Small Wind Farm Research at MSU

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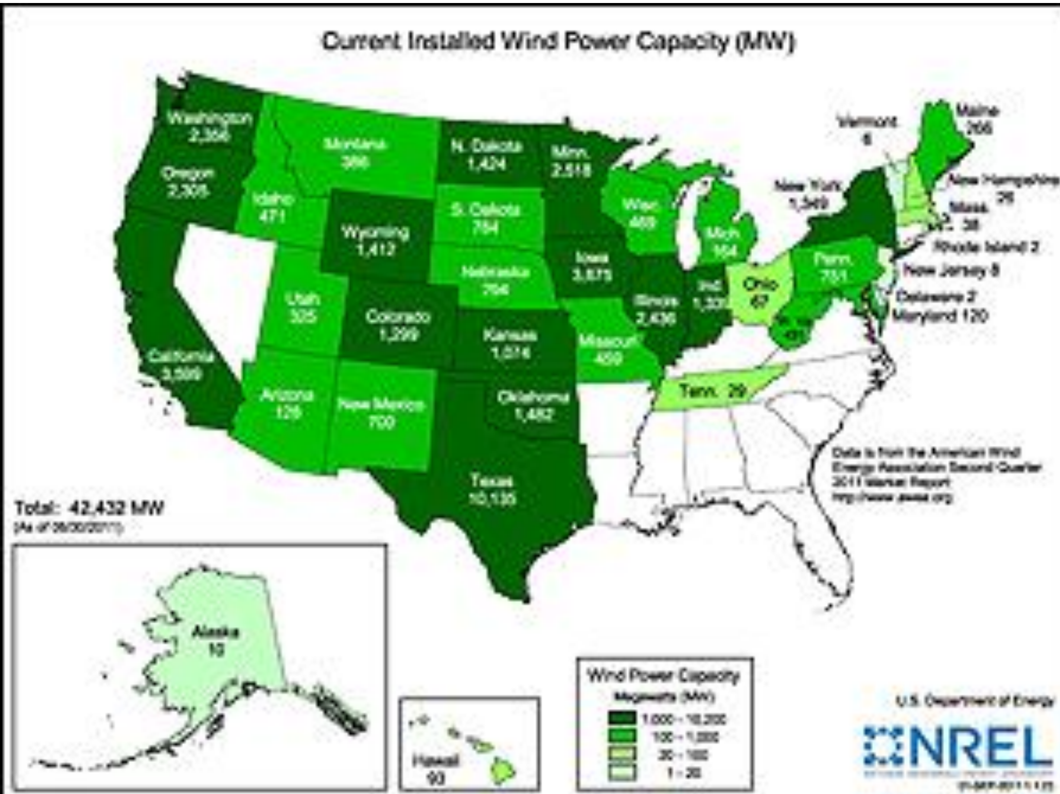
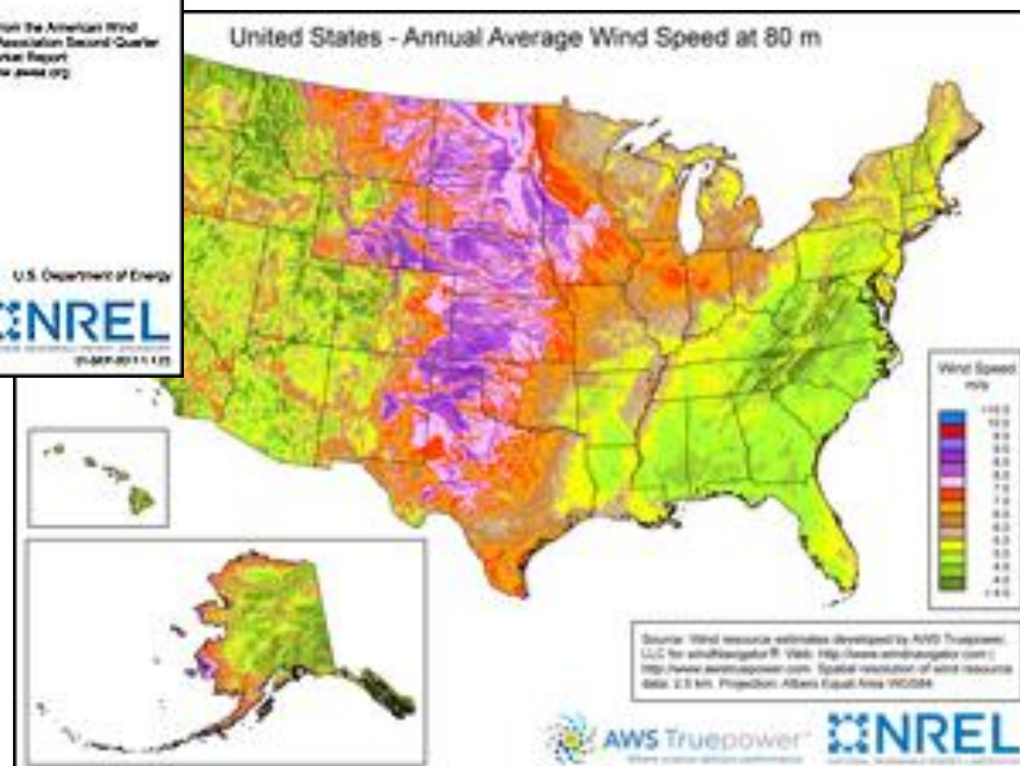
Topics

