Assessing Opportunities to Exploit Stranded Power

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Outline

• What is Stranded Power?
• Understanding Stranded Power
• Exploiting Stranded power
• Looking Forward (Grid, RPS)
**Scopes of Energy Efficiency**

- Rack, Data center
- Power Distribution, Power Grid
- Generators

**Talk Focus**

**Stranded Power**

- Grid economic management mechanisms can cause renewable power to be “stranded”
- Ramps, Transmission Congestion or Shortage, Correlated Production
- MISO “down dispatched” 2.2TWH of wind in 2014
  - Equivalent to 251 MW average; ~2%, MISO: Success!
UNDERSTANDING STRANDED POWER

Mid-continent Independent System Operator (MISO)

- 15 states, serves 42M people
- 130 GW peak load, >500TWh/year
- $37B Power (2014)
  - 413 Market participants
  - >2,000 pricing nodes
- >65,000 miles transmission
- $2.2B transmission charges
- ~10% Wind generated
Transformation of the Power Industry and Power Grid

Power Grid in 1975
- Vertically integrated
- Few, Large fixed generation sites
- Large loads, geographically fixed, 2x dynamic cyclic

Power Grid in 2015
- Separation of generation and distribution
- Explosion in large-scale distributed renewables
- Highly variable Generators
- Loads same

Central Control

Economic Dispatch, "open" market, Localized Pricing

October 29, 2015 Opportunities Stranded Power (UCSB-IEE)

Renewable Variation and Economic Dispatch in MISO

Capability Price info
- Feasible
- Cheapest
- Green
- Fair
- Fast (5-minute increments)
- + Reliable
- +"As much as you want"

- Technical: Generators bid “Eco_max,min”, and price curves hourly
- Economic: Global optimization, focused on “Merit order”, Day-ahead Market, Real-time Market
- Control: 5-minute dispatch (with 4-second adjustments)
- Payments determined by actual deliveries
Locational Marginal Pricing and Local Outcomes

- Market prices based on the "incremental" cost of each MWh
- Variation+Transmission+Economics: Complex, coupled behavior
- Produces wide variation at the edge (generators)
- LMP => the market price for the generator

Wind Power Pricing

- Feast and famine
- Variable Generation
- Prices from $100 to -$50  [Range is wider now]
- Generator’s Goal: a good “Average” Price
Example Site - Timeline

- Price vs. Time [2015: Jan-April]

Example Site – Timeline (zoom)

- Price vs. Time, Unit 8238, January 2015
Example Site – Stranded Power

- EcoMax (potential) vs Delivered [2015: Jan-April]

Stranded Power

- Precise model: Instantaneous
  - Power with no economic value, for a 5-minute interval

- Define: LMP0 as LMP < $0 / MWh

- Define LMP(x) as LMP < $x / MWh

- LMP0, LMP1, LMP2, ... LMP5
- $32/MWh is average for MISO
  - So, LMP5 is power 6x lower than the average price
Analysis of a Power Grid Market

- MISO Market Records Properties

<table>
<thead>
<tr>
<th>Period</th>
<th>Jan 1, 2013-Apr 14, 2015</th>
<th>28.5 Months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation Sites</td>
<td>1,259 Total</td>
<td>200 Wind</td>
</tr>
<tr>
<td>5-min Intervals</td>
<td>76.9M Total</td>
<td>36.6M Wind</td>
</tr>
<tr>
<td>Power</td>
<td>1,188 TWh Total</td>
<td>89 TWh Wind</td>
</tr>
<tr>
<td>$$ Revenue</td>
<td>$95 Billion</td>
<td>$4 Billion</td>
</tr>
</tbody>
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Wind Sites, SP Duty Factor: LMP0

![Bar chart showing duty factor distribution](chart.png)
LMP Stranded Power vs Price Threshold ($/MWh)

Interval Sizes, LMP
Stranded Power, V2

- A 2nd “stranded power” model

- NetPrice (average over a longer period)
  - Offer a good deal to the generator for the entire period
  - Idea: smooth out the fluctuations

\[
NetPrice = \frac{\sum_{period} LMP \cdot Power}{\sum_{period} Power}
\]

- NetPrice(C): NetPrice < C (C = $0, $1, ..., $5)

Wind Sites, SP Duty Factor: NetPrice0

![Histogram of NetPrice0](image)
NetPrice Stranded Power vs Price Threshold ($/MWh)

