The Söderfors Project: Experimental Hydrokinetic Power Station Deployment and First Results

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***Abstract*—The Division of Electricity at Uppsala University recently deployed an experimental hydrokinetic power station for in-stream experiments at a site in a river. This paper briefly describes the deployment process and reports some initial results from measurements made at the test site.**

***Index Terms*—hydrokinetic energy, vertical axis turbine, low-speed generator, experimental facility, deployment experience**

I. Introduction

The Division of Electricity at Uppsala University is developing a test site for marine current or hydrokinetic energy conversion in the River Dalälven at Söderfors. The *Söderfors Project* was presented at the 9th EWTEC in 2011 [1], and details of the project have also been published in [2]. Recently, an important milestone was reached as the energy conversion unit, comprising turbine and generator, was deployed into the river.

The experimental station is located in the River Dalälven at Söderfors, whence the project derives its name. The system comprises a vertically oriented cross-stream axis turbine and a directly driven permanent magnet generator situated on the riverbed. The necessary systems for control, power conversion and various measurements are housed in a small measuring station on shore.

This paper will briefly describe the practicalities of constructing and deploying the experimental power station and report some initial results from operating the unit.

II. Deployment

A. Background

As described in [1], research on hydrokinetic energy conversion has been conducted at Uppsala University since 2000. A prototype low speed permanent magnet generator was designed and built in a laboratory environment in 2007. The location of the test site at Söderfors (see Figures 1 and 2) was selected in 2009, and after analysing the characteristics of the site [3], [4] the test equipment was designed and constructed in the lab in 2010 and 2011. See [2] and [1] for details of the site selection process and design choices for the experimental station.

During spring and summer of 2012, the equipment was moved in pieces to Söderfors and reassembled. The plan was to deploy the energy conversion unit into the river in late summer, since statistics had shown that river discharge is relatively low at that time of year. However, due to unanticipated levels of precipitation during summer and autumn 2012, deployment had to be postponed several times and eventually into 2013.

The equipment to be deployed was the energy conversion unit (foundation, generator and turbine) and three water velocity measurement devices of type ADCP[1]. Attached to the generator was a cable bundle comprising the power cable and two signal cables. The ADCPs also had cables attached and foundations weighing around 100 kg for the two bottom-mounted units. The third unit, to be mounted on the bridge pillar, had a lighter foundation, but in the end that ADCP was deployed at a later date than the other components.

The general layout of the test site is illustrated in Figure 3. The turbine and the bottom-mounted ADCPs are placed on a line roughly aligned with the main direction of flow of the river. The distance from the turbine centre to the ADCPs is approximately 15 m in either direction, corresponding to 2 turbine diameters from the turbine periphery. The horizontal ADCP is mounted on a bridge pillar upstream of the turbine at the same distance. The water depth at the site is just less than 7 m, putting the turbine blade tips at 2 m below the surface. An electrical enclosure mounted on the bridge railing provides a connection point for cables coming up out of the water and cables going on to the measuring station on shore. The measuring station is about 170 m from the bridge enclosure in terms of cable length. It is approximately 800 m along the river from the hydro power station to the test site.

B. Time of deployment

As mentioned above, the original plan called for deployment in late summer based on predicted river discharge. It was necessary to have divers working in the water during deployment, to inspect the placement of the machinery on the river bed but also to secure the cabling on the river bed and to the bridge pillar where the cables come out of the water. For the divers to have a reasonable work environment, it was necessary to have Vattenfall AB, the utility company operating the hydro power station at Söderfors, shut down the water flow from the power station (if not completely at least nearly). With the

[1] Acoustic Doppler Current Profiler

Fig. 1. The location of Söderfors, approximately 1 hour's drive north of Uppsala.