- Applied Small Wind Project
- Wind Farm Modeling
- Simulation Efforts
- On-going Studies

Motivation

Minnesota State University Mankato

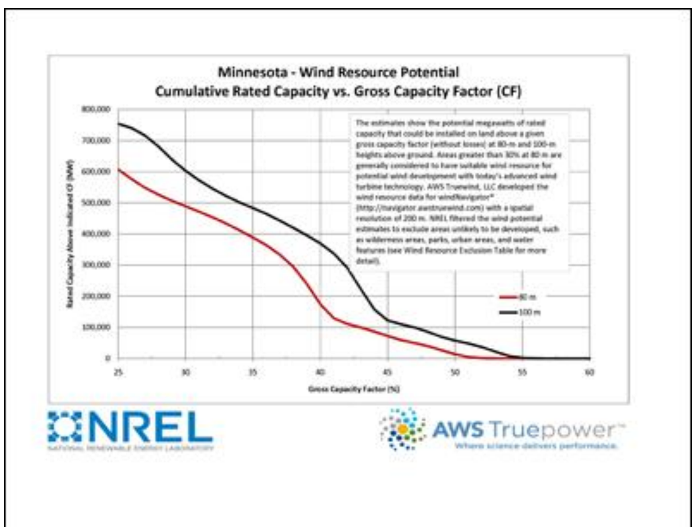




From: www.windpoweringamerica.gov

Motivation

- 2025 Energy Initiative
  - 25% electrical energy via renewables by 2025
  - How to get there?
- Minnesota is number 4 in installed wind in the U.S.
- What about residential installations?



