When Big Data Meets the Microgrid: Challenges and Opportunities

Wen Hua
Conventional Power Grid

Electricity flows in one way

- **Transmission lines** carry electricity long distances
- **Distribution lines** carry low voltage electricity to consumers

**Power plant** generates electricity

**Transformer** converts low voltage electricity to high voltage for efficient transport

**Substation transformer** converts high voltage electricity to low voltage for distribution

**Homes, offices and factories** use electricity for lighting and heating and to power appliances
Smart Grid

Electricity flows in two directions

**Power plant** generates electricity

**Transformer** converts low voltage electricity to high voltage for efficient transport

**Distribution lines** carry low voltage electricity to consumers

**Substation transformer** converts high voltage electricity to low voltage for distribution

Homes, offices and factories use electricity for lighting and heating and to power appliances

**TRANSPORT OF ELECTRICITY**
Smart Grid: Advantages

- Distributed resources including renewable resources
- Advanced electricity storage and peak-shaving technologies
- Advanced metering and communication technologies
- Provision to consumers of timely information and control options
- Dynamic optimization of grid operations
- Flexible energy trading scheme
- ...
Global Investment in Renewable Energy

- Australian Government Department of Industry
Total net energy consumption in Australia

- Australian Government Department of Industry
Microgrid

A localized smart grid that can operate in both grid-connected mode or islanded mode
Microgrid Examples

Kodiak, Alaska, USA

- The board of the Kodiak Electric Association (KEA) sets a vision statement to cost-effectively generate 95% of its electricity from renewable resources by 2020. Now that the wind turbines have been added and the system is over 99% renewable, the community is saving around $4 million per year.

- The addition of more renewable resources has reduced Kodiak Electric Association customer rates 3.6% since 2000.

<table>
<thead>
<tr>
<th>Population</th>
<th>Total Capacity</th>
<th>Peak demand</th>
<th>Ratio of renewable energy</th>
<th>Residential Electricity Price</th>
<th>Commercial Electricity Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>13000</td>
<td>75,000kW</td>
<td>27,800kW</td>
<td>99.7%</td>
<td>$0.14/kWh</td>
<td>$0.15/kWh</td>
</tr>
</tbody>
</table>
Microgrid Examples

King island, Tasmania, Australia

- The King Island Renewable Energy Integration Project (KIREIP) is a world leading power system project. It results in the use of renewable energy for up to 65% of the island’s energy needs, and reduces CO2 emissions by more than 95%
- By combining various renewable resources, storage, and control techniques, King Island has reduced CO2 emissions by more than 50,000 tons to date, while improving reliability and power quality

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<th>Residential Electricity Price</th>
<th>Commercial Electricity Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1800</td>
<td>8840kW</td>
<td>2500kW</td>
<td>65%</td>
<td>$0.19/kWh</td>
<td>$0.19/kWh</td>
</tr>
</tbody>
</table>
Microgrid Examples

UCSD, La Jolla Campus, California, USA

- UC Saint Diego's microgrid is one of the best examples of an electricity network that provides local control yet is interconnected with the larger electricity grid.
- With a core co-generation plant for heat and power, loads of solar PV, and real-time instrumented demand control across its 450 buildings, the microgrid provides 92% of its own energy needs.

<table>
<thead>
<tr>
<th>Population</th>
<th>Saving Electricity Cost Annually</th>
<th>Peak demand</th>
<th>Energy supply for the campus</th>
</tr>
</thead>
<tbody>
<tr>
<td>5400</td>
<td>$8 Million</td>
<td>45MW</td>
<td>92%</td>
</tr>
</tbody>
</table>
Renewable Energy in China

Mainland China

• In April 2017, Xinjiang’s Turpan Smart Microgrid Pilot Project obtained first electricity selling certification for the microgrids

• Its total installed capacity of distributed PV power is 13.4 megawatts, supplying green electricity to over 7,000 households and 20,000 residents

• State grid now allows retailers to use its grid as “highway”
One of Our Collaborators

Redback Company

• Redback is a technology company located in Brisbane, which is focused on the development of advanced, low cost solar solutions for residential and commercial users
• Redback received 9.3 million AUD from EnergyAustralia and 1.96 million AUD from Queensland Government
• Redback is one of the industrial partners of the DKE group
Microgrid @ UQ

The University of Queensland

• St Lucia campus
  – 19 buildings with rooftop PV arrays
  – More than 2.14 MW
  – Monitoring power output and weather data per minute