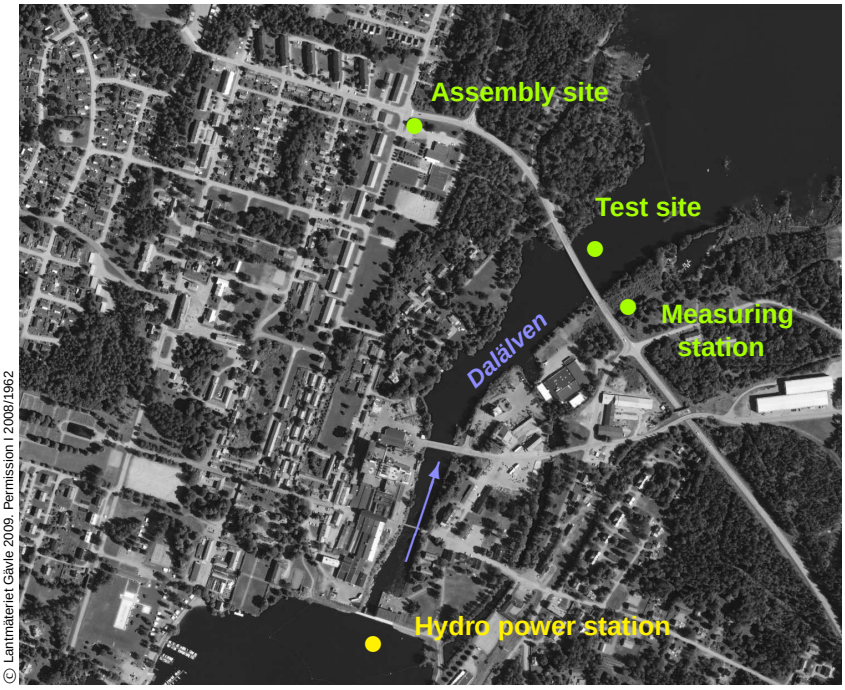

Fig. 2. A bird's eye view of central Söderfors. The experimental station is placed some 800 m downstream of the conventional hydro power plant.

heavy rainfall experienced in 2012, it was not until well into December 2012 that the discharge in the River Dalälven fell to such a level that a shutdown were possible.

On the other hand, in December temperatures are cold which means high season for the utility companies, and Vattenfall were reluctant to shut down their power station in the winter. Deployment was therefore postponed further.

In early March, Vattenfall planned a shutdown of the Söderfors hydro power station for some maintenance work. The date was 7 March 2013, and since control of the river discharge was the single most important factor for success, it was decided to seize the opportunity to deploy.

C. Execution

The deployment was carried out by lifting the energy conversion unit (see Figure 5) into the River Dalälven from the road bridge spanning the river by use of a mobile crane. Since the machine's mass was 11.5 tonnes (in air), a 55-tonne crane was required, just barely passing the load limit of 60 tonnes for the bridge.

The intention had been to reassemble the generator and turbine and mount them on the tripod foundation in close proximity to the measuring station. This would have facilitated connecting the generator to the control system in the measuring station prior to deployment in order to verify functionality. However, a 12 kV power line passes across the road close to the river shoreline on the south side of the river. With the turbine mounted, it would not be possible to pass that power line when moving the machine onto the bridge for deployment. Instead, a separate assembly site had to be established in a parking lot on the north side of the river.

The tripod foundation and the generator were assembled during summer 2012, but the mounting of the turbine was held off until it was time for deployment. The generator, including its Hall effect sensors and other instrumentation (for details of the generator, see [5]), thus spent the entire autumn and winter outdoors in temperatures occasionally reaching below $-20°$C.

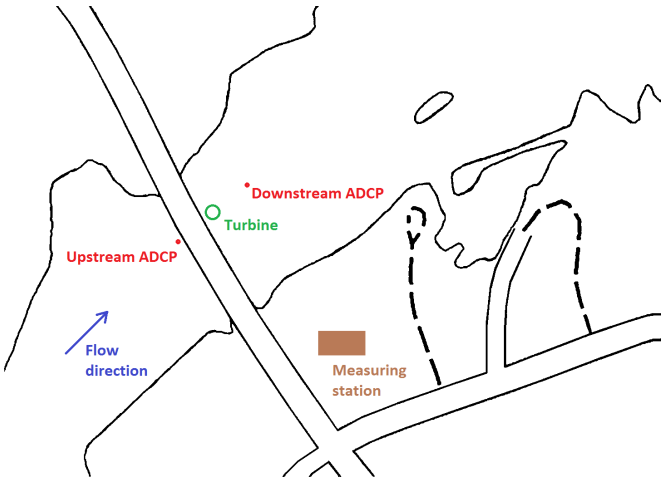

Fig. 3. Detail of the testsite. Cables runs from the turbinator and ADCPs to the downstream side of a bridge pillar, at the top of which they connect to an enclosure mounted on the bridge railing. From the enclosure, cables run on along the bridge to land and underground to the measuring station.

Photo: Uppsala University

Fig. 4. Deployment of the energy conversion unit into the River Dalälven on 7 March 2013. The turbinator is being lowered into the river from the bridge by a large mobile crane. Lines are tied to the upstream foot of the tripod to ensure correct orientation. The cable bundle, with protective plastic coating in bright yellow, is being paid out from the bridge, and divers are standing by in the boat ready to inspect the unit's placement and secure the cable bundle on the river bed.

