MWクラス風力発電機の出力性能評価のための風速定義の見直し
ギリシャCRES

Revising Reference Wind-Speed Definition for Power Performance Measurements of Multi-MW Wind Turbines

N. Stefanatos, D. Zigras, D. Foussekis, F. Kokkalidis,
P. Papadopoulos,E. Binopoulos

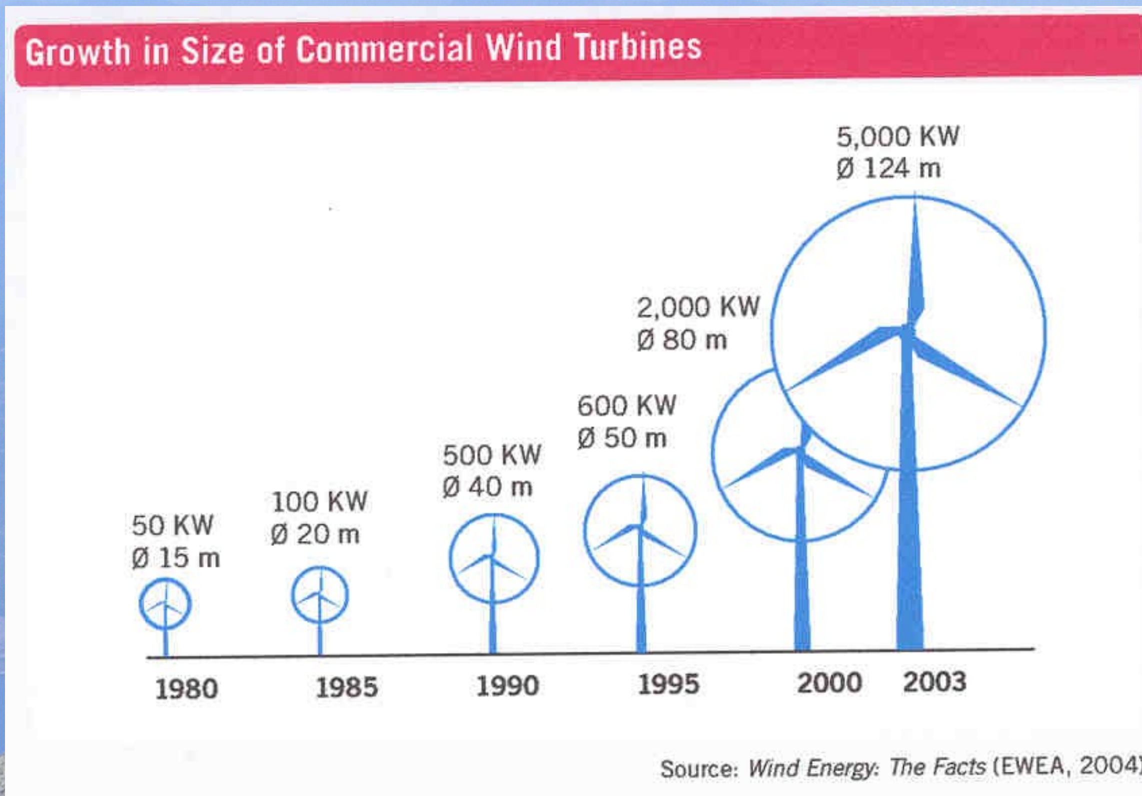
Laboratory for Wind Turbine Testing / Wind Energy Department
Centre for Renewable Energy Sources (CRES),
GREECE

KAΠE
CRES

Revising Reference Wind Speed Definition for Power Performance Measurements

Justification

風力発電機は近年大型化し、これまでにようにハブ高さ1点における風速のみを基準に性能評価することには無理がある。



- Wind turbines have grown up….
- Average size of w/t installed today:
  ~ 2.0 MW/ D=80m
- The definition of the reference wind speed as the (point measured) wind speed at hub height is a rough simplification.

かつては

ローター全域にわたる風速の評価の必要あり。CRESではかつて110kW程度の「小型」風力発電機でこれを計測を実施したことがある。現代の直径80m以上もある機種でのパワーカーブ評価にもはや同じことを実施しようにも現実的ではない。

Its an old problem …

- Need for evaluation of wind speed all over the rotor disk
- Example of early experiments in a small wind turbine:
  - CRES Lavrio Test Station 1995-MOUNTURB project : Array of anemometers upwind of the rotor disk
    (Wincon XT 110kW, D=21m, H_{hub}=22.4m)
- Not practical to reproduce such lay-out at 80m+ diameter wind turbines for commercial power curve measurements.

