Optimization of the hydrological utilization for hydroelectric power plants of flowing type

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Abstract. Hydroelectric power stations have as mission the generation of electric power starting from the kinetic and potential energy of the water. This energy production can be carried out by means of hydroelectric plants with storage capacity, or by means of hydroelectric plants without that capacity (denominated flowing hydroelectric plants).

Hydroelectric power stations of flowing type, object of this article, use the circulating flows along the river, presenting the necessary buildings and infrastructures for their conduction and utilization, but without presenting in their conception water storage systems. This type of power stations are designed and automated to operate between certain flow limits, working with constant water jump. The flow is adapted to the existent hydrological availability at any moment, presenting an appropriate operation to the behavior of the flow in the river. That is, the station produces energy when available flows exist that can be subtracted from the river inside the margins of admission of the power station: the "equipment flow" and a minimum operation flow called "technical minimum flow".

The optimization procedure proposed and developed in this work permits us to take advantage of the times of low-level flow (low water level) for production of electrical energy. The objective is to obtain that the turbine is able to work even below levels corresponding to the "technical minimal flow". The volume used in the turbine is then expanded; that implies a higher energy production for the same use, as well as an amplification of the operation period, which implies an improvement of their efficiency.

In this investigation work, the algorithms of regulation of the power station for every different flow have been devised and developed, as well as the increments in the production of the power station.

Key words

Renewable energies, Mini-hydroelectric Energy, Optimisation, Automatic control of hydroelectric power plants.

1. Introduction

The most complete structure in a flowing use of the hydrological sources generally responds to the graphic in Figure 1.

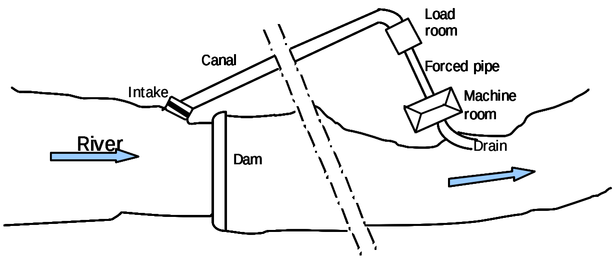

Fig. 1.- General diagram of a flowing hydraulic plant

In this type of exploitations, the dam facilitates the reception of the water of the river, by producing an elevation of its level, and presents the necessary elements for the circulation of the ecological flow in the affected section of the river. Once the flows subtracted of the river come in through the water intake, they are driven along the canal up to the load room. Then they descend along the forced pipe up to the turbines, located in the machine room, where mechanical energy is obtained in the axis of these turbines. They are coupled, directly or by a multiplier, with the generator that transforms this mechanical energy into electrical power, which is injected in the net.

Figure 2, [1], shows the different disposition possibilities that can be found in the hydroelectric power stations, depending on their situation along the river. With high water jumps and low flows, a disposition with forced pipe is more appropriate. With lower water jumps and bigger flows, the turbine can be placed in the camera. Furthermore, even the ideal type of turbine depends on the water jump and the flow.

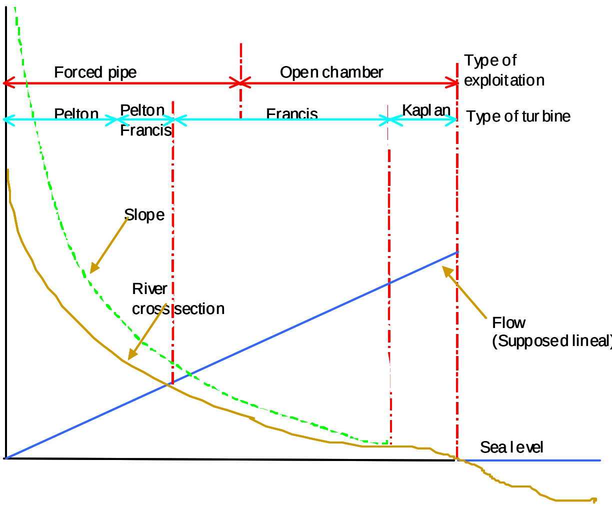

Fig. 2. Hydraulic plant exploitation options

The restrictive factor of operation of the power plants is found in the turbines, once the power station had been conceived for a maximum operation flow (equipment flow), since they cannot work for the whole range of flows that can exists in the river. These flows usually vary among 10, 25, 40 and 100% of the flow of equipment of the power station, depending on the type of turbine used.

