An Innovative Low Head Hydro Technology: The StreamDiver® in Action

AUTHORS

Philipp Daus

Voith Hydro Holding GmbH & Co.
Heidenheim, Germany

Brian A. Murtha

Voith Hydro, Inc.
York, PA USA

Jörg Lochschmidt

Voith Hydro Holding GmbH & Co.
Heidenheim, Germany

ABSTRACT

As the energy market is getting more and more diversified, low head hydropower has gained growing attention around the globe in the last years. Whereas the potential for small-scale hydro sites (often at existing dam infrastructure) in the US is enormous, the challenge is to get to a high degree of standardization to drive down cost while still considering the hydro-specific requirements.

In the last year, Voith launched the low-head hydro turbine StreamDiver® which specifically addresses the requirements of this sector to reduce cost of ownership while maximizing production. As a key aspect of low-head hydropower, this paper now focuses on operation and maintenance. It presents the lessons-learnt and accomplishments from operations of the running StreamDiver® plants in Europe and how expectation and reality balanced. The paper draws a wide view of operation and maintenance aspects with special focus on StreamDiver® specific features and achievements. The first pilot in Nussdorf which now goes into its fourth year of operation provides valuable feedback by comprehensive monitoring data over the years as well as on-site inspections. The results show how the “open bulb” solution of the StreamDiver® with no seals, oils or grease surpassed the expectations despite the considerably harsh water conditions of the Danube canal. Data from a bearing test rig to run durability tests on the drive-train configuration is taken into account to project and extrapolate the measurements in Nussdorf regarding the maintenance interval of such a unit.

The paper concludes with an operator perspective and how the field experience and StreamDiver® performance actually improves cost of ownership.

Introduction

It has been well documented that, of the 80,000 existing dams in the United States, only 3% produce hydroelectric power. This leaves 65 GW of renewable energy generation on the table. Recognizing the potential, in 2013 Congress passed legislation designed to encourage development by creating licencing exemptions for projects under 5 MW. In combination with this, the Federal Energy Regulatory Commission (FERC) created a streamlined process for qualifying 'in conduit' projects. As of June 2016, FERC had exempted 63 of the 77 applications with another 2 pending with most approvals coming within 2 months.

Although US regulating bodies have taken steps to encourage hydro development, the world economy has not necessarily cooperated. Historic low oil and gas prices have made development of new hydro difficult to rationalize. Particularly hard hit are the low head sites which tend to be more economically challenging anyway.

With an eye towards the future, there is a need for a long term energy solution that is both low cost and sustainable. Many would agree that hydro fits the bill. Nevertheless, to begin to meet the long term needs starting today, new hydro development needs to be extremely price aware. Building a strong business case for development must include considerations of the permitting of the site years before installation; the construction and installation costs during start-up; and the long term operation and maintenance costs of operating a hydro facility.

Today's environment for development is faced with four main barriers:

- Long and complex permitting procedures answering to many stakeholders
- Low level of energy prices
- Significant one time investments for new powerhouse construction
- Significant long term investments to properly maintain conventional powerhouse equipment

These four challenges make it difficult to rationalize new projects using conventional Return on Investment (ROI) metrics. Even where reasonable energy prices make hydro development a possibility, a significant one time investment in new equipment plus the outlook of long term maintenance makes the economics difficult for sites that are producing only a few hundred kilowatts.

In 2014, the StreamDiver® was officially launched by Voith as a new product specifically for the low head hydro sector which tackles the inherent challenges. While its design and integration concept can reduce the initial capital costs, the subject of this work will be focussed on aspects of plant operation, the performance of the innovative features and feedback from operations of the plants in Europe.

StreamDiver® Operation and Maintenance Design

A clear goal of the StreamDiver Technology is to offer a technical solution that can integrated in existing dams. To tackle this requirement a compact and submersible turbine has been developed that avoids any peripheral systems and power house structures. By doing so, the accessibility to the power unit itself will be changed to the negative. Therefore, the premise of the system design and its operation and maintenance (O&M) concept is to reduce the risk of unplanned outages and the service interventions in general. As a side effect, the approach reduces system downtime and therefore the risks for loss of revenue.

