Proceedings of the 2nd International Conference on Environmental Interactions of Marine Renewable Energy Technologies (EIMR2014), 28 April – 02 May 2014, Stornoway, Isle of Lewis, Outer Hebrides, Scotland. www.eimr.org

EIMR2014-770

Better together: The implications of tidal resource interactions from resource calculation to policy and governance

David K Woolf[1]
Heriot-Watt University
International Centre for Island Technology
The Old Academy
Back Road, Stromness
Scotland KW16 3AW
United Kingdom

Matthew C Easton
University of the Highlands and Islands
Environmental Research Institute
Centre for Energy and the Environment
North Highland College UHI
Ormlie Road, Thurso
Scotland KW14 7EE
United Kingdom

ABSTRACT

Tidal energy extraction at one location affects the strength and timing (phase) of tidal elevation and currents elsewhere, with immediate implications for the resource and the environment. More holistically, it is apparent that the entire approach to tidal energy and related marine and energy policy should be informed by understanding of this interaction. We examine first the physical phenomena of interaction using a range of models and then consider the broader implications.

Studies using 2-dimensional or 3-dimensional hydrodynamic models and precise environmental and tidal stream array characteristics provide specific case studies of the effects of tidal stream arrays. These studies are reviewed here, but we demonstrate that a simpler “wiring diagram” approach gives more generic results and insights.

Previous studies have categorised effects of renewable energy extraction on the flow as near-field (<1 km), far-field (1-10 km) and regional (>10 km). Here, we concentrate on interactions spanning far-field and regional (>1km) and introduce the alternative categories of “systemic”, “inter-channel” and “intra-channel”. We show that in the case of both inter-channel and intra-channel interactions that “parallel is good, serial is bad”. Policy and governance should address this fundamental truth, encouraging the positive interactions associated with parallel developments.

INTRODUCTION

There is a very great interest in extracting energy from tidal flows. That interest is informed by only a rather primitive understanding of tidal interactions. A consequence is that developers “go to the flow”, that is, they pick sites where the existing flows are suitable for their tidal-energy-conversion devices. That approach is understandable, but ignores the potential of devices (or more significantly, arrays of devices) to alter the flow. Further, though we are developing a fairly sophisticated capability to model the environmental consequences of specific proposals, it is often difficult to learn generic lessons from models of those cases. A more generic (and much quicker) understanding can be gained by using very simple models, particularly using an electrical circuit analogy [1]. This paper builds on the approach described by the first author in [1], with particular emphasis on systems of dynamically short channels. We explain how in a linear approximation, the effect of any tidal system on another can be described by a simple equivalent, thus defining “systemic” interactions. We describe a simple representation of sets of channels and sub-divisions of channels, thus defining “inter-channel” and “intra-channel” interactions. We are indebted to Draper and colleagues, [2], [3] for an analysis of inter-channel interactions in the Pentland Firth. The findings on intra-channel interaction are based on an interpretation of depth-averaged models of the Inner Sound of Stroma, Pentland Firth by the second author [4]. The physics teaches us some generic “truths” about the placement of arrays in systems of channels and the significance of not fully occupying the width of a channel. The remaining conclusions are a simple result of considering truths and consequences.

TECHNICAL METHODOLOGY

We rely on two main types of hydrodynamic model. Each type of model is described briefly here, but the reader is referred to the references and wider literature for a deeper analysis.

One type is the standard class of ocean and coastal model where Reynolds-Averaged Navier-

---

[1] Corresponding author: d.k.woolf@hw.ac.uk

Stokes equations (RANS equations) of fluid flow are applied to a sea region on a grid. The research primarily referred to here [3], [4] used two different RANS-type models, but similar in the important respects that a 2-dimensional (depth-averaged) representation is used with the horizontal domain divided into an unstructured grid. These models are an incomplete description of the physics, but give a validated description of the time-averaged flow (i.e. there is no attempt to simulate individual turbulent fluctuations, but variation in the tidal cycle including large eddies can be simulated).

