Use of Coal Mines Facilities in Northern Spain for the Production of Sustainable Energy

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Abstract: - The Asturian Central Coal Basin in northern Spain has been a highly exploited coal mining area for many decades and its network of tunnels extends among more than 30 mines. Parts of this infrastructure will soon become available for alternative uses since most of the coal mining facilities in Spain will fade out in 2018 (European Decision 2010/787/UE). By 2020 it is intended that the country produces 20% of its energy from renewable sources, therefore replacing the energy based on coal and gas. Then, one of the main challenges for making this happen is the energy storage system, which creates a robust network that balances surplus and peaks of energy demand over short coverage intervals. Pumped storage hydroelectricity from mine water in the closured coal mines has proved to be an effective solution for this purpose.

Key-Words: - Hydroelectricity, coal mines, mine water, pumped storage, coal mining, massive energy storage.

1 Introduction

The Asturian Central Coal Basin (ACCB) is located in northern Spain. It has been exploited for more than 200 years through open pit and underground mining, with indoor mining predominating in the last decades. It was one of the most important economic activities in the Principality of Asturias and an outstanding source of employment creation, which therefore contributed to the current development of the surrounding towns.

Over 81% of the total energy consumed in the world, of which 58% is represented by electricity generation in the countries members of the Organization for Economic Co-operation and Development (OECD), is obtained from fossil fuels [1]. This dependence is not sustainable because fossil fuels are limited and impact the environment (e.g., the greenhouse effect). It is therefore necessary to develop renewable sources of energy to replace the electricity obtained from fossil fuels in the near future.

The most important concern with respect to some forms of renewable energy, such as solar and wind energies is their intermittence and the fact that their production over time cannot be matched to variations in demand [2]. Therefore, energy storage systems have become the key to improve the efficiency of renewable energy and increase its utilization [3]. Energy storage systems allow the production of electricity to be managed according to the demand. These systems allow the excess energy to be stored during low demand periods and producing electricity when the demand increases.

Pumped Storage Hydropower (PSH) is one of the most commonly used storage systems [4] because it allows large amounts of electricity to be stored and produced. PSH plants, which consist of two reservoirs located at different heights, allow a large percentage (70%) of the excess electricity generated during the low demand periods to be reused. However, PSH technology is constrained by topography and land availability because it requires a minimum elevation difference between the two reservoirs as well as large volumes. In addition, PSH plants are controversial due to their impacts on landscape, land use, environment (vegetation and wildlife) and society (relocations).

2 Acknowledgements
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3 Coal mines facilities
Underground coal mines have a depth of up to 300-600 m, with a main infrastructure composed of one or several vertical shafts, used for mineral extraction and for access of personnel and materials. It has a network of horizontal tunnels at different levels, with an average separation between levels of 80-100 m (Figure 1).

Figure 1. Typical scheme of shafts and tunnels network in coal mines

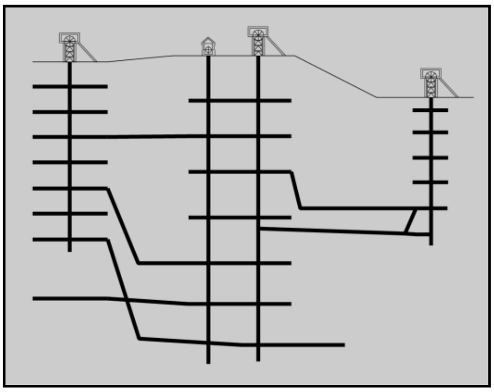
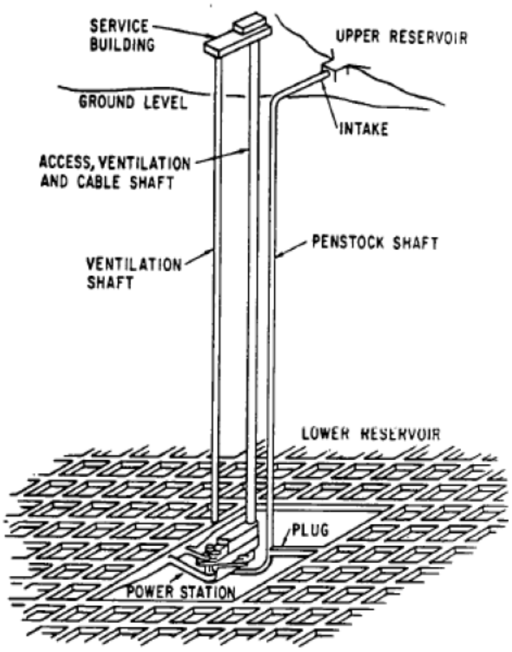


