INCOSE International Symposium
Philadelphia, PA
June 24-27, 2013

System Implications of Intermittent Generators

How to engineer reliable zero carbon wind systems

Dr. Alex Pavlak; alex.pavlak@INCOSE.org,
Future of Energy Initiative; http://sites.google.com/site/futureofenergyinitiative

Apollo lessons

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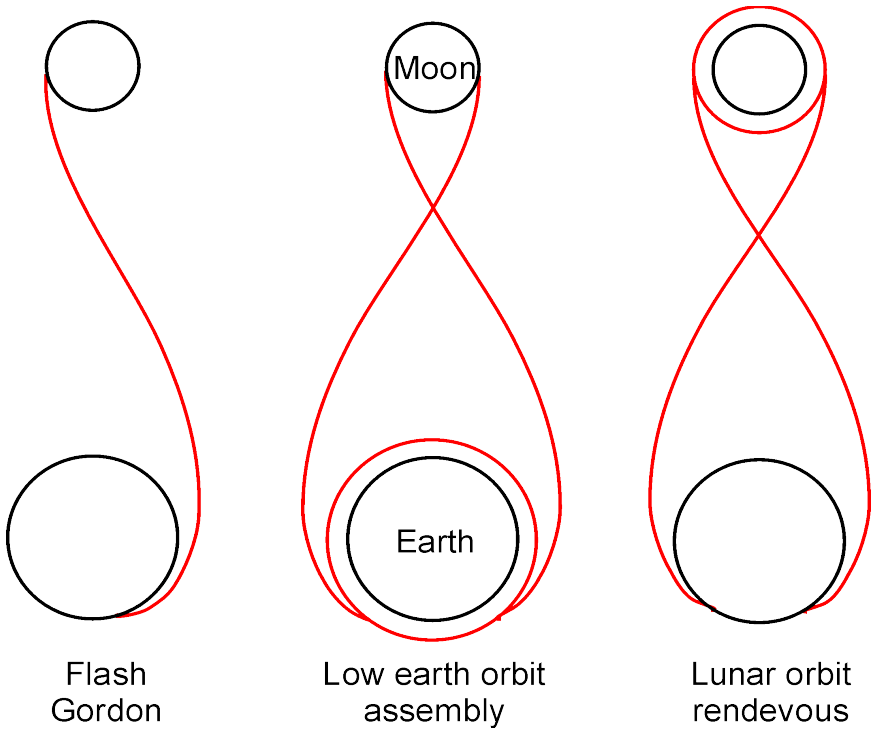

"We will put a man on the moon before the end of the decade and return him safely to earth"

JFK May 25, 1961

- Start with the ultimate goal
- Characterize alternative systems
- Choose a direction

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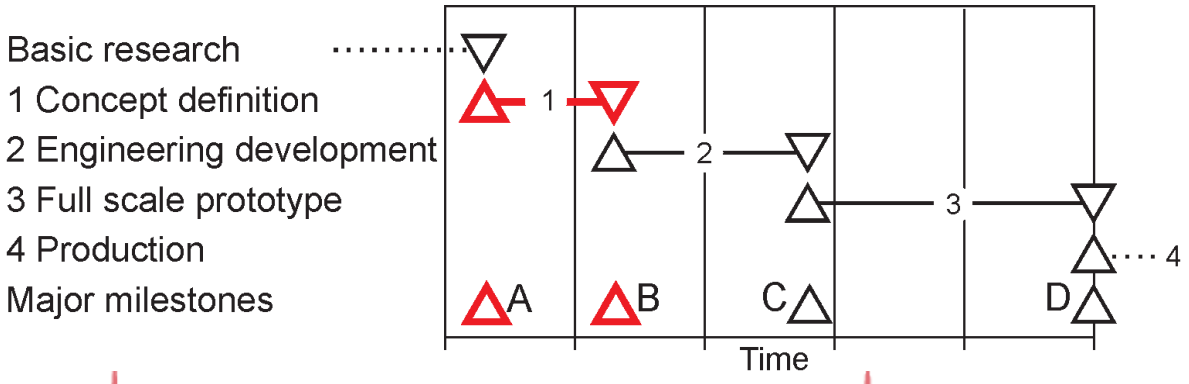
Classic concept definition