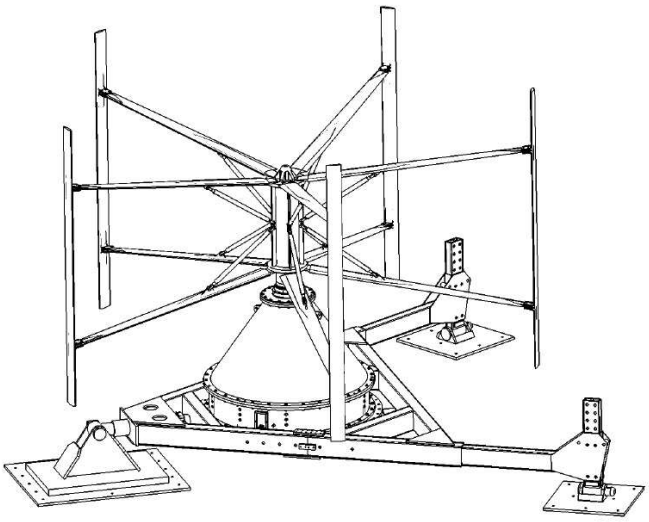

Fig. 5. Overview of the energy conversion unit with turbine and generator mounted on a tripod foundation. Design by Anders Nilsson.

Also during summer, power and signal cables had been laid from the enclosure on the bridge to the measuring station. A 50 m length of cable, prepared for easy connection, was attached to the generator to cover the distance on the river bed and up the bridge pillar to the enclosure. The power cable data sheet stated that the cable should not be deployed in sub-zero temperatures. In early March, temperatures might be expected to reach above zero in the daytime, but in the week preceding deployment day night temperatures routinely went below $-10°$C. In order to avoid cable damage, a small tent was erected over the cable roll on the generator. Three gas heaters were set up in the tent the night before deployment, ensuring that the cable was not deep-frozen.

The mobile crane first lifted the turbinator onto a trailer at the assembly site. Traffic was stopped briefly on the bridge, allowing the trailer and crane to move the 450 m onto the bridge. Luckily, the bridge was wide enough to allow traffic past the crane in single file while the deployment proceeded. Plastic tubing was added to the cable bundle in order to mitigate abrasion. Ropes were tied to the upstream foot of the tripod, allowing the machine to be turned slightly while hanging in mid-air to ensure its correct orientation relative to the main flow direction. The crane then lifted the machine off the trailer and lowered it into the river (see Figure 4). Divers checked that the tripod's feet were set properly on the river bed, then released the lifting device. The mobile crane placed the two vertical ADCPs, after which it and the trailer retired. The divers then proceeded to secure the cables on the river bed and the bridge pillar. Finally, the cables were all plugged into the bridge enclosure.

The horizontal ADCP was not deployed in March, but was mounted on the bridge pillar and connected to the system in June.

III. Measurements

A. Equipment

The following sensors are installed in the generator:

- Hall effect sensors, used for monitoring rotational speed, especially during start-up.
- Temperature sensors in various locations.
- A web camera, mounted on the floor of the generator housing.

The number of sensors on the underwater parts of the system has been kept to a minimum for low complexity.

Two Teledyne RDInstruments Workhorse Monitor vertically-looking ADCPs are placed on the river bed, upstream and downstream of the energy conversion unit. They are used for measuring water velocity before and after the turbine. A third, horizontal-looking ChannelMaster ADCP is installed on the bridge pillar upstream of the turbine. Together with the upstream vetical ADCP, it provides the possibility to monitor the velocity profile upstream of the energy conversion unit.

Voltage and current induced by the generator are measured on shore, inside the measuring station.

For details of the control and measurement system, see [6], [7].

B. Method

The Söderfors control and measurement system is based on a Labview program using pulse width modulation (PWM) to apply a DC load. For the experiments reported here, it was decided to disconnect the rectifier and instead rig the load as a fixed Y-connected AC load. The results will be useful for characterizing the generator, and it is also important for comparison purposes that the generator was run against an AC load in the lab prior to removal to Söderfors (see [8]).

Two load cases were tested, 2.5 Ω and 2.0 Ω per phase. After connecting the available resistors so as to achieve the desired resistance, the load was checked using a milliohmmeter. The turbine was started and the load was applied. When the rotational speed had stabilised, measurements of voltage and current were taken using a PicoTech PicoScope. Several measurements were taken for each load case.

