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RIVER GLOBAL HYDROELECTRIC POWER EVALUATION

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During COP21 participating countries agreed for 30% increase of renewable sources in energy mix at the horizon 2030. In parallel, energy suppliers have to satisfy a power demand which is both increasing and more distributed. Of the different renewable energy sources, hydraulic one is interesting by its higher steadiness and the large number of sites where its installation is economically attractive. There are two different types of hydraulic sources: potential ones based on exploitable water height requiring infrastructure investment for dam construction in a restricted number of sites, adapted for large transitory energy peak requests, and kinetic ones based on water flow velocity with continuous production in smaller units with reduced or even no infrastructure constraint. Present study aims at giving evaluation of the boundary between the two types of energy production from potential and kinetic origin in order to characterize the site parameters where each one is more adapted. In interesting cases, it is possible to return backward a dam site with potential exploitation to initial river site with kinetic exploitation of adapted production units at zero cost when correctly monitored, thus solving an important environment problem.

Key words : River Flow Rate, Basin Power Evaluation, Kinetic Power, Potential Power, Small Scale Turbine.

I. Introduction

Water covers more than 72% of Earth surface with oceans and lakes, 97% of it being salted (seas and oceans). Present study will be concerned with last remaining 3% (rivers, lakes, icebergs and ground water) which is soft. Water follows a cycle energized by the sun during which exchanges will take place and water will take liquid, solid or gas state. This cycle is immutable, and if some regions on the Earth can have very different pluviometry at different locations depending on the seasons and geographic situation, at global Earth level water is constantly renewing.

Water has been a very first energy source utilized by Man (first mills have been in use since higher Antiquity), but it is only during last century that electric turbines have been developed for exploiting water kinetic and potential mechanical energy to activate an alternator producing electricity. This is a renewable production, and to enlarge energetic best offer toward larger autonomy, it is interesting to raise some questions on possible role of this energy in proposed mix including solar and wind sources [1,2,3,4,5]. Contrary to these two sources which are strongly depending on climatic data, hydraulic energy only depends on the type of considered rivers [6,7] and as such, may significantly contribute to energetic demand, particularly when including small scale sources [8,9,10] more adapted for distributed demand. Hydraulic sources can be split into two main classes : the ones using kinetic energy of water flow and the ones using potential energy of water contained in artificial lake by constructed dams. There also exists another third class of intermediate ones which take advantage of water locks constructed for regulating boats circulation on too fast stream rivers. In order to determine the economic level of hydraulic contribution, a global study is proposed in the following where produced power optimization between the two main hydraulic energy sources, potential and kinetic ones, is made in a predefined territory domain in terms of a set of parameters describing the domain and the various water sources circulating in it. The result provides a guideline orienting the choice toward best combination of kinetic and potential sources for highest energy production with smallest investment. In a reverse way, it is also possible to specialize the analysis in terms of energy demand characteristics. As already known for instance, potential sources are needing considerable terrain reshaping and are only possible in specific places. They are adapted for large but time limited production which may not be in immediate vicinity. If the demand happens to be located in a region with flowing rivers, it might be economically more efficient to equip them with small turbines using kinetic flow energy. This kind of study attempting to create the matching conditions between production and demand from territory structure and technological possibilities is a new tool to satisfy environmental and economic constraints weighting more and more on global political decisions.

To show the versatility of present approach, in the sequel the study will consider economic analysis of river equipment with a number of modest size turbines exploiting its kinetic water flow. Such system will be seen to provide particularly well suited solution to nearby distributed demand with negligible maintenance and equipment costs in a plug-and-play type action. The conditions for which it can provide useful alternative to classical sources using potential energy source will be discussed depending on distance of production site. Interestingly, providing this information prior to any investment can save large side costs related to landscape reshaping. In a reverse way, it will be shown what conditions have to be imposed for a given already installed potential type source to be transformed back with corresponding landscape transformation into previous landscape and at least same energy production from kinetic type source, a problem with evident applications in evaluation of environmental impact of such decision. Other specific situations will be discussed elsewhere.

II. Applications

Eight sites have been selected in France with different flow rates and exploitable water height differences see Table **I**. The flow rates are average calculated ones from real measured values over the ten years period 2005-2015 [11] and a threshold value corresponding to 8 months period flow rate has been retained in the Table.