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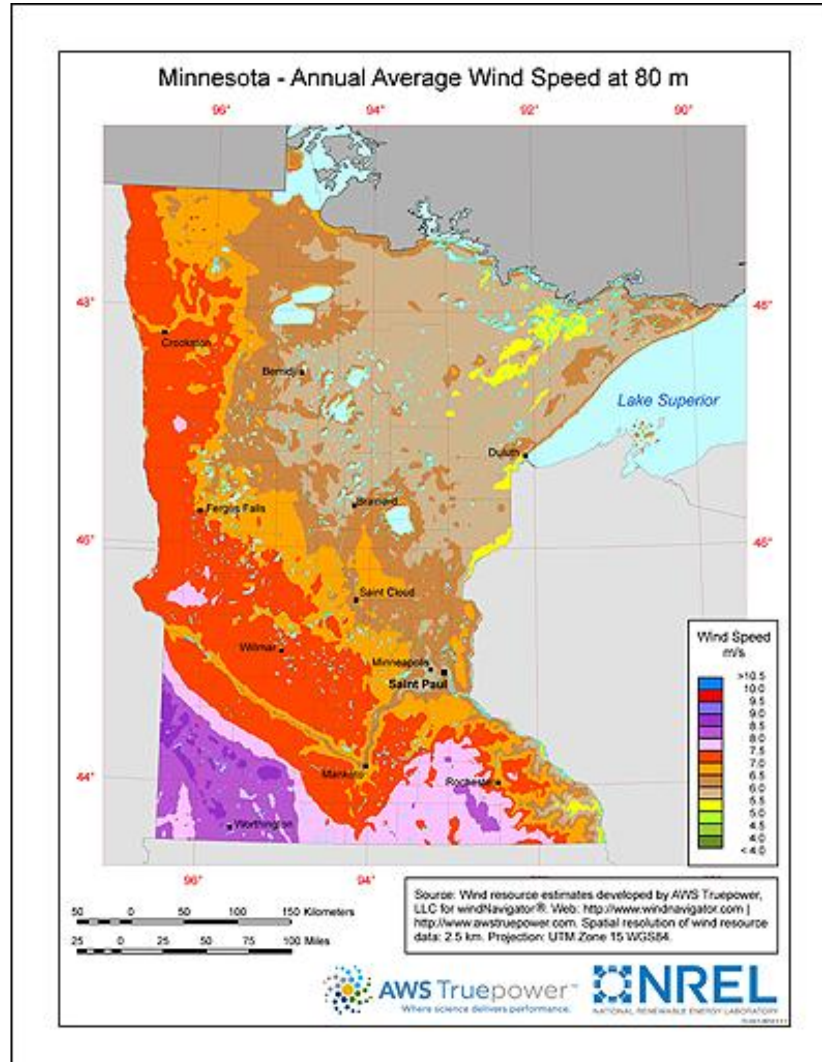

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Project Scope

- Small (Residential Scale) Wind Installations using commercially available systems
- Questions to answer: What are…
  - Costs associated with purchase, installation
  - Electrical code issues
  - Maintenance requirements
  - Performance capability vs. manufacturer data
- *Can the typically consumer benefit?*

Self-Imposed Constraints

- Roughly 2-3kW rated output
- U.S. manufacturer or distributor
- Some VAWTs (Vertical Axis) and some HAWTs (Horizontal Axis)

Decision Process

PacWind – Delta I
Southwest Windpower – Skystream 3.7
Urban Green Energy - SAWT 3kW
Southwest Windpower – Whisper 500

WindMax 2kW (similar)
Southwest Windpower – Skystream 3.7
Urban Green Energy - SAWT 3kW
Abundant Renewable Energy – ARE 110

Helixwind S322
Southwest Windpower – Skystream 3.7
Urban Green Energy - SAWT 3kW
Abundant Renewable Energy – ARE 110

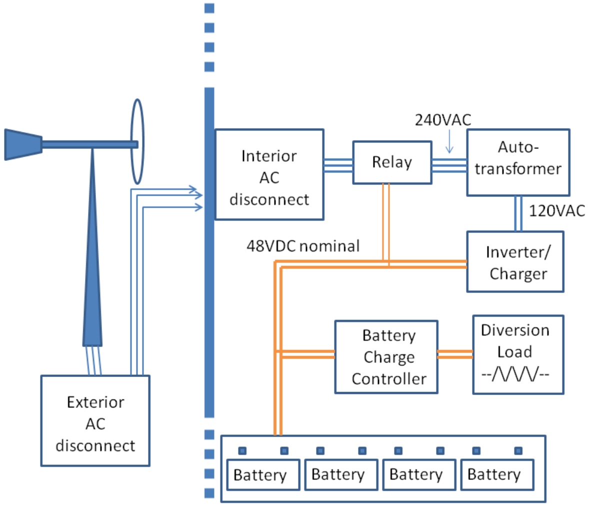
- PacWind becomes WePOWER
- WePOWER also markets SAWT turbines
- Abundant Renewable Energy becomes XZERES Wind

