SMALL HYDRO AS ONE OF THE OLDEST RENEWABLE ENERGY SOURCES

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The energy production has become an up-to-date issue that specialists and authorities have to deal with. The hydropower is one of the oldest energy sources of mankind, namely for irrigation and industry purposes. In Europe, the development of small hydro-energy had a new growing since the seventies, due to the world energy crisis and, more and more the concerns of negative environmental impacts, as well as due to the development of new technologies.

Nowadays, small hydro is one of the most valuable answers to the question of how to offer to isolated rural communities the benefits of electrification and the progress associated with it, as well as to improve the quality of life. The hydroelectric power plant utilises a natural or artificial fall of a river. The hydraulic conveyance circuit can be integrated in other components for multiple purposes (e.g. irrigation or water supply systems). This type of electricity production does not consume water, being considered so far one of the most important renewable energy source.

At present, the economic utilisation of renewable energies is based on new technologies and on environmental protection techniques. Small hydropower, with its multiple advantages, as a decentralised, low-cost and reliable form of energy, is in the forefront of many developing countries to achieve energy self-sufficiency. It represents an important environmental benefit to aid sustainable development due to no release of carbon dioxide that contributes to ozone depletion and global warming. Summing up, the small hydropower can fill the gap of the decentralised production, for private or municipal activity production for sale to national electric grid or for supply industries, rural or isolated zones, improving their development.

Key-words: renewable source, small hydro, water power, hydropower, hydroelectricity
1- A BRIEF INTRODUCTION

Small hydro can be seen as one of the most valuable answers to the question of how to offer to isolated or rural communities the benefits of electrification. The importance of small hydroelectricity growth to fill the gap of decentralised production and municipal activity production, in particular for isolated zones. Small hydropower, with its multiple advantages such as low-cost and reliable form of energy, is in the forefront of many countries to achieve energy self-sufficiency. The policy in most of countries is devoted to assure additional generating energy from renewable sources according to environmental constrains.

2- WATER USES

The water, as a scarce natural resource, must obey to specific exploitation rules, concerning the necessities of each country or region (e.g. consumption, irrigation, energy production and environment).

Thus, water resources can be used in different ways to serve the society, taking into account all demands arising from different social and economic sector-users. In addition to the exploitation and utilisation of water aims to obtain the maximum benefit, in a controlled way in order to reduce natural hazards and significant environmental impacts.

The importance of water uses is visible through the following list:

- Water supply;
- Power generation;
- Irrigation;
- Drought and flood prevention;
- Tourism and fisheries;
- Environmental protection.

Hydropower plants utilise natural or artificial falls of rivers saving consumption of fossil, fuel, or firewood, which constitute classic energy sources that contribute for greenhouse effects or atmospheric pollution. The small hydroelectricity depends mainly upon the local and regional characteristics. In these schemes, the hydraulic structures will be much less complex than in large hydroelectricity.

3- SUSTAINABLE MANAGEMENT

The use of new technologies allowed obtaining best turbine performances, efficiency of the system, automation control and computer codes for rapid simulations in order to analyse different alternative solutions.

Hydro-energy source can provide several countries with a reliable, efficient, safe and economic source for increasingly system effectiveness of decentralised industries.

The use of water to produce energy presents the main advantages in what concerns of air emission production no carbon dioxide, sulphur dioxide or nitrous oxides and no solid or liquid wastes productions. Therefore, the water sources should contribute to a substantial global reduction in emission of CO$_2$ and other harmful gases, which are responsible for greenhouse effects. The flow will continue to fall downhill, the water will continue to be available as a resource for men and environment needs, thanks to the natural hydrologic cycle.

Small hydropower plants does not require high dams and the majorities are run-of-the-river schemes, meaning simply that the turbine only generates when there is available water. A minimum daily storage and flow regulation is typically guaranteed.
Normally, these hydro schemes are completely automated with remote control (i.e. abandoned exploitation) using standardised equipment (e.g. turbines and generators).

The net head and the plant discharge are two important parameters to be considered in the small hydropower design. According to the mode of net head characterisation, the following main schemes can be identified:

- Dam scheme where the dam is used to concentrate the head, which raises the upstream water level. In this way, the powerhouse can be placed either at downstream or to incorporate in the dam;
- Diversion scheme, which uses diversion structures, such as canals, tunnels or galleries, or low-pressure conduits allowing the head gain. A small dam can be used together with long hydraulic circuit.
- Mixed scheme composed with a dam that can partly raise the net head, and a long hydraulic conveyance circuit to raise the other part.

