

# Summary of the CA-OE Workshop in Uppsala, Nov. 2005

## **Abbonel: Experiences of the Rance turbines**

The Rance tidal energy facility required preparation during long time: 25 years passed from initiation to inauguration 1969, dominated by planning, research and testing.

Anticipated problems: 1) Design of operation cycles  
2) Turbines that can handle variable conditions  
3) Protection against marine corrosion

Solutions: 1) “Double action”, i.e. power output twice per tide cycle  
2) Upstream bulb turbines (Kaplan type with adjustable blade pitch)  
3) Anodic as well as cathodic protection of virtually all metal parts in water

One major mishap: The generator stators had to be replaced due to magnetic problems.

Note: The tide can be predicted, but not “unexpected events”. On the average, there has been one per week since 1996, even though the control system is fully automated.

## **Baker: Air core tubular machine**

A linear generator for direct drive conversion of wave energy was designed, together with a test rig. The idea is to impose simulated forces from a wave energy converter on the linear generator, while rectifying and converting the electrical output into AC (50 Hz, 240 V).

The translator consists of a rod with permanent magnet disks, separated by steel disks. The surrounding stator is a basically a set of coils with air cores.

Special attention had to be paid to the assembly of the generator due to the forces from the very strong permanent magnets. The power electronics is designed to handle varying operating conditions.

## **Bard: Drive train concepts for variable speed operation (VSO)**

The main reasons for variable speed operation are reduced dynamic loads, improved part load efficiency, and less need for mechanical control.

A number of different drive concepts are being evaluated by ISET, inspired by previous developments e.g. in wind power. An interesting example is the “multibrid” concept, where a single stage gearbox is combined with a medium speed generator: The drive train mass can be reduced, and no high speed gears are needed.

The cost for the frequency converter is an important consideration. The critical size, above which price decreased slower, was found to be around 20 kW (at 200 €/kW in year 2000).

The price for a system of a generator and a frequency converter also decreased with increasing size. At 600 kW rated power, synchronous generators and doubly fed induction generators (at 130 €/kW) won over asynchronous generators.

Part load efficiency is an important figure of merit. Permanent-magnetized synchronous generators with frequency converters appear relatively efficient at part load.

Real system weights (wind power: nacelle, power train, generator) showed a tendency to increase with rated power (50-80 kg/kW).

Two commercial examples were shown: one small-scale hydro turbine (simplified Kaplan) combined with a permanent magnet generator and one 200 Hz 40 pole permanent magnet generator as such.

### **Boake: LIMPET wave power plant performance**

The LIMPET plant is based on the Oscillating Water Column (OWC) principle: The wave motion is converted into a water column moving up and down in a chamber. The air above the water column is pushed through a bidirectional Wells turbine

The plant has survived the harsh climate, but the performance has been lower than expected, partly due to suboptimal sea bottom topography outside the plant, partly due to the choice of a contra-rotating Wells turbine. The availability was > 80 %, whereas the plant spent 25-30 % of the total time producing electric power.

Main recommendations: 1) Do not over-rate the plant for the wave resource available; 2) maximise the efficiency closer to the mean generation level; 3) make model tests of the complete system in cyclic flow; 4) choose another type of Wells turbine than the contra-rotating.

Some general recommendations for energy conversion systems were also made, most of them related to cost-efficiency.

### **Cruz: Wave energy for desalination**

Wave-powered desalination may solve the fresh water problems in many places in the world. The theoretical minimum energy requirement is about 0.7 kWh/m<sup>3</sup> of sweet water. The main argument is that the raw material and the energy source are in the same place.

Two methods are mentioned: reverse osmosis (RO) and vapour compression. The latter method does not need any pre-treatment of the water in order to function well.

Two projects are described: “Delbuoy” using an up/down-moving buoy combined with an external system for reverse osmosis, and “the Edinburgh concept” using an oscillating cylindrical buoy with an internal system for vapour compression.

### **Georgiou: Pneumatic power take-off**

The pneumatic power take-off in an OWC device was studied using a simple model based on thermodynamics and mechanics. It appears that the pneumatic work cycle is an important part in the optimization of the total power take-off.

### **Gravråkmo: Wave prediction for latched wave-power buoy**

A buoy can absorb more power from sea waves if its motion is temporarily locked (latched). The mechanism needs some time to unlock, and therefore knowledge about future waves would improve the control algorithm. According to a simulation using a Karman predictor and sinusoidal wave state space model, the captured energy may increase by 1 %.