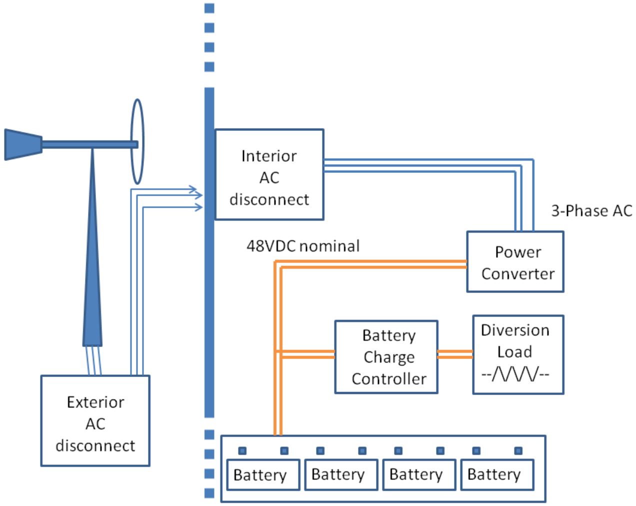
Specifications

- SAWT 3kW – 3.3kW rated
- ARE 110 – 2.5kW rated
- Skystream 3.7 – 1.9kW rated (later 2.4kW)
- Helixwind S322 – 2.5kW

Configuration

- Battery charging
  - 48VDC pack
  - Internal or external rectifier
  - Charge controller
  - Grid isolated
  - Diversion load

