Output characteristics of tidal current power stations during spring and neap cycles

Clarke J A, Grant A D and Johnstone C M
Energy Systems Research Unit, Department of Mechanical Engineering
University of Strathclyde, Glasgow, UK

ABSTRACT
Against rising targets for renewable-derived electricity generation, wind power is currently the preferred technology. However, it is widely accepted that due to the stochastic nature of wind, there is an upper limit to the capacity that can be accommodated within the electricity network before power quality is affected. This paper demonstrates the potential of tidal energy to provide base load power without compromising power quality.

KEYWORDS
Renewable energy, tidal current, base load generation.

INTRODUCTION
Recent policy developments in the UK have favoured the development of renewable technologies [DTI 2003, Scottish Executive 2003]. Targets of 20% and 40% for the UK and Scotland respectively have been set for the generation of electricity from renewable sources by 2020. The present trend is to develop sources which are stochastic in nature, principally hydro and wind power; this implies that target attainment will likely result in increased levels of vulnerability within the electrical supply network. This, in turn, will necessitate increased levels of reserve plant and network control to prevent supply disruption and maintain power quality.

It would clearly be helpful if predictable renewable energy sources could be developed. By arranging for tidal power generation at well phased locations, a near-continuous base load power supply should be achievable, which will impact positively on the integrity of the electrical network.

DEVELOPMENT OF TIDAL TECHNOLOGY
Technology for the exploitation of marine currents is still in its infancy. At the present time two systems are being investigated for commercial development: the oscillating aerofoil driving hydraulic accumulators [Trapp 2002]; and horizontal axis turbines evolved from wind power technology, with two prototypes installed off the coasts of Norway and England [Fraenkel 2002].

Tidal current turbines operate in a more definite environment than wind turbines. Maximum current velocities can be predicted with reasonable accuracy and while dynamic loading may occur as a result of velocity shear and misalignment, this is largely predictable. That said, some stochastic inputs will arise from the effect of storm surges, increasing current velocities and introducing dynamic loading due to surface wave action. Although this requires systematic investigation, sites will generally be close to land so that the fetch for surface wave development will be limited. Further, incoming turbulence will generate fluctuating loads, although the range of excursions, particularly in the direction of flow, will be relatively small.

For these and other reasons, research is continuing into determining the operational performance envelope of tidal stream rotors under real operating conditions [EPSRC 2003]. Such research will likely lead to tools that enable precise design solutions tailored to specific site conditions.

DESIGN OPTIONS

It is impossible at this time to predict the optimal configuration of future tidal stream energy conversion devices. However, comparisons with wind energy gives some useful pointers. Tidal stream devices are likely to have a cut-in stream velocity, with a period of enforced idleness at slack water. While wind turbines have a cut-out speed to avoid damage in storms, this should not be necessary for tidal turbines given the predictable nature of the flow regime. Shut-down procedures would only be executed in emergencies (e.g. loads caused by wave action in stormy conditions might be severe enough to trigger shut-down).

The concept of a rated stream velocity, above which power is held more or less constant, is universal for large wind turbines. The reasoning behind this is essentially economic, with the value of the rated velocity chosen to minimise the cost per unit of energy produced at the site in question. A similar economic argument is likely to apply to tidal stream machines, and the similarities in rotor fluid dynamics should allow the turbine to maintain constant power output above its rated velocity.

POWER OUTPUT CHARACTERISTICS

The instantaneous power, P, available to a single tidal stream turbine is given by

$$P = \frac{1}{2} p A V^3$$

where p is the fluid density, A the rotor swept area and V the velocity of the fluid stream. If the variation of V with time is assumed to be sinusoidal, P will vary as shown in Figure 1 (upper profile), which covers a typical tidal half-cycle of about 6 hours 12 minutes.