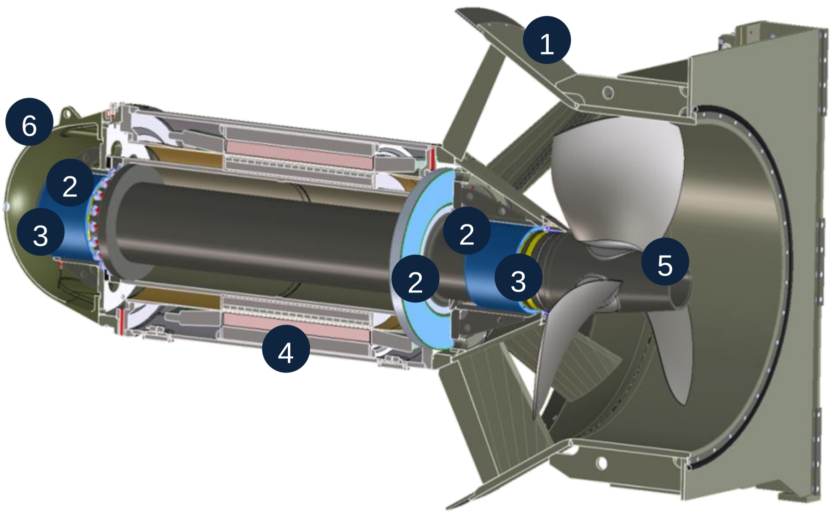
To reach the objectives regarding O&M performance, the StreamDiver® follows a consequent design strategy, which can be outlined as follows:

Premise	Objective	Execution
Reduction of System Complexity	- Shorten assembly work & time - Reduce probability of failure - Increase system availability	- Absence of support systems (oil lubrication & cooling water system) - Simplified drive-train design - Reduced number of components subject to wear
High quality standards	- Increase performance - Increase lifetime - Minimize failures	- Hydraulic model tests - Bearing durability tests - Use of high quality material (e.g. blades made of stainless steel)
Compactness and modularity	- High availability of spare parts - Reduce logistic efforts - Compact plant design	- 5 fixed sizes of turbine modules (runner sizes) - Compact, integrated turbine generator unit - Limited transport dimensions & weights
Remote condition monitoring	- Minimize staff at site - Improve operations - Allow planned service	- Remote plant access - Operation: data analysis & optimization - Interactive service planning

The design is shown in figure 1. As seen, the assembly is based on the key features of a fully-integrated system with slide bearings which are lubricated by the river water itself and a permanent-magnet generator with a statically sealed stator which is cooled by the same water. Therefore the bulb design does not need to be encapsulated and can forgo the use of dynamic seals, excitation, lubrication oil and cooling water system. As a consequence, the machine is free of oil and avoids equipment which not only needs to be purchased, but also maintained. In its non-regulated variant, it also comes without mechanisms to tilt the runner or stator vanes.

While former publications have already presented the design concept and its features, the focus now is to discuss these features with respect to its performance, what it changes in terms of service requirements and what it contributes to the overall value of the plant.

This paper first covers the Nussdorf prototype installation. It wraps up the technical backgrounds and presents performance characteristics. Also it summarizes the findings of the inspection which has been conducted in February 2016. The results are supplemented by results from the test rig for bearing durability and performance. The work concludes with a summary and some aspects regarding the resulting benefits from a project owner and operator perspective.



