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Designing a Small Water Power Plant in Poland in the Aspect of Minimizing the Impact on River Ecosystem

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Abstract: A small hydro-power plant designing in aspect of current legislation is an interdisciplinary problem because of the fact that efficiency priority is not so important as ecological one. In this article the regulations concerning permissions for plant operation are discussed. The small hydro-power plant designing criteria are presented in the aspect of a plant impact on the river ecosystem.

Keywords: hydropower plant multi-criterial designing, fish protection, environmental protection, CFD

1. Introduction

European Union, by implementing directives on the share of renewable energy sources (RES) in the energy balance, such as Directives 2009/28/EC and 2001/77/EC, predicts that in the year 2020, the member states will achieve a twenty percent share of renewable energy sources in final energy consumption. In the case of Poland, this level was set at fifteen percent, which is still a huge technological, political and economic challenge. It should also be noted that ensuring access to energy in accordance with the principle of sustainable development, i.e. in the interest of proper development of civilization while maintaining all environmental resources for future generations, is now a priority of world politics. Therefore, the search for new technological solutions in the field of renewable energy requires taking into account widely understood environmental impact in the design process.

Small Hydroelectric Power Plants (SHPP) are generating units which, due to their lower capacity are most often connected to low voltage lines, less often to medium voltage lines. In the farthest point from the transformer stations, the voltage will be lower than at the station itself (due to voltage drops and the so-called transmission losses). As a result, voltage drops will also be more dangerous and visible. Location at a point in the network between the network and the recipient of the source generating low voltage will limit the possible voltage drop, counted from the source to the recipient. At the point of connection of a small hydropower plant to the network, regardless of the voltage value before it is connected, it will be increased and will aim to the value generated from the power plant.

Additionally, the use of micro sources in low-voltage networks results in a favorable current flow limitation. After switching on the power plant at a point in the network far away from the transformer station, partial demand of the recipients behind the small hydropower plants will be supplied from a micro source. Thanks to this, with the increase in electricity demand the modernization or expansion of the distribution network will not be required or it may be postponed.

Renewable energy sources (including SHPP) are susceptible to changing weather conditions (mainly the amount of rainfall in the catchment area), which forces the electricity market to have power reserves that can compensate for these fluctuations. The replacement by intermittent RES, has two-fold effect on power systems: reduction in inertia and intermittent generation, lead to the degradation of the frequency stability. In modern power system, the frequency regulation (FR) has become one of the most crucial challenges compared to conventional system because the inertia is reduced and both generation and demand are stochastic (Umer et al. 2020). Currently, a number of studies (Pradhan et al. 2021, Hunt et al. 2021, Xin et al. 2021) are being carried out in the field of energy storage solutions (mainly from renewable energy sources) that enable the balancing of the electricity availability profile regardless of weather conditions.

One example is an innovative energy storage solution based on “buoyancy energy storage” in the deep ocean. The ocean has large depths where potential energy can be stored in gravitational based energy storage systems (Hunt et al. 2021). An interesting proposal for storing energy is storage in the form of hydrogen. Hydrogen has a good potential for energy storage because it can tackle the spatial differences in renewable energy supply, but its storage in compressed gas or cryogenic liquid form incurs high investment cost. Liquid organic hydrogen carrier offers a much cheaper and more convenient way of storing hydrogen as compared to conventional means (Xin et al. 2021).

Compared to other renewable energy sources, hydropower is characterized by very high productivity (Malicka 2018). In many countries (e.g. Norway, Switzerland, Brazil) it is the basic source of cheap and ecological energy that almost completely covers the country's electricity demand. Currently, there are 766 hydropower plants in operation in Poland with a total capacity of 988.377 MW, which in recent years, on average, generated approximately two thousand GWh/year of electricity from natural inflow. Of all hydropower plants, 685 are facilities with an installed capacity of no more than one MW. Total capacity of these installations is 103 MW and they generate approximately 320.5 GWh of electricity each year (Malicka 2018). Despite the small number of sites adequate for investments in large hydropower plants, it is estimated that there are nearly 6,000 sites with high potential for building small hydropower plants (Figure 1).