Revising Reference Wind Speed Definition for Power Performance Measurements

「ローター平均化」風速を評価風速に。
・ローター面を均一風速ゾーンに区分けして各ゾーンのエネルギー量をはじき出す。
・ローター平均化風速は、仮にローター全面に均一な風速が吹いていれば均一風速ゾーンの合計と一致するような風速となる。
・乱流を考慮した定義も提示する。

新定義の提案

A new definition proposed

- Use as reference wind speed a "rotor averaged" wind speed instead of a "point-measured" hub height wind speed.
- Rotor surface is divided in "constant speed zones". The energy flux through each zone is calculated
- The "equivalent rotor averaged wind speed" is the wind speed which, if constant over the whole rotor disk, would give the same total energy flux as the sum of the energy fluxes from all constant speed zones.
- Alternative definitions proposed when turbulence is taken into account.

$$U_{eqM1} = \frac{1}{A} \cdot \sum \overline{U_i} \cdot A_i$$

$$U_{eqT1} = \frac{1}{A} \cdot \sum \sqrt[3]{\overline{U_i^3}} \cdot A_i$$

- U_{eqM1}: rotor averaged wind sped
- U_i: wind speed at zone I
- U_{eqT1}: rotor averaged wind sped, turbulence included
- U_i^3: wind energy flux in zone i, turbulence included
- A_i : Surface of zone i
- A: Total rotor surface

- Source:
- I. Antoniou et all "Influence of wind characteristics on turbine performance", EWEC 2007

Revising Reference Wind Speed Definition for Power Performance Measurements

ローターの最高点から最低点までの風速を計測するといっても、高さ80mの2MW機の場合地上40m～120mにもなる。

これを実施しようとなると、高さ100mを超える非常に高い観測塔を立てるか、LIDARやSODARといったリモートセンシングの技術を使うことになる。

いずれにしてもコストは高い。

必要性と限界

Requirements & limitations

- Measure wind speed from lower tip position to upper tip position
- For a 2.0MW – 80m wind turbine, Lower tip position: 40m, Upper tip position: 120m

- Use of very high mast (>100m)
- Use remote sensing techniques (Lidar / Sodar)

- Both solutions involve considerable costs.

- Evaluation study of a ZephIR™ LIDAR system at CRES Lavrio test station (comparison with cups on a 100m mast, showed good correlation).

CRESテストサイトにおける、LIDER「ZephIR」の評価試験では、100m観測塔のカップ式風速センサーとの比較で高い相関が得られた。

ローターハブより下の風速勾配を計測し、ローターハブより上も同じ風速シアと仮定したうえで「ローター平均化」風速を当てはめる。

•長所
-ハブ高までの観測タワーで間に合う。
-風速シアを相殺できる。
-既存のデータを活用可能。

•短所
-ローターハブ上下の風速シアは必ずしも同一ではない。
-既存のデータは往々にして公開されない。

Revising Reference Wind Speed Definition for Power Performance Measurements

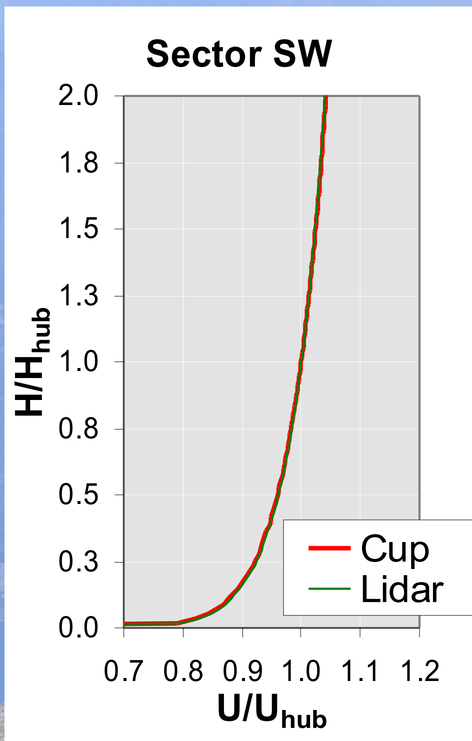
A low-cost approach

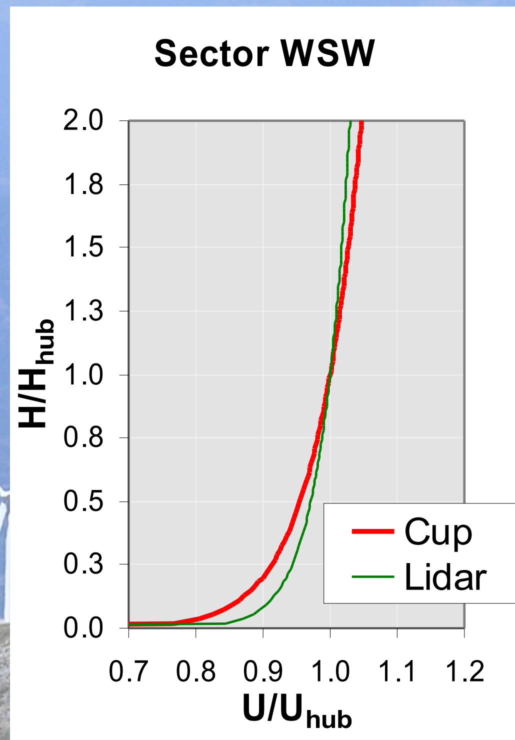
経済的アプローチ

- Measure wind shear in the lower part of the rotor by installing anemometers at more than one height (below hub height)
- Assume same wind shear profile above hub height
- Apply the method for the evaluation of the rotor averaged wind speed in the estimated profile.