- Start with ultimate goals
- Develop concept models to explore, contrast, compare alternative feasible solutions
- This is classic concept definition phase
  - Provide Society with factual feasible choices (m/s B)



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Ultimate Goal

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To power the planet without fossil fuel

FoEI

Allocated wind power goals

- Clean, (1% fossil fuel) systems
- Reliable electric power systems
- Competitive cost

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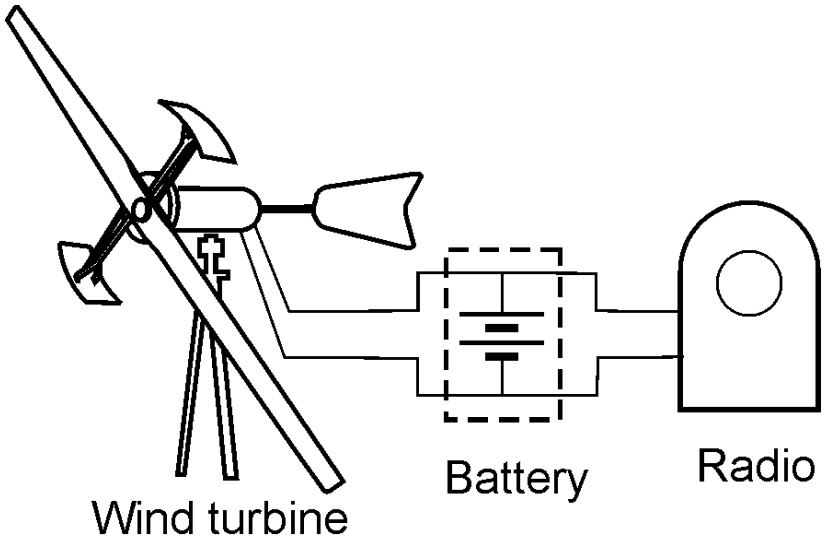
Wincharger system

- Zenith Radio “farm” (DC) radio
  - ~ 750,000 systems 1930-1940s
- Provided farmers with quality radio!
  - Radio was most expensive component
  - Battery sized for 4 days storage
  - High electricity cost ~ $2/kWh
  - Unreliable during July-August
- Did not survive rural electrification



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Bounded systems

- Rational system design requires defined boundaries
- Managing spatial boundaries
  - Initial model closed systems
  - Extended models define external interfaces
- Managing temporal boundaries
  - Many years of data clarifies magnitudes, accept risk
  - Or assume worst case (no wind)

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Wind system concept models

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Initial models

- Purpose
  - Identify system principles, primary constraints, interfaces
- Must include structural design driver (intermittency)
  - Scaled production data (best)
  - Atmospheric models (OK)
  - Rayleigh statistics (guidance)
  - *Be careful about wind averages*!
- Closed systems
  - Physically bounded
  - Multi year wind time series

Extended models

- Purpose
  - Metrics for region specific 1% systems
- Add complexity in stages
  - Variable load, synchronous time step
  - Storage
  - Distributed wind deployment
  - Overbuild wind
  - Other generators (solar)
  - Transmission
  - External interfaces
- Metrics
  - Cost, performance, risk