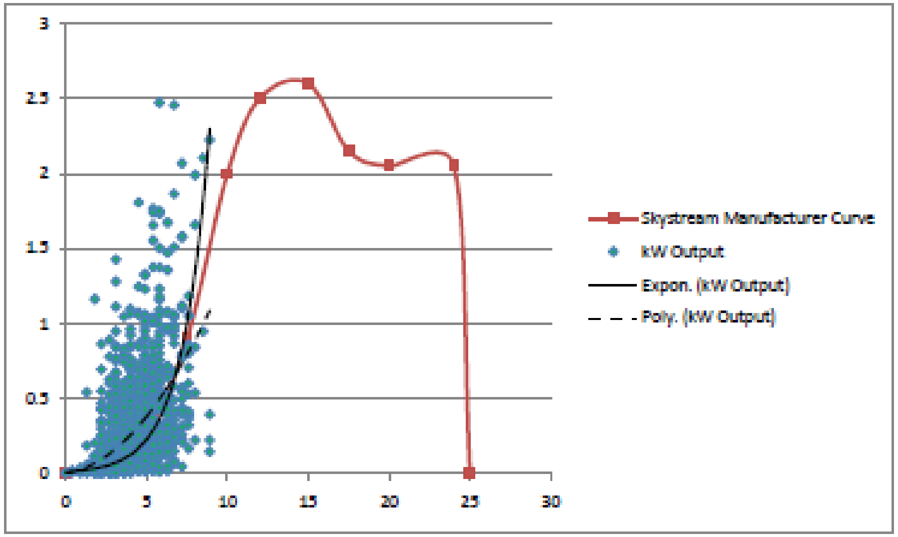




Results

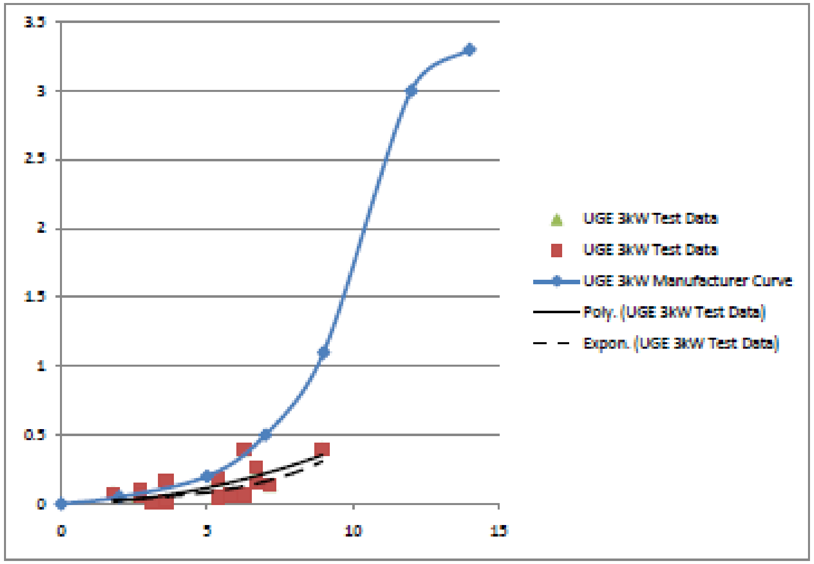
Southwest Windpower Skystream 3.7

18% average MN household demand



UGE SAWT 3kW

3.3% average MN household demand



Power law

$$\frac{U}{U_o} = \left(\frac{h}{h_o}\right)^m$$

Modeling

Turbine Power

$$P = (0.5)\rho A_d u_0^3 C_P$$

Wake Effect

$$u = u_0 * \left(1 + (\sqrt{1 - c_t} - 1) \cdot \left\{\frac{R_r}{R_r + k * x}\right\}^2\right)$$

where

- C_P = power coefficient
- c_t = turbine blade thrust coefficient,
- x = distance downstream,
- R_r = downstream rotor radius,
- u_0 = mean wind speed,
- k = empirical constant (entrainment constant α from other papers) $\longrightarrow$ [Jensen 83] uses 0.07

Graphical model of the wake effect

- Upstream turbine generates wake downwind
- Wake front evolves as a cone shape with reduced effective wind velocity u

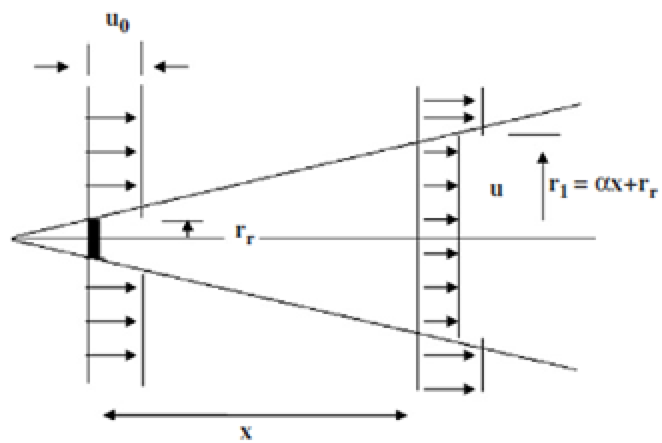
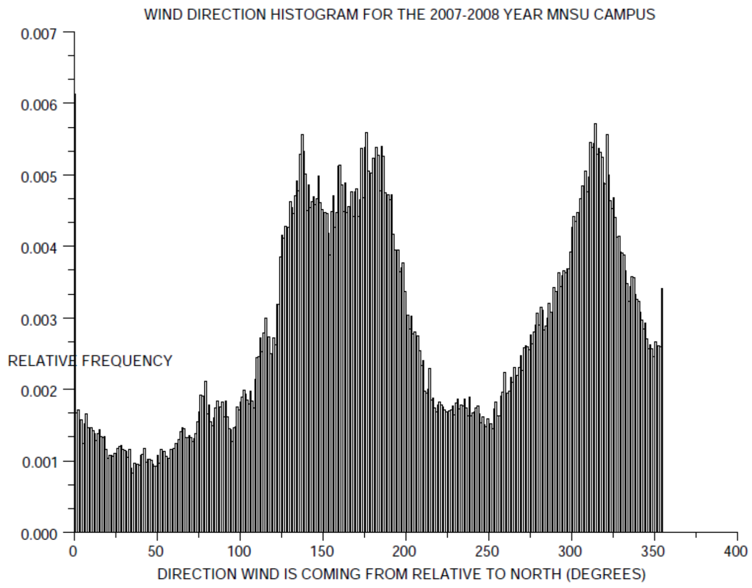
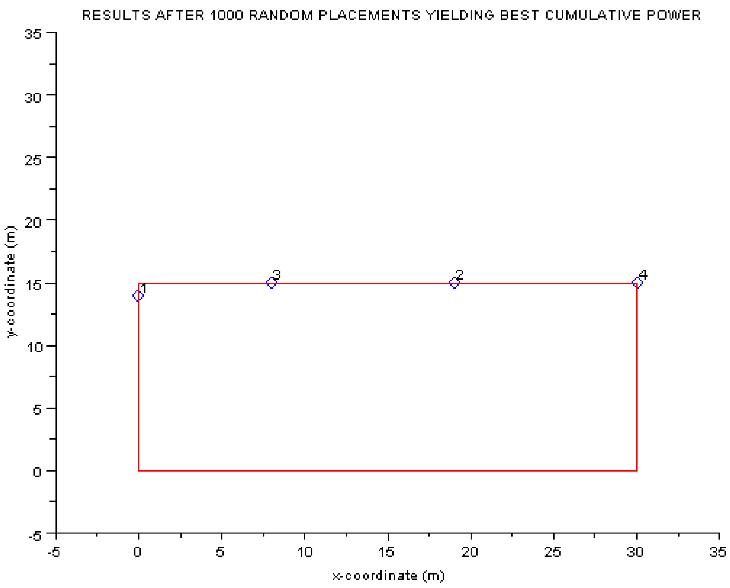