According to the mode of discharge exploitation, the following hydropower types can be identified:

- Run-of-the-river scheme in which the power is generated without inflow regulation.
- Daily regulation scheme where the power is generated according to the natural fluctuation of the daily demand, the water being stored in a regulating pond or small reservoir at off-peak times and discharging it at peak hours, resulting a bigger energy output comparatively to without regulation capability.
- Cascade scheme is typically a solution to optimise the potential of the river, in order to make the best use of the river falls using the same discharge.

In the future, a penalty cost by combustion of fossil sources should be applied. Being hydroelectric energy 12% from total generated energy in European Union, the small hydropower plants can still occupy a relevant contribution around the world, being estimated that the energy production through renewable sources can increase three more times than nineties.

### 4- HYDRAULIC DESIGN LAYOUTS

Civil works are quite significant in Small Hydropower Plants (SHP). The investment is generally limited and there is not capability to spend so much on geological or survey exploitation, hydraulic and structural design. Nevertheless, they have the main advantage in using local materials and attracting local people for the construction. A SHP design should be the result of the work of a multi-disciplinary engineering or multi-specialist team including hydrologic, hydraulic, structures, electric, mechanical, geologic and environmental experts. They can not be scaled down from large projects.

Several types of SHP layout schemes are characterised essentially through different intakes and diversion structures depending on the type of the conveyance system (e.g. total pressurised or mixed). The powerhouse depends on the type of turbines (e.g. impulse or reaction). The headwork typically includes a low dam or barrage belonging to low dam risk category (e.g. depending on the specific legislation of each country).

Sometimes, small hydropower plants can be very unconventional both in design concept and in components (e.g. the turbines can replace pressure reducing valves or other types of localised dissipation of excess flow energy).
There are different types of intakes with diversion flow to the turbine through the penstock: frontal, lateral, bottom drop and siphon type.

The rack is an important protection element against the inflow of solid material that can provoke damage in turbines.

A sedimentation basin allows settling fine particles in suspension that may wear parts of the turbine and decrease its efficiency and lifetime. The settling is due to gravity action through the reduction of the flow velocity by increasing the cross-section.
The conveyance system includes all elements designed to water transport from the intake to the powerhouse. The conveyance layout can be composed by either pressure galleries or pipes or by a mixed system composed by free-surface canals and pressurised pipes.

![Fig. 3 – Typical layout schemes for different types of conveyance systems](image)

The net head, $H_o$, is one of the most important parameters for a feasibility analysis and design solution. The material, the cross-section and the length of the penstock will influence the headloss, which is a function of the diverted discharge. Penstocks must be designed to bear the maximum internal pressure due to water hammer phenomenon during normal and abnormal operational conditions. For small slopes, the pipe must be buried to avoid temperature effects, or these effects must be considered in the pipe design.

![Fig. 4 – Hydraulic grade line in a pressurised system](image)

Powerhouses are used for housing and protecting turbo-generator groups and the auxiliary equipment (e.g. safety and protection valves, electric boards, control equipment, remote controller, switchgear panel and protection equipment). The powerhouse layouts need to allow an easy installation of the equipment, as well as access for inspection and maintenance of turbines and all other equipment. The dimensions of powerhouses are mainly determined by the size of the generating unit(s) and equipment.
In case of dangerous pressure variations occurrence, protection devices must be installed to control the overpressure due to turbine operation. Typical protection devices for small hydropower plants are listed (RAMOS, 1995):
- surge tanks;
- air vessels;
- synchronised valves;
- automatic discharge valves;
- pressure relief valves;
- flywheels.

These devices can act by supplying or removing water, or through flow energy accumulation or dissipation.

5- CASE STUDIES

Vila Real was the first Portuguese town to have hydroelectricity. After 98 years of energy production, the region where was installed the first Portuguese hydropower plant in 1894 and, despite of a posterior developed of another hydro scheme (1917) that was upgrading later (1926 and 1932), it takes place the new Terragido hydropower plant in the Corgo river, in 1991.

