Risk Analysis Methods for Small Hydro Power Plants in Creating Insurance Policy

Andjela Lazarevic[a], Rade Karamarkovic[b], Vladan Karamarkovic[c] Dragoljub Lazarevic[d]

[a] *Faculty of Mechanical Engineering, University of Nis, Nis, ISO 3166-2:RS, andjela.lazarevic@masfak.ni.ac.rs*
[b] *Faculty of Mechanical and Civil Engineering in Kraljevo, University of Kragujevac, Kraljevo, ISO 3166-2:RS, karamarkovic.r@mfkv.kg.ac.rs*
[c] *Faculty of Mechanical and Civil Engineering in Kraljevo, University of Kragujevac, Kraljevo, ISO 3166-2:RS, v.karamarkovic@mfkv.kg.ac.rs*
[d] *Faculty of Mechanical Engineering, University of Nis, Nis, ISO 3166-2:RS, dlazarevic@masfak.ni.ac.rs*

Abstract: Small Hydro Power Plants provide more diversity in terms of financing projects, location selection, ownership, its applications as well as insurance methods, comparing to the Conventional Hydro Power Plants. Electricity produced by small hydro power plants could be used to improve energy efficiency of different production facilities, domestic and public lighting and other applications. However, those energy objects are exposed to the variety of risks that should be taken into consideration in different ph ases of objects' construction, operation and maintenance. Understanding of those risks is crucial for undertaking of different techno-economic analysis, as well as establishing of the insurance policy for those power plants. The approaches used to create insurance policy for Small Hydro Power Plants in certain countries depend of the technology applied and development level of the country and will be provided in this paper.

Keywords: Small Hydro Power Plants, Energy Efficiency, Insurance Policy.

1. Introduction

Hydropower is one of the oldest energy sources and therefore has been exploited for centuries. The interest for Small Hydro Power (SHP) Plants was changing since the time of the first usage of hydropower turbine for electricity generation in 1880's. The basic turbine technology was developed by the end of the 19th century, when SHP was intensively used. The next period stimulated usage of larger units therefore SHP Plants were not a trend. However, the oil crisis and circumstances that increased concerns for both environmental protection and energy supply security led to the increased interest for SHP Plants, especially at the beginning of 21st century. The development of automation and remote control, as well as standardization of the equipment also contributed to the increased interest in SHP Plants [1].

There is no international consensus on the definition of SHP Plants. Criteria for this definition are various, starting from the most common criteria - installed capacity. Outside of Europe, in Canada SHP refer to upper limit capacities of between 20 and 25 MW, in United States upper limit is 30 MW. However, in Europe a value of up to 10 MW total capacities is becoming generally accepted. This limit is accepted by Portugal, Spain, Ireland, Greece and Belgium, together with European Small Hydropower Association –ESHA. The limit is fixed at 3 MW in Italy, 1.5 MW in Sweden, 20 MW in UK and 12 MW in France [2]. Sometimes, categorization of SHP plants is associated with the catchments area of the river (for SPH catchments area should be less then 200 km2, according to some sources) [1]. SHP Plants could be stand-alone systems in isolated areas, but could also be connected to a grid.

A well designed SHP Plant should fit within its surroundings, having minimal negative environmental impacts. The advantages of SHP Plants are numerous, since they can represent renewable, decentralized and low-cost form of energy. However, SHP Plant can be shared with other types of water uses, being a by-product of some other activity (e.g. irrigation systems, water supply systems, flood protection structures or discharge regulation structures), and generating energy whenever excess discharge exists. Those SHP Plants are classified as supplemental hydropower systems.

Considering the economy of SHP Plants, the investment cost is very site sensitive and is not comparable with other renewable energy sources. Independently of the investment cost, low operating and maintenance costs, long life span and low failure rate are the common features for the vast majority of SHP Plants. They have high number of annual operating hours, and require very small number of operational staff.

SHP Plants are environmental friendly, producing no carbon dioxide, sulphur oxides or nitrous oxides, no air emissions and no solid or liquid wastes [1]. However, the additional effort is needed to protect downstream aquatic biota through different design solutions enabling fish migration and the passage between the downstream to upstream sides and vice-versa (fish passages, fish ladders etc.).

2. General technical principals SHP Plants

Hydropower plants capture the energy released by water falling through a vertical distance, when turbine converts the hydraulic potential energy of the water flow into kinetic energy, which is transferred to the generator producing electricity. SHP potential (the amount of electricity which can be generated) depends on the quantity of water flow and the height of the head (vertical distance through which the water falls). The electricity produced is proportional to the product of the head and the rate of flow.