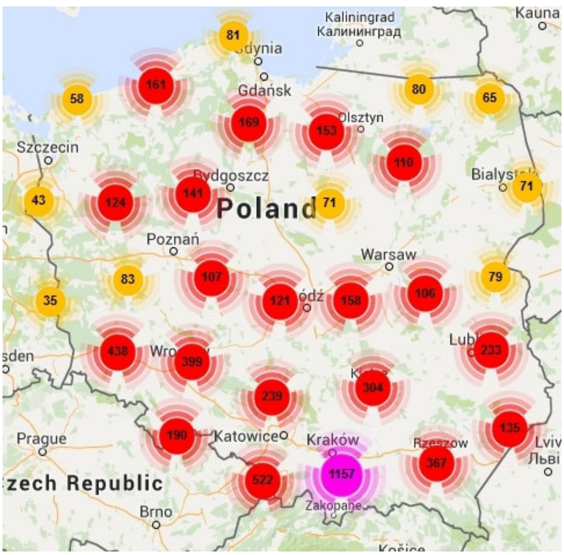

Fig. 1. Potential locations for SHP in Poland, http://www.restor-hydro.eu/restor-hydro-map/

With the exception of piedmont areas, the vast majority of dams that can be developed (or built) in Europe are low-fall (drop below 20 m), with ultra-low-fall objects (drop below 2.5 m) having the largest share (Malicka 2018).

Most European, including Polish, SHP installations are technologically outdated, having low efficiency and do not taking into account the ecological aspects of using water courses (e.g. protecting migrating fish). Moreover, they are not adapted to work on watercourses with low, medium flows and small falls (these conditions prevail in Poland and Europe). It is also important that many currently operated turbines will have to be replaced with new ones within a few years due to expiration of the existing water-legal permits enabling their operation. The amendment to water law shortened the validity of water permits to a maximum of 20 years since obtaining a final decision, and regulations of Regional Water Management Authority (RZGW) on the conditions of using the waters of water regions introduce numerous requirements. Permits cannot be renewed, but new permits must be obtained. Obtaining new permits in the light of the applicable legal regulations poses numerous challenges for designers.

A small hydropower plant is a hydropower facility listed in the Polish Act of July 20, 2017, Water Law, qualified for water facilities. The use of water for energy purposes is a special use of water, referred to in Art. 37 point 5 of Water Law. The execution of SHP and the use of water for energy purposes has not been mentioned in Art. 123a of Water Law, which means that it cannot be implemented on the basis of a water law notification. However, this requires obtaining a water law permit, which will set out the rights and obligations to an appropriate extent, resulting from Art. 128 of the Act, according to the information contained in a water law survey and other documents collected on the matter.

Small hydropower plants operating in Poland are currently struggling with the renewal of water permits due to the applicable legal regulations, but above all because of their different interpretations by administrative authorities issuing permits. The introduced regulations should apply to newly built devices, but many of them impose new obligations on the existing devices (Basiński 2015).

Current law makes it necessary to increase intact flow even on river courses with a highly developed infrastructure, poor in flora and fauna. This situation often determines profitability of further SHP's activity, as it directly translates into limitations in the amount of available water, which determines the efficiency of a power plant (Augustyn 2010, Basiński 2015, Khudhiri et al. 2018).

In addition, damming of watercourses' inland surface waters or their sections in question is unacceptable if the damming structures are not equipped with devices ensuring free migration of fish. There are now known cases of properly functioning fish passes, which although once received positive opinions, do not meet requirements for their operation. Such requirements include larger chambers due to planned restitution of salmon and other migratory fish species in particular streams (Malicka 2018).

2. The impact of small hydropower plants on a river ecosystem

Currently operating small hydropower plants, including micro-power plants with a capacity of less than 300 kW, have a detrimental effect on ichthyofauna. Losses in the natural environment of rivers and streams are very serious and threaten the survival of protected species. Basic problems related to location and operation of small power plants are: isolation of species occurring due to transverse development of rivers, blocking flows during the so-called low waters, causing channels to dry up and killing fish turbines. These threats also concern rivers flowing in protected areas, including Natura 2000 areas. Taking into account marginal energy potential of small hydropower plants, despite their large number (in the Pomorskie Voivodeship 86 power plants generate a total of 6.3 MW only), environmental damage caused by their operation is disproportionately high (Witkowski et al. 2009).

The quality of rivers depends on a catchment area, therefore their condition (especially biological) is the sum of all events taking place in the basin (Waters et al. 2015). Construction and operation of river infrastructure has many negative effects on flowing waters, mainly due to their natural continuity disruption. Division into separate parts of the previously homogeneous whole system causes rapid abiotic and biotic changes in the structure and functioning of a river. Their impact on ichthyofauna in the river below a partition is expressed by (Waters et al. 2015):

- physical changes to habitats,
- modifications to thermal, seasonal and daily water flow regime,
- changes in the availability of food base,
- changes in the composition and structure of fish communities leading to changes in biotic interactions.