Figure 2. Current status of underground drifts

4 Pumped-storage power plants
The pumped hydro constitute a solution for the electricity grid exercise problems caused by the non-programmable energy plants. The scarcity of topographic gradients to be used without constraints as well as problems of public acceptance suggest the evaluation of an "underground pumped hydro" scheme, obtained through the exploitation of cavern reservoirs built several meters below the surface. In a typical hydropower pumped storage project the two reservoirs are located on the surface level. Some studies have considered the use of underground reservoirs, however until now there have been no known projects of this type under operation.

As early as 1960 Richard D. Harza had suggested the idea to use an abandoned mine as underground lower reservoir, and build a hydro pumped storage plant. The use of mines for such purposes requires extensive studies for certification. At the end of the 60s, Swedish engineers had proposed the exploitation of a surface reservoir and the construction of a new lower artificial reservoir in an underground cavity, with a cross section of 200 m^2 at a depth of 450 m below the ground level [5]. In 1978 it was presented an underground Pumped hydro plant project, with a lower reservoir conformed by a grid of 15x25m elliptical tunnels, to a depth of 1,000 m (Figure 3). To increase the useful head of more than 1,500m, a two-stages configuration could be used: a smaller intermediate reservoir is located half-way between the ground and the lower cave. The reservoir in the intermediate cave allows the two stations to operate in series without the need for a machine synchronization.

Figure 3. Grid gallery underground pumped lower reservoir example [6]



In 1969, Sorensen had suggested an optimistic future for the development of underground pumping stations [7]. Despite several projects have been studied over the past 50 years, there are currently no large size pumped underground hydro plant in operation. However after 2001, the new market conditions and the general development of not programmable renewable generation sources revived the need for a subsequent upgrade of large storage technologies, and the interest starts to grow again.

Mount Hope project, located in northern New Jersey was initially proposed in 1975. It intended to use the facilities of an abandoned iron mine as a lower reservoir but it was never developed

In the last few years it is proposed not only pumped installations with the construction of new underground reservoirs, but also the possibility of exploitation of existing cavities, such as the ore, coal or limestone abandoned mines with different experiences [8][9]. In 2006 a project for the underground hydro pumped plant in Yangyang in Korea was presented, with an exploitable head of 1500 m and 1000 MW of installed capacity (four 250 MW machines each), developed with a two stages pumped system.

5 Materials and methods

A hypothetical underground pumped storage power (UPSH) plant whose lower reservoir is an underground coal mine is considered. The lower reservoir has to be established subsurface and in great depth. The dominant mining method in the Asturian Coal Basin is the long-wall mining technique, which involves a controlled collapse of the sediments. To store the necessary amount of water, a network of tunnels with a length of 6,000m and a cross section of $30m^2$, must be built. These are larger cross sections, than those commonly used in these mines, so it is necessary to do the geotechnical studies. From the hydraulic line point, in the filling of the tunnels a multiphase flow intervenes, making the construction of ventilation shafts to expel the air, necessary.

The present document makes a preliminary analysis of the possible uses of mine water after the closure of coal mining basins. An analysis of the possible hydroelectric use is made. It is necessary to study the amount of energy produced as a function of flow and net head. Finally we include the conclusions of the study that has been carried out.

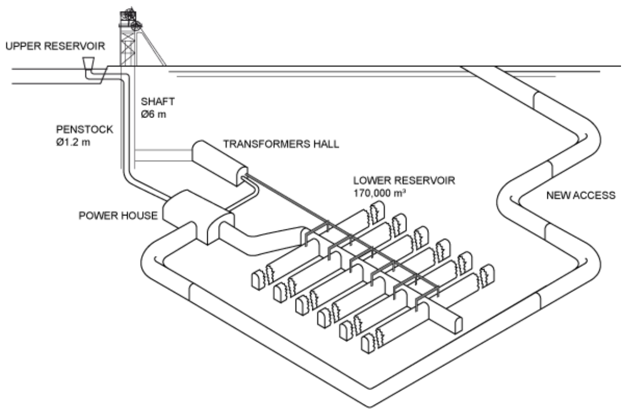
6 Description

In a typical hydropower pumped storage project, the two reservoirs are located on the surface level. In contrast to a conventional PSHP plant, the upper reservoir of an Underground PSH power plant is the smaller problem, as it can basically be established on the surface. If an abandoned coal mine is envisaged, the (potentially large) area of the former mine may be available for use In the generally densely populated Asturian Central Coal Basin, at least small- and medium-sized storage reservoirs on the surface, may often be done without too much conflict with settlement areas. In the surroundings of the shafts there exist buildings that are protected as industrial heritage, which cannot be demolished.

