The use of ADCP data from the Inner Bristol Channel, UK and CFD to study power attenuation effects on HATT performance

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Tidal stream devices

- 250kW OpenHydro turbine trials at EMEC* in the Orkney Islands
- 1.2MW tidal energy converter in Strangford Lough

* European Marine Energy Centre
UK Tidal resources

Tidal Barrage/lagoons

7.5% of the UK resource is in the Mersey

90% of the UK resource is in the Severn Estuary

Tidal stream

58% of the UK resource is around the Pentland Firth

4% of the UK resource is around Rathlin Island

3.7% of the UK resource is around the Mull of Galloway

15% of the UK resource is around Alderney


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Proposed region for HATT siting

Figure 6 - Peak Flow for a Mean Spring Tide

Atlas of UK Marine Renewable Energy Resources

Notes:
1. Model accuracy is less robust in areas closer than 1km to land.
2. Tidal model based on daily predictions throughout one year.
3. Tidal flow is calculated in metres per second.
4. Tidal power is calculated for the upper (50%) water column.
5. June 2004, version 1.0
6. © Crown copyright, All rights reserved.
School of Earth and Ocean Sciences
Acoustic Doppler Current Profiler (ADCP)
Bathymetry of proposed site
Potential HATT site

Peak velocity $\geq 1.8\text{m/s}$

$\sim 35\text{m at spring ebb}$
Processed ADCP Data

- Processed velocity data was subsequently filtered by removing velocity data to the north of the flat southern area which biased the velocity data.
- Velocity profiles averaged directly upstream of proposed location of turbine.
- Peak velocity profile used for CFD models HWS + 3.
Velocity profiles over tidal cycle

Average Current Velocity Profiles for each Transect of the Filtered Domain

- Transect 1 (HWS+2)
- Transect 2 (HWS+2.5)
- Transect 3 (HWS+2.75)
- Transect 4 (HWS+3)
- Transect 5 (HWS+3.5)
- Transect 6 (HWS+4)
- Transect 7 (HWS+4.25)
- Transect 8 (HWS+4.5)
- Transect 9 (HWS+4.75)
- Transect 10 (HWS+5)
- Transect 11 (HWS+5.75)
- Transect 12 (HWS+6)
- Transect 13 (HWS+6.25)
- Transect 14 (HWS+6.5)
Average profile directly upstream of turbine HWS + 2 hrs

Current Velocity Profile at HWS+2 Reference to CD

- HAT
- Water surface
- LAT
- Max. vessel draft
- Seabed
- Velocity profile
- 10m Turbine

Turbine diameter

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Average profile directly upstream of turbine HWS + 3 hrs

Current Velocity Profile for HWS+3 Referenced to CD

- HAT
- Water surface
- LAT
- Max. vessel draft
- Seabed
- Velocity Profile
- 10m Turbine
Average profile directly upstream of turbine HWS + 6 hrs

Current Velocity Profile for HWS+6
Reference to CD

- HAT
- Water surface
- LAT
- Max. vessel daft
- Seabed
- Velocity profile

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3 Blade Laboratory Turbines

Geometry used for 10m diameter turbine
Quasi-Static CFD Models

- Three CFD models were developed with two domains:
  - A flat seabed was used to limit cell count.
  - For all models no water to air interaction at the water surface was modelled. Zero friction was applied at the surface boundary to remove near wall effects.

Site domain - One model:
- The measured maximum tidal velocity at spring ebb for the site = 1.8m/s at approximately 3.6m below the water surface. This was rescaled for velocity only to 3.1 m/s chosen as this is approaching the upper boundary of most of the UK resource.
- A depth of 35m was based on water depth at spring ebb for the site. The domain width was 50m as in the reference model to limit boundary effects.