An example of hydrotechnical infrastructure impact on biodiversity in the area of ichthyofauna is presented in Table 1.

Table 1. The numbers of fish caught in the Liw and Wierzyca rivers and the number of their species before and after the construction of hydrotechnical structures for the SHP and as a result of its operation (Witkowski et al. 2009)

River/fishing	*Year*	*Fish abundance*	*Number of species*
The number of fish caught on the site in Liw below the Młyniska power plant near Gąty in years 1999, 2004 and 2011	1999	228	11
	2004	116	9
	2011	44	9 (4 left but 1 arrived)
The number of fish caught on the site in Wierzyca below the power plant in Zamek Kiszewski in 1997 and 2012	1997	251	12
	2012	103	9 (4 left but 1 arrived)

As can be seen from the example presented in the table, construction and operation of SHP, despite obtaining water and legal permits for its commissioning, has a significant impact on the ecosystem.

Factors affecting, directly and indirectly, river ecosystem in the case of a small hydropower plant are:

- mechanical damage to fish bodies as a result of turbine rotor blades blows,
- damage to fish bodies as a result of pressure in a device (fish die sometime after leaving a device due to damaged gills),
- introducing lubricants to waters,
- vibrations and oscillations generated by devices,
- interference with a natural water threshold (construction works),
- disturbance of a river course natural continuum.

One of the technical solutions of a small, ecosystem-friendly hydropower plant is the use of a water turbine using an Archimedean screw (Waters et al. 2015, Dedic-Jandrek et al. 2019). By limiting pressure fluctuations and the speed of the flowing medium, aquatic organisms can flow through the power plant without damage. The Archimedes screw is regarded as one of the earliest hydraulic machines. It is built of a helical array of simple blades that are surrounding the central cylinder. The Archimedes screw is supported within a trough. A small gap separates the screw and the trough. It allows the screw to rotate freely. This design allows only a small amount of water to drain over the edges of the blades (Piper et al. 2018).

Another solution, proposed by the authores, is the advantageously selected shape of the blade of a slow-running water turbine. Due to the appropriate shaping of the stream of the flowing medium, the organisms located in the inter-blade space are repelled from the edge of the blades, which limits the possibility of mechanical damage to the organisms.

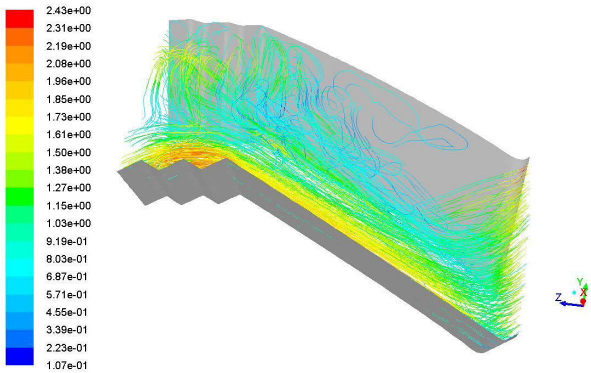

Fig. 2. Stream lines in the interscapular space (own research)

Fish passes can also be an alternative. The specificity of modern ecological fish passes is the variability of their construction parameters, which must be adapted to the biological requirements of the fauna inhabiting the river (fish, invertebrates) and the local conditions of the investment implementation. The biological and environmental conditions that inspire the fish to migrate and the limited ability to overcome obstacles on their way constitute the basis for the design assumptions of these devices. Their common feature is a loose structure, maintaining a system of gaps and gaps. These devices can be constructed in the form of (Wiśniewolski 2003):

- walk around imitating natural streams that avoid the obstacle,
- half-timbered fish passes (a combination of a bypass and a chamber fish pass), where the partitions separating individual chambers are made of loosely positioned boulders, between which a system of different widths of gaps is left,
- rapids (ramps), imitating the gorge sections of the river strewn with boulders and stones.

These design proposals are complemented by slot fish passes, intended for high damming in the terrain conditions preventing the execution of a sufficiently long ecological fish pass.