1 Turbine housing with guide vanes
2 Radial and axial bearing coating on shaft ends
3 Shaft ends
4 PMG Generator
5 Runner
6 Hub

Figure 1 StreamDiver® 3D Model

StreamDiver® Turbine in Nussdorf, Austria

The Nussdorf site itself has been commissioned in 2005 with a total installed capacity of 4.8 MW (accommodating 12 units). It is located near the heart of Vienna at the historical Schemerl Bridge, where two large spherical gates protect the city in case of flood water. Due to the historic value of the site, the plant construction was demanding as the power house had to be fully submerged and therefore not be visible from the river shore. In 2011, the operator Verbund together with Wien Energie and EVN decided to use this site to test the new Voith prototype StreamDiver®. The installation and commissioning of the StreamDiver® unit in Nussdorf took place in August 2012. The turbine is a SD 13.10 with the following technical specifications:

- Type	SD 13.10
- Runner diameter	1.310 m
- Generator speed, frequency	333 rpm, 50 Hz
- Nominal voltage	690 V
- Nominal net head / max head	3.58 m (11’ 9’’) / 4.68 m
- Nominal power / max power	314 / 450 kW
- Nominal flow	9.96 m^3/s (352 cfs)

Figure 2 illustrates the structural integration of the turbine generator unit into the existing conduit. Although the unit has been a perfect match to the structural limitations, there were some adjustments to be made – e.g. the cable routing required a chimney-type housing in the front to guide the cables upstream to the terminals.

The right-handed figure 3 shows the StreamDiver in the tube above the water channel waiting to be installed. The tube accommodates the service crane, the cables and all auxiliaries required to drive the hydraulic gates of the plant.

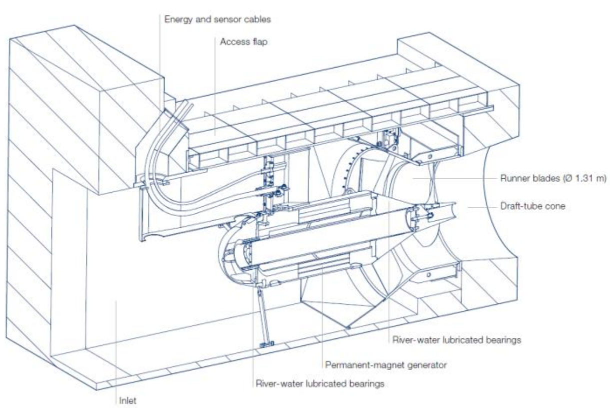


Figure 2 Sectional drawing of the StreamDiver® unit in installation position at Nussdorf site

Figure 3 StreamDiver® on crane hook before installation

To track the condition of the prototype machine and allow detailed assessment of the performance and durability of the design, the unit has been equipped with a surveillance system. Numerous sensors have been added to the standard equipment inside the bulb to monitor the following:

- Temperature sensors: monitor water, bearing, generator stator phase temperature
- Leakage sensors: control dry condition of generator stator
- Water level sensor: ensure bulb is filled with water before start-up
- Distance sensors: monitor displacements in the drive train
- Vibration sensor: track vibration of machine

Nussdorf feedback from operations

General Performance during Operation

The StreamDiver unit is now completing its 4th year of operation in Nussdorf. Due to constraings of the Danube canal, the unit is running 365 days a year and now has a total of over 30,000 hours of operation (April 2016):

- Operating hours > 30,000 hrs
- Exported electricity > 8,000 GWh
- On-site inspections 2
- Maintenance services 0

To date, the operation of the unit had been inconspicuous without any forced outage. For bearing performance tests, the unit had been operated with fresh water during the first year of operation. During a first planned inspection in summer 2013, the shaft seal had been removed and the unit ran with river water of the Danube canal from this day on.

Figure 4 shows 1-hour averaged samples of the normalized power output with respect to the gross head. As the unit is non-regulated and running at fixed speed, the power is directly dependent on head. The output is superimposed by a change of discharge (changing with head) and hydraulic and electrical efficiency as a matter of machine design. In addition, the actual output is affected by water temperature and rate of seasonal pollution of intake, guide or runner vane (grass and debris moving through the trash rack) which causes different head and secondary efficiency losses. This results in an about 30% range of power outputs for the same measured gross head.