Figure: Source: G. Marmidis, et. al. (2008), *Optimal placement of wind turbines in a wind park using Monte Carlo simulation*, Renewable Energy 33, 2008, pp. 1455-1460.

- Modeling efforts based on manufacturer power curve, tower height, wind direction/speed and wake effect

Simulations

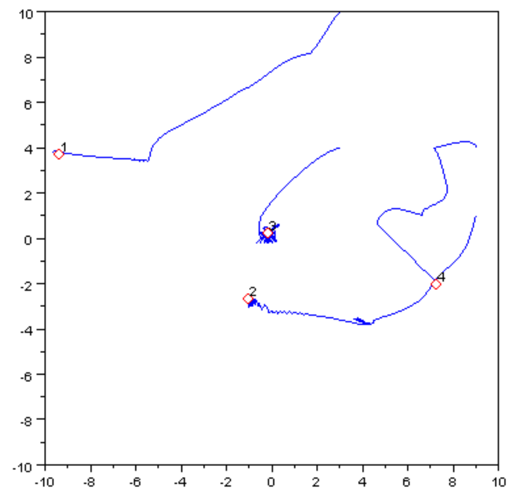




- Results of wind sensor data and Monte Carlo based turbine placement

Simulations

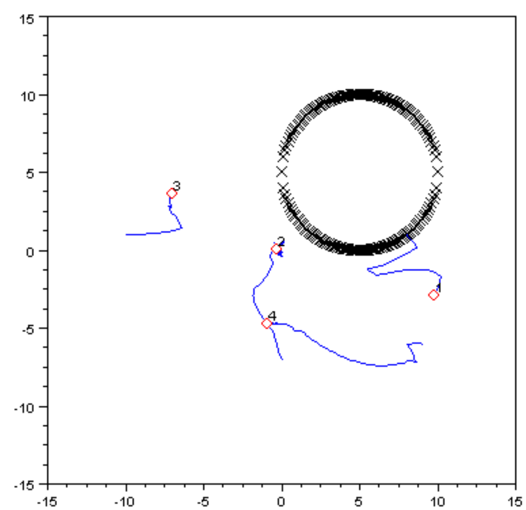
- Steepest descent algorithm driven by multi-criteria cost function



Steepest Descent Algorithm

$$J = \left[\frac{\partial F}{\partial x_1} \; \cdots \; \frac{\partial F}{\partial x_n} \; \frac{\partial F}{\partial y_1} \; \cdots \; \frac{\partial F}{\partial y_n} \right]^T$$

$$\begin{bmatrix} x^{i+1} \\ y^{i+1} \end{bmatrix} = \begin{bmatrix} x^i \\ y^i \end{bmatrix} - \frac{1}{2} \cdot \frac{J(x^i, y^i)}{||J(x^i, y^i)||}$$



Next Steps

- Applied projects
  - Helixwind S322 power converter
  - Advanced power data acquisition (smart grid capable)
- Simulation studies
  - Convergence proofs
  - Terrain/obstacle incorporation

Questions?