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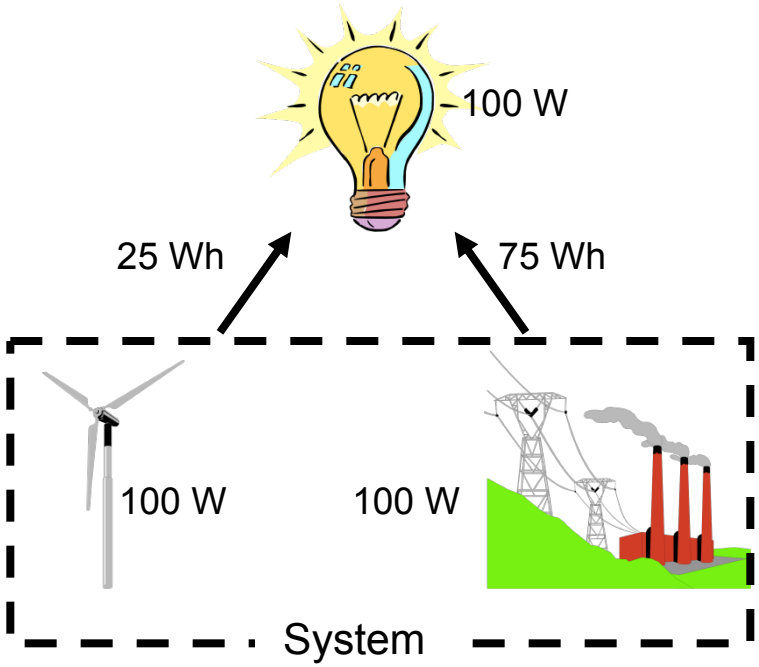
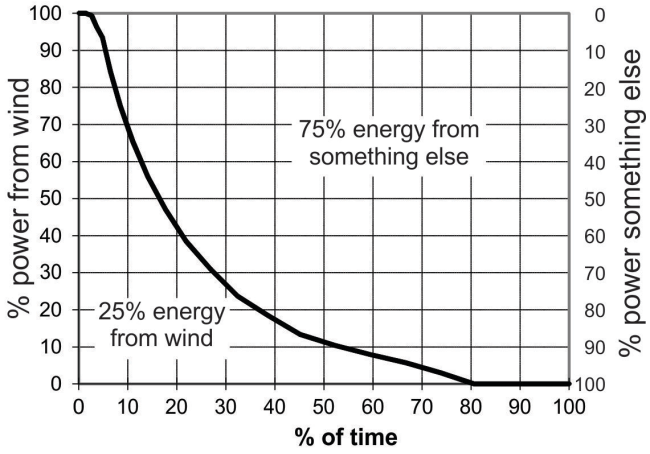
Initial wind concept model





Generation duration for 25% capacity factor

System principles

1. System reliability comes from fossil fuel
2. Value of wind is variable cost of backup
3. Reliable wind systems have emissions
4. Costs escalate beyond 25% penetration
5. Wind commits the rest of the system to backup

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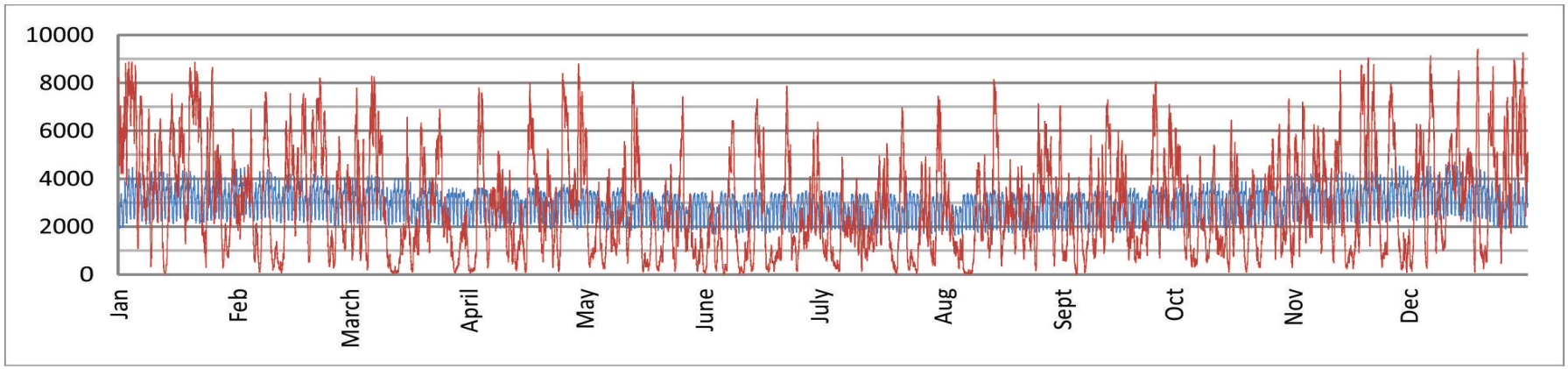
Wind + storage