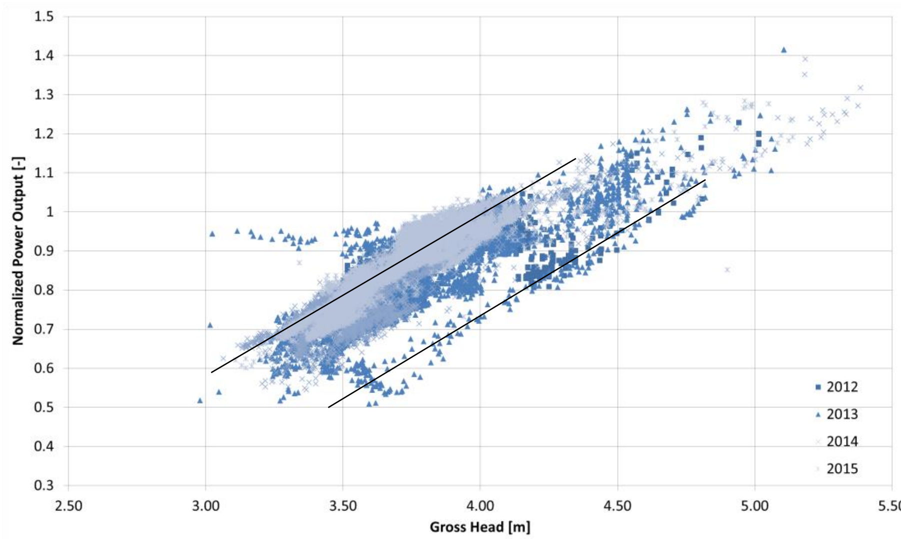


Figure 4 Normalized power output versus gross head – results show that performance is stable over the past 4 years

The generator condition and cooling effectiveness can be monitored by looking at the stator phase temperatures. Figure 5 shows the temperatures of phase W in comparison to the power output during the four quarters of the year (Q1 – Q4). The cooling effect of the surrounding river water can clearly be seen as the phase temperatures are in the range of 30 – 40 °C during Q1 (Jan, Feb, Mar), whereas they reach 60 – 70 °C during the hottest months in Q3 (Jul, Aug, Sep) for the same level of power. This effect is also illustrated in figure 6 which directly compares water temperature in the bulb with generator stator phase temperature. The points are biased due to the different heads and power outputs. The temperature levels are significantly lower as the design limits of the generator insulation (NEMA insulation class F, i.e. 155°C allowable temperature limit), and considered class of the temperature rise B (80°C). Both indicate that the generator lifetime will benefit from the favorable cooling conditions.

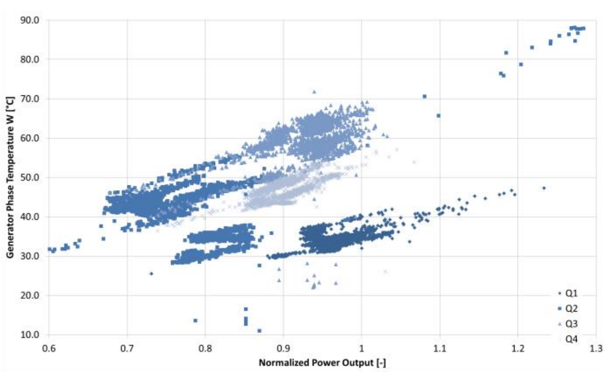


Figure 5 Generator stator phase temperatures during different periods of the year versus normalized power output

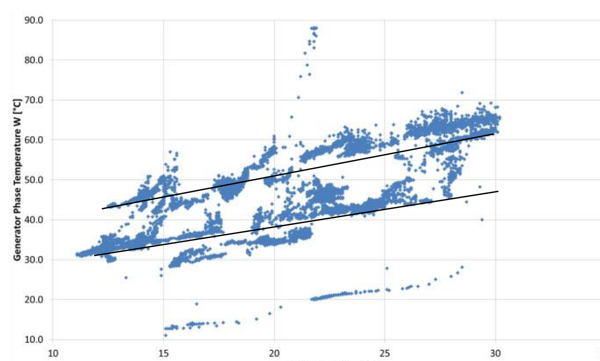


Figure 6 Generator water temperature versus water temperature in bulb (for full power range)

Inspection Feedback – February 2016

A second planned inspection took place in February 2016 after 3.5 years of operation. The objectives of the inspection were to get an overall impression on the machine condition.