Main factor that influence water flow is average annual precipitation while head is mostly influenced by available site geographical characteristic (topography, geotechnical conditions etc.)

Geographical characteristics of the available site determine the type of head, according to which SHP Plants could be high head SHP Plants and low head SHP Plants. Low head SHP Plants generally use heads up to a 50 meters in elevation or function on run-of-river. Run-of-river plants imply that they do not have any water storage capacity. The power is generated only when enough water is available from the stream. However, when the stream flow is reduced below the design flow value, the generation ceases as the water does not flow through the intake structure into the turbines.

High head SHP Plants generally include a dam to store water at higher elevation. Although the civil works are bigger for high head SHP Plant, the total investment cost is lower. The reason is lower turbine and other equipment cost compering to the low head SHP Plants, since high head SHP Plants require less water to produce the same amount of power, so their equipment is smaller, simpler and less costly.

The dam is used to concentrate the head, which raises the upstream water level. There are two fundamental ways to create the head:

- Building the dam across a stream, in order to increase the water level, where powerhouse is incorporated inside the dam (dam scheme of SHP Plant)
- Building the dam or weir to divert the part of a stream, where powerhouse is located far away from the dam or weir (diversion scheme of SHP Plant)

Hydropower plants with dam are usually considered as conventional hydropower plants since they use conventional dammed method of power generation. Another method of power generation which could be used at SHP Plants is already mentioned run-of-river. Run-of-river SHP Plants are those with small or no reservoir capacity, so that the turbine generates electricity only when there is available water coming from upstream. There is no inflow regulation, which is usual approach for SHP Plants.

Not very often generation method for SHP Plants is pumped storage. This method produces electricity to supply high peak demands by moving water between reservoirs at different elevations. However, great advantage of this method is that they provide the most efficient and profitable option to store electricity [3].

Depending of the method of power generation, SHP Plants consists of different components. The most common components are presented below:

- Reservoir constitutes a storage form of the available potential energy and creates the conditions for water diversion through the intake. This reservoir usually stores enough water to operate only on peak hours.

- Dam has different functions. Apart from the provision of additional head and storage capacity, they intend to divert the river flow into conveyance system leading to the powerhouse. There are different classifications of dams. The most important for our consideration is according to the dam function (storage, diversion, detention dam etc.) and structural design (concrete, masonry, earth dams etc.) [4]. Diversion dam is the dam that diverts all or a portion of the flow of a river from its natural course, while forming artificial water course or canal. Detention dams are built to catch surface run-off to prevent floods and trap sediment by regulating the flow rate of the run-off into channels downstream. They could be used in the cases of supplemental hydropower systems (power generation is by-product of some other activity such as irrigation or floods prevention). Earth dams are made of soil and resist the forces mainly due to shear strength of the soil. There are different types of concrete dams: gravity dam, arch dam and buttress. Gravity dam resists the pressure of water by its weight, while arch dam resists the pressure of water partly due its weight and partly due its arch action. Buttress dams have the supporting flat slabs, where the face of the dam is held by a series of supports or buttresses that are placed at intervals on the downstream side.

- Water Intake serves as a transition between river stream and controlled flow of water. It diverts the required amount of water into a power channel, tunnel and other waterways or penstock with minimum possible head losses, where handling debris and sediment transport is very important [5].

- Sediment traps or sedimentation are projected downstream of the water intake, in order to prevent the entrance of suspended sediment transport, which may wear parts of turbine and decrease its efficiency and lifetime. A sediment trap is based on the principle of diminishing the flow velocities and turbulence.

- Conveyance system includes all elements designed to transport water from the intake to the powerhouse. It converts part of the available energy into kinetic energy, another part into reversible flow work capacity (pressure head) and another part is dissipated in heat (by fluid viscosity) resulting in the net or useful head. The conveyance system could be composed either by pressure galleries or pipes or by a mixed system composed by free-surface canals and pressurized pipes (penstock etc.).

- Tailrace represent short canal through which water returns to the river after passing through the turbine.

- Powerhouse serves as housing and protecting turbo-generator groups and its auxiliary equipment, providing enough space for an easy installation of the equipment as well as access for inspection and maintenance of the turbines and other equipment [6].

- Hydraulic turbine converts the net head into rotating mechanical energy. There are different types of hydraulic turbines: impulse (Pelton, Turgo, cross-flow turbine) and reaction turbine (Francis, Kaplan, reverse-pump turbine).

- Generator and additional electrical equipment provide conversion from mechanical to electrical power. There are two mail types of generators: synchronous and asynchronous generators.