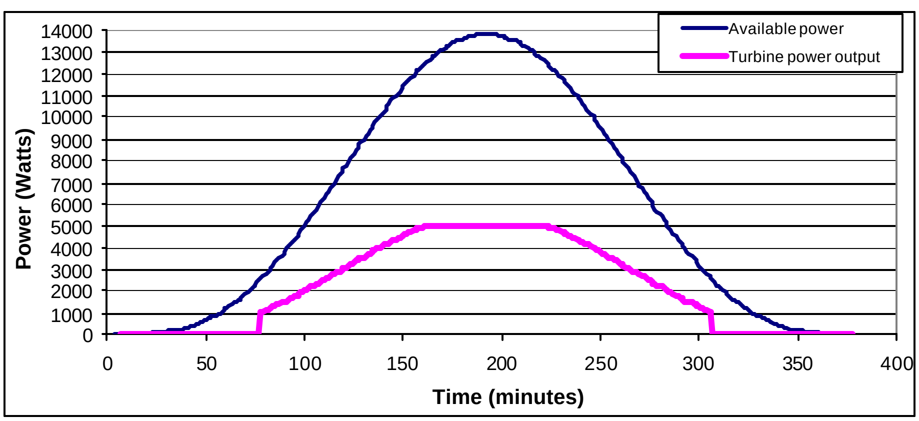

Figure 1: Turbine output relative to available power.

Figure 1 also shows the variation of turbine power output, $C_P P$, (lower profile) for arbitrary cut-in and rated stream velocities. This result is obtained against the assumption that the coefficient of performance, C_P, could be maintained at a value of 0.4 between cut-in and rated conditions.

FIRM POWER

Tidal energy is unusual among renewable source technologies in that it offers 'firm power' whereby the quantity and timing of power flows may precisely predicted. By phasing suitably located tidal energy power stations, the aggregate power output, although not exactly constant, could provide a substantial portion of base load. While this idea is not new [Bryden 1994], the implications for future resource planning are only now being appreciated. With large demands being placed on renewable energy sources to meet future electricity supplies, the utilisation of tidal power where available will contribute to the maintenance of network stability.

To investigate further this firm power characteristic of tidal power, a study was undertaken covering three geographically separated but complementaty Scottish coastal sites:

- Cape Wrath off the North-West coast;
- Crinan at the Sound of Jura off the West coast; and
- Sanda off the Mull of Kintyre, a peninsula to the South-West.

The distance separating Cape Wrath from Sanda is 237 miles.

The hourly stream velocities were determined from published charts for the three locations during both spring and neap tidal conditions, which arise due to the gravitational interactions between the Sun, Earth and Moon [D'Oliveira 2002]. Figure 2 depicts the site velocities over a 24 hour period, under both spring and neap tide conditions. Note the distinct departures from a sinusoidal curve.

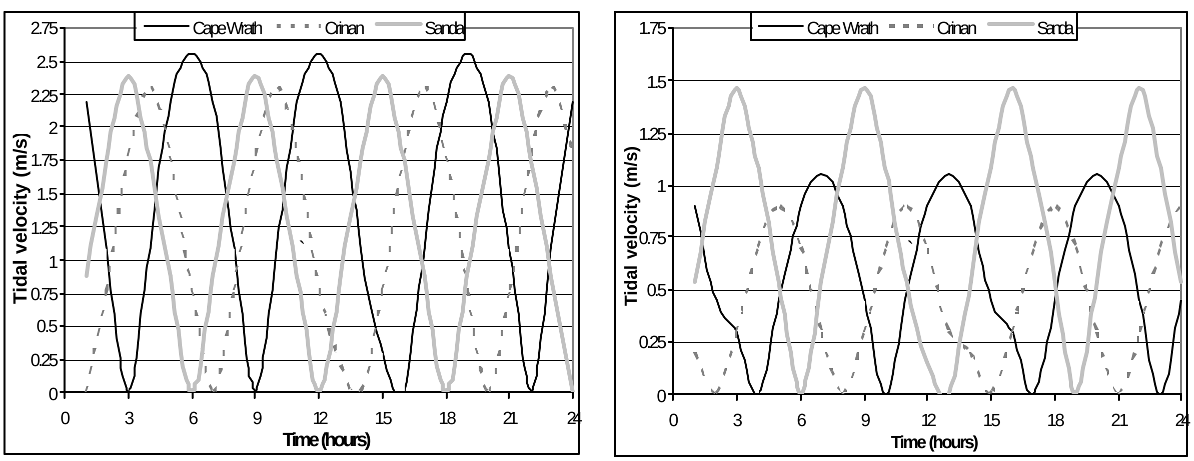

Figure 2: Spring and neap tide velocities at three sites on the West coast of Scotland.