- Advantages:
  – Avoid use of very high masts. Use hub-height masts (already used for power curve measurements.
  – Compensate for wind shear
  – Data already available from older campaigns.
- Disadvantages:
  – The assumption that the wind shear profile above hub height is same as below is not valid in every case.
  – Data available are (usually) commercially confidential

Low cost approach : Validation and limitations





- Comparison of shear profiles measured with
  - cup anemometers (up to hub height)
  - Lidar system up to 2*Hhub
- Differences in shear profiles as estimated from cups at the lower part of the rotor compared to shear profiles as measured by Lidar system are seen in some direction sectors.
- Still, this is an easy to apply, low cost approach, which could give valuable information.

ローターハブまでの風速を計測し、その2倍の高さまでのLiDAR計測値と比較。

- 方角によってはローターハブ下のデータから推測した風速シアは、LiDARで観測したシアと食い違う場合がある。
- それでもなおこの方法は簡単で経済的な方法であり、有益な情報が得られると言える。

At least it deserves a try …..

少なくとも試みてみる価値はある。

Share the experience – respect confidentiality

実測例を紹介する。ただし非公開のデータを使っているので詳細は不問とする。

•The Laboratory for Wind Turbine Testing (LWTT) of CRES is a Testing Laboratory accredited by DAP GmbH according to ISO/IEC 17025 for wind turbine power performance measurements (and others).

•Numerous power curve measurements in complex terrain sites have been successfully completed by CRES-LWTT

•In some cases, wind speed was measured at more than one heights, allowing for estimation of wind shear (at the lower half of he rotor)

•A pool of data to experiment on the “low cost approach” is available, but these data are commercially confidential

•Lets talk Confidential:

- ➢**No site names**
- ➢**No wind turbine types**
- ➢**Non-dimensional results**

Standards applied

- IEC 61400-12-1:2005 -Wind Turbines-12-1: Power performance measurements of electricity producing w/t
- MEASNET Power Performance Procedure
- Additional features
    - ➢ Shear profiles measured at reference mast and at wind turbine position

Overview of Cases studied (no photos, sorry..)

次の４サイトを比較
- P1平坦地形
- P2複雑地形
- P3非常に複雑
- P4非常に複雑

All Cases : Pitch controlled

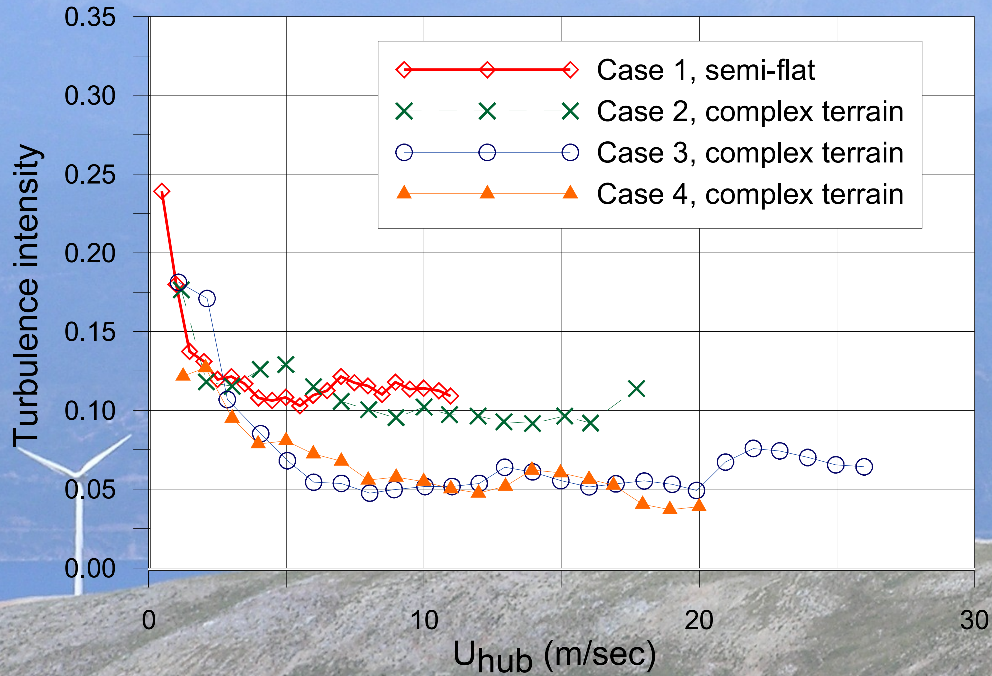
CASE P1
- Semi-flat terrain (terrain inclination typical 4%)
- Power curve measurement campaign complete

