Power conversion system design for tidal stream generators

This report describes the development of a power conversion system to capture energy with a floating horizontal axis tidal stream generator. All data provided in this report is for informational purposes only. Reproduction and citations are allowed after appropriate referencing to the full report.
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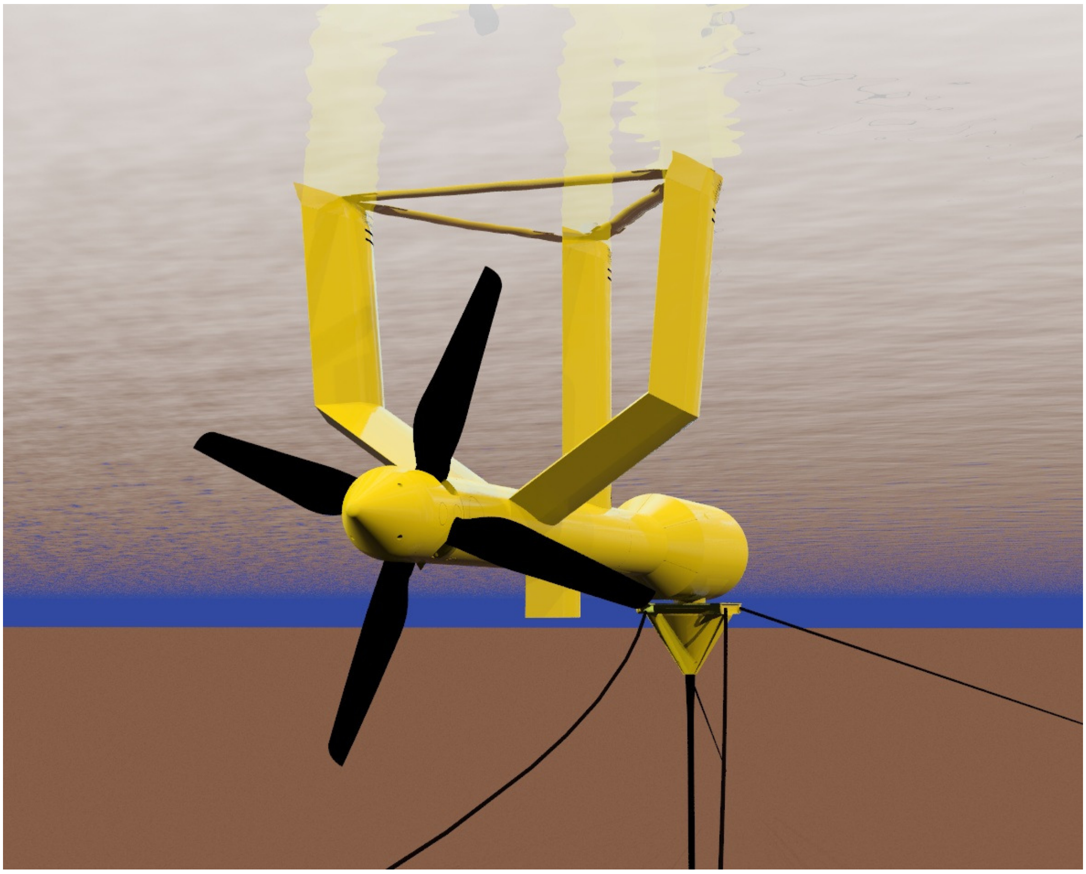
Generating energy from ocean tidal flow is an emerging technology which could contribute between 6GW to 12GW of clean power to the renewable energy mix in the UK. Tidal flows are highly predictable and the power generation cycle can be calculated years in advance. However, there are many technical challenges that must be overcome before placing electrical generating devices in the hostile marine environment. Tidal generators can be located in the sea at 1km or more from the shore. They are susceptible to the effects of fast tidal streams and must survive waves generated by storm activity. In addition, a robust electrical transmission system is required to transmit generated power back to the shore with minimal losses.



Ocean Flow Energy Ltd. (Oceanflow) has been working on the design of a floating tidal stream generator for approximately 5 years. This project is part funded with the support of Scottish Enterprise WATERS grant and consists of a mono turbine floating device known as the Evopod™.

This patented device floats with most of the structure just below the surface of the sea and is moored to the sea bed using cables. As the tide flows past the submerged hull, the turbine turns and this generates electrical energy from an on board generator. When the tide changes direction, the Evopod™ hull turns around on a swivel in a similar way to a boat at anchor. Energy is then generated on the return tidal flow in a similar way.