To illustrate trends, a single 10m diameter turbine was postulated at each site. For simplicity, a constant power coefficient of 0.4 was applied throughout the speed range and no rated power limit was imposed. The resulting power output curves are shown in Figure 3 for the three individual turbines along with a summation for the system as a whole. For spring tides a significant base load is produced, amounting to about one-third of peak power output. A similar trend is observed for neap tides but the outputs are much lower. Some changes between successive cycles are evident. On investigation, it appears that one of the sites (Sanda) is cycling at a higher frequency than the other two, a phenomenon which will reverse at some other point in the lunar cycle. Three main conclusions emerged from the study as follows.

- the aggregate power output is sensitive to the characteristics of its component parts;
- given the natural variations that are likely to occur between successive tidal cycles (under the influence of weather or the longer cycle of spring and neap tides), the irregularity in aggregate power output is likely to occur in practice; and
- accurate prediction of performance for systems of this kind may be problematic (this is not to say that the output is unpredictable, but that accurate data are needed to make the prediction).

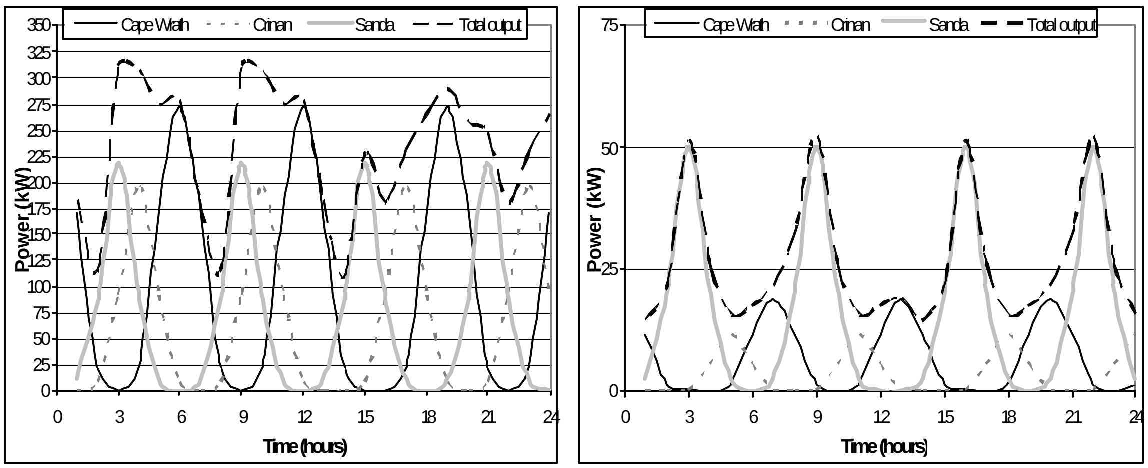

Figure 3: Site and aggregate power output for a 10m diameter tidal turbine in spring and neap tides.

The disparity between spring and neap tide power production can be made clearer by adopting a longer time-scale as illustrated in Figure 4, where power outputs are shown for a 28-day period. The dramatic variation in power output level is due to the cubic relationship between power and stream velocity.

DISCUSSION

The analysis presented above is simplified in its treatment of the output characteristics of the turbines and no attempt has been made to match the installed capacities to the sites chosen. Demand for electricity varies with time, and the notion of firm power must be viewed in this context. Also, the concept of linking widely dispersed sites would place extra demands on the electricity supply network.

However, from Figure 3 it is clear that some level of base load provision can be achieved. The twice-daily cycle could be further smoothed by the use of hydraulic pumped storage, or the phased operation of conventional hydro power plant, which could be especially useful in a local context.