Reference domain - Two models:
- A peak velocity of 3.1m/s was again used.
- A domain depth was rescaled to 50m.
- Reference model 1 - with a plug flow of 3.1 m/s was used as a datum
- Reference model 2 - used a velocity profile rescaled from site ADCP data.
Reference and site CFD models

Reference CFD model
(50m x 50m x 400m)

Site CFD model
(50m x 35m x 400m)
Power coefficient with blade pitch variation for the reference domain with a plug flow
Power curves generated from reference domain with plug flow

10m diameter turbine with varying tidal velocities

Angular Velocity $\omega$ (rad/s) vs. Power (kW)

- - Available Power
- - - Betz Power Limit
Δ Power Curve U=1 m/s
• Power Curve U=1.5 m/s
— Power Curve U=2 m/s
— Power Curve U=2.6 m/s
○ Power Curve U=3.1 m/s
— — Power (Turbine Power Fit)
Performance characteristics under plug flow conditions using reference domain.

- The peak power coefficient was calculated with a blade pitch angle of 6° which proved insensitive to tide velocity between 1 m/s and 3.1 m/s.
- The peak torque occurred at $\omega = 1.3 \text{ rad/s (12 rpm)}$ with a TSR (tip speed ratio) of 2.1.
- The turbine starts to freewheel at $\omega = 4.13 \text{ rad/s (39 rpm)}$ and a TSR of 6.7.
- $C_{p_{\text{max}}}$ of 40% occurred at $\omega = 2.25 \text{ rad/s (22 rpm)}$ and a TSR of 3.6.
Introduction of profiled flow derived from ADCP data

- Curve fit of average velocity profile upstream of turbine scaled and applied to velocity-inlet boundary for site (velocity) and reference (velocity and depth) models.
- Study effects of power attenuation through depth.
- Power coefficient calculation with profiled flow.
Turbine position and velocity profiles for both site and reference models

Site and reference domain velocity profiles

- Rescaled ADCP data site domain
- Plug flow 3.1 m/s
- Rescaled ADCP data ref domain
- ADCP curve fit
- Raw site data
- 1/7th power law at 1.75m/s
- - 1/7th power law at 3.1m/s

Water depth (m)

Current velocity (m/s)

Turbine diameter

15m vessel draft position for site domain

mid position reference CDF domain

lowest position reference CFD domain

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Normalised power attenuation through water column

For site and reference CFD models (pitch angle = 6°)

Reference turbine rotation centre (profiled flow)

Site turbine rotation centre (profiled flow)

Turbine rotation centre (plug flow)

Curve fit for normalised power (reference model)

Curve fit for normalised power (site model)

Water surface

Seabed

Normalised power (\(P_n\))

Water depth \(D\) (m)

\[
P_{n\text{ (ref)}} = -0.0002D^2 - 0.0066D + 0.7845 \\
R^2 = 0.9985
\]

\[
P_{n\text{ (site)}} = -0.0004D^2 - 0.0095D + 0.7845 \\
R^2 = 0.9985
\]
Plug and profile flow in site model (35 m depth) with rescaled velocity profile

Plug and profiled flow in site domain
(Uplug = 3.1m/s : Uav (across turbine) ~2.2 m/s)

[Graph showing power and torque for plug and profile flow]
Power coefficient calculation: plug and profiled flow

Dependency of power coefficient calculation with plug and profiled flow.
Summary

- The bathymetric and ADCP surveys produced excellent data to investigate the feasibility of installing a HATT in the inner Bristol Channel.

- The ADCP transect surveys produced detailed current velocities through the water column for use in reference and site CFD models.

- The maximum peak spring ebb tide velocity was found to be \(~1.8\) m/s toward the water surface. However, the rate of decrease in velocity through the water column was considerable.

- The peak power extracted under plug flow was circa 466kW for both reference and site CFD models. However, with the rescaled profile flow this value was reduce to 142kW.

- Turbine performance: the tidal velocity should be monitored between 2 and 5 turbine diameters upstream of the HATT and at the depth of its rotation axis.
  - using a plug flow across the turbine diameter \(C_p = 40\%\)
  - using the average (profiled) flow velocity across the turbine diameter \(C_p = 34\%\).
  - using the peak upstream near surface tidal velocity (3.1 m/s) \(C_p = 12\%\).

- Further ADCP measurements are required in higher local tidal flows.