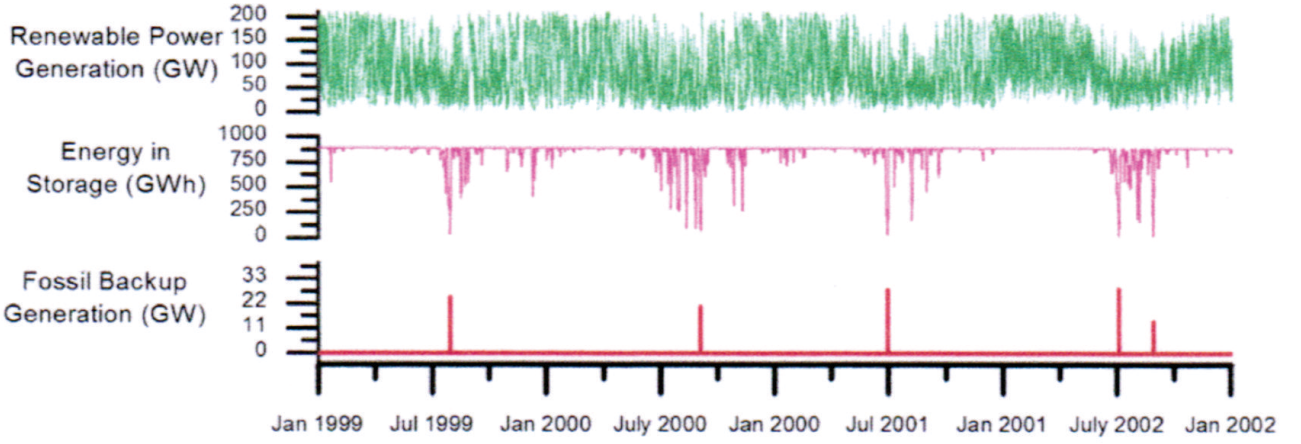
- EirGrid 2012
  - Average load (blue) equals average (adjusted) wind (red)
  - Size the battery to match wind and load



- Lessons
  - Battery is huge (8x Irish GNP), driven by seasonal variations
  - Any finite sized battery is eventually overwhelmed by too many low wind days
    - By itself, wind + storage is not a reliable system

Gilligan, B., Energy Storage on the Irish Grid and the Possibility of a Wind Only Scenario, UMBC ENMG698, www.pavlak.net/ENMG698.Brendan.pdf

Wind + fossil fuel + storage*



Load was met with renewable generation and storage 99.9% of hours over 4 years; fossil backup needed on five occasions

Report summary

* Budischak, et al, Cost minimized combinations of wind, solar, storage, *Journal of Power Sources* 225, 2013, pp. 60-74

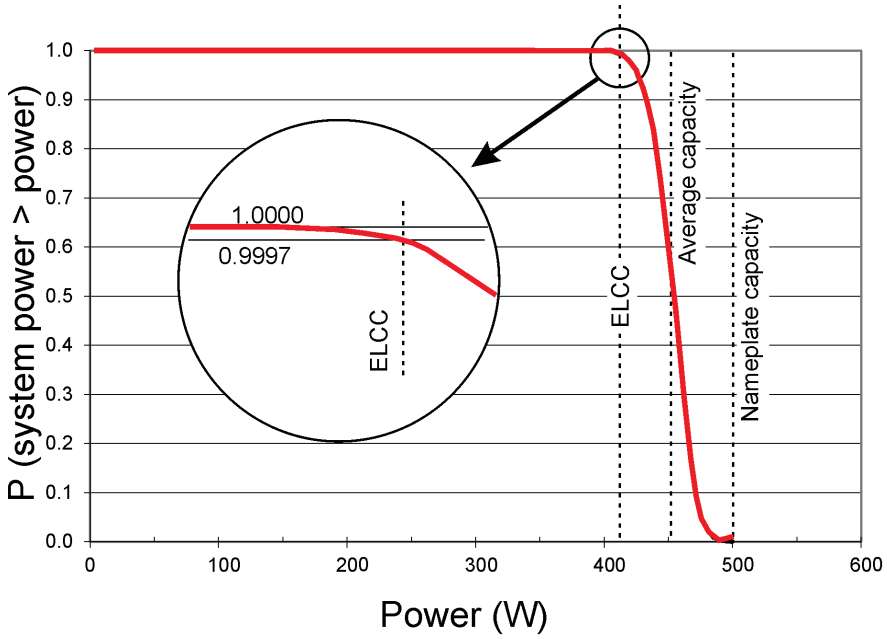
- PJM region
- 0.1% fossil fuel
- 3x wind energy overbuild
  - 9x nameplate overbuild
  - Discard 2/3 of electricity
- ~24 hours storage
- Full fossil fuel backup ~8 hrs/yr
- Stated cost ~ 38¢/kWh