CASE P2
- Complex terrain (terrain inclination typically over 20%)
- Power curve measurement campaign complete

CASE P3
- Very complex terrain (terrain inclination typically 30% to 40%)
- Only site calibration and wind shear measurements available

CASE P4
- Very complex terrain (terrain inclination typically 30% to 40%)
- Only site calibration and wind shear measurements available

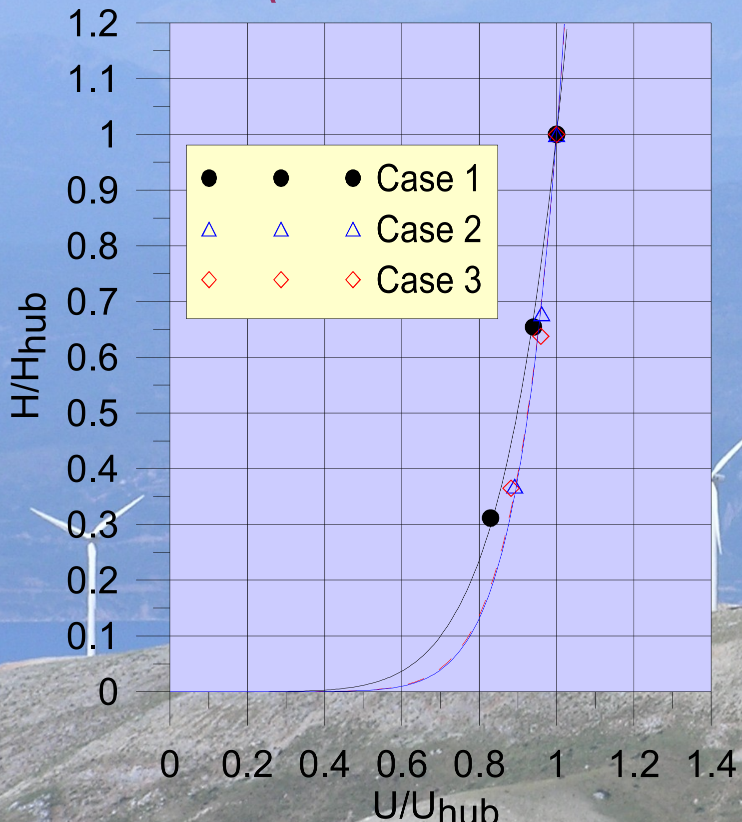
Wind flow characteristics (1) : Turbulence



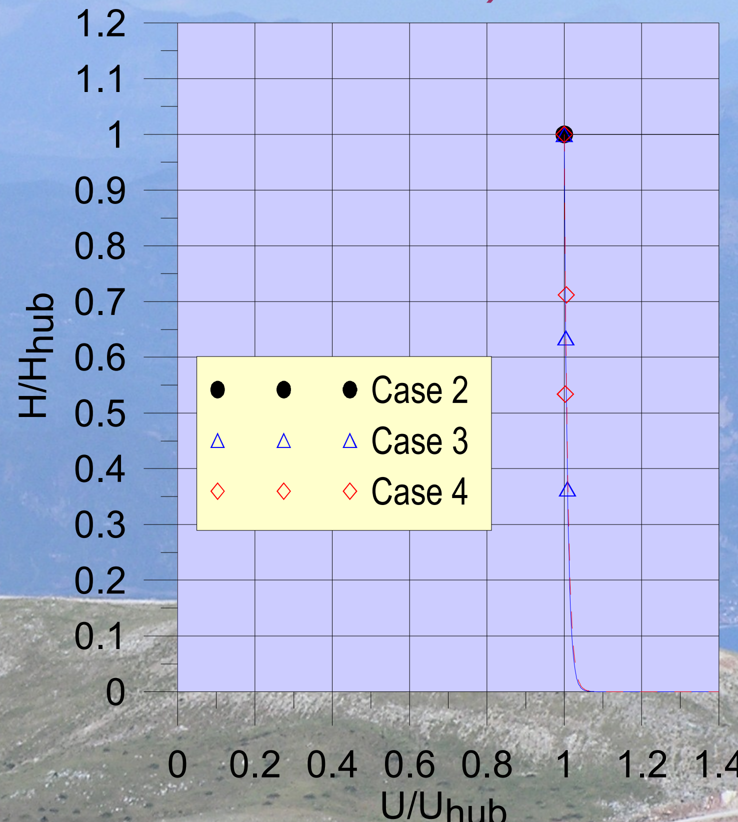
Turbulence intensity binned per velocity at the wake free direction sector for each of the cases studied

