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Layman´s Report

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1 Introduction

In the European Union, hydropower accounts for approx. 10 % of the total power supply. Electricity from hydropower is mainly generated in large dams, i. e. dams with a height of at least 15 m above the base or plants with a height of 5 to 15 m and with a reservoir volume of at least 3 million m^3.

The head was often artificially increased by damming or diversion to increase the amount of generated energy. Especially the extensive water diversion is no longer tolerated by the EU as the strong reduction of the river’s water discharge has negative effects on the environment. But there is a great amount of existing small weirs on rivers all over Europe. These small weirs are mostly river barrages to avoid river bed erosion as a result of a past river regulation, to establish the navigability, former locations of a mill or a former irrigation system. These location often have small head differences und thus, even with the deployment of the latest technologies, the generation of energy without water diversion is usually uneconomic. Another disadvantage of these river barrages is that they are often not passable by fish and therefore make a fish migration impossible. This reduced the fish stock and the biodiversity in many European rivers considerably. This condition cannot be resolved by modern hydropower systems but the ecological situation is rather worsened and thus there are economic as well as ecological limits to a continued use of the present hydropower technology.

With the support of the EU Life Programme Project it was possible to realize a completely new hydropower principle for the first time in the course of a demonstration project. In this approach, turbine and generator are directly coupled inside a frame which is movable and where water can flow around. This new system showed that the ecological aspects of the re-establishment of fish passability can be combined with economic aspects and an improvement of the efficiency of hydropower plants.

2 Technology

There are many unused locations with low-pressure power plants with a head < 5 m all over Europe. These locations hardly require water diversion and are thus more likely to be authorized.

Rather than the head difference, the decisive factor for the plant's output is the (large) amount of water. But large amounts of water require large constructions and components which results in high costs. Due to the low head, the hydraulic loss should be as small as possible but the bedload sediment and a backflow in the downstream water cause a quick loss of the head difference and thus reduce the output. In addition, environmental regulations require that fish can safely pass the plant. Conventional hydropower plants can only comply with these regulations by the construction of additional expensive structures.

The demonstration project supported by the EU Life Programme therefore had the aim to realize the world's first movable hydropower plant of overflow and underflow type on an industrial scale. On one hand the changes on the existing local ecosystem should be reduced to a minimum and on the other hand the significantly improved cost-effectiveness should ensure an economic operation due to a high level of energy efficiency, even with the still low prices for primary energy. Existing weirs should be utilized directly and without water diversion while taking fish protection into account.

For that purpose a new powerhouse design was realized for the first time in a demonstration plant of overflow and underflow type. In this way it is possible for fish, bedload and flotsam to pass the hydropower plant above or below the turbine.

The innovative feature of this hydropower plant (see Figure 1) is mainly the ability to change the gradient of the complete powerhouse with an integrated unit of turbine and generator according to the hydraulic fluctuations caused by high and low water. Similar to a movable upper part of the weir, the level of the headwater is kept constant at surplus water supply and at the same time counteracts sedimentation of the weir by a bedload transport downstream the powerhouse. The flow with surplus water additionally causes an ejector effect that increases the utilizable head for the operation of the turbine. Depending on the location of the plant, these effects can increase the efficiency up to 35 % compared to the present conventional hydropower plants. Moreover, the direct coupling of turbine and permanent magnet-excited synchronous generator achieves an increase in efficiency and a reduction of operating costs.