Comments on Budischak

- 4 extreme events (July) drive system size
  - Need many more events to size a system
- Cost is optimistic
  - Model predicts 40% CF vs 26.7% actual CF for PJM in 2012
  - Does not include capital carrying charge for fossil fuel system
  - Transmission and its constraints will significantly increase costs
  - Large size (~25,000 sq miles for PJM region) will drive wind farms offshore
- Concept is sound but needs classical concept development
  - Parametric tradeoffs
  - Many years, many regions
  - Independent critical review

Traditional reliability

- Often cited reliability criteria is loss of load for one day in ten years (0.9997)
  - Used to estimate effective load carrying capacity (ELCC)
- This is an empirical heuristic
  - Decades of experience has shown that the system is manageable
  - Based on a large number of similarly sized generators with statistically independent failure rates



CDF for a large number of equal size generators with statistically independent failure rates

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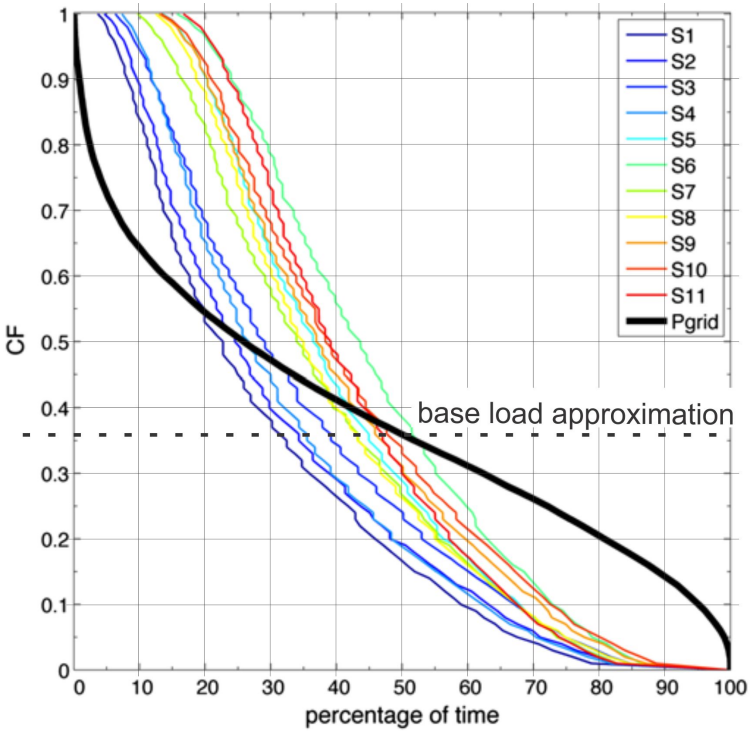
Interconnected wind farms

- 5 year average generation-duration for offshore buoy sites between Maine and Florida
- Pgrid shows synchronous interconnection
- No guarantee that wind is always blowing somewhere



Kempton, et al. Electric power from offshore wind, PNAS 107:16, 2010 pp. 7240-7425

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Can wind have firm capacity?