Mean Turbulence levels in complex terrain sites may vary significantly, but are not always higher than typical flat terrain values

Wind flow characteristics (2) : Shear –"Typical" profiles (4 m/s to 16 m/s, at main direction bin)



REF-mast:

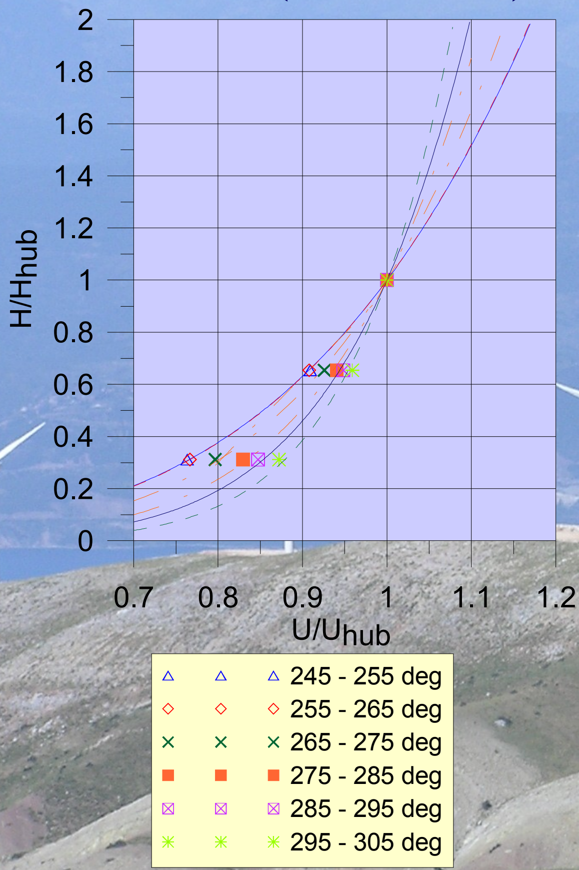


Inverse shear at w/t position for Cases 2,3,4

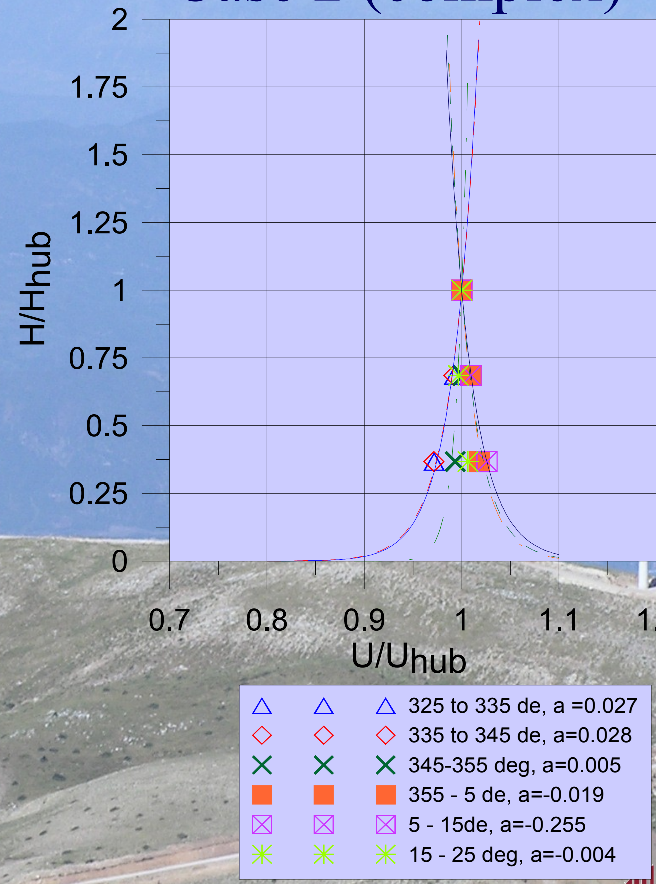
Nikolaos Stefanatos
Laboratory for WT Testing (LWTT)
ΚΑΠΕ
CRES