The second type of model is a simple electrical circuit analogy. This study draws directly from two recent applications of this method [1], [2], but as noted in those papers, the method has an illustrious history. In this method, we can represent any channel very simply without subdividing it into a grid of cells. The method is generally useful to understand an interconnected system, for example a system of channels, which are then represented by a circuit diagram. In this circuit, elevation difference is represented by a potential difference, while the transport through each channel is represented by electrical current. Inertia is represented by inductance and friction by resistance. In the simplest, “linear”, version of the method it is also possible to amalgamate a set of elements into their Thévenin or Norton equivalent [1]. The reader is referred to [1] and [2] for justifications and discussions of these methods.

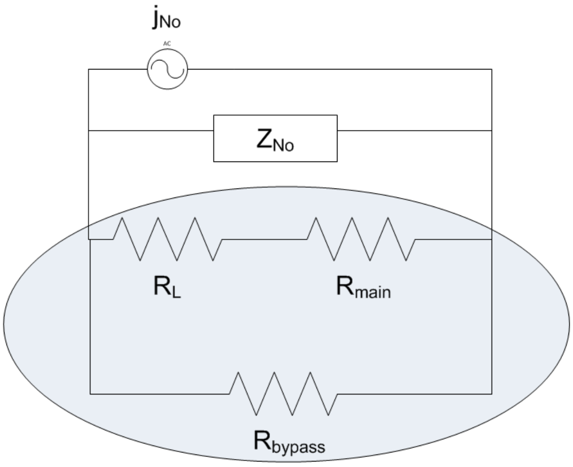

Figure 1 A representation of a split channel. The blue oval identifies the development area and the remaining world is represented by its Norton equivalent. Both channels are assumed to be purely frictional in nature with natural resistances, R_{main} and R_{bypass}. It is assumed that turbines will be placed only in the main channel and their effect on flow is represented by a load resistance, R_L.

The simplest representation of a pair of parallel channels or a single channel divided into two across the stream is equivalent and is shown in Figure 1. Here, the development zone is represented by the circuitry within the blue oval, while the “external world” is represented simply by a Norton-equivalent current source and impedance. The method can be inverted where the external world is described more fully, while the development area is reduced to its equivalent impedance, thus allowing systemic effects of the development area on the external domain to be assessed. As drawn, we can use simple circuit theory to understand the inter-channel or intra-channel effect of an individual development, represented by a load resistance, R_L, on the transport in that channel and in a parallel channel.

The application of such methods to inter-channel interactions has been adequately validated by Draper and colleagues [2], [3], who show that the remarkably strong interactions between parallel channels of the Pentland Firth can be explained successfully by considering an electrical analogy. Here, we investigate whether a similar reasoning can be applied to a single channel, where arrays are proposed to only fill part of the width of a channel. As for inter-channel interactions, the method for validating intra-channel interactions relies on comparing the representation of a hypothetical development in a high-resolution depth-averaged model with our expectation from a highly simplified circuit model. A validated model of the Inner Sound of Stroma, Pentland Firth within a wider computational domain has been presented by Easton [4]. Part of this research considered a hypothetical but reasonable array of tidal turbines arranged in the deeper waters of the Inner Sound. Some results are illustrated by a map of the computed change in the mean tidal currents associated with introducing the tidal array, Figure 2.

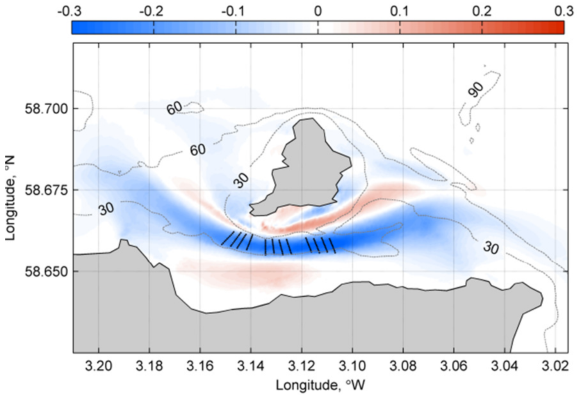

Figure 2 Change in mean current speed resulting from an array of tidal turbines. The location of the turbines is represented by black dots, the numbers are depth contours in metres below low water (from [4]).

It is clear from Figure 2, that there are subtle changes in the currents that cannot possibly be simulated by a simple circuit model. The real test is whether there are important gross features that we can use an electrical analogue to explain and that is the focus of the comparison. We compute transport across the entire width of the channel, the section filled by turbines and the side regions free of turbines and seek to explain these by an electrical analogue.