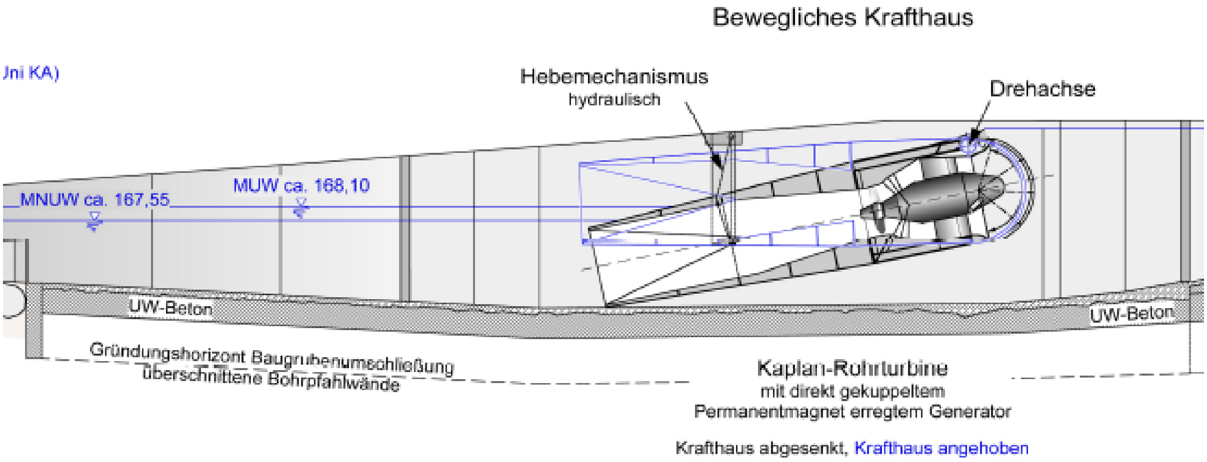

Figure 1: Longitudinal cut of the movable hydropower plant of overflow and underflow type for the demonstration activities in Gengenbach

The frequency converter usually used with these generator types is omitted which achieves an additional average increase in efficiency of approx. 3 to 5 % compared to conventional turbines with transmission and high-speed generators. Figure 2 (left) shows a 3D CAD image of the coupling of Kaplan turbine and PM generator (PM = Permanent Magnet). We were able to build on experiences gathered at a hydropower plant on the river Fils near Faurndau were the direct coupling of turbine and permanent magnet-excited synchronous generator was realized for the first time.

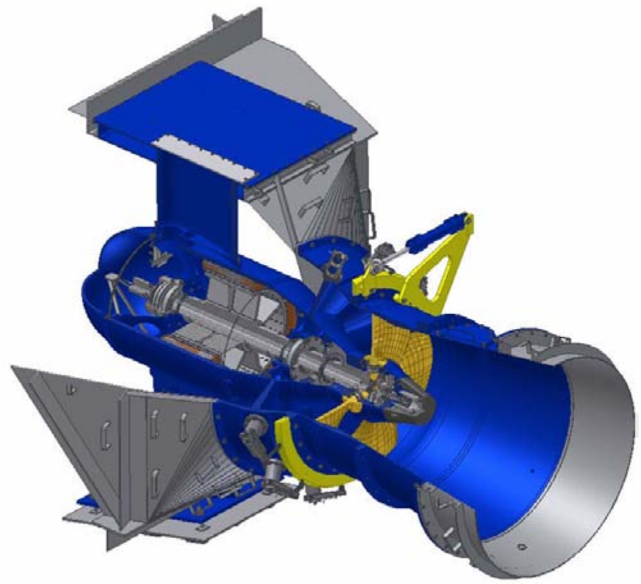

Figure 2: 3D CAD of Kaplan turbine with directly coupled PM generator

A major advantage of a PM generator is a loss in nominal capacity of 30 % due to the elimination of the electromagnetic excitation device. Since the excitation power at a near constant supply voltage is independent of the performance there is a significant gain in efficiency in part-load operation (see Figure 3).