Shear –Profiles used for the calculation of rotor averaged wind speed

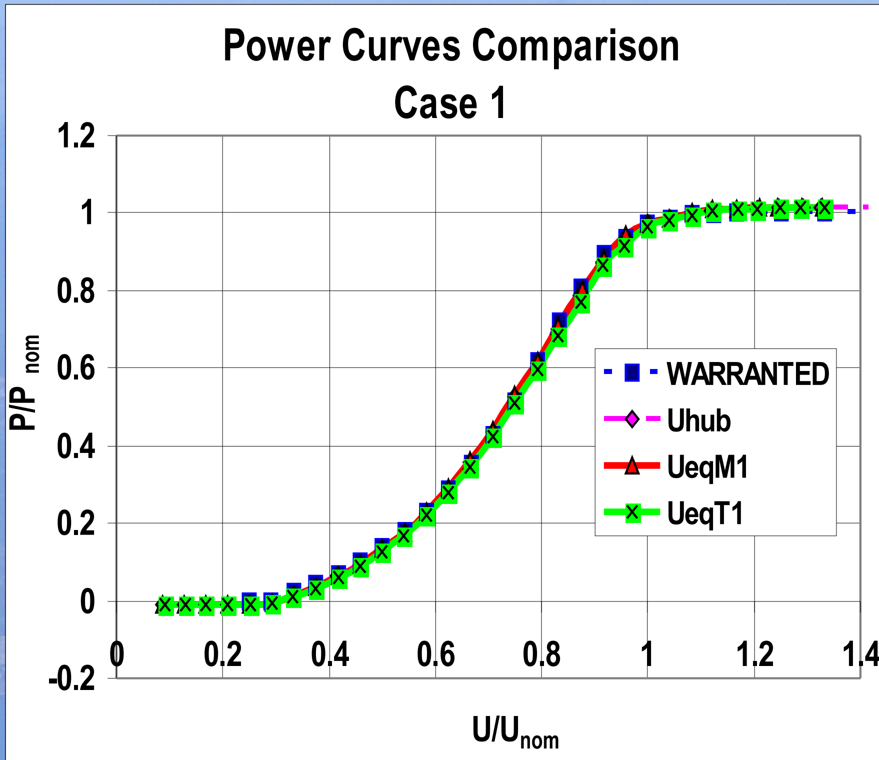
Case 1 (semi flat)

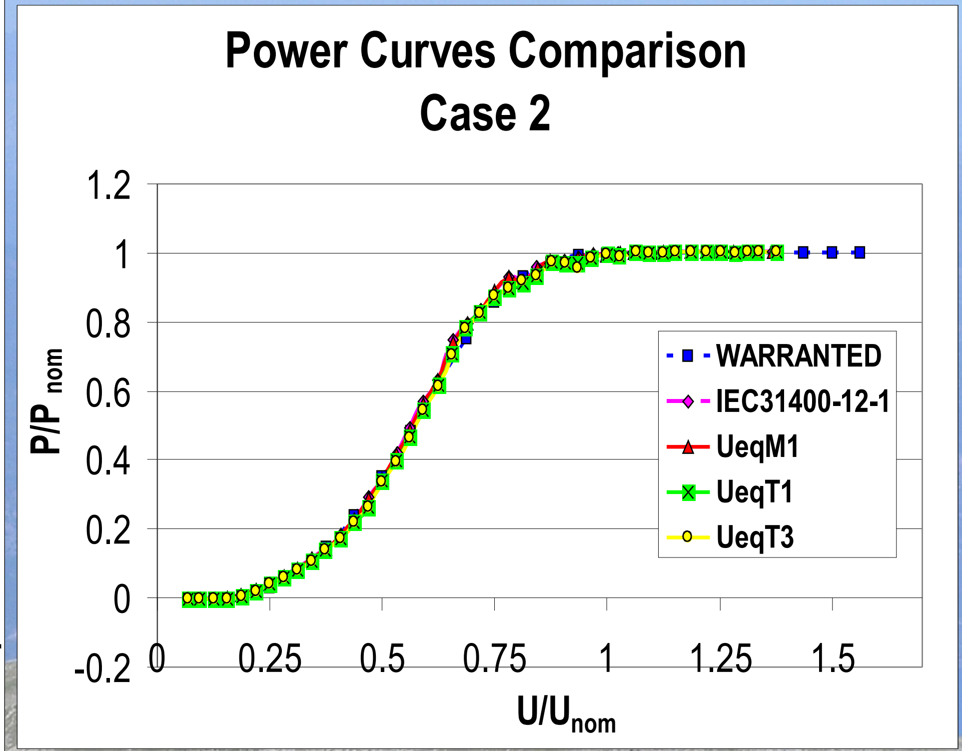


Case 2 (complex)



