

Sección **ESPECIAL**



Decisions that make a hydropower project successful

Decisiones que hacen que un proyecto hidroeléctrico sea exitoso

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Abstract

Hydropower design is an interdisciplinary task which needs both the understanding of natural mechanisms and technical expertise. The initial investment in a hydropower plant is reasonably high. Once the project is complete, the options of modification are relatively poor – consequently a set of decisions has to be managed very carefully and with high responsibility. It makes complete sense to invest some time and money in detailed analysis, particularly of the natural mechanism, which is always a unique task. Engineering has to act with nature and not against it. Unfortunately, hydrological data, including bed load transport, are in many projects the weak point. Significant efforts have to be made to close this gap and to design hydropower plants that can run smoothly for hundreds of years.

Keywords: hydropower, hydropower plant design, technical-economic optimization, bed load transport.

Resumen

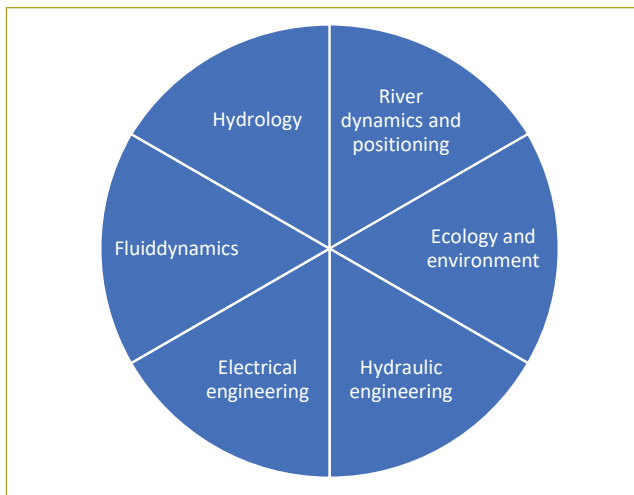
El diseño de una planta hidroeléctrica es una tarea interdisciplinaria que requiere entender tanto los mecanismos naturales como un profundo conocimiento técnico. La inversión inicial de cualquier proyecto hidroeléctrico es considerablemente alta. Al completar el proyecto, las posibilidades de modificarlo son virtualmente nulas, por lo tanto, se deben tomar decisiones que requieren una gestión cuidadosa y que conllevan una gran responsabilidad. Es evidente que se requiere invertir tiempo y dinero para realizar análisis detallados, en especial de los mecanismos naturales, los cuales son extremadamente peculiares para cada caso. La ingeniería debe estar en línea con la naturaleza y no en contra de ella. Desafortunadamente, los datos hidrológicos, incluyendo transporte de carga de fondo, son los puntos más débiles en la mayoría de los proyectos. Se deben realizar esfuerzos suficientes para cerrar la brecha y diseñar plantas hidroeléctricas que funcionen sin novedades por cientos de años.

Palabras claves: energía hidroeléctrica, diseño de centrales hidroeléctricas, optimización técnico-económica, transporte de sedimentos.

INTRODUCTION

The design and engineering of a hydropower plant is a quite complex exercise and needs expertise in various disciplines. Few of those are crucial regarding the overall quality of the project. Due the fact that hydropower is harnessing a natural resource the engineer has to fully understand the natural processes. The water cycle and the dynamics in the river remain completely individual and a general rule is impossible. The better the knowledge about the river and its flow the higher the chances to develop a successful project. The following graph gives an overview of competences necessary.

Figure 1
Competences necessary (own design)



Of course, there are many more topics addressing the engineering of a hydropower plant in later stages of design like connection to the grid, used materials, accessibility and several operational aspects not to be discussed in this article. All of them are very important as well. This article will concentrate on very early decisions, not to be revised later on and therefore essential for all the future of a plant.

What makes a Hydropower project successful?

Building and operating a hydropower plant is a business that needs significant investment, particularly in an early stage. Success is the core of any business and different kind of business need individual criteria to measure the overall success.

In terms of hydropower the focus can be laid on five criteria:

- Economic viability.
- Operational reliability.
- Minimised maintenance.
- Long lifetime.
- Public acceptance.

Economic viability means that the project meets the targets of a critical cost-benefit analysis considering the investment, the expected income and the lifespan of the plant respectively of its components. As the real minimum request the technical lifespan should be higher than the payback period of the plant.