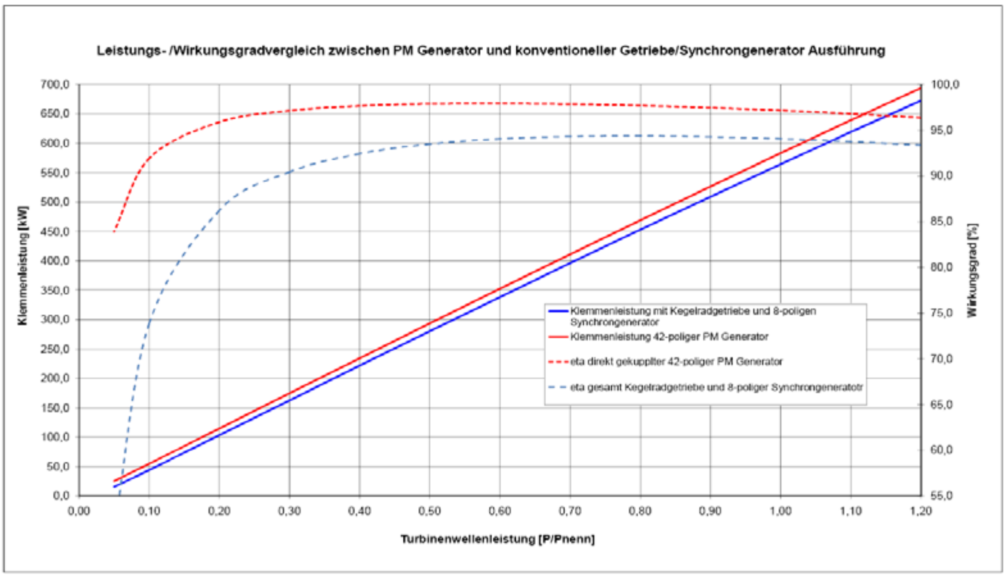

Figure 3: Comparison of the performance improvement and efficiency by use of the PM generator with Kaplan turbine

The curved bar screen at the turbine inlet and the automatic screen rake were newly developed and implemented for the first time (see Figure 4).

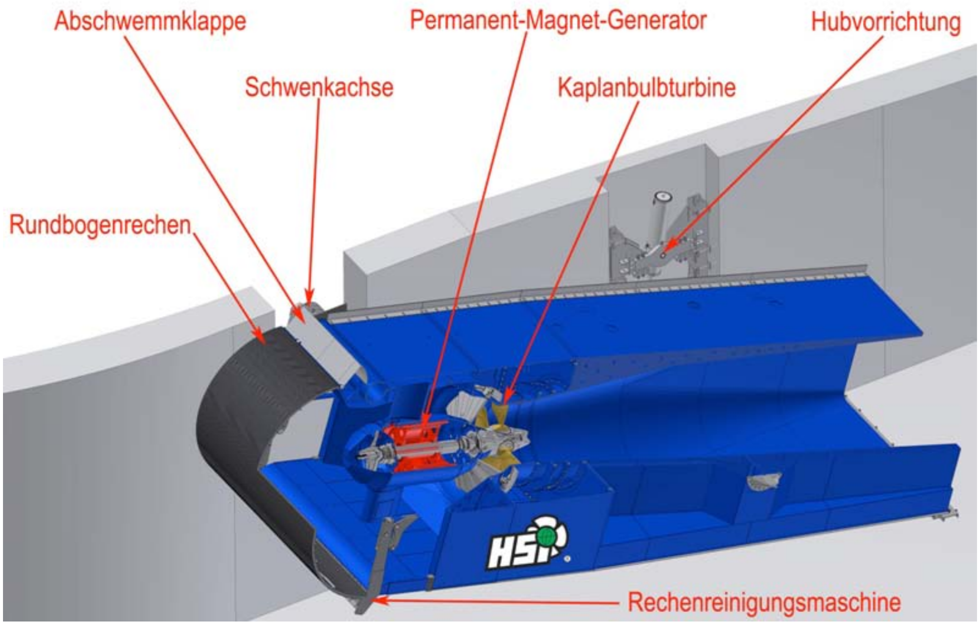

Figure 4: System of the movable hydropower plant

Preliminary analyses showed that the acceleration and tangential discharge of the flowing water in the upper and lower area have a positive effect on the migratory behaviour of fish. In contrast to conventional screen rake systems, the cleaning rake is always in contact with the rake during one cleaning cycle. In connection with the particular design of the cleaning rake, the risk of injuring fish is greatly minimized. At the same time and especially with a high water discharge along with a high proportion of floating debris, the trash rack is cleaned twice during one cleaning cycle which is not possible with any conventional bar intake screen system.

3 Results

The weirs at the river Kinzig in Gengenbach and Offenburg were considered as ecologically particularly in need of improvement as they could not be passed by fish. At both weirs we realized demonstration plants with the new principle of the movable hydropower plant of overflow and underflow type. The construction and planning of the demonstration plant was conducted by the company Hydro-Energie Roth GmbH, the permanent magnet-excited synchronous generator was constructed by the company Krebs & Aulich GmbH, the Kaplan turbine along with casing, suction line and screen rake were constructed by the company HSI Hydro Engineering GmbH and the curved bar screen was delivered by the company Arpogaus GmbH.

The trough structure was realized by secant pile walls (see Figure 5). Figure 6 shows on the left side the lowering of the powerhouse with turbine and generator and the completed plant in operation on the right side.