• Gatton campus solar research plant
  – $40.7 million Federal Government Education Investment Fund
  – 3.275 MW
  – Battery storage system
  – Monitoring 3000+ types of data per second

PV system and data monitoring system of UQ St Lucia campus
UQ St Lucia Campus
UQ Gatton Campus
UQ Gatton Campus

Dual-axis tracking array

Fixed-tilt array

Battery storage

Control center

Power conversion system

Single-axis tracking array

Fixed-tilt array

Battery Energy Storage System (BESS)
UQ Solar PV Data Visualization

Key Requirements of the Microgrid

Renewable energy
- Variability
- Uncertainty

Current situation
- No monitoring
- No active control

High reliability  High efficiency  High flexibility  Profitability

More equipment  More reserve energy
Expensive, Passive Control

Big Data analysis  Smart energy management
Cheap, smart, flexible, active control
Data Analysis Based Smart Energy Management

Data → Analyze → Insight → Decide → Beer & Diapers

Collaborative Filtering
Research Agenda

Research Goal

• Build an efficient and accurate framework for dynamic balance among energy generation, demand, storage, and trading
Possible Research and Applications

<table>
<thead>
<tr>
<th>Category</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data cleaning</td>
<td>• Outlier, missing value</td>
</tr>
<tr>
<td>Data compression</td>
<td>• Trade-off between size and value of big data</td>
</tr>
<tr>
<td>Renewable energy prediction</td>
<td>• Secure renewable energy, energy storage systems and reserve energy cooperate seamlessly</td>
</tr>
<tr>
<td>User behavior analysis and demand optimization</td>
<td>• Data mining on user data, to optimize the matching of the supply and demand in the grid</td>
</tr>
<tr>
<td>Real-time electricity price prediction and trading strategy optimization</td>
<td>• Maximize the profit of the system operators and consumers</td>
</tr>
<tr>
<td>Microgrid real-time management and optimized operations</td>
<td>• Ensure the security and reliability of the grid. Highly efficient monitoring of each device</td>
</tr>
<tr>
<td>Cyber security of the power grid data</td>
<td>• Enhance the security of private information and system robustness</td>
</tr>
</tbody>
</table>
Data Compression in the Microgrid
High Volume, High Velocity, and High Variety

Case Study: UQ Gatton campus

- **Volume**
  - 50GB data per month
- **Velocity**
  - Data resolution: per second
- **Variety**
  - Time series, system status, image, etc.

<table>
<thead>
<tr>
<th>Type</th>
<th>Electrical Data</th>
<th>Weather Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td></td>
<td>Irradiance</td>
</tr>
<tr>
<td>Current</td>
<td></td>
<td>Wind Speed</td>
</tr>
<tr>
<td>Frequency</td>
<td></td>
<td>Wind direction</td>
</tr>
<tr>
<td>Power</td>
<td></td>
<td>Humidity</td>
</tr>
<tr>
<td>System status</td>
<td></td>
<td>Rainfall</td>
</tr>
<tr>
<td>Etc.</td>
<td></td>
<td>Etc.</td>
</tr>
<tr>
<td><strong>Update frequency</strong></td>
<td>1 second</td>
<td>1 second</td>
</tr>
<tr>
<td><strong>Start time</strong></td>
<td>01/2015</td>
<td>01/2015</td>
</tr>
<tr>
<td><strong>Size</strong></td>
<td>≈ 50Gb per month</td>
<td>≈ 30Mb per month</td>
</tr>
</tbody>
</table>

The conflict between the size and value of big data

Compression ratio vs. max-error
Compression Methods

• Lossless vs. lossy compression
Lossless Compression

• Run-length encoding
  – Combine consecutive repeating characters

```
Original data: BBBB BBBAAAAAAAANMMMMMMMMMM
Compressed data: B09A16N01M10
```
Lossless Compression

• Huffman encoding
  – Information entropy
Lossless Compression

• Lempel Ziv encoding
  – Build the dictionary
  – Compress

What is the problem of applying lossless compression method to microgrid data?