Results



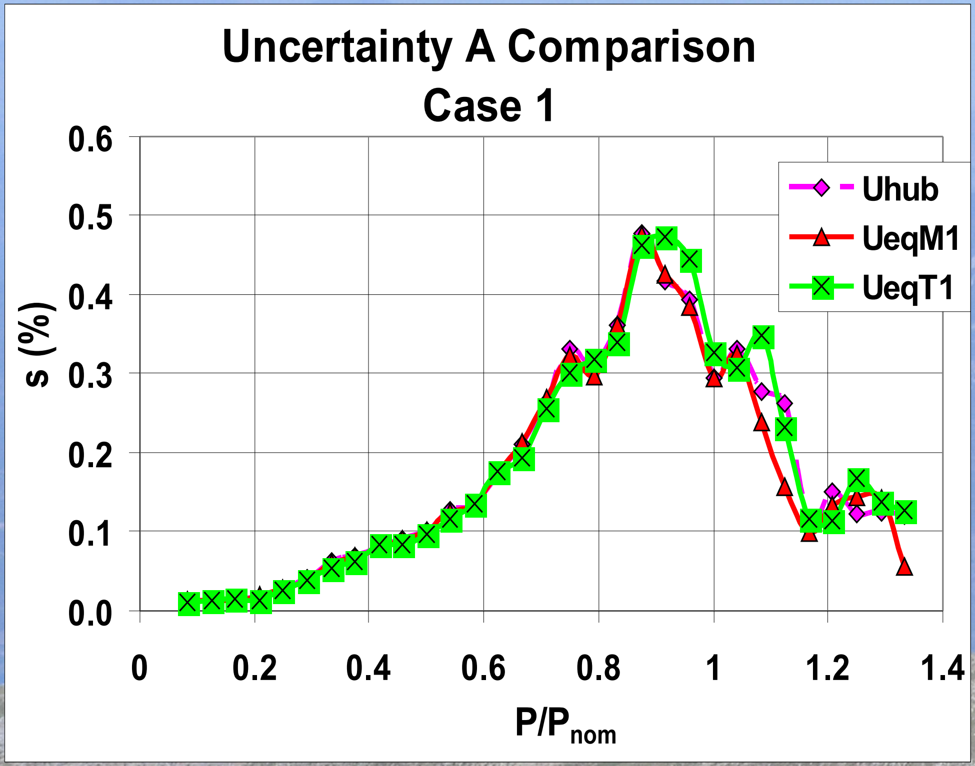


Good overall agreement between of “rotor averaged” and “point measured” power curve with warranted power curve

Nikolaos Stefanatos
Laboratory for WT Testing (LWTT)

ΚΑΠΕ
CRES

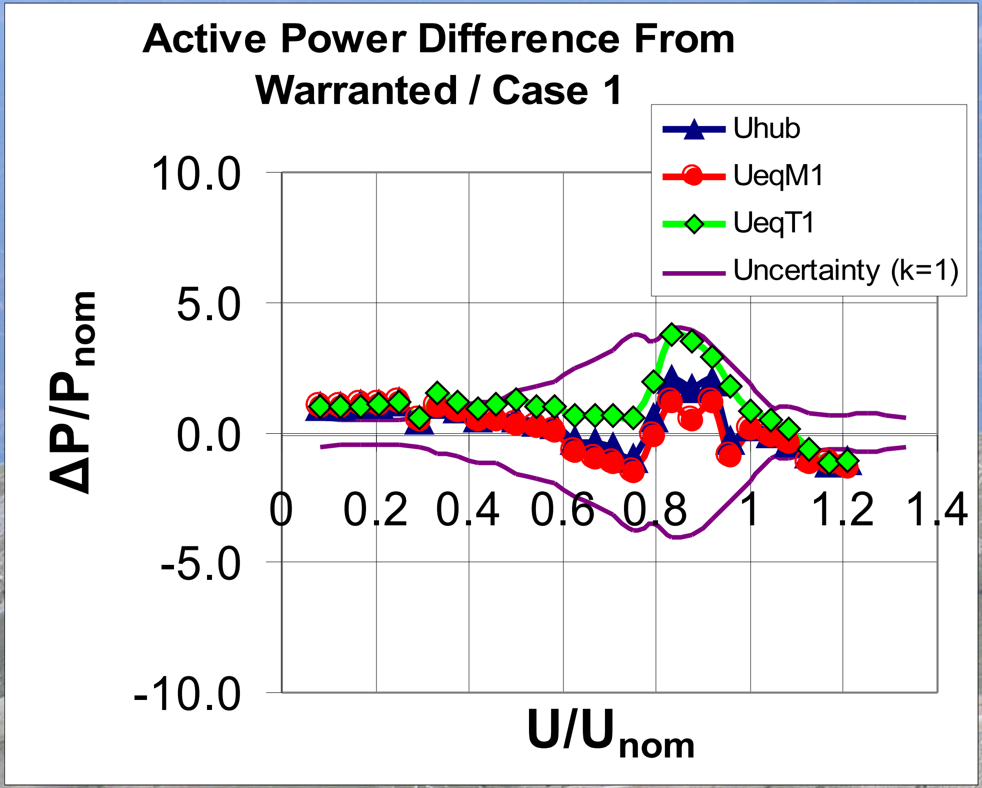
Results



Type A Uncertainty (statistical scatter of active power points within a wind speed bin) not affected

Results

When turbulence term is included in the "rotor averaged' wind speed, deviations from point measured and from warranted power are slightly increased.

