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Online optimal power distribution between units of a hydro power plant

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ABSTRACT

The paper presents a novel methodology for the operation of those hydro power plants provided with a single penstock by the optimal distribution of the dispatched power among its available generating units, aiming at the maximum efficiency of the whole power plant energy conversion. While previous optimization methods made use of off-line static curve and parameters or expensive flow meters, the proposed method is on-line in nature and uses a single pressure meter at the end of the power plant penstock. The method was applied to a power plant and has resulted in a higher efficiency operation under several conditions.

1. Introduction

Hydro power plants have been used for electricity generation for a long time due to its low operational cost, high energy conversion efficiency, and because it uses a renewable primary resource, the water. Nevertheless, water is an important resource that must be handled with care, to ensure long term sustainability.

In the design of a hydro power plant the gross head is defined by the regional topography and by the dam height. The total power and the number of generating units is a function of economic factors and of the hydrological availability of the site. The flexibility of hydro power plants allows its operation to accommodate both base and peak loads.

When meeting the peak load the generated power must follow the load variations, therefore the loading and the number of employed units of the power plant must be chosen to provide the dispatched power with the highest efficiency. When supplying the base load all the available units are operated to generate their maximum power. Nevertheless, due to the hydrologic cycle, there is a percentage of the year, the dry season, when there is not sufficient water to push all the units of a power plant at their rated power and, again the available units must be dispatched to achieve the highest efficiency.

The optimal operation of a single hydro power plant, nevertheless, has not been treated properly in the technical literature, as long as very few papers cover this subject [1–9]. The great majority of published material regards to the hydro cascade operation, aiming at the maximum energy generation for a given inflow scenario [10–12].

Theoretically, the operation of a single hydro power plant can be accomplished by applying the equal share criteria or some offline optimization technique, which are based on historical data, and goodness function with constant parameters. However, power plant parameters vary continuously over time, including head, flow, temperature, efficiency, equipment aging, and other variables, with which none of the previous methodologies can manage correctly.

2. Conventional optimal power plant operation

There are many methods that can be used to obtain an optimal distribution of the dispatch power among the units of a power plant. One can, for instance, consider that the power plant has n-twin machines and divide the dispatched power using an equality criterion, other can use the previously measured efficiency curve of the units to achieve an optimal operation, or efficiency can be measured online for an optimal distribution. Such methods are described as follows.

2.1. Classical economic dispatch

As long as the efficiency of each generating unit is a function of the delivered power, the power plant optimization problem can be stated as defining the output of each unit that maximizes the total power generation efficiency or, in other words, to reach the minimum generation cost subject to system constraints to meet the

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demand and the capability of the machines. The simplest economic dispatch formulation is.

$$\begin{array}{ll} \min & C_T(P_i) \\ s.t. & \sum P_i = P_d \\ & P_{Li} \leq P_i \leq P_{Ui}. \end{array} \quad (1)$$

where C_T is the cost function, P_d is the total dispatched power and ΣP_i implies the sum of all generating units, P_{Li} and P_{Ui} are the lower and upper generation limits of each unit.

Notice that for hydro power plants, from now on, the cost function is considered as the water consumption as a function of the generated power, as long as the water has not a direct associated cost. The basic idea behind many methods is to convert the minimization problem from being constrained minimization to unconstrained. The minimum of an unconstrained function is found at the point where the partials of the function to its variables are zero [13].

Therefore, the solution is reached when all incremental costs are equal and, at the same time, the load is being met. In other words, if the generating groups of a power plant are considered to have the same characteristics, i.e., twin units, with same cost functions and partials, the power delivered by each unit will be the total dispatched power divided by the number of available units.

2.2. Dispatch based on efficiency tests

Unfortunately, it is well-known that each machine, even from the same manufacturer and design, has its own characteristics and the generation cost will eventually vary between like units.

Therefore, a procedure for optimal load distribution among the available units of a power plant can start from the presented equal load distribution criterion, as a quasi-optimal solution, to perform an iterative process based on the efficiency curve of each unit to obtain an overall maximum efficiency. In this case, field tests must be done to obtain the efficiency curve of each unit, which explains their efficiency behavior with the dispatched power under several operating conditions of head and flow [7,8].

Fig. 1 presents an example of an operating chart of a hydro turbine model obtained from laboratory tests. The efficiency of the hydro turbine depends on the turbine flow and net head, leading to a three-dimensional diagram, which is the unit efficiency characteristic for any load and head conditions.