### **Hoff: A helix-shaped wave machine**

An idea for a novel wave power take-off device was tested in the laboratory. The preliminary experimental model consisted of a plastic foam cylinder bent into a spiral around a straight rod, the latter oriented along the motion of waves in a narrow tank. The machine rotated, but power conversion was very small, and the sensitivity to wavelength was large. Several improvements were suggested.

### **Josset: Power take-off model for the SEAREV device**

The SEAREV device is based on a floater with a pendulum inside, viewed as two coupled oscillators. A numerical model simulates the behaviour from waves to electricity for a system with oil pressure accumulators acting as temporary energy storage. Two important issues for performance turned out to be proper dimensioning of system parts and tuning with respect to available torque from the waves.

### **Knapp: Water turbines for overtopping devices (Wave Dragon)**

Water turbines for overtopping devices have to meet tough specifications: harsh sea climate, small and varying turbine head and rapidly varying flow rates. The experiences gained so far indicate that one should use several small Kaplan propeller turbines that can be run at varying speeds. The control includes turning on or off several turbines, depending on the situation at hand. The turbines should be simple and rugged in order to reduce maintenance costs.

### **Kofoed: Power take-off system onboard the Wave Dragon prototype**

The working principle is to let two long arm reflectors focus sea waves onto a small water reservoir with a doubly curved ramp. The reservoir has a set of small variable-speed Kaplan turbines with fixed vanes and runners. The turbines are constantly regulated against the variable turbine head and rapidly changing water flow.

The experience shows that the well-proven hydropower technology needs to be adapted for the very different conditions at sea. Among the problems that had to be overcome were marine growth on turbine draft tubes, corroded bearings, insufficient sealing, sand/mud entering the structure and practical problems when doing maintenance at sea.

### **Leijon: Welcome speech and presentation of research at UU/Electricity**

The activities at the Div. for Electricity and Lightning Research are focusing both on applications physics related to electromagnetism, especially electric generation for renewable energy. The largest project is on wave energy, where the simple concept is to let the motion of a buoy drive a linear PM generator placed in a container on the sea bottom. A special message is that it is very important to pay attention to economy when designing renewable energy converters.

### **Molin: Mooring of offshore systems**

The cost of anchoring is relatively large for typical offshore systems and is likely to be significant also for wave energy converters (such as e.g. Pelamis). The design of anchoring can be a time-consuming process. Still, the details of slow-drift excitation and damping are not satisfactorily mastered. Yet more investigation will be needed for wave energy applications.

### **Mueller: Integrated design of direct drive electrical power take-off**

Directly driven electric generators need many poles and large diameters (if rotating). The electric design should be integrated with the mechanical design in order to optimize the energy converter as a whole. Electromagnetic forces, core weight and bearing design (for linear machines) are important in this respect. It is argued that air-cored machines will reduce costs for manufacture and installation.

### **Polinder: The generator system of the Archimedes Wave Swing (AWS)**

The AWS system has a directly driven linear double-sided PM generator. A number of generator topologies have been compared to find a cost-efficient solution. It is argued that a double-sided Transverse Flux Permanent Magnet (TFPM) topology is the most promising due to lower costs and higher efficiency. However, more research is necessary, regarding eddy current losses, low power factor and mechanical construction.

### **Retzler & Henderson: Hydraulics of the Pelamis wave energy converter**

The Pelamis concept is based on a chain of floating cylindrical bodies aligned with the wave motion direction. The joints are connected to hydraulic pistons that transfer energy into oil pressure accumulator tanks. Hydraulic motors drive electric generators with smooth output power. Peak power is handled by the mechanical and hydraulic part of the system, so that the generators can be dimensioned for a lower average power.

Hydraulics is considered by the authors as a good design choice because of well-proven technology, possibility for temporary energy storage for smoothing output power, ease of control and high efficiency (80%). The primary transmission concept has been proved in 1/7<sup>th</sup> scale and finally in full scale over a period of seven years.