In the Figure 3, the performance curves can be observed for diverse types of hydraulic turbines, where it can be observed that, for the case of the Pelton turbine, their minimum technical flow is approximately 10% of the nominal flow, while for the Francis turbines the minimum technical flow is around 40% of the nominal flow.

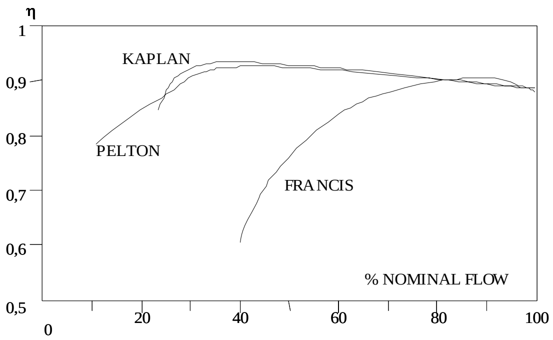

Fig. 3. Performance of the turbines

Once the turbine to be used is chosen, the most appropriate equipment flow is determined in order to obtain a maximal energetic production in the power plant. With this objective a hydrological study is carried out starting from the data of the flows along the river object of the exploitation (see Figure 4).

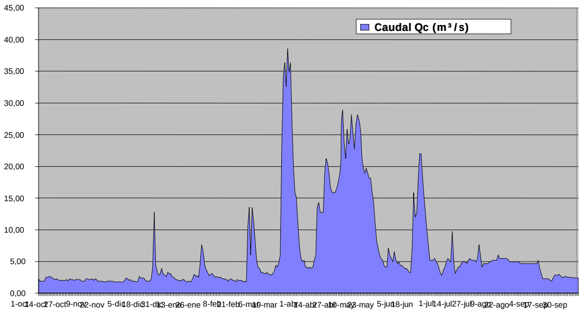

Fig. 4. Volume of water flowing along the river

The energy obtained in the plant will depend on the volume that passes though the turbines. From the graph of circulating flows (Figure 4) and by means of the treatment of the information (basically to put it in order), the curve of classified flows is obtained (Figure 5).

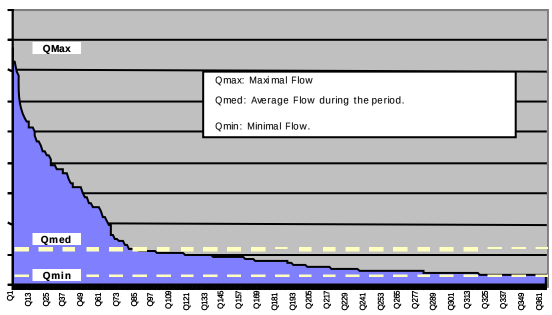

Fig. 5. Curve of classified flows: minimal, maximal and average flows

The maximum energy that can be obtained from the utilization of the flow is obtained by passing through the turbines all the volume represented by the curve of classified flows. But not all this volume can be utilized, since there exist flows that are higher and lower than the selected "equipment flow", which cannot be utilized in the turbines due to different causes:

1) Ecological flows: Minimum flow that must always be circulating along the river in order to allow that the habitat of the river subsists in the section of the river affected by the exploitation;

2) Flows higher than the equipment flow: As their name indicates, they are flows that overflow the equipment flow, and therefore they will not pass through the turbines of the power plant, and must be released in the river;

3) Minimum technical Flow (Q_{mt}): Minimum flow of operation of the turbine, that is, the minimal flow that provides an acceptable performance of the turbines.

The strategy of optimization of the utilization is centred in the use of these last flows: higher than the equipment flows cannot be subtracted from the river, and the ecological flow must be assured. Therefore, lower than the minimum technical flows are used during the low water times, periods of time during which energy could not be produced under normal conditions, etc., as can be seen in the graph represented in Figure 6, in the right side, with dotted line.