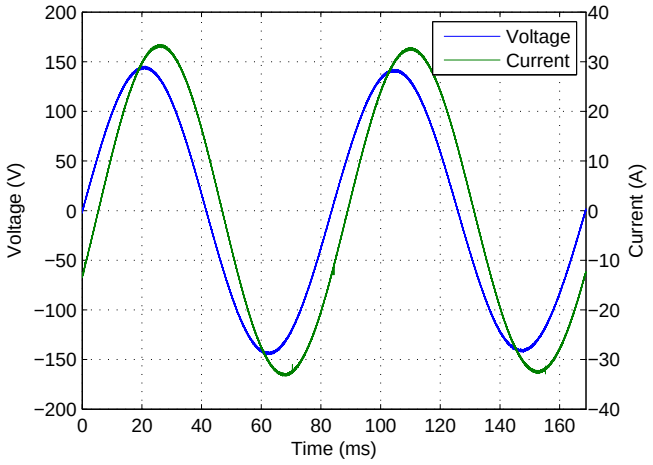

Fig. 6. Two periods of line voltage (blue line) and phase current (green line) captured during an AC load measurement at 2.5 Ω per phase.

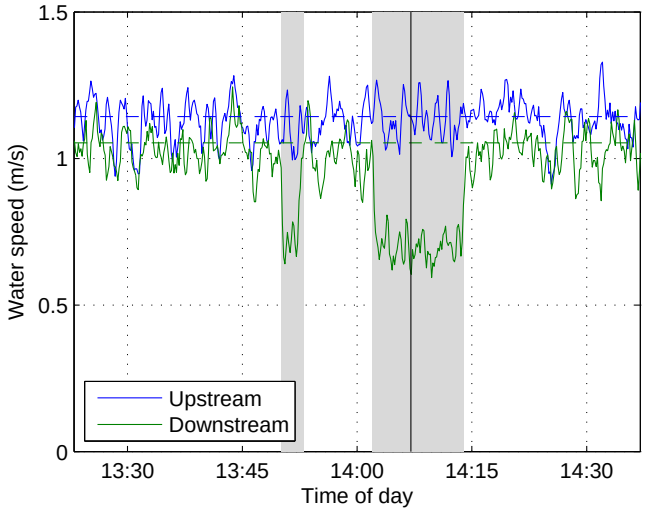

Fig. 7. Mean waterspeed measured by ADCP upstream (blue line) and downstream (green line) of the turbinator on 29 April 2013. The horizontal dashed lines show the time-averaged mean speed for the undisturbed flow at the two locations. The shaded areas indicate time periods during which the machine was operated. The solid vertical black line marks the time when the waveforms displayed in Figure 6 were captured.

Water velocity was monitored by ADCP throughout. Velocity profiles were taken upstream and downstream of the turbinator in 10 second intervals. Time-averaged values for the water speed at both ADCP locations were calculated.

C. Results

The mean values for water speed during an hour are plotted in Figure 7. On average, the speed of the undisturbed flow was 1.14 m/s at the upsteam ADCP and 1.05 m/s at the downstream instrument. When the turbine was operated, a significant decrease in the water speed at the downstream ADCP was clearly distinguishable. For the operational period beginning at 14:02, the average mean speed downstream of the turbine was 0.71 m/s.

Two periods of voltage and current captured during a 2.5 Ω load experiment are plotted in Figure 6. The electrical frequency was 11.8 Hz, corresponding to a rotational speed of 12.7 r.p.m. The RMS values of line voltage and current were 103 V and 23.7 A, respectively. Note that the diagram shows line voltage (L1-L2) but phase current (L2).

A summary of some measured and calculated values is at Table I.

D. Discussion

The results given above are rough and perhaps not very novel. The main point in reporting these measurements is not the voltage, current and velocity figures themselves, but

TABLE I
MEASUREMENT RESULTS

Parameter	Value
2.5 Ω load	
Electrical period	84.4 ms
Electrical frequency	11.8 Hz
Mechanical frequency	12.7 r.p.m.
Tip speed ratio	3.5
Line voltage (RMS)	103 V
Current (RMS)	23.7 A
2.0 Ω load	
Electrical period	120 ms
Electrical frequency	8.3 Hz
Mechanical frequency	8.9 r.p.m.
Tip speed ratio	2.5
Line voltage (RMS)	68.2 V
Current (RMS)	19.5 A

the purpose is rather to demonstrate the capabilities and possibilities that open up once an experimental station of the Söderfors kind is operational.

Once the systems have been properly characterized and calibrated, the expeimental station will facilitate comparisons of different control strategies for different flow regimes. It will be possible to study the wake of the turbine, both using the fixed bottom-mounted downstream ADCP, but also by establishing the extent of the wake under different operational conditions through the use of a boat-mounted ADCP measuring from the surface. Since the river channel where the energy conversion unit is situated is regulated, various stationary and time-varying operational cases can be studied through cooperation with the hydro power station operator.

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