Figure 5: Construction of the trough of the plant made out of secant pile walls

Figure 6: Lowering of the powerhouse and completed hydropower plant in Gengenbach

Numerous pictures demonstrating the construction progress can be found on the internet at www.das-bewegliche-wasserkraftwerk.de or moveable-hepp.com. The site also shows up-to-date images of the webcams that are installed on the location and you can access the current performance data for the plants.

Both plants were tested over the course of several months and have proven their functionality during an automated operation in low water as well as in high water situations.

Conclusions of the ejector effect

The installed measuring technology and the corresponding visualization of all relevant technical parameters made it possible to show the predicted significant increase in performance caused by the flow around the powerhouse (see Figure 7). To demonstrate the performance improvement caused by the ejector effect, the upper water level was at first controlled by the waterflow below the movable powerhouse while the turbine was fully opened and the flap gates were lowered at a water discharge of the Kinzig of about 40 m³/s.

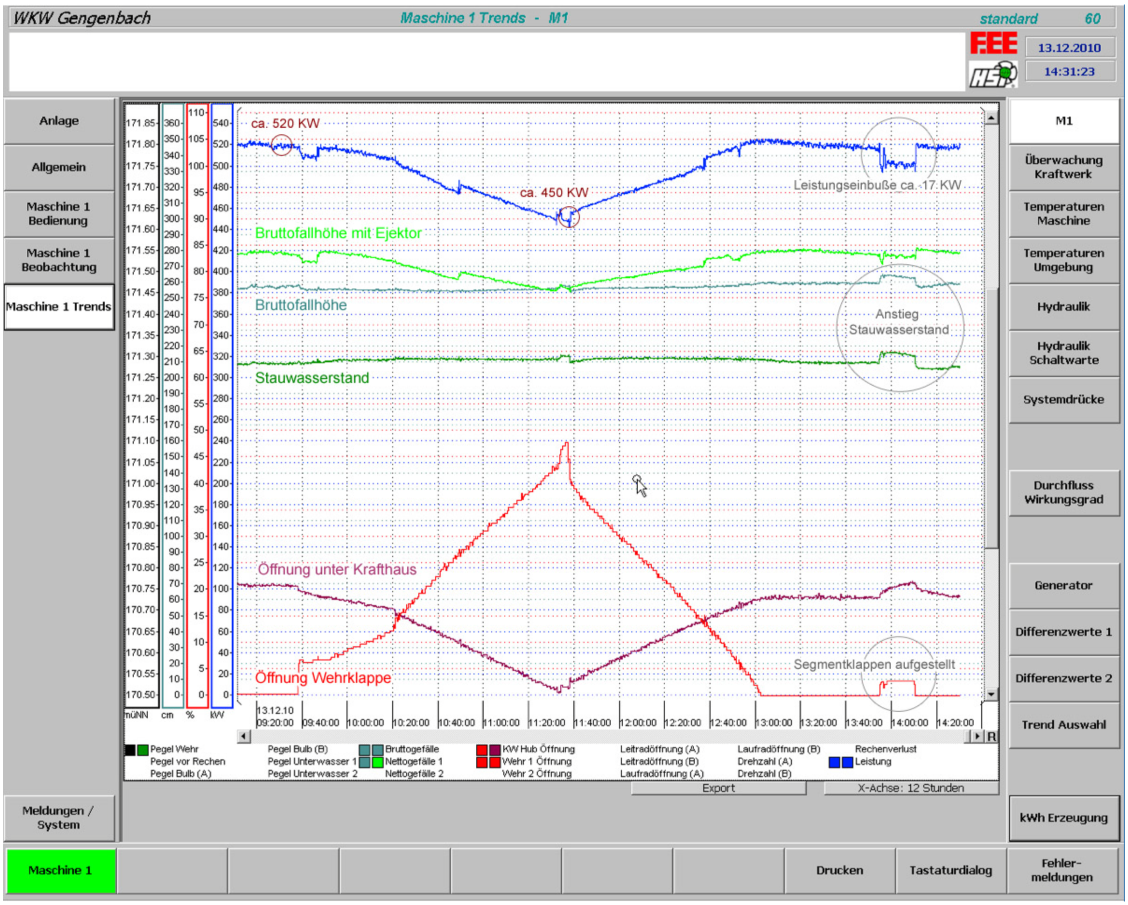

Figure 7: Screenshot of the visualization for the detection of the ejector effect

Then the lift inlet under the powerhouse was decreased from 20 % to 0 % by a minimal raise of the water gauge above the setpoint of the weir gate control. The excess water was discharged at the same rate over the weir flaps, which is evident in figure 7 from the opening level of the weir gate. Similarly, it is evident that the gross head remains almost constant at a level of about 2.55 m. To illustrate the ejector effect, a second sensor was installed approximately 2 m behind the suction tube.