Site	**River Name**	**Flow Rate m^3/s**	**H m**	**P_{nom} kW**	**P_{inst} kW**
Limoges	**La Vienne**	**48.2**	**1.5**	**708**	**566**
Nice	**Le Var**	**53.15**	**4**	**2083**	**1979**
Saint Yorre	**L'Allier**	**82**	**25**	**20082**	**16066**
Millau	**Le Tarn**	**36.2**	**5**	**1772**	**1648**
Marignane	**La Cadière**	**.63**	**2**	**12.4**	**10.2**
Aurillac	**La Jordanne**	**3.9**	**4**	**152**	**145**
Brive	**La Corréze**	**18.25**	**10**	**1789**	**1431**
Besançon	**Le Doubs**	**100**	**2**	**1961**	**1079**

Table **I**. Expectable Power Outputs from Potential Turbine Installation at Indicated Sites

With the values of Q and H from the first two columns, the adapted turbines for potential exploitation can be determined from Figure **1** and their nominal power is reported in column 5.

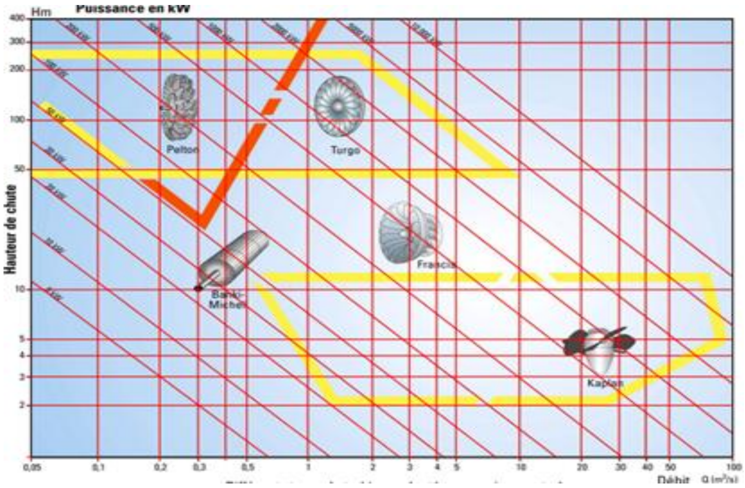

Figure **1**. Turbines for Different Domains in (Flow Rate,Height Fall)-Plane

To get final expectable output power the efficiency rates η_p of the different recommended turbines is obtained from Figure **2**, and calculated installed power is given in column 6 from analytic expression of P_{pot}.

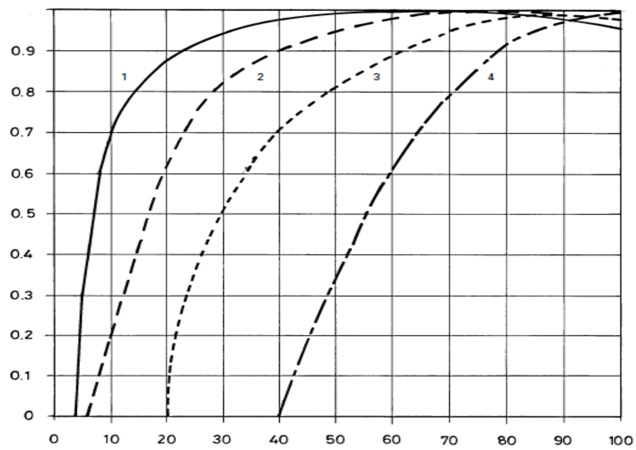

Figure **2**. Efficiency Curves for Different Turbine Types

(1-Pelton, Crossflow;2-Kaplan;3-Francis, Crossflow 1cell;4-Reverse Pump)

For comparison with the other kinetic approach, the water depth h in the rivers has similarly been obtained from [11] and averaged over the 2005-2015 period, out of which a threshold value corresponding to 8 months of the year has been extracted. In column 4 of Table **II** the parameter h is taken as $h = \mathrm{Min}\{h,h_{crit}\}$ where h_{crit} is a typical size above the smallest acceptable diameter size of kinetic turbine for power output ≅ 10kW. The range of its possible values indicates the flexibility of acceptable kinetic turbines distribution choices (ie fewer larger turbines vs larger number of smaller ones). In present case the calculation has been performed with $h_{crit} = 1$m which is an upper limit. To determine flow velocity $V = Q/S$ where S is river cross section, it will be supposed that it is a rectangle $S = hD$ where D is river width. Evaluation of river width will be made by [12]

$$D = 2.73\, Q^{1/2} \qquad (4)$$

The expression is valid for an interval of 5 to 50% of vegetation on the river banks. Then flow velocity is given by $V = Q/hD$ and nominal power output per station writes

$$P_{kin} = \eta_k \rho S_T V^3/2 = (1/8).\pi\eta_k\rho Q^{3/2}h^{-1} \cong .39\eta_k\rho Q^{3/2}h^{-1}\ (\mathrm{kW}) \qquad (5)$$