3. Risks associated with SHP Plants and creation of the insurance policy

The components of SHP Plant, with respect to the analysis of its cost structure as well as its risk exposure could be grouped into three categories: civil engineering, turbine and additional equipment. In cost structure, civil engineering has the highest share of 50-60 % and is cite specific. Turbines are the most expensive standard components, while the share of other electrical equipment is approximately 25 % of the total investment cost.

The risks associated with SHP Plant could be distinguished as construction risks (risks associated with the objects in construction) and risks of operation and maintenance. Some risks that are not subject to insurance should also be mentioned, since those risks could extend the construction phase and provoke some unplanned activities and damages in both construction and operation of the plant.

The beginning of SHP Plant construction is constrained by obtaining appropriate licenses and permits. The situation is additionally complicated by the fact that one SHP Plant construction lot is formed by larger number of registry lots. The precondition for obtaining location permit is clear property and legal relations for all land registry lots. If SHP Plants is constructed on land registry lots bordering with water and forest lots construction lot is formed within the land registry lot on which the main facility is being built [7]. The pipelines, open channels, penstock and other elements of the conveyance system are set through water and forest land, where the ownership and legal relations should be resolved as well. The contract about the determination of usage rights with a public company or other organization which manages the water or forest land should be concluded. One of the main risks in this phase is incomplete and incomprehensive above mention contract, which could provoke many difficulties and delays in activities.

Evaluation of the water resource and its generating potential, the estimation of the civil and other works, and the economic feasibility, must be studied before the construction, taking into consideration the geographical characteristics of the available site. The risk of inappropriate selection of SHP Plant capacity, hydropower scheme and required hydraulic equipment is very high in this phase, and mostly influence the SHP Plant owner. The mistakes done during this phase will track some or all steps in following phases, therefore represent the reasonable risk transferred to the next phases.

3.1 SHP Plants in the construction phase

Risks in the construction phase are the same as risks associated with any other object in construction, especially taking into consideration that civil works have the highest share in total SHP Plant investment cost. The insurance subject could be the object in construction, together with the material and equipment to be built-in the object, and construction machines and equipment and auxiliary and temporary objects, built for the construction purposes.

The right hydro technical proposition of the intake structures, taking into consideration all complex issues, is very difficult and is specific at each case. Appropriate selection of intake location is very important during the construction phase, since there is risk of floods. Time of the year for the construction works should be carefully selected with respect to this risk. The factors that should also be taken into consideration are: topographical and geotechnical characteristics, nature of the stream bed, bends and the access, stability of the soil etc.

During the construction phase there are also different risks associated with the conveyance system. This is why it is important to carefully explore the topography and geomorphology of the site. This will significantly influence the selection of the components of the conveyance system and its position therefore the risks associated with each selection are different. Risk during construction is different in the case that pipeline is underground, above-ground or mixed. The slope of the pipeline is also important, since the construction of the steeper pipeline carries higher risk for material and workers. Also, important factors for the risk assessment are: soil composition and geological characteristics of the site, existence of landslides, type of the pipelines, and danger of pipeline unaccepted floating during the construction etc.

Although the risks related to the powerhouse are the same as in the case of any building construction, there is the increased danger of floods, taking into consideration the site location. This is the reason why the time of the year planned for the civil works is crucial. Other risks associated with the powerhouse could be diminished by adequate protection from the big waters as well as adequate selection of the switching gear and transformers.

3.2 SHP Plants in the operation phase

Low head SHP Plants and run-of-river SHP Plants have small dams or, usually just a weir and generally little or no water is stored. The civil works purely serve the function of regulating the level of the water at the intake to the hydro-plant. Therefore low head and run-of-river SHP Plants do not have the same kind of risks as high head SHP Plants.

Dam is component characteristic for high head SHP Plants. However, hazards with dam failure are usually associated with large dams and reservoirs, but depending on localization and circumstances even small dams and reservoirs could be potentially dangerous, and considering their large number they pose a significant threat to the health and environment [2, 4]. Dam safety can be improved by installation of monitoring systems, performing reviews and undertaking dam inspections on a regular basis, which could be considered as risk prevention measures in insurance. In a case of dam failure it should be noted that dam is not isolated, but integral part of a complex system. Therefore, it could have severe effects downstream of the dam. During the lifetime of a dam different flow conditions are experienced and a dam must be able to safely accommodate high floods that can exceed normal flow conditions in the river by orders of magnitude.

For this reason carefully designed overflow passages are incorporated in dams or weirs as part of the structure. These passages are known as spillways. Due to the high velocities of the spilling water, some form of energy dissipation is usually provided at the base of the spillway. The level of the water surface is also regulated by weir. In the case of intake, weir increases the level of water surface so that water flow can enter into it.