Operational reliability means that the components of the plant fulfil more or less perfectly the functions the components are built or installed for. To give an example – The water intake of a plant should divert a certain amount of water from the river. And this function must be guaranteed for the entire lifetime of the plant. If the intake is blocked by gravel or logs during a flood event or if sand or bedload material in general is getting into the headwater channel or pipeline, this guarantee will fail.

Of course, in case the operation of the plant is running smoothly, the maintenance necessary will be at the minimum. That does not mean, that zero maintenance is possible or recommended. Even a well-designed and perfectly operating plant needs continuous maintenance and control in order to identify upcoming problems as soon as possible. Similar to human health, early identification of problems will ease the repair work necessary.

Hydropower is definitely not a short-termed business. The initial investment is rather high and the plant will reach the most profitable period approximately after 10 – 15 years. The real lifetime is much longer; 50 – 70 years can easily be reached if the plant is operated carefully. In case the concept of the plant is very good, components of the plant like a turbine or a pipeline can be replaced and prolong the lifetime further on.

A non-technical criterion of success is the public acceptance. It is not a simple task to reach this target and the process starts very early with the planning and the construction. Interaction with the local population and inclusion of local workforce are important steps to create a psychological “ownership” among the population. The direct supply of electricity to households or local companies will strengthen this feeling during the entire

lifetime of the plant. Maintenance and repair work can be done by local companies.

The following chapters will deal with selected specific topics to be addressed during the design process. It is by far not a complete list and in all cases we talk about optimisation, which is finally one of the secrets of success.

IDENTIFICATION OF THE MOST ATTRACTIVE RIVER REACH

When starting with the idea of a hydropower project it is highly recommended to firstly get a clear picture of the river to be used. The research includes a longitudinal section and the calculation of the size of the catchment respectively sub-catchments both based on available maps or GPS data.

The second critical information needed is the hydrology of the river. In best case there is a gauging station available providing data series. This best case remains in the great majority of projects a wish of the engineer. Usually he has to find other methods to at least estimate the flow conditions. Although hydrological data are the crucial point in hydropower design this topic will not be subject of this article.

In this stage precise hydrological data are not yet necessary, because they do not have an impact on the identification of the most attractive river reach.

Having the information about topography and hydrology it is possible to create a “Longitudinal section energy” shown in the following picture.

As it is described in the legend, the input data are elevation, catchment area and specific discharge, a very

useful unit in $\text{l.s}/\text{km}^2$. Particularly when hydrological data are not available, this value allows the comparison with other observed catchments with similar character in terms of altitude, size and precipitation. As a first approximation and only allowed for smaller catchments this value can be assumed constant. The specific discharge relates the size of the catchment with the mean flow.

The result is the energy potential in kW/km (red line), calculated river reach by river reach. In the specific example there are several reaches offering potential of different attractivity. Between $\text{km } 17 - 18,7$, $12,2 - 13,5$, $10 - 11,4$ and $0 - 2,9$. The best seems to be between $12,2 - 13,5$.

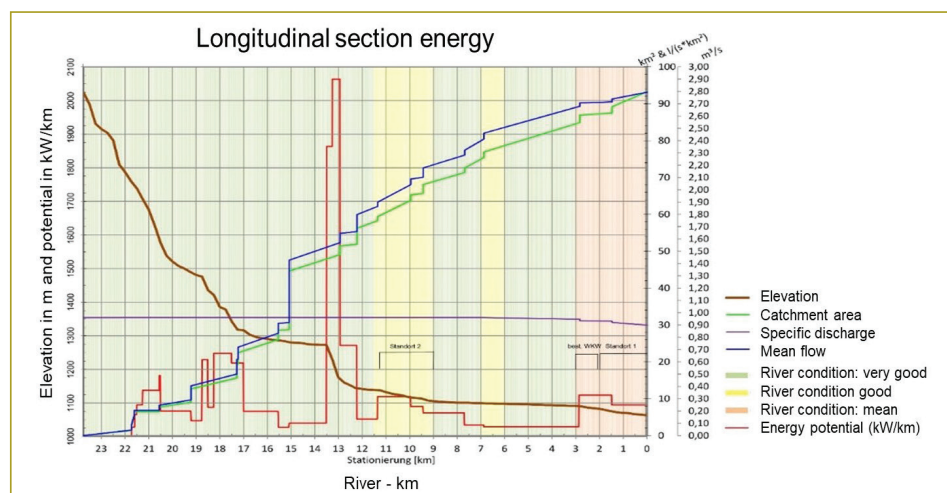
But the theoretically best solution cannot be realised due to environmental restrictions. A waterfall with a head of approximately 100m is located in the potential diversion reach and environmentally protected. The colours – light green, light yellow and light red – indicate the environmental river condition.