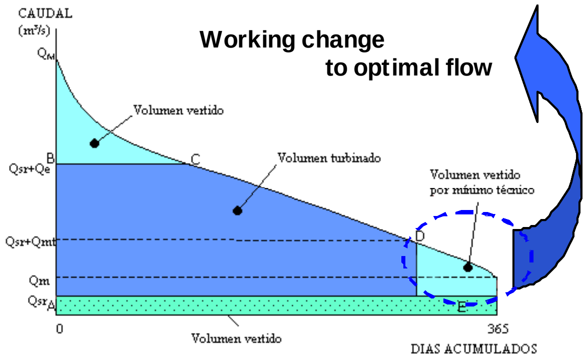

Fig. 6. Optimization policy

2. Hydroelectric system

The installation where the regulation algorithms are simulated for their later implementation is a hydroelectric power plant of flowing type, with forced pipe, net water jump of 10 m in height, an equipment flow (Qn) of 6 m³/s, a turbine of Francis type, and a generator of 500 kW.

For the determination of the circulating flows, the "36th utilization station" of the Iregua river has been taken, which belong to the Ebro river basin, in La Rioja (Spain). The circulating flows in the mentioned station for a series of 40 years have been obtained from the "Ebro Hydrographical Confederation" (the public organism that controls all the utilizations in the Ebro river basin). Once the previous information has been studied, the *standard year* has been determined, which will be used as the typical year for the tests and simulations.

3. Working policy

The operation strategy is based on the measurement of the input flow toward the power station (Q_ENT). Under normal conditions of flow the power station carries out its regulation with a constant parameter (Hu_CTE). The normal conditions of flow for the input flow Q_ENT are considered the conditions belonging to the interval between the equipment flow (Qn) and the 40% of the mentioned flow, which corresponds to the minimal technical Q_MT.

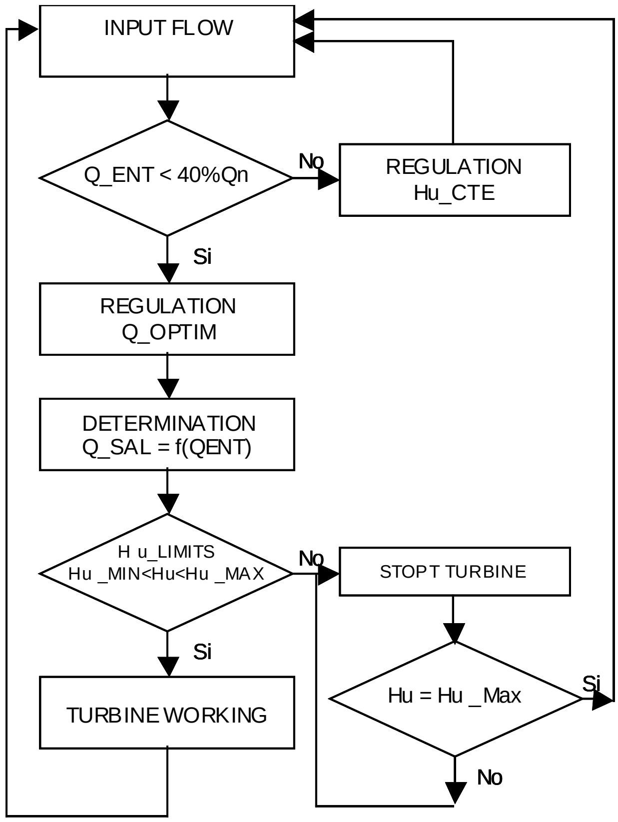

Fig. 7. Working sequence

Starting from the detection of the minimum value of flow for the operation of the power station, the minimum technical flow (Q_mt), the power station passes to regulation by means of Q_Optimo, which represents a regulation form different to the employees up to now [2] (see Figure 7). This regulation consists on determining for each value of input flow, the flow of admission of the turbine to obtain the maximum production of energy in the exploitation.

The hydroelectric power plant also presents limitations related to its operation, due to the work height, the measurement in the load room, and the bounded flow values, which should stay between a maximum (determined by the Hu) and a minimum (determined by the turbine).

The power station works with an optimal input flow until the minimum level of operation Hu_MIN is reached, which implies the stop of the power station until maximum level of operation Hu_MAX is reached again due to the input flow. For any operation condition, if Q_ENT > 40% of the Q_EQUIPAMIENTO the power station passes to regulation by constant jump Hu_CTE.