A prototype quarter-scale Evopod™ device is currently being constructed which will generate approximately 25kW steady state in nominal tidal flows. Using this prototype, the effect of the marine environment will be studied in preparation for a full scale device which is expected to generate 1MW at nominal tidal flow.

Approximately one year ago, **Optima Control Solutions** received the contract to design and deliver the power conversion and transmission equipment for the prototype Evopod™ tidal generator to be located in Sanda Sound, South Kintyre, Scotland. A number of challenges were immediately apparent such as how to deliver the power to the shore at minimal losses and also the fact that some elements of the power conversion equipment would be within the submerged hull and not accessible between the scheduled annual maintenance slots. Other unknowns were the control strategies required to extract the maximum power at all tidal flow states and how to protect the device during wave activity caused by storm conditions.

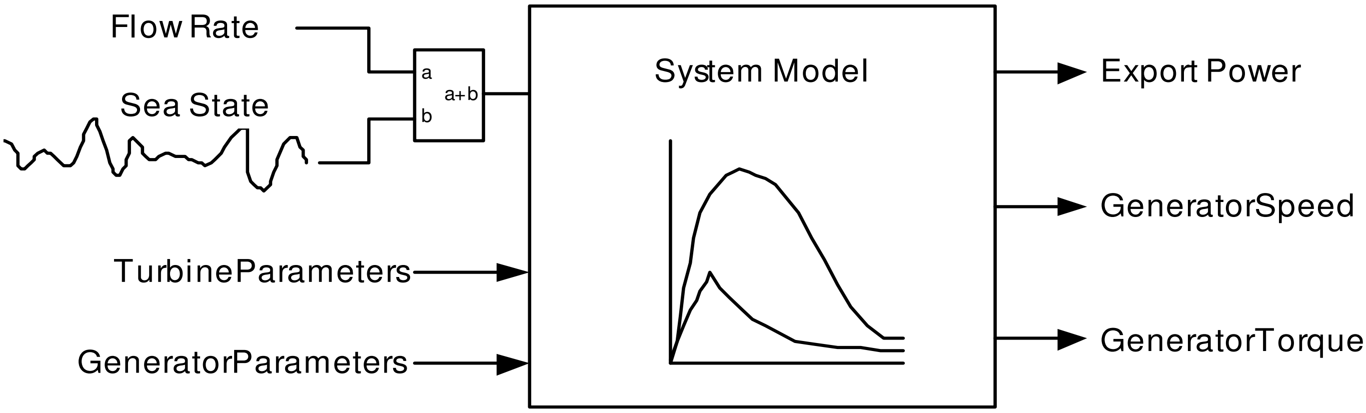
After much discussion about power conversion equipment topologies, it was decided to locate a fully regenerative power converter within Evopod's hull. This transmitted power via the mooring swivel slip rings to an umbilical cable down to a sea bed located transformer. The 400V supply was boosted to a high voltage and sent over a custom designed submerged 1km long cable to the shore. This approach considerably reduced the cost of the sea bed cable and minimised transmission losses. A step down transformer on the shore allowed connection to the SSE local grid connection point.

Siemens was chosen as the preferred supplier for all power conversion and low voltage switchgears. A 37kW Rotor induction generator was used, together with Siemens SINAMICS S120 drive and active interface modules to generate power at close to unity power factor with low harmonics. The generator was operated in closed-loop vector mode in order to allow accurate control of generator torque and speed. A Siemens three phase power supply was used to generate all the on board auxiliary power supplies. This power supply, together with the SINAMICS S120 drive allowed operation over the wide voltage range expected due to transmission equipment impedances. All control equipment was fitted into a dedicated equipment skid that will be fitted into the hull.

Local supplier **Admagnetics** was chosen to design and supply the two power transformers. A rugged steel waterproof container was designed by Oceanflow to house the sea bed transformer, together with special dry mate connectors for the high voltage sub-sea cable and Evopod™ umbilical.

A major challenge still remained as to how to control the turbine to achieve maximum generated power at all tidal flow states. Another problem was how to protect the turbine from overload due to wave activity arising from storm conditions. It was also difficult to experiment with different control strategies with a deployed device due to the long time periods (6 hours) between similar tidal flow rates. In order to overcome these difficulties, a two-pronged design approach was used.

A full computer based simulation was designed by Optima using existing models of a drive and motor, together with a new model of the turbine using data supplied by Oceanflow. The software model was written within a **National Instruments LabVIEW** programming environment and operated in real time. Various control algorithms were tested at different tidal flow rates, in order to maximise power generation capability at all times.