Here it is evident that the head useable for the performance rises with an increased opening at the end of the suction tube. Figure 7 shows that the lowered powerhouse produced an output of about 450 kW while a lift of the powerhouse of only 20 % increased the output to 520 kW. If we took into consideration the ejector effect which results from the overflow by turning down the segment flaps on the back of the powerhouse (which is not given in conventional systems) with an additional output of approx. 17 kW, this would gain an increase in performance compared to a conventional hydropower system of

520 kW - (450 kW - 17 kW) = 87 kW, or approximately 20%!

The maximal performance increase of nearly 36 % could be measured at a power house lift of about 40 %.

The data are provided on the internet which allows a comparison of both plants at any time. The plant in Gengenbach provides a higher energy production due to the higher head and the approx. 8 m³/s larger utilizable water amount. In Offenburg, this share mainly has to be transferred due to preferential water rights.

Fish ecology

In terms of fish ecology the movable powerhouse is of special interest as fish can pass downstream above the constantly overflown power plant. On the other hand fish that prefer to swim near the river bed can pass downstream below the plant as this is slightly lifted in periods of fish migration.

For both demonstration plants we installed curved bar screens with a distance of only 15 mm between the bars. Based on convenient current fields in front of the rake, fish are prevented with a high efficiency from swimming into the hydro power plant or to be sucked into it due to a lower flow velocity (see Figure 8).

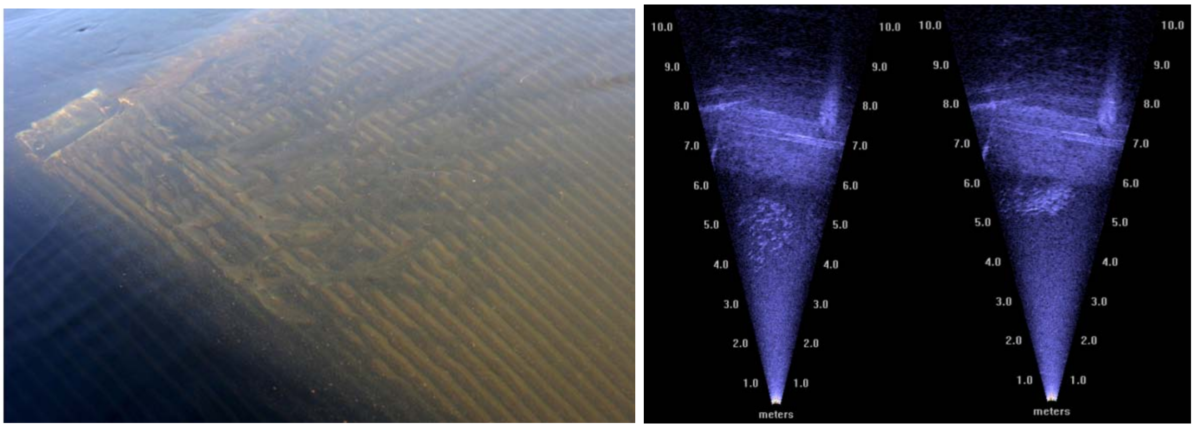

Figure 8: Shoal of spirlin in front of the rake (on the right two scans with a DIDSON sonar)

The impacts of the movable hydropower plant of overflow and underflow type on fish were examined by fisheries biologist and ecologist Klaus Blasel, Freiburg. He instructed the company “Büro für Umweltplanung, Gewässermanagement und Fischerei“ (office for environmental planning, river management and fishery) in Bielefeld and the economic business operations of the “Landesfischereiverband Westfalen und Lippe e. V.“ (federal state fisheries association) to work on special problems concerning the compatibility of fish with the movable powerhouse.

For this purpose the sonar method of „DIDSON“ was used (see Figure 8 on the right) that makes the observation of fish migration possible, independent of turbid water and of discharge and without any kind systematic influence (fishing nets or traps) on fish. The examination showed the possibilities of the fish pass above and below the plant in which the fish pass for descending fish can be supported by the operation of the screen rake.

