells categorized based on type of light-absorbing material in the photoactive layer
  - 12 listed cell-types, from which Multi-Si PV material cells stand out as the market leader with 21.3 GW production in 2013
- Various cells rapidly being developed
  - Priorities are efficiency, robustness, cost-effectiveness

IMPROVEMENTS ACROSS PVS

- Doubling production of Si panels lowered cost by 20% when measured in $/peak Watt
  - Energy payback period of <2.5 years
  - 16%-21% power conversion efficiencies
- Thanks to reduction in manufacturing costs
  - Higher production and improvements in materials

R&D IN IMPROVING PHOTOVOLTAICS

- Panels can be streamlined to reduce production and installation costs
  - Lighter materials that would provide same high mobilities and efficiencies of current crystals
- Utilize natural light absorbers found on Earth
  - Higher efficiencies, preferably in thin-film form
- Quantum confined systems

BALANCE OF SYSTEMS

- 30-30-40 breakdown of panel, material costs, installation labor and customer acquisition
- Carefully selected materials can substantially lower costs, along with higher production
- LCOE depends on deployment site

GRID INTEGRATION AND ENERGY STORAGE

- Intermittent energy sources currently backed up by utilities with energy derived from other sources
- Batteries are currently expensive storage technologies
- Flow batteries being researched because of their higher cost efficiencies

SOLAR THERMAL SYSTEMS

- Oil or molten salt can be used to store heat from the sun for a period of time
- Improved thermal storage capabilities currently being researched
- Better to have these thermal charging installations in regions of high direct irradiance value

SOLAR FUELS

- Direct production of fuels from sunlight can provide scalable grid storage technology
- Research into fully nonbiological version of photosynthesis
    - Semiconductors, in conjunction with cocatalysts have been shown to act as artificial photosynthetic systems, separating electrons from sunlight
    - Separated electrical charges coupled with catalysts for reactions of interest – energy can be used to separate H_2 and O in water

COST AND COST REDUCTION

- H_2 production methods from photosynthesis is more than triple similar prices with conventional methods
- Again, R&D in this area is being conducted, with industry-wide disruption of existing beliefs needed to find answers

TANDEM PHOTOELECTROCHEMICAL CELL

- Model for how mechanical photosynthesis would work
  1. Separates sunlight into H_2 and individual electrons.
  2. Pairs H_2 with O_2 catalyst.
  3. H_2 and O_2 passed through permeable membrane to facilitate H_2 collection.

PROMISE AND POTENTIAL

- Remarkable progress made in cost reduction and commercial deployment of solar energy technologies thanks to investments in R&D
  - Promise of further advances in the field
- More research has to be done in order to fully understand and harness the potential of solar energy

INTRODUCTION TO SOLAR FORECASTING

- Most effective and economical way to integrate solar energy in a large scale and plan for the uncertainty in its use
- Forecasts used to schedule generation, procure operating reserves, ensure sufficient flexibility to manage changes in output
- Take variety of factors, combine them, interpret them to suit needs

CHALLENGES TO SOLAR FORECASTING

- Accommodating factors such as aerosols, dust, clouds that distort the detected irradiance from the sun
  - Panel inefficiency, temperature dependent
- Solar panels installed Behind the Meter (BTM)
  - Less data available

CURRENT FORECASTING TECHNIQUES

- Based on time frame, data available, and how it's to be used
- Numerical weather prediction (NWP)
  - Climatology
- Numerical weather prediction with model output statistics
- Statistical learning models, ensemble techniques, blending
- Satellite imagery and sky imaging

TIME SERIES PREDICTION WITH STATISTICAL LEARNING METHODS

- Direct observation and historically gathered data can be used to project future predictions
- Real-time data provides information on current state of site
- Data science with machine learning and regressive modeling

SKY IMAGERS

- Digital cameras producing quality images of the sky from horizon to horizon
  - Detect clouds and estimating height above ground
  - Calculate/predict cloud motion across horizon
- Use scattering of wavelength of aerial objects to determine what object is
- Not of high value beyond 30 minute time frame

SATELLITE IMAGING

- Geostationary satellite data from networks supply information on cloud properties and movement
- Sequential imaging used to predict future cloud locations
- Irradiance can be predicted from a minute to over five hours ahead

NUMERICAL WEATHER PREDICTION

- Workhorse for forecasting applications for many years
- Performs best for time horizon of 6 hours to 2 weeks
- Historically, optimized to predict temperature, humidity, probability of precipitation and wind
- Blended output from multiple NWP models can improve forecast by 10%-15%

ENSEMBLE FORECASTING

- Collection of forecasts to deal with uncertainty
- Two major techniques used in creating ensemble forecast:
  1. Add complex motions and variables to initial state of forecasting model.
  2. Use different numerical models or physics schemes to compose one single model/forecast.