Finally, only two positions remain, because there is already an existing plant between $\text{km } 2,1 - 3$. Further calculations and research work have to address additional parameters like the existence of electrical lines or access conditions and will find out, which position has to be preferred.

SELECTION OF RATED DISCHARGE

Assumed the procedure described in the previous chapter ended up in the decision for one of the two options, the next decision is again crucial regarding the success of the project: the selection of the rated discharge. In

Figure 2
Longitudinal section
energy (own design)



a first preliminary project the rated discharge can be estimated by taking the rule of thumbs: 1 – 1,2 mean flow. In several cases this estimation will be quite ok but a serious and understandable engineering must be based on an optimisation process.

A precondition of the optimisation are reliable hydrological data in a daily resolution and a period of some years at least. Depending on the institution operating the gauging station, it is recommended to check the validity of the rating curve used by individual control measures. The investment for the installation of a gauge is negligible compared with the investment of the plant.

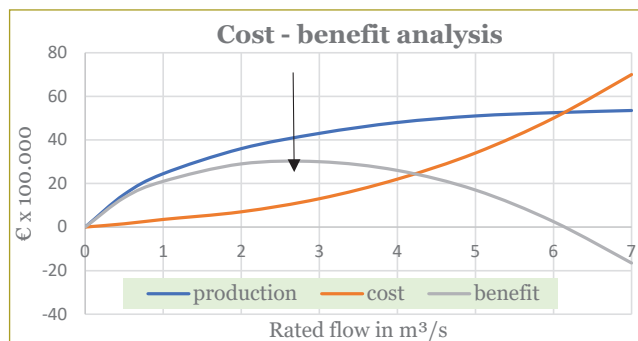
The optimisation is well known as “Cost-benefit analysis” and requires the definition of a remarkable number of alternatives to be compared. The selection of these alternatives can most easily be done by using different percentages of the mean flow.

An experienced strategy is the use of 90%, 100%, 110%, 120% and 130% of mean flow. Of course, such an optimisation creates detailed work particularly regarding the cost. It is necessary to perform at least a preliminary design for several solutions, calculating the bills of quantity and collecting offers from different suppliers of turbines, pipes etc.

Assumed the good hydrological data are available, the calculation of the annual electricity production is relatively simple. The basis of the calculation should be the daily values of the hydrograph. Using mean values – for example monthly mean values – will significantly overestimate the production because very wet or very dry periods got hidden.

The following picture shows the final result of the procedure. The production (blue line) is – according to the shape of a flow duration curve – a degressive function. The cost (red line) is usually slightly progres-

Figure 3
Cost benefit analysis (own design)



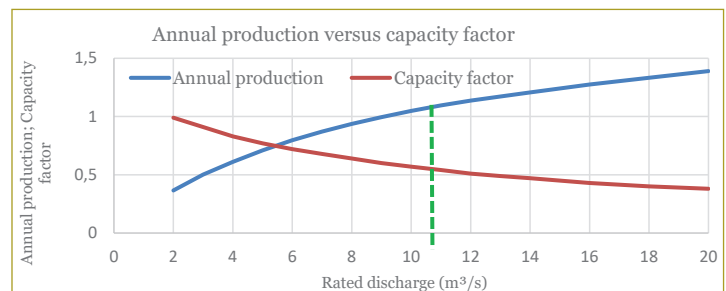
sive because the increase of the rated flow will activate additional topics to be included in the design. An example is the cost of pipes.

The grey line is the difference curve and shows a clear maximum at around 2,6m³/s – the recommended rated flow.

Of course, the picture simplifies the process, because the period of amortisation and interest rates have to be included and any change will change the result as well. Additionally, the value of the electricity produced may significantly influence the result.

Another hot topic related to the rated discharge is the capacity factor. It is defined as: real annual electricity production / theoretical maximum annual electricity production. A high capacity factor is not indicating the quality of a project. Experienced based values vary between 45 and 60%. Higher values indicate an incomplete exploitation of the existing hydropower potential.

Figure 4
Annual production versus capacity factor (own design)



SURFACE WATER INTAKE

The water intake is one of the most critical elements of a hydropower plant. The technical request is the division between clean water to be used in the plant and other material like sand, gravel or floating debris transported by the river. All that solid material will cause problems within the water conveyance structure. The very best solution is to keep the solid material in the natural river and to fully block any entrance.