The fluctuations in output due to the lunar cycle are more intractable as shown in Figure 4 as they affect all sites simultaneously. Here, the power output could either be regulated so that the maximum rated output is that experienced during neap tides thus only utilising a small proportion of the site's resource; or long term (weekly) energy storage could be introduced so that the excess capacity captured during spring tides can be stored for use during neap tides to maintain the capacity of delivered power. A third option during neap tides would be the introduction of other sources of energy to meet the shortfall.

CONCLUSIONS

The aggregate outputs from a number of dispersed tidal current power stations can provide a base load. The magnitude of the delivered power can readily be increased by using hydraulic pumped storage to smooth fluctuations in the twice-daily cycle. The lunar cycle of spring and neap tides cause long-period variations in power output of a magnitude that may be accommodated by complementary sources of energy or energy storage. The predictability of tidal power output may be regarded as a major asset in energy supply management.

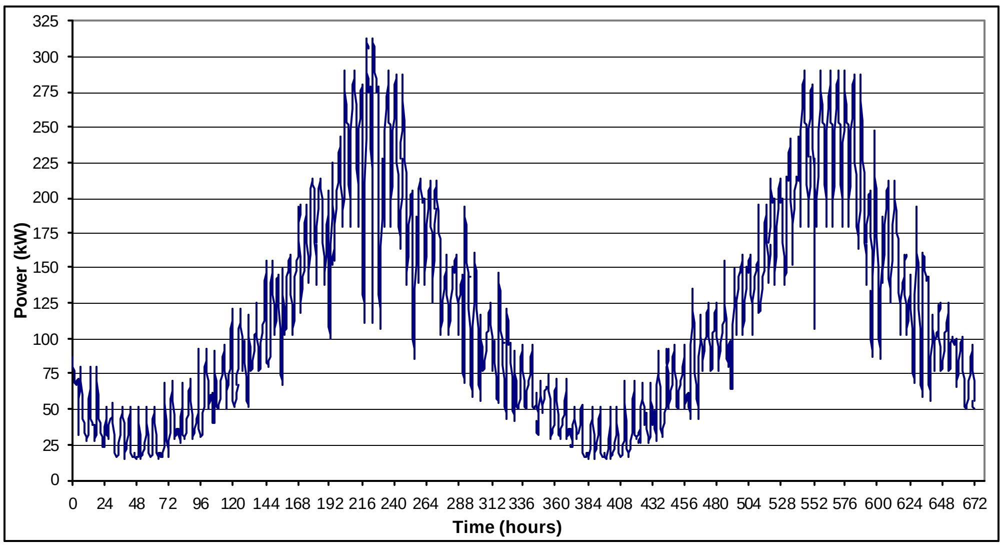

Figure 4: Fluctuations in power outputs between spring and neap tides.

REFERENCES

Bryden I G, Macfarlane D, 1994, ‘The Utilization of Short Term Energy Storage with Tidal Current Generation Systems’, Proc. 1st European Wave Energy Conference, UK.

D’Oliveira B, Goulder B and Lee-Elliott E, 2002, ‘The Macmillan Reeds Nautical Almanac’, UK, ISBN 0 333 781821.

DTI, 2003, 'Our energy future – creating a low carbon economy', UK Department of Trade and Industry, London, UK, URN 03/658.

EPSRC, 2003, 'SUPERGEN Wave and Tidal Research Programme', Engineering and Physical Science Research Counci, Swindon, UK.

Fraenkel P, 2002, 'Marine current turbines: A new clean method for power generation', European Energy Venture Fair, Zurich, Switzerland.

Scottish Executive, 2003, 'Securing a Renewable Future: Scotland’s Renewable Energy', Scottish Executive, Edinburgh, UK, ISBN 0-7559-0766-3.

Trapp T and Lomax C, 2002, 'Developing a Tidal Stream Energy Business', Proceeding of Oceanology International, London, UK, M02-013-01.ADT.