DISTRIBUTED AND BTM FORECASTING

- Data is necessary to create strong forecasts
  - Whether generation is recorded on its own or is aggregated with customer load
  - Whether telemetered meter data is available in real time
  - Whether detailed static data is available (plant location, PV geometry, obstructions nearby)
- Usually available at large solar plant, but not BTM PVs

"BOTTOM-UP" APPROACH

- If detailed metadata available for BTMs, it can be combined with irradiance and weather data from satellite and NWP sources
  - Basically, we match/pair information together so that it makes more sense
  - PV systems info with irradiance and weather data

PROS AND CONS OF "BOTTOM-UP" APPROACH

- Pros
  - Cost-effective, allows for wide area of aggregation to be simplified for better prediction
- Challenges
  - Dynamic elements about individual PVs will still be unknown

"TOP-DOWN" APPROACH

- Very useful when less data exists regarding PVs
- Use combinations of existing data, comparing metered data on statistically significant number of sites for benchmarking overall accuracy
- Starting at high level and making predictions about individual constitutents

PERFORMANCE OF SOLAR FORECASTING

- Standardized metrics employed to facilitate comparison among solar forecasts
  - Mean (bias) error
  - Mean Absolute Error (MAE)
  - Root Mean Square Error (RMSE)
- Some systems based on “smart persistence”, assuming cloud cover and temperature remain same

FORECAST PERFORMANCE IMPACTED BY MANY FACTORS

- Look Ahead Time – Error rises and then plateaus as we look farther ahead: forecasting over multiple years lowers error
- Variability in Solar Production – Cloud impact and other atmospheric factors may cause much variation in metric
  - Variation tends to follow a pattern, errors may tend to repeat
  - Variability can be tracked, such as how MAE of production variability will always be near 0 around sunrise and sunset

FACTORS CONTINUED.

- Specific Plant Attributes – patterns vary with different plants
- The variation of error across plants can be lessened by using a Spatial Scale
  - Aggregation effect prompts aggregate of data to have smaller errors than individual samples
  - Effects local to one specific site are more difficult to forecast resulting in higher error

PATHS TO IMPROVED SOLAR FORECASTING

- All of the techniques discussed have their deficiencies or at a growing stage
- Methods still being developed to properly forecast BTM panels
- Probabilistic forecasting techniques still being explored
- Clients need to be trained in how best to use the data science models they are given

RESEARCH AND DEVELOPMENT

- Major research being conducted in US and Europe to improve key areas of forecasting
  - SunShot initiative to develop more accurate cloud profile
  - IBM researching optimal blending of different models
  - National Center for Atmospheric Research researching combining sky imaging, satellite methods, and solar-tuned NWP model to maximize forecasting capabilities

INCORPORATION OF BTM INTO FORECASTING

- Forecasting community looking at cost-benefit analysis of bringing BTM PVs into the picture
- California leading the way with government-funded initiative to use PV installation information to predict day-ahead and hour-ahead power output of entire solar fleet

FURTHER RESEARCH & DEVELOPMENT

- Cloud Propagation Techniques
  - CSU developing satellite insolation (sun's rays) forecast with respect to collocated (tracked/shared data) winds from an NWP model to capture movement of clouds at different heights
- Probabilistic Forecasting
  - Improved representation of uncertainties in cloud formation/decay
  - Analog Ensemble Approach: Searches past for similar forecasts and makes corrections to current forecast: auto-fixer essentially

INTEGRATION INTO SYSTEMS OPERATIONS

- Utilities need to be trained how to effectively use forecasts
  - Hawaiian Electric Company
    - Integrate forecast directly into energy systems, determining which energy source to use in when and what time of day.
  - Red Electrica Control Centre of Renewable Energies in Spain
    - Identify risk and anticipate behavior of solar supply
  - Probabilistic models better understood so power operators and producers can use forecast uncertainty directly in decision making

MORE ON INTEGRATION

- The Department of Energy is developing useful metrics for assessing performance of forecasts with respect to their economic value
  - Basically, cost-benefit analysis, or cause-effect of using a forecast – its return value

SUMMARY AND CONCLUSIONS

- Research focused on not only improving solar forecasting methods, but improving their integration into operating systems and bettering how they are used
- Efficiency and cost really matter, especially when solar energy is a newcomer to an already established field
- R&D heavily focused in this areas and future looks bright