The existence of the spillways and weirs set at the appropriate positions so that they could protect the dam and different elements of the conveyance system should be very good reason for the decrease in premium, since those measures could be considered as prevention measures in order to diminish the risk exposure.

An important part of any SHP Plant is also water intake. If water intake type and structure are not carefully chosen the number of operational difficulties or failures of already constructed objects could appear.

The greatest deficiencies in the design of intake structures arise after the plant is built. At one flow may one type of intake structure have very good results, but at another flow, even if partly similar, the same type may show poor results. Operational issues adversely affect mainly SHP Plants with a low output level and even become a limiting factor for their further development [5]. There are number of factors that need to be considered during the SHP Plant operation, which are related to the intake. Risk highly related to the intake is connected with the danger of leakages and danger of sediments and contaminants pulled with water intake, which could jeopardize the operation of turbines. Proper dimensioning of sediment (sand) trap or traps by considering the minimum diameter of particles that the chosen turbine can withstand and the river load is of importance for proper functioning of a SHP Plant. If there are more than one sediment trap working in parallel provision of uniform flow distribution among the traps is required [8]. The existence of another SHP Plants at the same stream is very important and could provide information for the proper sand traps design. The existence of fish passages should also be taken into consideration.

Risks associated with the conveyance system in the operation phase are numerous. The system has to be secured from the landslide as well as shear due to the earthquake. If the pipeline is made of steel, there is the risk of increased pipeline corrosion. Therefore, the cathode protection needs to be provided, in order to protect main agent of corrosion, which is electro-chemical processes. Protection of the pipeline floating, as well as hydraulic shocks is necessary. The insurers should take into consideration also the length of the pipeline, since in that case is increased danger of leakages. If the pipeline is characterized by curves at higher angles, the curves should be carefully positions and fixed. At the locations where the pipeline exits from or enters the ground, or change the direction concrete anchor shall be provided in order to resist the forces caused by the pipe. Those anchor blocks should be properly dimensioned.

As it was mentioned before, the selection of turbine reflects to the construction of all other components of SHP Plant. In turbine selection should be taken into account that larger turbines have larger efficiencies. Moreover, turbine cost is higher for low-head plants, which have to pass more water than high-head plants for the same power output (therefore they are larger). Low-head power plants also run more slowly and thus cannot be connected directly to the generator. The consideration of the sediment load carried by the river and therefore by the conveyance system is crucial. The existence of the security system for water turbine failure could be very useful as well as frequent maintenance.

In creating the insurance policy related to the SHP Plants very interesting cases are related to the supplemental hydropower systems. This is especially important when the SHP is used within irrigation and flood prevention system. SHP Plant could be installed in irrigation canal or in a lateral by-pass canal, with a small penstock, in order to take the advantage of the head created by the upstream dam. Dams could be also used to prevent floods through the creation of reservoirs that should be emptied ahead of a rainy season, although allocating a certain volume in the reservoir for power generation. The insurers should take into consideration these hybrid systems providing lower premium or certain benefits for the insured.

4. Conclusion

It is expected that number and capacities of SHP Plants, especially low head will probably increase in the future, as research on low head turbines, and standardized turbine production, lowers the costs of hydro-electric power at sites with low heads (which is currently higher then cost for high head SHP Plants). New computerized control systems (systems automation) and improved, standardized turbines and other SHP Plants' parts may allow more electricity to be generated from existing facilities in the future. Considering the conditions in our country, the introduction of feed-in tariffs influence the increase in number of SHP Plants

The risks associated with SHP Plants are numerous and the most important and adverse risks and dangers are presented in this paper. The most usual classes of insurance in the case of SHP Plants are: machinery and breakdown insurance and financial loss insurance coverage due to the business interruption following a machinery breakdown. Although usually all electro-mechanical installations in SHP Plants are insured against machinery breakdown (loss of profit), sometimes SHP Plant owner decide to insure only components with a high risk potential.

The determination of the sum insured is crucial, but very sensitive aspect in the insurance process of SHP Plants. Particularly, it represents the constant problem which is difficult to solve satisfactorily. The installed capacity and average productivity should be the leading criteria for the determination of the sum insured, since it could reflect the incurred damages and losses. Important aspect is also determination of the actual price of major components. However, those processes are followed by the strong fluctuations, especially at the markets with strong competition. Periodical checking of the installation, jointly between the insured party and the insurance company, could help keeping the situation updated. This periodical checking could be associated with the application of measures preventing risk realization.

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