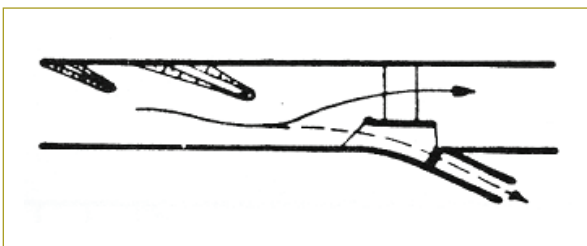
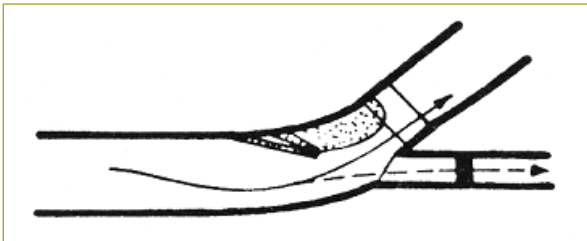
The very beginning of the solution is not the construction itself but the position in the river. The following picture shows clearly the behaviour of the river in a bend. Bedload is always moving at the inner side of the bend. That means any intake should be positioned at the outer side of the bend.

Figure 5
Bend at river Ybbs/Austria (own picture)



The following drawing shows good solutions – either in a bend of the river or in a straight river reach. In both cases groins will be helpful in order to intensify the river morphological mechanism.

Figure 6
Positioning of water intake (Radler, 1981)



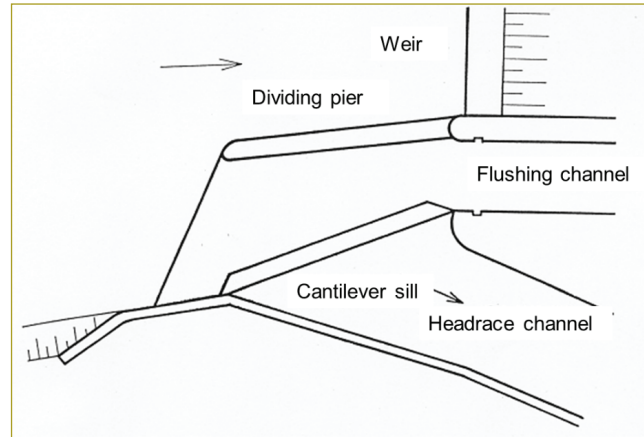
The two groins in the second picture simulate an artificial bend of the river and initiates the morphological reaction.

Usually any free surface intake is related to a weir, increasing the water level at the intake. The increase of the water level will slow down the flow velocity and consequently initiate the sedimentation of bedload material. The backwater area will be filled up very soon and an effective flushing gate is essential for the effective

operation of a plant. Otherwise bedload will enter the water conveyance structure and mechanical digging out will become a never ending and costly story.

The following drawing shows a very good solution on how to keep bedload in the river.

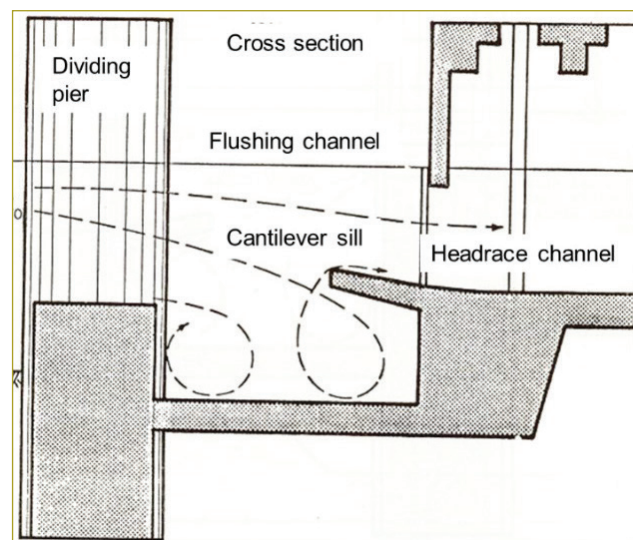
Figure 7
Intake with cantilever sill (Radler, 1981)



The function of the flushing channel is essential because the bedload must not remain in front of the intake but must be flushed as soon as possible. Depending on the recent bedload transport in the river the opening of the flushing gate can be adjusted.

The innovation is a cantilever sill instead of a traditional sill. It strengthens the function significantly.

