METHODOLOGY FOR PLANNING AND MANAGEMENT OF MULTIPURPOSE HYDRAULIC SCHEMES WITH A SYSTEM THINKING APPROACH

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Repeated failures as well as difficulties related to the implementation of new hydroelectric powerplants in industrialized countries illustrate the paradigm evolution which manages relationship between human society and nature. Problems resulting from these plants, often ignored during planning phases, in addition to current trend to restore a natural state, require ecological analyses for new constructions as well as for scheme restoration or river corrections. Taking into account energy and ecology, together with security, financial and socio-economic aspects, transforms the design of hydraulic schemes into a complex problem. Designing, dimensioning and managing in an integrated way such multipurpose hydraulic schemes thus require new approaches.

The first objective of the present work is the comprehension of the complex system formed by a multipurpose hydraulic scheme and the determination of its most important characteristics. The second objective aims at developing a methodology to quantify the installation impacts on the key factors of the system. The third objective is an optimization of the system itself as well as the determination of the distribution of the cost between the different purposes. The developed methodology includes at first a qualitative analysis of the system which then allows a quantitative modelling. Optimization is carried out on the basis of this second modelling. The cost distribution is finally obtained by comparison of partial optimizations of the system.

The qualitative analysis is based on a cognitive representation in order to model the complex system behaviour. This representation includes feedback loops between the various factors. The mathematical analysis of the network classifies the factors and highlights the key factors. In the particular case of the multipurpose run-of-river hydroelectric scheme, this method distinguishes the decisional level from the functional level. It underlines the variable, namely the downstream flow, which constitutes the bond between the two levels. The purposes of this project are to reduce hydropeaking, to produce energy, to offer a retention volume for flood mitigation and to allow a social use for leisure activities.

Quantitative modelling is carried out by simulation models, considering an optimized operation of the reservoir which determines the downstream flow. This optimization is performed by a mathematical resolution using the software AMPL. It includes the constraints to reduce the downstream flow variations with the objective of maximizing energy production. It also results in minimal reservoir water level variations. The simulation models then calculate the scheme behaviours (hydraulic, energy, thermal, ecological, social and financial). The flood management is treated separately, with the objective of reducing the flood peak by preventive draining of the reservoir. A financial comparison of the probable

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impact of retention on peak floods is carried out by evaluating the potential of lowering downstream dams. An optimization of the turbine dimensioning, specifically applicable in case of highly variable water levels (upstream and downstream) and flow discharge, is also developed.

The general optimization of the system, performed with the optimization tool QMOO (developed at LENI - EPFL), is related to variables which determine the size of the scheme. This optimization is carried out in two stages. The first stage determines, for each goal of the system (partial optimization), the optimum production conditions of the set goal. This stage defines a transfer function between the optimal production and the minimal investment. The second stage determines, by a complete optimization using the transfer functions, the set of optimal solutions. These optimal solutions are then filtered by two successive filters: the synergistic filter eliminates solutions which do not reduce the investment, whereas the filter of the actors eliminates solutions which produce quantities below the limit or which require investment above the fixed limit.

The complete methodology, developed in 12 steps from the qualitative analysis to the final set of solutions, is applied to a study case on the Swiss Upper Rhone River. The solutions found are able to satisfy the requirements of the various actors while generating a saving in investment higher than 10%. This reduction, called synergistic profit, is compared to the sum of the optimal investments of a single purpose scheme carried out separately. The solutions found require an investment in the range of 150 to 180 Mio CHF. They permit to produce 42 GWh/yr of electricity, to reduce the current hydropeaking by approximately 30% and to offer a social impact calculated to 55'000 visits per year. The available volume for flood management oscillates between 5 and 8 Mio m^3.

This research work, carried out within a team of ecologists, architects, civil and mechanical engineers, producers of hydroelectricity and public authorities, showed the relevance of the selected approach which led to the feasibility of the suggested solutions. In addition, the modularity of the developed methods (qualitative analysis, hydropeaking management, probabilistic retention impact on flood peaks, optimisation of turbine dimensioning, partial and complete optimizations) allow a wide range of possibilities for partial use, for applications to other works or for future developments.

The principal results of this research can be defined as follows: 1) an operation method is developed in order to absorb more than 50% of the current hydropeaking while losing less than 10% of the energy potential, 2) the financial retention impact on flood peak is justified, 3) turbine dimensions are optimized in case of strong variability on both flow and head, 4) conception and dimension of multipurpose schemes are performed in an integrated way and lead to solutions which allow cost saving for each objective.

Keywords: Multipurpose reservoir, Complex system, Hydropeaking mitigation, Flood mitigation, Simulation, Optimization, Hydraulic, Energy, Social, Thermal, Finance, Ecology, Decision support system tool, Cost distribution.