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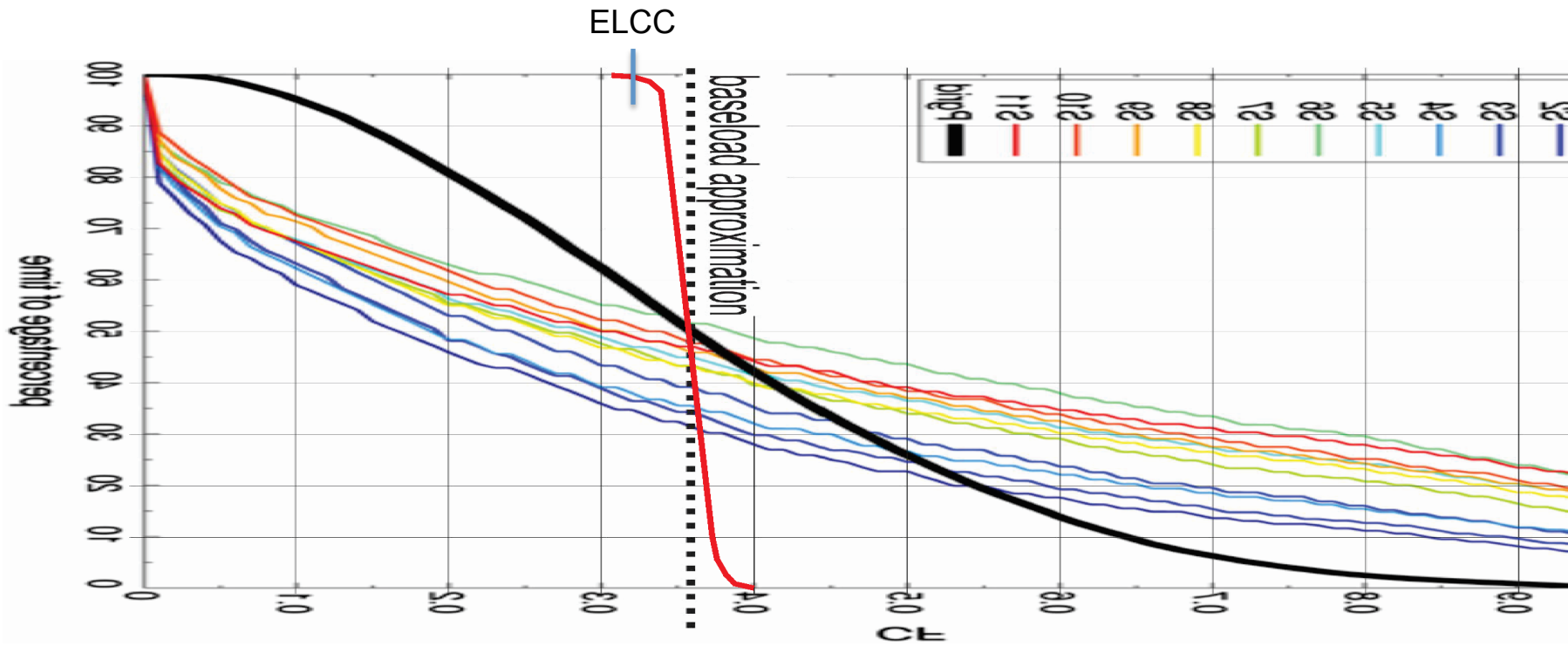

CDF

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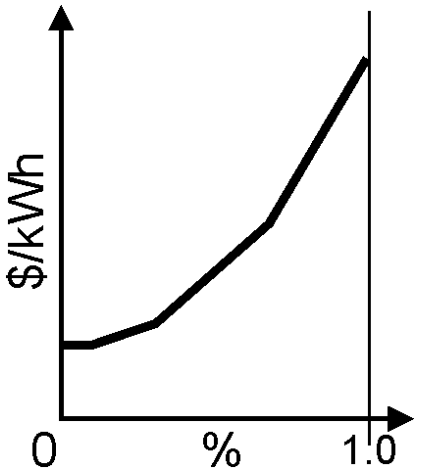
Intermittent system frontier

- Quantify the system impact of long distance transmission
- Estimate the cost and environmental impact of 1% carbon wind systems
  - Real data for wind, load, solar
  - Region specific
  - Metrics - Cost, performance, risk
- Estimate system electricity costs as a function of wind penetration (carbon emissions)
- Evaluate PV load leveling concepts



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