Figure 8
Intake with cantilever sill (Radler, 1981)



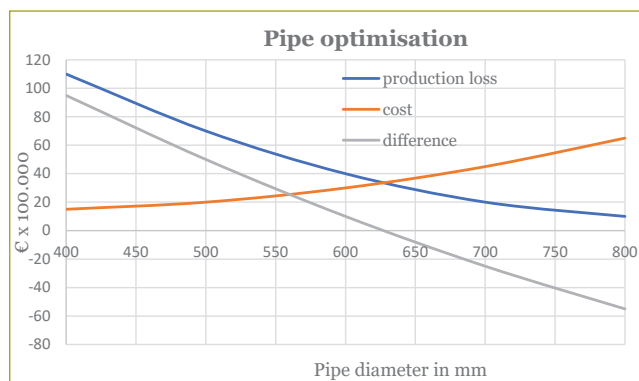
As already mentioned, the defence of the bedload is only one part of the whole concept. The drawing above shows the positions of a trash rack, a skimming wall and an intake gate, protecting the water way against floating debris, which is not welcome in the channel as well.

DIMENSIONING OF A PIPELINE

A pipeline and/or a penstock is an essential part of a high head plant. A rough estimation allocates around 50% of the total cost to it. Therefore, it is important to take the best possible solution and to invest some time in the optimisation process. Equal to the optimisation of the rated flow, the optimisation is a cost-benefit analysis. The input is on the one hand side the cost of the pipe and on the other hand side the variation of electricity production due to variable head loss.

The calculation of the production loss is again based on hydrological data and should be done for “mean” years but for dry and wet years as well. The results will vary. The calculation of the cost is a bit trickier, because different pipe material will cause different cost resulting in different pipe dimension.

Figure 9
Pipe optimisation (own design)



As the final result the graph above indicates a pipe dimension of maximum 625mm. If a larger diameter is selected the cost will not be compensated by the revenues due to higher production. The process may become even more difficult if different pipe dimensions should be used. Such a decision is recommended. The higher pressure in the lower part of the pipeline usually asks for smaller diameter reducing the cost. Using even more than two different pipe diameters within one

pipeline is a clever decision because during transport the pipes can be telescoped. This approach is also called “nesting”.

DESIGN AND DIMENSIONING OF A HEADRACE CHANNEL

In some projects the waterway includes a headrace channel. The design and the dimensioning have to meet more restrictions than the dimensioning of a pipeline. The economical optimisation is only a first step of the engineering. The following criteria should be respected:

- Little head losses.
- No sedimentation.
- No erosion (max flow velocity, stabilisation of the banks).
- Ecological function.

Ad 1

Head loss is in many topics the key factor. Regarding an open channel the optimisation is equal to a pipeline. Input factors are the cost of construction and the head loss.

Ad 2

Despite optimised solutions at the water intake it may happen, that little grainsize sand or even smaller particles will enter the channel. Particles of this size may not cause any problems at the turbine depending on its type and size. The potential problem can be found in the sedimentation in the channel due to very low flow velocity. Sedimentation will further on reduce the size of the cross section and increase the flow velocity. A specific equilibrium is the final situation. Consequently, a minimum flow velocity has to be defined in order to avoid sedimentation. Sedimentation will not occur in low flow periods because there will be practically no bedload transport in the natural river.

Ad 3

High flow velocities will usually not be the preferred solution following the results of the technical optimisation. Nevertheless, it must be said, that higher velocities need additional measures to stabilise the bed and the embankment resistant against erosion mechanism. Those measures will cause additional cost. Concluding—

the maximum flow velocity will decide upon technically necessary stabilisation measures.

Ad 4

Since approximately 20 years even an artificial channel, being part of a hydropower plant is seen as animal and plant habitat. This view of the authority causes additional claims that must be considered.

Some of the essential design elements are:

- **Structured embankments:** Instead of smooth concrete troughs, flattened banks are created with deadwood, rough riprap or fascines. These elements create retreat spaces.
- **Habitat diversity:** The installation of groynes, sturgeon stones or small gravel islands creates different flow velocities and water depths in the canal.
- **Vegetation:** Companion vegetation will serve as habitat for specialised species of birds and will shade the water course.

Some of the ecological criteria contradict the technical objectives. The designer has to find a compromise and bring together the different goals.

The following picture is a quite good example to meet several targets mentioned above.

Figure 10

Headrace channel in Austria (own picture)



SUMMARY

The successful design of a hydropower project depends primarily on long lasting engineering experience. Technical knowledge and competence including interdisciplinary cooperation are the preconditions. Any hydropower project is very individual and cannot be designed following general rules.

REFERENCES

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