![Cumulative Duty Factor Graph](Image)

NetPrice Stranded Power: Intervals (by Count), NetPrice5

![Duty Factor Bar Graph](Image)

Best Single Site
NetPrice Stranded Power: Intervals (by time), NetPrice5

Best Single Site

Lots of Stranded Power
Dispatchable Loads: Approach

- Idea: Create on-demand computational loads that can exploit the stranded power
  - Reduce grid waste and increases stability
  - Provides greater financial return for renewable generators
  - A means to achieve higher RPS and lower grid costs

- Two types
  - Spot Instances, Preemptible instances, Peer to Peer, Desktop Grid
  - High-Performance Computing
Zero-carbon Cloud (ZCCloud)

- Build distributed computing servers that act as a "dispatchable load"
- Start on demand when there is stranded power
- Consume the power, continuously while available
- Shutdown gracefully when the power is no longer available

Amazon’s Spot Instance Model

- Execute a “virtual machine” or “container” at a time when the computing is below a bid price
- Start time + End time: dictated by the system
- Queue of “persistent” and “new” spot requests
DISPATCHABLE COMPUTING LOADS: HIGH-PERFORMANCE COMPUTING

Batch High-Performance Computing Model

- Execute a parallel job (array of machines or VM's), 1-16,384
- Start time + End time: dictated by the system (jobs request runtime)
- Queue of “new” parallel job requests
Traditional Data Center System Limits

- Power limit
- Heat limit
- Physical space limit
- Carbon emission limit

Augmenting Mira with ZCCloud

- 10 Petaflops, 4MW, 786K Cores
- 2nd System of the Same Size
  - 10 Petaflops, 4MW, 786K Cores
ALCF Workload Traces

- Mira: #5 Supercomputer in the World
- IBM Blue Gene/Q System, 768K Cores, 10 Petaflops

<table>
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<tr>
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<tbody>
<tr>
<td># of Jobs</td>
<td>78,795</td>
</tr>
<tr>
<td>Runtime (Hours)</td>
<td>Range: 0.004 to 82, Average: 1.7, StDev: 3.0</td>
</tr>
<tr>
<td># Nodes</td>
<td>Range: 1 – 48K, Average: 1.975, StDev: 4,100</td>
</tr>
</tbody>
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Basic Performance, by Workload Shape

- Understanding Intermittent Resources
- Adding resources translates into Improved Performance
- Even better than basic capacity increase (1.5x)
- Shape doesn’t matter
Performance, by Job Size

- Understanding Intermittent Resources
- Performance improvement Overall, but varies with size
- Benefit Weighted heavily to “large, capability jobs”
  - Insights for system mgmt?

Performance, by “Ontime” or “Late”

- Ontime jobs can complete in the current “volatile resource” available window
- Late jobs cannot (arrived too late)
- Ontime jobs benefit more! But Late jobs benefit as well...
• LMP models lower duty factor produces less benefit
• Some loads are infeasible
• Netprice high duty factors provide growing benefit

• LMP models provide lower duty factor
• LMP models perform worse than periodic model with equal duty
• NetPrice models can provide higher duty factors
• Can provide better performance
Related Work

• Integration of Renewables into the Power Grid
  • Wind Vision, CAISO, Grid expansion, Power Markets
• Energy-efficiency in Data Centers
• Solar Augment and LT-Purchase for Wind, Colocation
  • A good thing “generally”, support the finances of renewable power
  • Create covariation with renewables in the grid: counter-variation of load (bad)
• Follow the Sun
  • Closest, create co-varying load (good)
• ZCCloud: New “volatile” computing resource model

Summary

• Stranded power is a growing challenge for renewables
• Computational Dispatchable loads are promising
  • Benefits grids and renewable generators
• Cloud Services Evaluation
  • Initial Economic Evaluation
• High Performance Computing Evaluation
  • Intermittent resources can be gracefully integrated
  • Stranded Power models are important
Looking Forward

- What other uses of stranded power are feasible?
  - Lightweight manufacturing
  - Opportunistic tasks: Carbon removal? Reduction?
- What opportunities are there to create higher value computing services from intermittent energy?
  - Combining sites
  - Intelligent migration
- What benefits can “dispatchable loads” accrue to the grid?
  - Increased stability, reduced operating margin
  - Increased ability to exploit renewable power
  - Partial Load shifting

BENEFITS OF DISPATCHABLE LOADS FOR GRID