4. Optimization methodology

The methodology of optimization can be divided into two parts.

a) Determination of the optimal operation flow Q_Optimo.
b) Implementation of the algorithms.

a. Determination of the optimal operation flow

For the determination of the optimal operation flow Q_Optimo, the performance curves of the machines of the power station have been modelled, obtaining a curve of global performance of the power station that will serve as a base of the study of the diverse operation flows (see Figure 8).

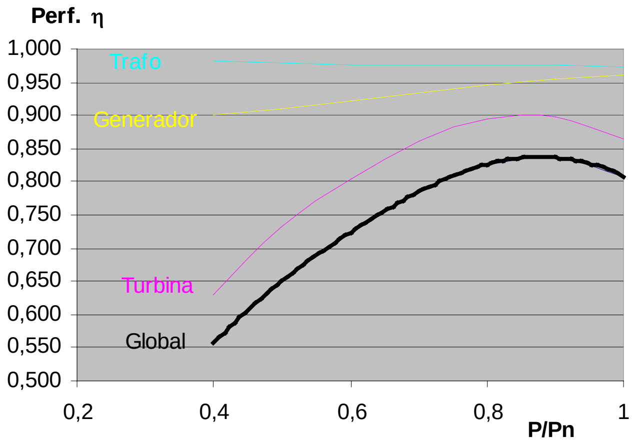

Fig. 8. Performance curves of the machines and global

With those mentioned curves and with the input flow in the power station (Q_ent) the output flow (Q_sal) that maximizes the energy produced (E_gen) due to the emptying of the pipes is determined.

$$E = K * V * \eta(Q\_SAL) * Hn(Q\_SAL)\frac{Q\_SAL}{Q\_SAL - Q\_ENT}$$

Where:

V: Useful volume of emptying between the limits Hu_MIN and Hu_MAX.
η(Q_SAL): Global performance of the system depending on the input flow.
Hn(Q_SAL): Net water jump in the power station (deduced the losses in the pipes) depending on the output flow.
Q_ENT: Input flow towards the power plant.
Q_SAL: Optimal output flow for the maximal production of energy in the power station.

From the results of the mentioned regulation by Q_Optimo the following conclusions can be deduced (Figure 9).

Q_ENT >= Q_MT the power station regulates by Hu_MAX admitting a flow in turbine (Q_SAL) similar to the input flow in the station(Q_ENT). (ZONE A)

Q_ENT < Q_MT the power station is regulated by Q_OPTIMO. For this condition two differentiated values can be given:

Q_MT>Q_ENT>0,2Q_EQUIPAMIENTO: the power station works with a value of regulation for the fixed flow of 0,2Q_EQUIPAMIENTO. (ZONE B)

Q_ENT < 0,2Q_EQUIPAMIENTO: the power station works adjusting its output value (Q_SAL) to the input value (Q_ENT), depending on the previous graph, with values close to 85% of Q_EQUIPAMIENTO. (ZONE C)

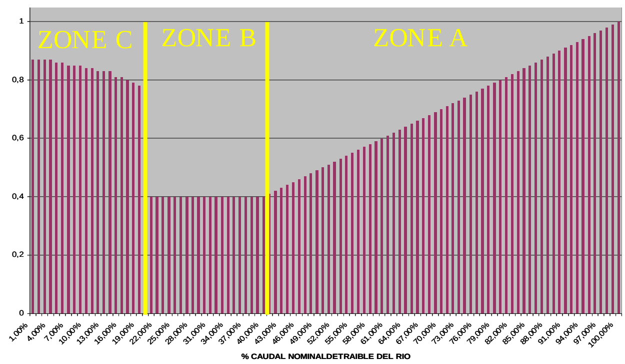

Fig. 9. Opening of the distributor, with optimal performance, for flows subtracted from the river

b. Implementation of the algorithms

The algorithms are implemented in the own control system of the power station, imposing, as new operation conditions, that when the input flow (Q_ENT) is lower than the minimum technical flow of the turbine (Q_MT) the power station starts the regulation with the optimal flow (Q_Optimo).