SUMMARY OF RESULTS - TECHNICAL

The approach is successful in explaining both inter-channel and intra-channel interactions. The circuit diagram shown in Figure 1 shows a set of 3 parallel impedances (the impedance of the developed channel consisting of two resistances in series). Following the normal calculation for parallel impedances, we can infer some simple properties of this circuit as follows:

- Increasing the impedance of the main channel always increases the impedance seen by the current source ("the circuit impedance") and thus the voltage drop (elevation change).
- The current in the main channel is always decreased by the development and increased in the parallel channel.
- The smallest of these three impedances is most significant to the circuit impedance.
    - If the main channel has the smallest impedance then there may be a dramatic effect of development on the remainder of the system.
    - If the Norton impedance is much smaller than the impedance of the main channel, then the effect of the development on the rest of the world may be imperceptible.
- Leakage through the bypass will be substantial unless either the load resistance is much smaller than the main resistance, or the bypass resistance is much higher than the main resistance. Since the load resistance needs to be substantial compared to the main resistance to approach full exploitation, leakage is an issue unless the bypass resistance is high.
- Even if the main channel and bypass are purely frictional (resistance only), the complex Norton impedance of the external system implies that phase changes will occur in these channels on development.

The problem of leakage is pernicious since it both implies a waste of power potential and implies a far-field increase of currents away from the main channel with consequences for biotopes. For inter-channel interactions as shown by Draper and colleagues [2], [3], the most obvious solution is the development of all parallel channels (while serial developments are unhelpful). In the case, of intra-channel interactions, a full width development is theoretically optimal but probably impractical. Ensuring the bypass resistance is sufficiently large may be sufficient to prevent significant leakage, but the transport through the bypass will always increase unless its resistance is also increased.

SUMMARY OF RESULTS - POLITICAL

The tides can be turned carelessly, thus limiting energy generation and increasing far-field environmental effects, or strategically, thus maximising useful generation and avoiding some of the more pernicious environmental effects. A number of broad implications are obvious.

For both economic and environmental reasons, developments in parallel channels should be encouraged, while serial developments should be discouraged. Developers and statutory bodies should be wary of developments that only introduce hardware to part of the width of a channel. Such proposals may appear sensible since they leave free a navigation and migration route, but that route will be altered with likely consequences for sediment distribution and biotope [5].

Governance that empowers local communities has merit, but should not prevent a systematic and strategic approach to tidal energy development. It is important that dialogue leads to mutually beneficial "parallel developments" rather than to competing serial developments or to needless "leakage".

CONCLUSIONS

A strategic approach to the development of tidal stream energy is necessary. The development and application of simple models can enable strategic thinking.

ACKNOWLEDGEMENTS

We thank former or current colleagues at University of the Highlands and Islands and at Heriot-Watt University for their encouragement and constructive criticism. We thank Scott Draper and others for lively discussions of this approach.

REFERENCES

[1] D. K. Woolf, "The strength and phase of the tidal stream", Int. J. Marine Energy., vol. 3-4, pp. 3-13, 2013.

[2] S. Draper, T. A. A. Adcock, A. G. L. Borthwick and G. T. Houlsby, "An electrical analogy for the Pentland Firth tidal stream power resource", Proc. R. Soc. A, vol., 470, 20130207, 2014.

[3] S. Draper, T. A. A. Adcock, A. G. L. Borthwick and G. T. Houlsby, "Estimate of the extractable Pentland Firth tidal stream power resource", Renewable Energy, vol. 63, pp. 630-657, 2014

[4] M. C. Easton, "An assessment of tidal energy and the environmental response to extraction at a site in the Pentland Firth". PhD thesis, University of the Highlands and Islands / University of Aberdeen, 2013.

[5] Shields, M.A., D. K. Woolf, E. P. M. Grist, S. A. Kerr, A. C. Jackson, R. E. Harris, M. C. Bell, R. Beharie, A. Want, E. Osalusi, S.W. Gibb and J. Side, "Marine renewable energy: The ecological implications of altering the hydrodynamics of the marine environment", J. Ocean & Coastal Management, vol. 54, pp. 2-9, 2011.