- General visual inspection
- Measure the wear at the bearings
- Any damages which require maintenance

Figure 7 a) to f) show the general condition of the machine. The coated surfaces (bulb housing, inlet cone, guide vane) have a thin organic film, but the coating itself it fully intact. Some minor impacts can be seen at the leading edge of the guide vanes (a). The runner vanes are in perfect condition (b,c d) with no visual erosion or abrasion.

All leakage sensors were found in dry conditions, meaning that all static seals (i.e. generator stator) are fully intact and no maintenance s required for replacement.

In dead water zones, e.g. behind the inlet cone outside of the inflow stream, some Silver mussels could be found. None of them were present inside the bulb or at the inflow section.

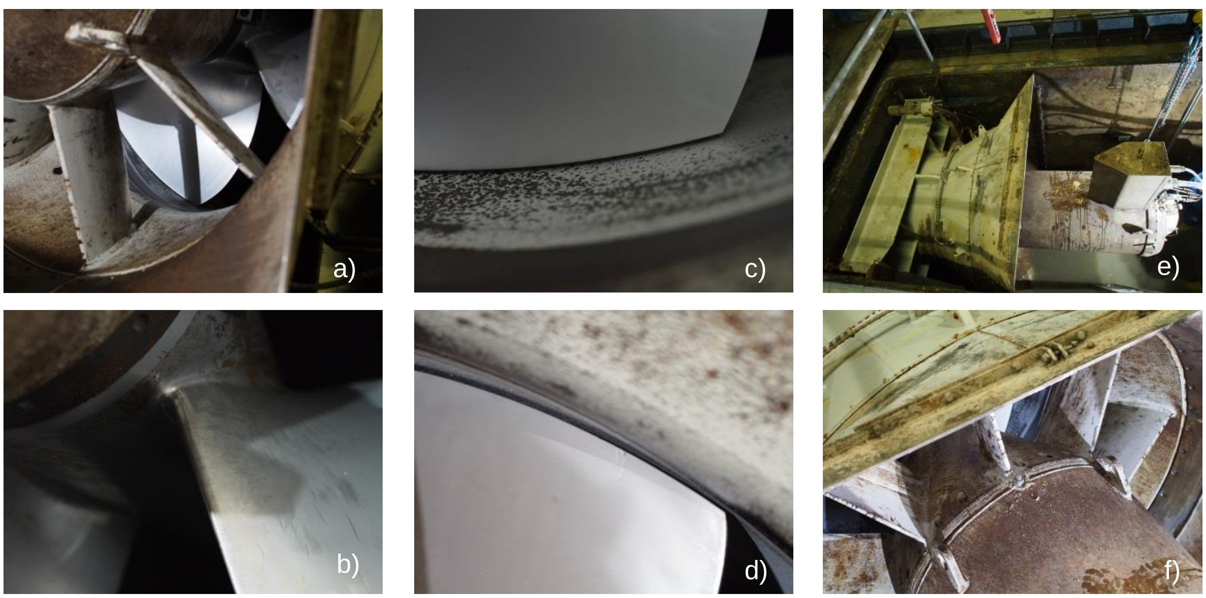


Figure 7 Pictures a) to f) show the overall conditions of the surfaces and components exposed to river water. The runner is in excellent conditions as well as the coated surfaces. Picture e) shows the unit with disassembled front cover and cable cover to get access to the NDE radial bearing and shaft end

Bearing Condition

The bearing design is one of the key features of the StreamDiver®. Therefore it was an objective to assess the bearing condition within this intermediate short-term inspection. To minimize the downtime, it was decided to only disassembly the front cover of the bulb to get access to the radial bearing at the non-driven-end (NDE). Therefore the chamber only needed to be dewatered and the unit did not need to be lifted out of the conduit. Operation could have started again after only one day.