The diversity of environmental conditions, the degree of transformation of river ecosystems and the hydrotechnical structures existing on them, forces an individual approach to each situation of building a fish pass. Each of them is an individual, unique structure. Using the already developed solutions, the technical parameters of several selected types of fish passes are given in the further part of the paper. They should be treated as examples that, after modification taking into account local conditions, can be used in the development of new designs of fish passes built to restore the ecological permeability of Polish rivers.

3. Obtaining water legal permits

In order to obtain a water permit, an application must be submitted to the State Water Holding of Polish Waters. The most important elements of the set of documents are:

a) application for a water permit,
b) water law survey,
c) description of the intended activity,
d) decision on environmental conditions,
e) an excerpt and a sketch from a local spatial development plan,
f) decision to determine the location of a public purpose investment,
g) decision on development conditions,
h) water law assessment,
i) excerpts from a land register or simplified excerpts from a land register for real estate located within the range of the impact of the intended water use or within the range of the impact of the planned water facilities,
j) draft water management manual,
k) hydrogeological documentation.

The most important and problematic element of the application is the water law survey. The survey is made in writing in a descriptive and graphical form, as well as on IT data carriers as a text document, and the graphic part of the survey in the form of raster-type files (PDF) or files in vector format of spatial data, mapped in one of the applicable geodetic coordinate systems (Radtke et al. 2012).

The descriptive part of the water law survey (adjusted to the type of activity covered by the water law permit) includes, inter alia (https://wody.gov.pl/pozwolenie-wodnoprawne):

- specification of the purpose and scope of the intended use of water, the purpose and type of planned water facilities or works, the type of measuring devices and shipping signs, the type and range of impact of the intended use of water or the planned water facilities, the legal status of real estate located within the range of impact of the intended use of water or water facilities

planned to be constructed, specifying the seats and addresses of their owners – in accordance with the land and building records, obligations of the applicant for a water permit in relation to third parties;
- description of the water device, including basic parameters characterizing this device and the conditions for its implementation, and its location by means of information on the name or number of the cadastral area with the number or numbers of registration plots and coordinates;
- characteristics of the waters covered by the water permit;
- land use plans, river basin management plan, flood risk management plan, drought counteracting plan, marine water protection program, national municipal wastewater treatment program, plan or program for the development of inland waterways of special transport importance;
- determination of the impact of planned water facilities or water use on surface waters and groundwater, in particular on the condition of these waters and the implementation of environmental objectives specified for them;
- the size of the intact flow, the method of its calculation and reading its value at the point of water use;
- the size of the multi-year average low flow (SNQ) or groundwater resources;
- the planned start-up period, the procedure to be followed in the event of start-up, stoppage of operations or failure of devices essential for the implementation of the water permit, as well as the size and conditions of water use and water facilities in these situations, along with their maximum permissible duration;
- information on forms of nature protection created or established pursuant to the Act of 16 April 2004 on nature protection, occurring within the range of the impact of the intended water use or water facilities planned to be constructed.

The graphic part of the water law survey includes, inter alia, (Witkowski et al. 2009):
- the plan of water facilities and the impact range of the intended use of water or water facilities planned to be constructed, along with their surface, marked on the situational and height map of the area, with the property marking;
- basic longitudinal and transverse sections of water devices and flowing water channels within the range of their impact;
- the diagram of the measuring devices' arrangement and shipping marks;
- functional or technological diagram of water devices.

Another important document, the quality of which has a key impact on obtaining a permit, is the decision on environmental conditions, which specifies, inter alia, (Witkowski et al. 2009):

- conditions of land use at the stage of implementation and operation or use of the project, with particular emphasis on the need to protect valuable natural values, natural resources and monuments, and to reduce nuisance to neighbouring areas;
- environmental protection requirements necessary to be included in the documentation required to issue other decisions listed in Art. 72 sec. 1 of the Act on the provision of information on the environment and its protection, public participation in environmental protection and environmental impact assessments on a building permit, approval of a construction design or a permit to resume construction works. In particular, these requirements must be included in the construction design necessary for the issuance of certain decisions, e.g. a building permit, a permit to resume construction works, or a permit for a road investment.
- requirements for limiting transboundary environmental impact in relation to projects for which the procedure for transboundary environmental impact was carried out.

The most important factor guaranteeing obtaining a water permit for the operation of SHP is undoubtedly its appropriate design in the light of applicable regulations - primarily regarding its impact on the environment.