The previous power plant had a power about 400 kW and was replaced by a new one with the capacity of 10960 kW limited by the output power of 10 MVA. The net head and the plant discharge are two important parameters to be considered in the small hydropower design. The gross head changed from 33 m to 125.5 m so as the discharge from 1.6 m$^3$/s to 10 m$^3$/s. New Terragido power plant was a result of improvement, structural reinforcement and rising of existent small dam. Furthermore, gates were installed in order to elevate the full storage water level (FSWL).

This small power plant is aimed at energy production with a powerhouse equipped with three turbo-generator groups (two of them with vertical shaft and output power of 4650 kW each one, and a third group with horizontal shaft with 1660 kW).

The main components of Terragido power plant are:
- **Headworks**: a small dam with a weir, the intake, a sluice bottoms outlet discharge and a fish ladder;
- **Conveyance system**: a tunnel with a differential surge tank and a penstock;
- **Powerhouse**: power building and tailrace.
The tunnel has the length of 1200 m with a cross-section of 12 m² where at downstream a differential surge tank was installed. The penstock has the length of 375 m with a diameter of 1.80 m. The powerhouse is located on the left river side, being a mid-buried concrete structure. The tailrace is a reinforced concrete canal.

Fig. 6 – Terragido small power plant: profile and plan in a schematic view
(adapted from a courtesy of Enersis)

Fig. 7 – Views of dam, surge tank and turbines during installation stage
Table 1 – List of eight small hydropower plants in Portugal with different characteristics

<table>
<thead>
<tr>
<th>Identification</th>
<th>L (m)</th>
<th>Hg (m)</th>
<th>Qo (m³/s)</th>
<th>Po (MW)</th>
<th>Turbines</th>
<th>Prot. device</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ermida</td>
<td>3900</td>
<td>395</td>
<td>2.35</td>
<td>7.7</td>
<td>Pelton (1)</td>
<td>None</td>
</tr>
<tr>
<td>Ovadas</td>
<td>3025</td>
<td>334</td>
<td>2.15</td>
<td>5.9</td>
<td>Pelton (1)</td>
<td>None</td>
</tr>
<tr>
<td>Sordo</td>
<td>3600</td>
<td>321</td>
<td>3.6</td>
<td>9.8</td>
<td>Pelton (2)</td>
<td>None</td>
</tr>
<tr>
<td>Torga</td>
<td>1200</td>
<td>60</td>
<td>20</td>
<td>9.1</td>
<td>Francis (2)</td>
<td>None</td>
</tr>
<tr>
<td>Nunes</td>
<td>2500</td>
<td>107</td>
<td>12</td>
<td>9.9</td>
<td>Francis (2)</td>
<td>Relief valve</td>
</tr>
<tr>
<td>V. Viçosa</td>
<td>1935</td>
<td>23</td>
<td>3.59</td>
<td>3.6</td>
<td>Francis (2)</td>
<td>Relief valve</td>
</tr>
<tr>
<td>S. Pedro Sul</td>
<td>4000</td>
<td>74</td>
<td>14</td>
<td>8.2</td>
<td>Francis (2)</td>
<td>None</td>
</tr>
<tr>
<td>Terragido</td>
<td>1575</td>
<td>125</td>
<td>10</td>
<td>10</td>
<td>Francis (3)</td>
<td>Dif. sur. tank</td>
</tr>
</tbody>
</table>

In the Table 1 are presented the main characteristics of eight small hydropower schemes, in the North of Portugal, analysed by the authors. All of them have long hydraulic conveyance systems, in which one of them has a differential surge tank (Terragido) and two are equipped with relief valves (Nunes and Vila Viçosa). All of schemes equipped with Pelton have no special protection devices against transient pressures. Two schemes with Francis turbines have not also any special protection device through a detailed computing research based on several simulations using a complete model in order to be able to analyse different scenarios.

6- FINAL REMARKS

The implementation of small hydro in sites with relevant hydro potential must be encouraged not only in rivers but also in irrigation and water supply systems.

Regarding small hydro plants are of a renewable kind of energy production, come together with the EU aims. These solutions enable a significant sustainable development, in particular through socio-economic and environmental components. They can represent important environmental benefits in what concerns the ozone depletion and global warming. In addition to the economic utilisation of renewable energies suits to new technologies and environmental protection techniques.

BIBLIOGRAPHY