- General visual inspection
- Measuring of clearances and displacements of the drive train
- Crack detection measurement by penetrant testing following ISO 3452-1
- Surface roughness
- Wear measurement of hard-coated layer of the shaft end by coating thickness gauge

The crack measurement (figure 8) did not indicate any porosity or cracks on the hard coated layer. The surface roughness measured at four different locations compared to original state remained at the same level or even indicated a smoother surface (lower level of Ra). As the natural abrasion of the bearings is comparable to grinding process, this seems reasonable. The abrasion, i.e. remaining thickness, of the hard coated surface layer also has been measured with an eddy current-based method for non-magnetic base materials. The results shown in figure 9 show that only 5-10% of the layer is gone after almost 30,000 hours (Feb 2016).

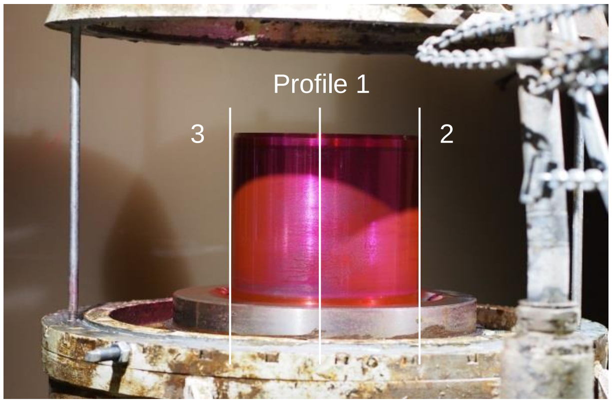


Figure 8 Hard-coated shaft end during crack measurement by non-destructive penetrant testing

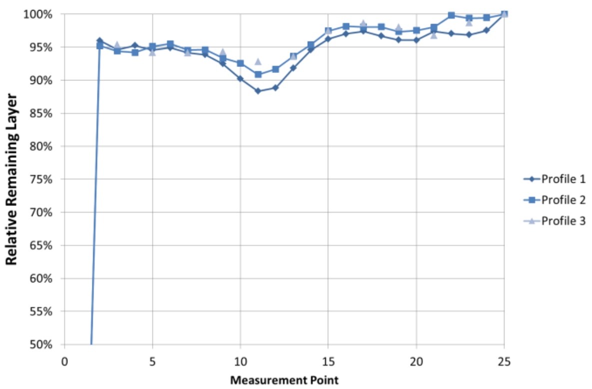


Figure 9 Measurement of the hard-coated layer thickness at three-different measurement planes

Due to the site-specific heads and loading of the machine, it is not possible to compare absolute levels of wear with the durability test results of the bearing test rig which have been conducted in 2011. As the “grinding” is driven by hard particles such as contents of Quartz which have similar or higher hardness rates as the coating, the sediments in the river water do play a role here. In the testing, different densities from the relative clean river water to up to 2 g/L of Quartz have been tested. In total, the trials ran slightly over 18,000 hours. It could not be concluded that there is direct correlation between the sediment density and the rate of abrasion. Results showed that there rather seems to be a threshold where noticeable abrasion takes place when densities of hard particles such as Quartz are exceeding this value.