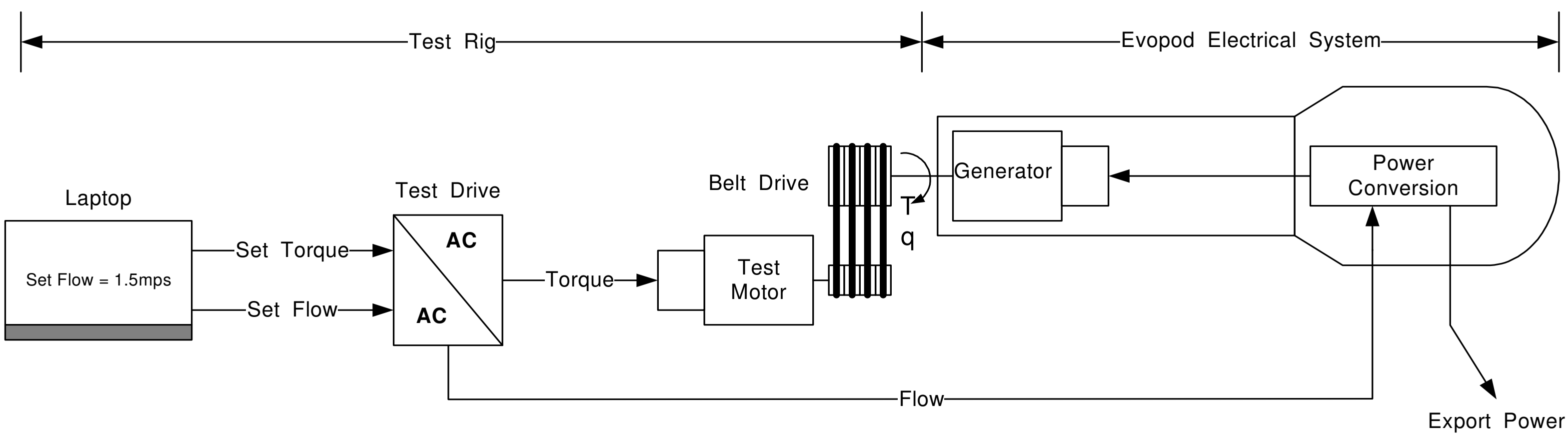
With any tidal flow (or indeed wind) generation device a protection mechanism is required to protect the power conversion equipment from overload due to excessive flow rates. The turbine is designed to cope with steady state flow rates occurring during spring tides. However, storm-induced wave activity causes transient disturbances in the flow rate due to the additional wave particle velocity which varies in magnitude and direction as the wave passes. If the disturbances are added to the steady state flow rate then the resultant peak flow rate may exceed the maximum designed value and an overload condition will exist.

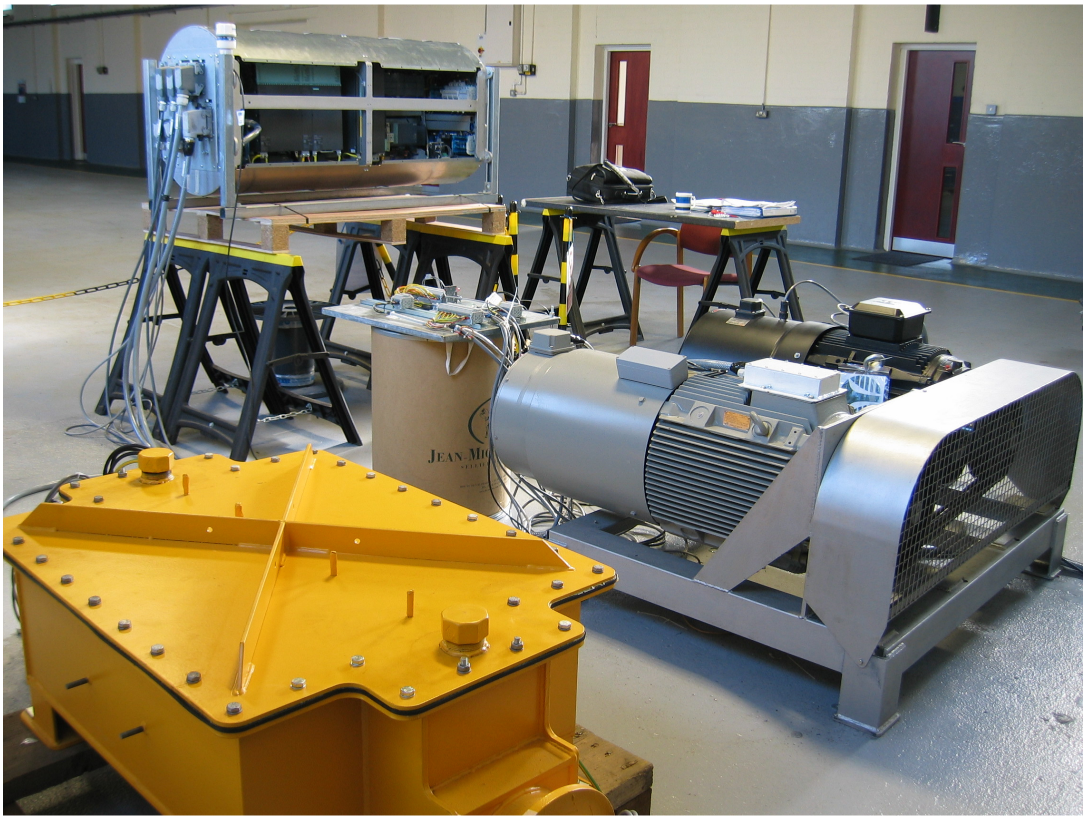
Given that the power output from the turbine follows a cube law based on flow rate, if the flow rate is doubled then the turbine will absorb eight times the power. This would overload the turbine generator and give rise to a damaging speed run away situation. This situation was modelled by adding a sea state flow factor, based on a JONSWAP wave spectrum analysis. This effectively modelled the effect of transient flows caused by real wave activity and allowed algorithms to be designed to protect the turbine from overload. An additional sea state aggregate was also computed to shut down the turbine in the case of low flow rates and large wave activity.