A near-natural fish pass for ascending fish was constructed next to the trough structures that were in Offenburg additionally completed by a technical fish pass. They were constructed according to the appropriate latest findings.

Figure 9: Webcam images of the plants with fish lader (left: Gengenbach; right: Offenburg)

On the whole, the principle of the hydropower plant of overflow and underflow type was certified a high degree of fish-friendliness. Due to the achieved passability of both weirs the various fish species have the possibility to migrate through the river Kinzig and reach their former spawning grounds.

Another accompanying measure for the ecological improvement was the remodelling of the former canal in Gengenbach into a near-natural tributary that created new spawning grounds. In Offenburg, a new fish ladder was realized at the inlet of the canal making it passable for fish at least until the old hydropower plant.

4 Environmental benefit

The environmental benefit of the movable hydropower plant results from the improvement of the ecological situation on the site as the river Kinzig was not passable for fish at the reaches and canals in Offenburg and Gengenbach prior to the start of the project. The demonstration activities guarantee the fish passability and the descend above and below the turbine and thus directly fulfilled the goals of the programmes “Rhine Action Programme“, “Salmon 2000“ and “Rhine 2020”. These programs strive for instance for a recreation of the ecological fish passability in feeders of the Rhine.

Furthermore, the use of hydropower reduces the carbon dioxide emissions according to the Kyoto protocol (1997) and the goals of Rio de Janeiro (1992). A particularly positive effect had the energy efficiency of the demonstration plant that results from the additional ejector effect of the flow and the direct coupling of turbine and generator. The verification of the energy efficiency could be made in the context of the project. With an operating life of 50 years, both plants can save about 175,000 tons of carbon dioxide.

Particularly with regard to the nuclear power debate since the Fukushima disaster and the consequential need for more energy from renewable energy sources, the new hydropower technology can make a limited but nevertheless important contribution to the future local energy supply in Europe and in the world.

5 Transferability of the project results

There is a great amount of several hundred existing small weirs on rivers all over Europe. These small weirs are mostly river barrages to avoid river bed erosion as a result of a past river regulation, to establish the navigability, former locations of a mill or a former irrigation system. These locations often have a low head difference so that even with modern technologies the use of these locations is mostly inefficient without water diversion for energy production. These river barrages often have the disadvantage that they are not passable for fish and thus make fish migration impossible. In many European rivers the fish stock and biodiversity was thus considerably reduced. Conventional hydro power plants were not able to avoid this fact but rather worsened the ecological situation.

The new movable hydropower plant of overflow and underflow type of this demonstration project could be realized in a number of these river barrages und could thus enable the passability of the weirs and reduce the impact on the environment by the regenerative production of energy.

The largest unit that can be transported on streets has a maximal turbine throughput of approx. 25 m³/s which can be used in areas with a head difference of approx. 1.5 m up to approx. 8 m.

The significant advantages of this hydropower plant are that the use of additional weirs and gravel traps during the operation of several parallel units becomes superfluous and for this reason there are already inquiries of international engineering companies concerning the use at larger locations with a design flow of up to 300 m³/s. An interesting alternative could be to join two units to a double unit which would double the width of the discharge below the power plant. This would be a significant improvement of the security concerning the flood water flow. Prior to an initial implementation the appropriate modelling and calculation will take place in the next couple of months.

6 Summary

This demonstration project showed that hydropower and nature conservation can complement each other very well and that the construction of the new hydropower technology of overflow and underflow type can achieve considerable ecological improvements on existing weirs.

In the context of the demonstration project the newly developed hydropower principle with a movable powerhouse of overflow and underflow type was realized for the first time on an industrial scale at the above mentioned locations at the river Kinzig.

An independent consultant proved that fish can pass the plant without being injured and certified the demonstration plants a high degree of fish-friendliness.

The demonstration projects were thus able to restore the passability of the river Kinzig for salmon and other fish species at the locations in Offenburg and Gengenbach and both plants generate renewable energy with a significantly improved efficiency compared to the presently existing hydropower plants.

Conclusion: With all the advantages regarding ecology and flood protection, the technology of the hydropower plant of overflow and underflow type especially offers a higher efficiency than conventional hydropower plants which has a positive effect on the energy output.

With construction costs that are not higher than the costs of a conventional hydropower plant technology and operational costs even below them, the movable hydropower plant also offers significant economic advantages.