The Danube canal does contain such sediments – and the measurement presented above also shows, that there is abrasion on the coating. As the same drive-train design and configuration was considered as in the test rig, preliminary indication of the relative loading and abrasion of the different bearing sets could be outlined. The relative abrasion was as followed:

1. Radial bearing – non-driven end (NDE) (as measured) 1
2. Radial bearing – driven-end (DE) x 1.7
3. Axial thrust bearing x 2.7

This would mean that the axial thrust bearing would currently show an abrasion of up to 27% (cf. with the measured 10% of the NDE radial bearing). If these values and relative behaviour can be confirmed during the comprehensive measurements after full retrieval of the prototype (i.e. end of pilot installation), the projected lifetime of the axial thrust bearing (which determines the maintenance interval) for the given project-specific loading and water conditions would be around 90,000 hours of operation. For 365-day operation as in Nussdorf, this means a 10 year maintenance interval. Obviously, these figures are assumption-based and remain to be confirmed.

Present and future installations, such as the installation in Bruksfors, Sweden, which is being operated since March 2015, will give additional inputs on these projections.

Summary

While providing the hydraulic performance of the well-known Kaplan and propeller machines, the StreamDiver® technology introduces certain new features, such as the innovative bearing and generator design. The open bulb concept with no dynamic seals concludes in a simplified plant concept regarding civil integration, balance of plant and O&M management. Clearly this promises to offer advantages over conventional designs for low head hydro sites. But the nature of innovation and compared to the history of hydro power, the technology is still young and therefore inherent to a lack of substantial track record. The work presents O&M aspects as part of the feedback from the running prototype in Austria.

The work first introduces the overall, integrated concept regarding its machine operation and maintenance and then presents results and feedback from the Nussdorf prototype installation which is now completing its fourth year of operation. As substantial assessment will be done after final retrieval and disassembly of the unit, the results now represent an intermediate testimony of the operations with preliminary conclusions regarding the lifetime performance of the design. However both, visual and general conditions of the machine as well as quantified abrasion and maintenance requirements confirm the design and its reliability as well as durability expectations.

With now over 30,000 hours of operation, the condition of the machine was outstanding. The runner presented itself in perfect shape; also the coated surfaces which are exposed to the water stream are intact. The cooling condition of the generator seems to be excellent with a temperature rise under load significantly below design values. This fact normally results in a good lifetime expectation of the windings and therefore increases the generator maintenance interval.

What does this all mean to the operator and plant owner?

As by nature of the concept, the risks for forced outage due to failure of dynamic seals, roller bearings, generator excitation system, lubrication oil or cooling water system is reduced to a minimum. Combined with long service intervals for the bearings, an easy plannable service plan and a simplified drive-train design (and therefore fast exchange of equipment), this results in the following:

- Reduced maintenance cost for staff and material
- Higher availability due to plannable service interventions
- Reduced risk for unexpected outages and therefore revenue loss

References

Voith Hydro’s StreamDiver: Small Hydro Solutions to Meet 21st Century Demand, Irrigation Leader Volume 6 June 2015
StreamDiver utilises new hydropower potential, International Water Power & Dam Construction, March 2015
DIN EN ISO 3452-1
World Energy Outlook Special Report, September 2013 (www.worldenergyoutlook.org)

The Authors

Philipp Daus joined Voith Hydro in 2010 and started as a development engineer in the department for hydraulic development for tidal energy converters. Since 2014, he works as an Engineering project manager for small hydro. He is currently responsible for the central product development and business development for the StreamDiver technology in the core team located in Heidenheim, Germany. He graduated with a master’s degree in Mechanical Engineering from the University of Karlsruhe (KIT).

Brian A. Murtha has worked at Voith for 9 years in the fields of hydraulic engineering, product development, and marketing. He is currently the Sales Manager of Small Hydro in York Pennsylvania. He has a master’s degree in Engineering Science and Mechanics from the Pennsylvania State University.

Joerg Lochschmidt graduated in 2007 from the University of Applied Science in Ulm, Germany with a degree in industrial engineering and management. Since 2007 he works as a Product Manager at the headquarters of Voith Hydro in Heidenheim, Germany. Between 2007 and 2010 he he executed various projects within the development of the small hydro division at Voith. Since 2010 he is project manager for the development of the StreamDiver technology.