Therefore, based on the knowledge of efficiency function of the units of a hydro power plant, it is possible to obtain an optimal solution that maximizes the efficiency of the entire power plant.

$$\begin{array}{ll} \max & \eta_T \\ s.t. & \sum P_i = P_d \\ & P_{Li} \leq P_i \leq P_{Ui}. \end{array} \quad (2)$$

where η_T is the total plant efficiency, which is a function of the dispatched power P_i and the efficiency η_i of the i-th unit.

$$\eta_T = \frac{\sum_{i=1}^{n} P_i}{\sum_{i=1}^{n} \frac{P_i}{\eta_i}} \quad (3)$$

Nevertheless, this efficiency curve is a single picture of the machine behavior at a given moment and does not consider eventual variations on the machine or on the power plant parameters over time. Another approach based on loss minimization rather than efficiency maximization can be applied [9]. In this case the head losses on the penstock and the tailrace level as a function of the flow are also necessary, and, again, are considered invariable and do not depend on machine aging, temperature variation and other factors.

2.3. Dispatch based on efficiency measurement

The energy conversion efficiency is obtained by the ratio between the output and the input power. Equation (4) depicts this concept by including the related variables.

$$\eta = \frac{P \cdot 10^3}{\rho \cdot g \cdot Q \cdot H} \quad (4)$$

In this equation P is the electric power (kW), ρ is the fluid density (kg/m^3), g is the gravitational acceleration (m/s^2), Q is the turbine flow (m^3/s) and H is the net head (m), which is the difference between the gross head and the hydraulic losses. Based on Fig. 2, which is a typical installation for hydro power plants, the net head is obtained as

$$H = \frac{p_1 - p_2}{\gamma} + \frac{v_1^2 - v_2^2}{2g} + z_1 - z_2. \quad (5)$$

where p, v and z are the static pressure (N/m^2), flow average velocity (m/s) and quota (m) of the hydro turbine input (subscript 1) and output (subscript 2) respectively, as described in the main hydro turbine test standards [3,14,15].

Therefore, a suitable device can be conceived to determine the online efficiency of each unit based on field measurements [2,16]. The same function can also be implemented using power plant SCADA system capabilities.

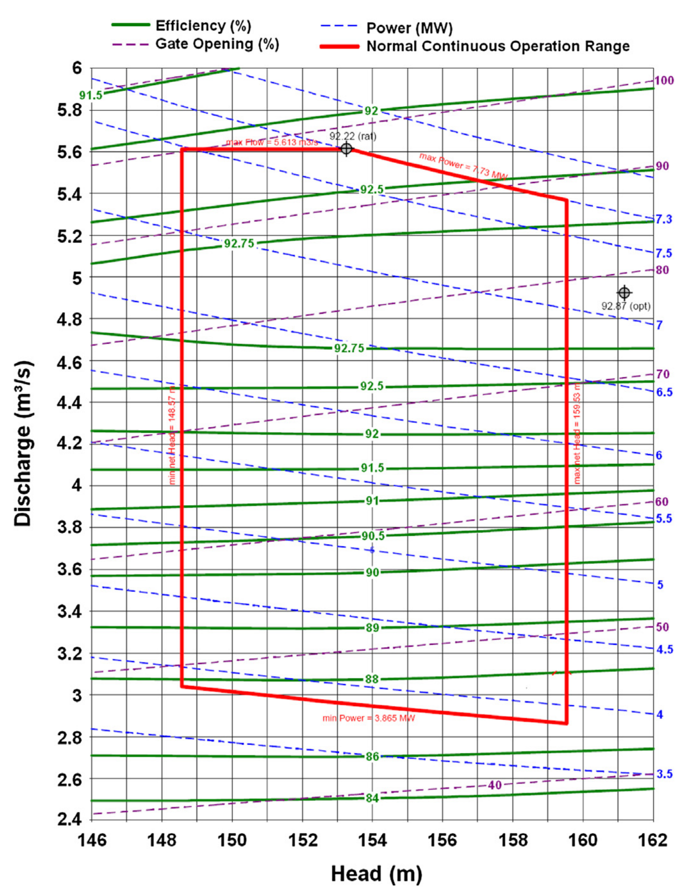

Fig. 1. Operational chart of a hydro turbine.