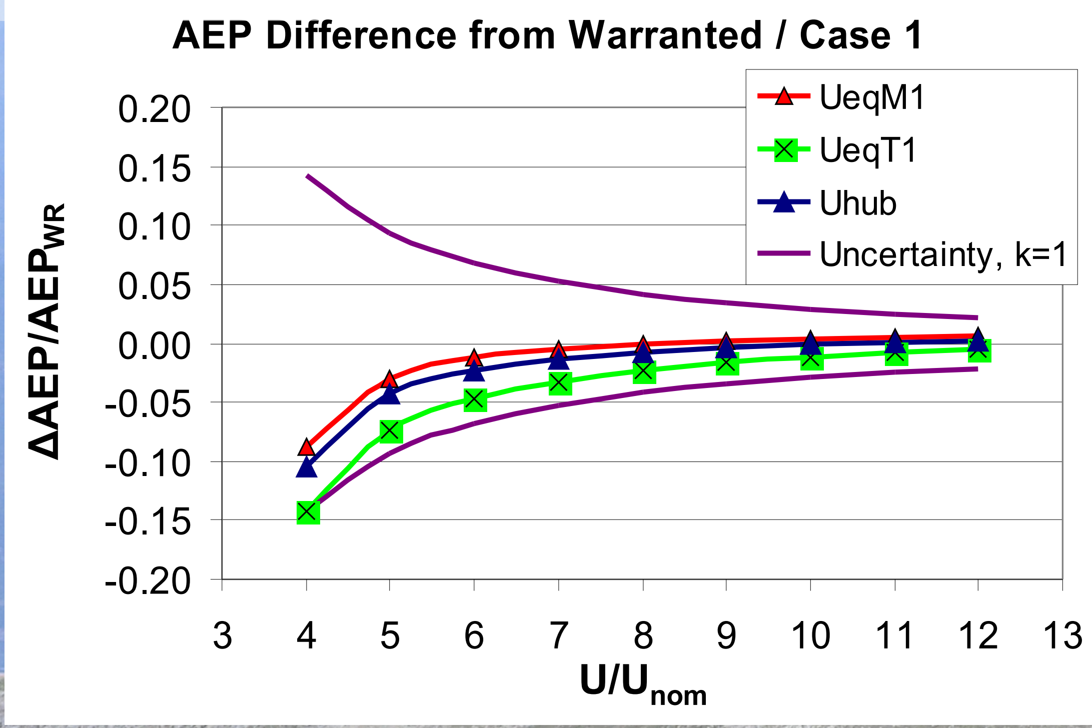


Nikolaos Stefanatos
Laboratory for WT Testing (LWTT)
ΚΑΠΕ
CRES

Revising Reference Wind Speed Definition for Power Performance Measurements

- 乱流影響をフィルター処理済の「ローター平均化」風速を使うと、保証パワーカーブへの近似がよくなる。
- 乱流影響をデータに混入するとAEPが過大評価される。

Results



•Rotor averaged wind speed (without turbulence term) slightly improves agreement with warranted
•When turbulence term is included, expected AEP is overestimated

Nikolaos Stefanatos
Laboratory for WT Testing (LWTT)

- パワーカーブ評価のための風速基準は見直しの時期に来ている。
- その風速基準には風速の鉛直シアが反映される必要がある。
- 将来技術としてはリモートセンシングが期待される。
- 経済的なアプローチ（従来式のハブ高より下の風速シアを使う方法）も単独もしくはリモートセンシングと合わせて利用はできる。ただし乱流要素は除外して。
- MEASNETでも取り組まれている。
  サイトのキャリブレーションに用いられる、リモートセンシングもしくは従来型の方法による風速シアの観測について。「bin averaged (for velocity and direction) shear tables」参照。

Revising Reference Wind Speed Definition for Power Performance Measurements

Discussion

- **The increase in wind turbine hub height and diameter makes necessary the redefinition of reference wind speed for power curve measurements**
- **A definition taking into account the vertical wind speed shear is needed.**
- **Remote sensing techniques are expected to be applied in the future**
- **Low cost approaches (shear profile measurements below hub with conventional systems) can be used alone or in parallel with remote sensing systems – Uncertainty evaluated accordingly**

➢ **MEASNET Procedure (New draft under discussion) :**

Recommendation for shear measurements in site calibration using either remote sensing or conventional systems. Shear conditions, if measured, to be presented in test report as “bin averaged (for velocity and direction) shear tables”.