where $S_T = \pi h^2/4$ is the flow intake surface of the turbine. The number $n = S/S_T = 3.48Q^{1/2}/h$ is the number of turbines cross section in the flow Q and the product

$$P_{k,tot} = hDP_{kin}/S_T = 1.36\eta_k\rho Q^2h^{-2}\ (\mathrm{kW}) \qquad (6)$$

represents the total power output from the complete flow Q in the river to be compared with potential power P_{nom} in 5th column of Table **I**. It is thus reasonable to distribute turbine stations over the river length L already utilized by the potential approach to get height H, and their maximum number N will be fixed by the minimum distance d required for the flow not to be perturbed. So one will take $N = \mathrm{Min}\{L/d, S/S_T\}$ and the total expectable maximum kinetic output will be taken as $P_{k,tot} = NP_{kin}$. In the calculation the efficiency coefficient η_k has been taken as the Betz limit [13,14]. Application to previous selected sites gives the results of Table **II**.

Site	River Name	Flow Rate m^3/s	h m	N	P_{kin} kW	$P_{k,tot}$ kW
Limoges	**La Vienne**	**48.2**	**1**	**25**	**77**	**1965**
Nice	**Le Var**	**53.15**	**.8**	**24**	**115**	**2824**
Saint Yorre	**L'Allier**	**82**	**1**	**31**	**181**	**5688**
Millau	**Le Tarn**	**36.2**	**1**	**20**	**54.8**	**1096**
Marignane	**La Cadière**	**.63**	**.6**	**1**	**.8**	**.8**
Aurillac	**La Jordanne**	**3.9**	**.6**	**11**	**3.1**	**35.7**
Brive	**La Corréze**	**18.25**	**1**	**15**	**13**	**281**
Besançon	**Le Doubs**	**100**	**1**	**35**	**241**	**8460**

Table **II**. Expectable Power Outputs from Kinetic Turbine Installation at Indicated Sites

As expectable, only very small flow rates < $1m^3/s$ are disqualified for kinetic exploitation, and minimum flow rate ≅ $20m^3/s$ is required for reasonable unitary output > 10kW. In all other cases, it is verified from expressions of potential and kinetic power outputs that even if total collected kinetic power may be smaller than corresponding potential one for intermediate flow value, it overtakes above some critical threshold given by

$$Q_{crit} = (\eta_p g/1.36\eta_k)Hh^2 \cong 10Hh^2 \qquad (7)$$

For instance from Tables **I** and **II** one gets for first river "la Vienne" $Q_{crit} = 15 << 48.2$. Even in intermediate range, as for before last river "la Corrèze" for which $Q_{crit} = 15 < 18.25$, there is no problem to increase the number of kinetic stations as their (minimum) number used here is quite small. Covering potential output with kinetic one requires 5 times more kinetic units. Even if d = 10m, they do not extend over more than 350m if where are distributed on both sides of the river, so electric connections for current transportation is still extremely easy. This also gives some flexibility in the choice of unit size which for some of them are too large and can be replaced in proportion by smaller more manageable ones.

In all cases it is instructive to use present analysis to evaluate advantages of the two potential and kinetic approaches in each specific situation. In particular, it ought to be recalled that investment costs are much larger for potential electric power, so there is already in a large range of parameters, and independent of exploitation costs, a definite advantage in choosing kinetic approach. An interesting consequence is when it is possible to return back from potential to kinetic source, as for instance by application of new regulations forbidding the interruption of flow lines. From Tables **I** and **II** and (7) there is no difficulty to use difference in power outputs for a specific site and to evaluate the backward transformation from potential source with a dam to the initial landscape configuration with kinetic source. For a given kW price, it is possible to determine the speed of transformation so that, by maintaining an adapted level of electricity production, the transformation cost is reduced to strictly 0€, which occurs when the total cost of a new kinetic unit is just covered by equivalent potential production which can then be replaced step by step.

III. Conclusion

Electrical power delivery from potential and kinetic origins have been evaluated and compared for the production on a river segment in view of optimizing electricity production of the basin. From their expressions it is verified that independent of very different investment costs, there exists a large range of landscape and river parameters for which produced electric power of kinetic origin is much larger than potential origin. Examples of different river parameters have been discussed showing that above the modest flow rate threshold $Q_{crit} \cong 20m^3/s$, kinetic production is definitely more attractive in terms of regularity, of maintenance costs and of ease in distribution. An interesting consequence for reducing exploitation costs in this case is to program a switch from potential backward to kinetic production which can be managed so that it can be operated at rigorously 0€ cost. Specific cases of application will be discussed elsewhere.

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