4. Design guidelines for small hydropower plants in the aspect of obtaining water legal permits

Designing flow devices requires a multi-criteria concept, taking into account phenomena occurring in liquids. Currently, designers are helped by the latest computer-aided design tools. An example of such an approach is the Zawiślak method presented in Figure 3 (Zawiślak 2017).

The application of the method includes the design of a water turbine for SHP, but it is extremely important to correctly formulate the problem to obtain a technical solution that can meet the requirements of a water permit and to be used to prepare the survey. In this case, the efficiency criterion of the device gives way to the priorities related to environmental protection.

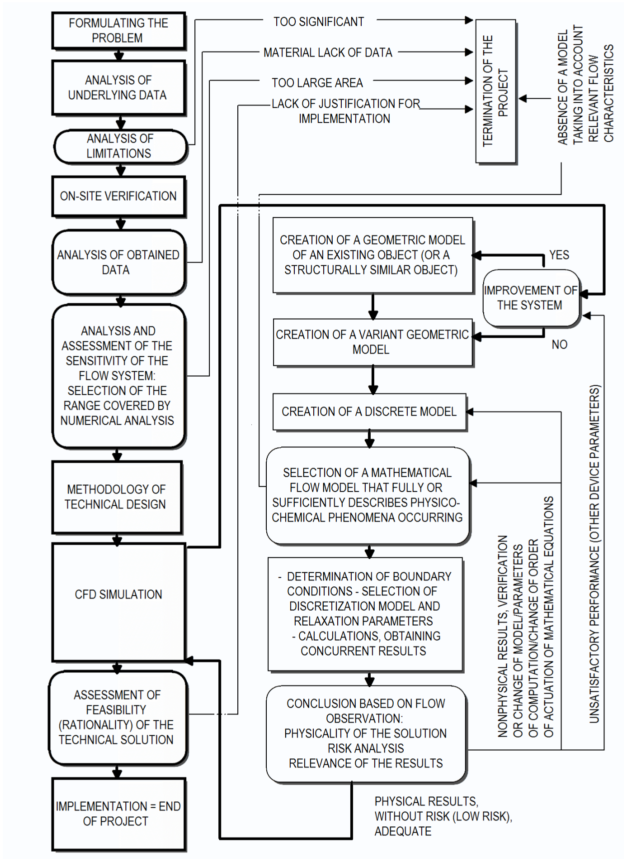

Fig. 3. Scheme for the design and modernisation of machines and flow-through systems using CFD software

For the design of a water turbine, apart from the criterion of its efficiency and the obvious for this type of devices, ensuring the amount of available water appropriate for a given watercourse (which translates into the size of the turbine), the following assumptions should be made:

I. the geometry of turbine cannot cause mechanical damage to fish fauna (the shape of rotor blades and spaces available for fish flow with dimensions characteristic for a given river ecosystem);

II. pressures inside the flow device must not damage the gills of fish (pressures causing cavitation are not allowed);

III. the design of turbine should ensure that the lubricant does not come into contact with river water (bearings are raised above water level);

IV. the noise of device should not exceed 80 dB;

V. the device should be optimized in terms of vibration emission (installing anti-vibration solutions);
VI. installation of the device should have the least possible construction interference with the existing water threshold/natural damming;
VII. the device should enable free fish migration, including upstream (e.g. hydroelevator system);
VIII. ensuring adequate durability of the device (e.g. by applying coatings on the rotor blades);
IX. the device should ensure the use of a water threshold with natural falls (usually low or ultra-low), which will enable the use of existing, natural dams.

Formulation and parameterization of the above criteria and then inference based on the results of numerical calculations concerning their fulfillment will allow to design a device that will enable obtaining a water permit according to new legal regulations.

5. Conclusion

1. The theoretical resources of hydropower in the world are estimated at 40,700 TWh/year (23 TWh/year in Poland), while exploitation resources are estimated at nearly 15,000 TWh/year (12 TWh/year in Poland).
2. Designing small hydropower plants (SHP) with a capacity of < 5MW, including micro (0.1-05 MW) and mini (0.5-2 MW) power plants, in the face of current legal regulations, is an interdisciplinary issue, because efficiency priorities are now not as important as environmental ones.
3. The study analysed current regulations enabling obtaining of water-legal permits and proposed design guidelines in the area of small hydropower plants, taking into account the impact of SHP on the condition of river ecosystem.
4. Taking the formulated criteria into account in the design process will allow obtaining water-legal permits in the light of the current legislative conditions.

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