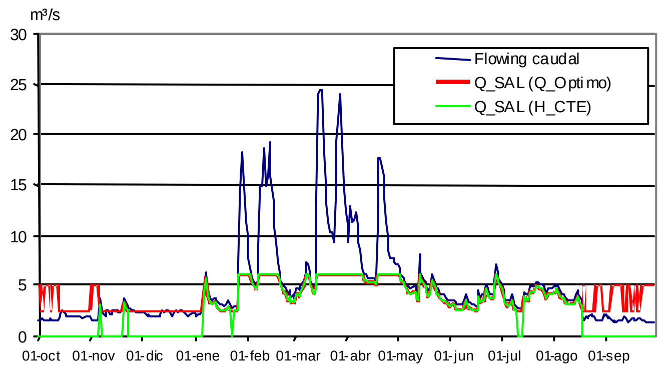

Fig. 10. Working flows (Q_SAL)

In the implementation phase, sensors will be placed in the intake floodgate to determine the input flow, apart from the existent ones in the exploitation for the determination of the ecological flow along the river. Furthermore, a level sensor will be placed in the load room in order to determine the limits of the operation conditions.

When the input flow (Q_ENT) is equal or bigger than the minimum technical flow of the turbine, the power station returns to its conventional regulation by constant jump.

5. Results

Once the system has been implemented and analyzed for the average hydrological year (1st October to 30th September), the operation of the power station in conventional way (Hu_CTE) and in optimal way (Q_Optimo) can be compared from the analyzed series.

During the months of September to December, the power station in conventional operation way (Hu_CTE) must practically stay stopped, while in optimal operation way (Q_Optimo) the power station takes advantage of the circulation flows for energy production. This allows a temporary use of 100% in optimal way (Q_Optimo), compared to the use of 61,37% in conventional way (Hu_CTE).

The working flows, as can be observed in the graph in Figure 10, are superior in optimal way (Q_Optimo) to the circulating flows along the river, due to the storage capacity of the utilization and the emptying limits settled down for the pipes.

The powers of operation during the studied period correspond to the established algorithms for optimization of the energy production (see Figure 11), starting from the optimal flows of operation (Q_SAL).

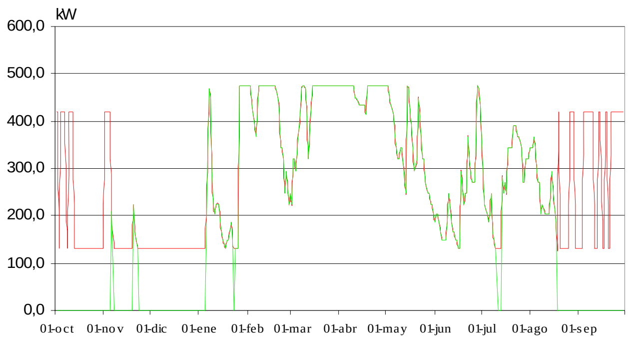

Fig. 12. Generated power (kW).

The annual energy production obtained in the utilization of the hydroelectric plant have been increased in optimal flow operation in 16,18% compared with the conventional operation (see Figure 11).

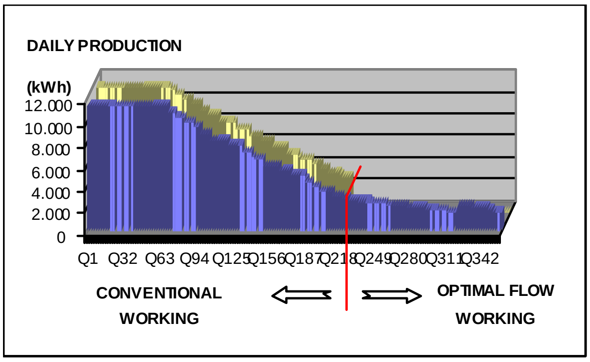

Fig. 12. Daily production

Conclusions

Hydroelectric power stations of flowing type presents limitations in their operation, since they must stop when the flow conditions do not reach the minimum level of operation. With the presented algorithms the range of operation of these power plants is expanded, avoiding the previous limitation and making working the hydrological power plant for all the flow ranges; this constitutes a useful global employ of the power station. Therefore the energy production of the exploitation is increased, and its energy efficiency is improved, as well as its profitability [3].

The easiness of the implementation of the proposed techniques in power plants that exits must be emphasized, since it is only necessary the control of the flows in the intake, the measure of the level in the load camera (minimum level), and the implementation in the control system (SCADA and PLC) [4] of the presented algorithms.

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