Abraham Lempel  Jacob Ziv
Lossy Compression

- Transformation-based
Lossy Compression

• Transformation-based
  – Discrete Fourier Transform
  – Linear combination of sines and cosines
  – Store phase and amplitude
  \[ C(t) = \sum_{k=1}^{n} (A_k \cos(2\pi w_k t) + B_k \sin(2\pi w_k t)) \]
  – FFT: \( O(n \log n) \)

Lossy Compression

• Transformation-based
  – Discrete Fourier Transform: only reflect frequency
Lossy Compression

- Transformation-based
  - Discrete Wavelet Transform
  - Linear combination of Wavelet basis functions
  - Capture both frequency and time
  - FWT: $O(n)$

Lossy Compression

• Piecewise approximation
  – Constant
    • Piecewise Aggregation Approximation (PAA)
    • Adaptive Piecewise Constant Approximation (APCA)
Lossy Compression

- Piecewise approximation
  - Linear
    - Piecewise Linear Histogram (PWLH)
- Slide Filter
Lossy Compression

• Piecewise approximation
  – Non-linear
    • Polynomial Approximation
    • Chebyshev Approximation
Lossy Compression

- Symbolic representation
  - Symbolic Aggregate approxXimation (SAX)
  - Convert the result from PAA to symbolic string

\[
\text{baabccbc}
\]
Solar Forecasting in the Microgrid
Solar Forecasting Methods

Method:
- Persistence
- AR, ARIMA...
- NN, Regression
- Numerical Weather Prediction (NWP)

Challenges:
- Too Simple, Clouds...
- Linear, Stationary
- Input Selection, Model Design
- Coarse Resolution

Improvement:
- Cloud Imaging
- Time Series Preprocessing
- Preprocessing, Corr. Analysis
- Cloud Assimilation

Forecast Horizon:
- Minutes
- Hours
- Days
## Solar Forecasting Methods

<table>
<thead>
<tr>
<th>Numerical Weather Prediction</th>
<th>Statistic Models</th>
<th>Machine Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Climate models</td>
<td>• Autoregressive(AR)</td>
<td>• Nearest Neighbor</td>
</tr>
<tr>
<td>• Atmospheric models</td>
<td>• Moving Average(MA)</td>
<td>• SVM</td>
</tr>
<tr>
<td>• Geophysical models</td>
<td>• ARMA</td>
<td>• Hidden Markov Model</td>
</tr>
<tr>
<td></td>
<td>• ARIMA</td>
<td>• Neural network</td>
</tr>
<tr>
<td></td>
<td>• Exponential smoothing</td>
<td>• Deep Learning</td>
</tr>
</tbody>
</table>
Solar Forecasting Methods

• Moving Average (MA)
Solar Energy Forecasting

- Nearest Neighbor (NN)
Solar Energy Forecasting

• Numerical Weather Prediction
Research Agenda

Research Goal

• Build an efficient and accurate framework for dynamic balance among energy generation, demand, storage, and trading

New domain, new opportunities

Data preprocessing

Forecasting

Smart control strategies
Data Characteristics in the Microgrid

High periodicity & randomness
- The generation of renewable energy consists of significant periodicity and randomness simultaneously

Spatial – temporal correlation
- Data in the Microgrid have spatial correlation according to the implementation of the sensor networks
- Correlation with historical data too

Hierarchical structure
- Due to the topology of the physical power grid, the corresponding data shows hierarchical property
High Periodicity & Randomness

Electrocardiograph:
high periodicity, low randomness

Stock price:
low periodicity, high randomness

Solar energy:
high periodicity, high randomness
Decomposition-Based Compression

• Low compression ratio of model-based methods when dealing with highly periodic and random time series data

• A novel time series data compression technique with max-error guarantee is proposed based on STL decomposition

• Season, trend, and random part will be compressed separately
NN-Based Forecasting

most similar segment
next segment as output

- fluctuation part
- stationary part
Limitations of NN Search

- Low local similarity
  - High global similarity

- High local similarity
  - Low global similarity
Ours: Multi-Window NN-Based Forecasting
Spatial-Temporal Correlation

<table>
<thead>
<tr>
<th>Location</th>
<th>Real distance</th>
<th>DTW distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>St. Lucia campus internal</td>
<td>&lt;1km</td>
<td>7~8</td>
</tr>
<tr>
<td>St. Lucia – Herston</td>
<td>≈6km</td>
<td>25</td>
</tr>
<tr>
<td>St. Lucia – Pinjarra Hill</td>
<td>≈10km</td>
<td>22</td>
</tr>
</tbody>
</table>
Hierarchical Structure

Physical system

Data monitoring system
Application Requirements

• Need to guarantee max-error for each point in compression?
  – K-window compression
• Household-level forecasting?
  – User behavior modeling
  – Load disaggregation
• Load scheduling, or battery scheduling?
• Privacy, Security and Trading?
THANKS