The conclusion for lower reservoirs is that the use of natural caverns is not possible; the artificial extraction of large cavities is technically demanding and financially expensive and thus does not seem to be very reasonable [10]. In certain cases, existing drifts may at least be partly usable, e.g. after additional extension measures. However, for a general concept, considerations have to be based on the fact that the drifts for a rib-shaped storage system in the completion stage, would have to be built totally new.

The penstock is located inside the main shaft. It is a vertical pipeline. If the diameter of the penstock is reduced, the load losses increase. If the penstock's diameter is reduced, the head and the output of the turbine are reduced also. The switchyard would be located on the surface, and the rated voltage would be 11,000-30,000 kV. The Figure 4 shows a general scheme of the project with the main components

Figure 4. Schematic configuration of main components



6.1 Energy Production

The storable amount of energy depends on the head and the water mass moved. Table 1 reports on selected possible heads in relation to different masses of water plotted and the resulting capacity in each case for the efficiency assumed.

The initial approach is to use the main shaft to introduce the hydraulic and electric equipment and materials. If the dimensions of the shaft are not enough, we can make a new access drift, between the outside and the power house (Figure 4). The dimensions of this drift would be 5 meters wide and 4.5 meters high.

Table 1. Storage capacity (storable amount of energy) of a PSH power plant [in MWh] for different heads and water masses.

Head [m]	Water Mass [Mt]					
	0.05	0.1	0.15	0.2	0.25	0.3
100	12,36	24,71	37,07	49,43	61,78	74,14
200	24,71	49,43	74,14	98,85	123,56	148,28
300	37,07	74,14	111,21	148,28	185,35	222,41
400	49,43	98,85	148,28	197,70	247,13	296,55
500	61,78	123,56	185,35	247,13	308,91	370,69
600	74,14	148,28	222,41	296,55	370,69	444,83

The pumping period takes 9 hours and the turbine period takes 6 hours. Also we can run the turbines at a 50% capacity and produce the same energy in double the amount of time, than if it were to run at 100% capacity. As we want to increase the profitability of the project, we can participate in a secondary electricity market, offering our availability. If we run the turbine during 12 hours at 50% capacity, we can run up and down the turbines output, between the rated output (100%) and the minimum technical output (40% rated output). Nine projects have been studied in mines that are not currently flooded.

6.2 Cost Assessment

The main characteristics of a project type, are reflected in the Table 2. The main cost of the project is the construction of the tunnel network for the lower storage.

Table 2. Main characteristics and cost assessment

Characteristic	PSH
Total Cost (M€)	40
Cost/kW (€)	1701
Lower Reservoir Length (m)	5700
Cross Section Lower Reservoir (m^2)	30
Net Water Head (m)	300
Reservoir Volume (m^3)	170000
Flow (m^3/s)	8
Turbine Power (MW)	23,52
Production time 100% Capacity (h)	6
Energy/cycle/MWh	141

The water necessary for the initial filling of the reservoirs as well as for the replacement of the losses by evaporation, will be taken from the runoff of the mine, so a public water course is not necessary.

7 Conclusion

The implementation of an underground PSH project using coal mine facilities, is an appealing option for energy storage, particularly in Spain where the underground mining is currently phased out, with an expected closure date at the end of 2018. Also, the significant reduction of the adverse impacts on the landscape and local residents, could be an advantage.

The main drawback is the cost of building the new underground drifts, which are more expensive than the construction of a surface reservoir.

The water necessary for the initial filling of the reservoirs as well as for the replacement of the losses by evaporation, will be taken from the runoff of the mine, so a public water course is not necessary

The most relevant technical aspect is related to the storage structure for the lower reservoir. Based on the techno-economic evaluation, it has been concluded that it is necessary to build a new network of tunnels for the lower reservoir.

PSH can provide many services to the power system, as flexibility of operation and speed to vary the power delivered to the grid. This aspect is fundamental to deal with the variations in production due to fortuitous failures in the thermal power plants and of any significant variations in the production of intermittent renewable power generation.

In the present work the technical feasibility of the projects has been analyzed, resulting feasible projects.

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