### **Ruellan: Design methodology for the electric PTO of the SEAREV device**

A simpler version of the SEAREV device consists of an oscillating buoy with an internal pendulum connected directly to an electric generator. The mechanical damping coefficient ( $\beta$ ) needs to be optimized in order to maximize energy production. One method has been investigated:

As long as the output power is lower than a design threshold, the damping coefficient is set at a single value (optimal in an average sense). Above the design threshold, the damping coefficient is varied to keep the electric output constant. The result was that the oscillations of the internal pendulum increase and the rated power of the electric generator can be reduced.

Another investigation concerned the use of a gearbox (multiplier): The result was that output limitation/levelling allowed for a reduction in generator size, but the reduction was much larger by introducing a gearbox. For the future, an energy storage for reducing output power variation will be considered.

### **Sustronk: PTO of the Wave Rotor prototype**

The Wave Rotor is basically a vertical axis “wind turbine” with inclined straight blades, mounted on the sea bottom. The idea is to let the rotor absorb the mechanical energy in sea waves. The power take-off system for a Wave Rotor prototype has been investigated. The requirement to use components available on the market resulted in a combination of a gearbox, a PM servomotor as generator and a modified photovoltaic module inverter. The control is based on speed-dependent on-off-regulation.

### **Taylor: The well-tempered Duck**

During the development of the Salter Duck wave energy converter buoy, it was realized that very high efficiency high-pressure bi-directional oil hydraulic transmissions were needed. Such transmissions can implement the advanced control algorithms required to get the most energy out of waves.

In the early 1980s, the wave power group at University of Edinburgh began to develop a new generation of high performance hydraulic machines based on designs by Robert Clerk. Building on that experience, a new company called Artemis Intelligent Power Ltd. was founded in 1994 to develop the next generation of hydraulic machines.

This new technology is called “digital hydraulics”. It is based on computer-controlled high speed solenoid valves, which give a hydraulic machine high part load efficiency and good controllability. The technology has been applied to e.g. wheel motors in cars and hydraulic pumps.

### **Tedd: Turbine control strategy for the Wave Dragon**

The Wave Dragon is a small hydropower dam at sea, where gravitational potential energy is captured by collecting water from waves spilling over the dam edge.

The height of the dam over the average sea surface level can only be changed slowly, by varying the buoyancy with compressed air. The turbines, on the other hand, can be controlled quickly, but knowledge about future waves is important for optimizing the performance.

The immediate goal is to keep an optimal level in the storage reservoir, so that the incoming water neither falls too much (loss of potential energy) nor simply spills outside (reservoir already full).

Numerical simulations indicate that only a few waves need to be predicted in advance in order to increase energy output significantly (5-10 %). In reality, the energy increase will be lower, but predictive control is cheap enough to be worthwhile economically.

### **Traylor: The Seaflow marine current turbine**

The Seaflow device is a two-bladed pitch-controlled horizontal axis “underwater wind turbine”. The turbine is mounted on a tower standing on the sea bottom. The tower has a stable platform for operation and maintenance. The turbine can be lifted out of water for inspection and service. Operational experience indicates that the pitch control of the turbine blades works well. Furthermore, the marine environment with corrosion and fouling requires appropriate treatment of *all* surfaces. Moving parts like cables need to be protected against mechanical forces. Larger equipment will be needed for future installations. And, the sea bottom of a site needs to be investigated *before* designing the foundation.

The total costs excluding overhead and design amounted to £4480/kW.

### **Thorburn: Ocean energy at Uppsala University**

The Division for Electricity and Lightning Research is heavily involved in research in power from ocean waves, marine currents and wind.

The main topic is wave power, where the philosophy is based on making simple energy converters in small sizes and large numbers. The technology should not only be functional but also economical while keeping the impact on the environment at a minimal level.

The wave energy converter is basically a buoy (point absorber) connected via a rope to a permanent magnetized directly driven linear generator in a watertight container on the sea bottom. Coil springs act as a temporary storage releasing energy to the generator when the buoy is moving downwards. The wave energy converter concept is currently being tested outside Lysekil on the West coast of Sweden, with environmental impact as an important auxiliary project.

For wind power, the concept is based on a vertical axis turbine with three straight blades and two supporting struts per blade. This type of turbine is not sensitive to wind direction and the noise will be relatively low. The generator is also of the direct drive permanent magnet type,

with relatively many poles and large diameter. The first prototype is planned to be installed in the autumn of 2006.

For marine currents, a similar concept is based on a vertical axis “wind turbine”, albeit modified for the different operating conditions. The first step will be to design, make and test a prototype generator in the laboratory during 2006.