Small-scale wind turbines in cities and suburbs

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Introduction

- Small wind
  - <200 m² = 16 m diameter
  - typically smaller <10kW

- Cities and suburbs
  - “dirty” wind
  - rooftop mounting

- Reputation
Small wind turbines in the urban environment: Current Research at McMaster University

Nominal performance:
Full-scale wind tunnel testing

Actual performance:
Rooftop testing

Structural and vibrations:
FEA, Measurements

CFD Analysis:
Flow within turbine and around building

Kevin McLaren

Stephen Kooiman
Outline

- Introduction
- Wind in the urban environment
- Traditional HAWTs in cities
- VAWTs
- VAWTs in “dirty” wind
Main Issues

- Technical
  - power performance
  - noise
  - vibration
- Regulatory
  - certification
  - grid connection
  - bylaws
- Economic
  - cost and payback
  - incentives
Urban wind

- Lower wind velocity due to larger ground roughness within urban environments
- Rooftops can give height
- Complex vortical flow structures over and around buildings
- High turbulence levels
Horizontal axis small wind turbines

- Numerous suppliers of turbines for tower/field installation
- Yaw to face wind -
  - high mount and blade loads with rapid yaw
  - maintenance, servicing, warranties
- Non-uniform wind into turbine
- High tip speeds lead to noise
Vertical axis wind turbines

- Combination of blade rotation and incident wind give blade lift (torque)
- Research and commercialization of medium/large VAWTs in 1970s & 1980s
- Small VAWTs mainly H-type
VAWTs in “dirty” air

- Non-directionality
- Ability to handle unsteady, non-uniform, turbulent wind
- Renewal of interest in VAWTs for urban installation
  - Turby
    - Quiet Revolution
    - Cleanfield Energy
- Issues
  - power performance
  - noise
  - vibration
Power performance

- Peak power tracking
  - eg using known “clean” wind performance curves
- Even look at constant RPM

Wind speed and turbine power for rooftop installation at constant RPM (Not peak power tracking)
Power performance

- All has to do with response times
  - aerodynamic respond to wind gusts and lulls is fast
  - non-linear due to large scale flow structures and turbulence

- Peak power tracking controller

- Spin up / spin down time depends on turbine inertia
Noise

- One of the pros of VAWTs - relatively quiet

- Noise is proportion to blade velocities

- Blades are all at the max radius,
  - no high speed tips
  - actual blade speeds are low relative to HAWTs
  - low noise
Vibration

- Coincidence between structural modes and excitation frequencies.
- Structural modes affected by installation, tower, turbine whirl
- Sources of excitation:
  - unbalance,
  - aerodynamic loading of blades
- Rooftops are not usually designed or built for such loads
Vibration reduction

- Reduce excitation
  - helical blades
  - low RPM (high solidity)
  - blade design
- Controller deadbanding
- Isolation, damping
Conclusions

- “Dirty” air in urban environment is unsuited to traditional small-scale HAWTs
- Small VAWTs are able to handle the “dirty” air
- Main technical issues
  - power
  - noise
  - vibration
Acknowledgments

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Nominal Performance:
Full scale wind tunnel testing
Performance: Power curves (dimensional)

![Power curves](image)

- Power from load cell
  - 6 ms
  - 8 m/s
  - 10 m/s (day 1)
  - 10.5 m/s (day 2)
  - 12.4 m/s (day 1)
  - 12.1 m/s (day 2)
  - 14 m/s (day 1)
  - 14 m/s (day 2)
  - 16 m/s

- Rotary speed (RPM)
  - 0
  - 20
  - 40
  - 60
  - 80
  - 100
  - 120
  - 140
  - 160

- Power (W)
  - 0
  - 500
  - 1000
  - 1500
  - 2000
  - 2500
  - 3000
  - 3500
Performance: Power curves (dimensionless)

\[ C_p = \frac{\text{Shaft power}}{\text{Wind power}} \]

Tip speed ratio = \( \frac{\text{Blade speed}}{\text{Wind speed}} \)
Total vibration levels

Total rms (Streamwise)

Total rms (Crosswise)
Vibration spectra - Campbell diagrams