The computer model produced outputs of export power, generator torque and generator speed and these were trended to examine and refine system behaviour for all expected flow rates and wave activity. With the control algorithms completed, the second design approach was to construct a dynamometer test rig to verify complete system operation.

In order to simulate the torque produced by the turbine a 37kW test motor was connected to the generator using a belt drive. The test motor was supplied from an inverter drive operating in closed loop vector torque control. Using the software model, the expected torque value produced by the turbine was used to supply the test drive torque set point. In addition, a simulated flow rate was supplied by the model to the actual Evopod™ control equipment. The software model was run on a lap top computer such that the test rig could be operated under exactly the same flow and sea state conditions as the original software simulation.

The two transformers were connected up with a test length of sub-sea cable, together with the Optima-designed shore control panel, such that as much electrical equipment as possible was in use for the load tests. The complete length of sub-sea cable was not available for the tests but, due to the small currents, cable core sizes and relatively short length in transmission terms, this omission was considered to have a negligible effect.





The above images show the complete development test rig with the sub-sea transformer within the yellow enclosure. The Sinamics power conversion equipment is shown located within the Evopod™ equipment skid and the shore transformer, shore control panel and test drive are also shown. Optima provided complete hardware design, software and construction services for the shore panel and equipment skid. The modular system design has made testing easier as it can completed away from Evopod's hull.

The test rig was used extensively to further refine the control algorithms to cope with all expected flow and sea states. Sufficient tests were performed to prove operation and to provide confidence that the generator, power conversion and transmission equipment would operate correctly when the tidal generator is deployed. The power generated from the generator matched exactly with the calculated values produced by Oceanflow using estimated turbine characteristics. A turbine calibration algorithm was developed to allow fine tuning of the control algorithms based on the actual turbine in real tidal flow conditions.

A triple redundant communications system was designed to allow basic control of the remote Evopod™ device. The extensive software running in a Siemens PLC within the equipment skid is responsible for complete control of the generator, independently of the communications link. A comprehensive alarm system is used to shut down the generator in case of equipment failure or extreme operating conditions.

Since this is a development prototype, a comprehensive data logging and trending system was designed to collect all operational data such as export power, speed, torque, equipment temperatures and mooring line tensions etc. via the communications link. A universal marine GPS sensor is used to measure the geographic position, pitch, roll, compass heading and weather information for subsequent control and data logging. A tri-axial accelerometer is used to measure dynamic motion.

The data collection system is based on the InfoServe365 data collection platform which allows historical and real time data to be collected and displayed from any location using web browser technologies. The data logging system was integrated into a custom designed, tag based SCADA system based on the

National Instruments LabVIEW programming environment which is ideally suited for the application.

In conclusion, the extensive use of software simulation and a comprehensive dynamometer test rig has ensured that the overall hardware and software design has been tested to a level where minimal commissioning will be required during sea trials of the tidal generator. An additional benefit is that the on board equipment has been used sufficiently to expose any early life failures and provide a more reliable solution. Considering the marine operations costs involved during recovery and deployment of the tidal generator, the additional design costs incurred during this design approach are negligible.

References:

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