HIGH PERFORMANCE ASPECTS OF MHP EQUIPPED WITH EOS AND FO TURBINES

ASPECTE PRIVIND FUNCŢIONAREA CU RANDAMENT RIDICAT A MHC ECHIPATE CU TURBINE EOS ŞI FO

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Abstract: *The micro-hydro aggregates for small hydro power plant (SHPP) and micro-hydro power plants (MHP) in low-energy hydro power have been designed to operate on the basis of the ″evrything or nothing″ principle, taking into account their exploitation at optimum efficiency and simplification automation scheme. This principle proved to be inadequate due to the fact that small rivers are characterized by a daily, monthly or seasonal drainage with significant variation. Also, most of the micro-hydro power plants built in Romania after 1980 have the high installation coefficients (installed 2-3 times the power that could be obtained in continuous operation at the multi-annual average flow), which has the effect of producing energy discontinuous power distributed in hours of low operation for most of the year. Starting from the consideration that type FO (Horizontal Francis) and EOS type turbines (horizontal helical with the S-shaped hydraulic circuit) have very sensitive flow characteristics, the paper presents some technical ways of increasing the efficiency of the functioning of micro-hydro aggregates (MHA) equipped with standardized turbines.*

Keywords: efficiency, micr-hydro power plant, micro-hydro aggregate, multi-year average flow

Rezumat: Microhidroagregatele ce echipează centralele hidroelectrice de mică putere (CHEMP) şi microhidrocentrale (MHC) din cadrul amenajărilor hidroenergetice de mică putere au fost concepute să funcţioneze pe baza principiului „tot sau nimic" (TSN), avându-se în vedere exploatarea lor la randamente optime şi simplificarea schemei de automatizare. Acest principiu s-a dovedit a fi inadecvat datorită faptul că râurile mici se

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caracterizează printr-o scurgere zilnică, lunară sau sezonieră cu variaţie însemnată. De asemenea, majoritatea microhidrocentralelor construite în România după 1980 au coeficienţi de instalare mari (putere instalată de 2-3 ori mai mare decât puterea care s-ar putea obţine în funcţionarea continuă la debitul mediu multianual), acest lucru având ca efect o producţie energie electrică discontinuă repartizată în ore de funcţionare puţine în cea mai mare parte a anului. Pornind de la considerentul că turbinele tipizate de tip FO (Francis orizontal) şi EOS (elicoidal orizontal cu circuitul hidraulic în formă de S) au caracteristici de randament foarte sensibile la variaţia debitului, în cadrul lucrării sunt prezentate câteva modalităţi tehnice de creştere a randamentului de funcţionare al MHC-urilor echipate turbine tipizate.

Cuvinte cheie: randament, microhidrocentrală MHC, microhidroagregat MHA, debit mediu multianual

1. Introduction

Under the EU Directive on Renewable Energy Sources [1], it is set as a mandatory national target for all EU countries that, by 2020, renewable energy should account for 20% of the energy consumed. Within these sources, the production from hydro sources is estimated at about 18200 GWh / year, of which 1100 GWh in power plants with powers < 10 MW.

At the beginning of 2017, there were 118 economic operators that owned 317 low-capacity (less than 10 MW) electric power generation capacities - SHPPs and MHPs.

These low-energy hydro power together have an installed capacity of 341.6 MW, which represents about 5% of the total installed capacity on hydro. The production made in 2016 by these privately-owned SHPPs and MHPs was approx. 493 611 MWh, which represents about 3% of hydro power generation [2].

According to a study by Hidroelectrica [3] it is estimated that by 2025 the production of electricity from hydro sources will be at approx. 20 000 GWh / year (Figure 1).

The main features of these MHPs are diversity, specificity, design and execution concepts, exploitation mode.

These characteristics have resulted from the fact that they have been made at certain historical moments and in certain technical and economic circumstances.

Taking into account these desiderata, it is clear the necessity that, together with the new hydro-energetic facilities that will be built, the existing ones should be exploited in safety and efficiency, simultaneously with their rehabilitation or retrofitting.
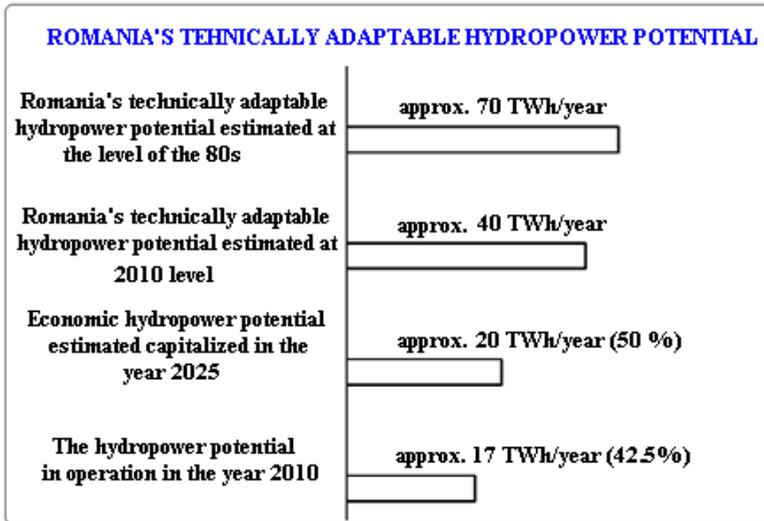
Figure 1. Scheme of Romania's technically feasible hydropower potential

The behavior and exploitation of equipment within MHPs requires the existence of indicators that characterize how well the intended purpose corresponds to its intended purpose through its design and execution.

In this respect, it would be necessary to separate the technical factor predominantly pursued in a specialized study, the human factor that should not be approached simplistically or insufficiently, as well as the conditions in which the equipment is exploited. Starting from the fact that these factors are difficult to separate due to the many relationships that exist between them, the analysis of the hydro-energetic equipment exploitation should be started by fixing and characterizing the conceptual structure of the MHPs equipped with EOS and FO turbines and their effective exploitation.

2.   Conceptual Structure

At the basis of the design of these micro-hydro power plants (MHP with powers from 10 to 200 kW) and of small hydro power plants (SHPP with power from 200 to 3600 kW), the normative framework PE 306/90 [4] stipulates the main conditions technical, layout schemes and construction solutions. According to this normative, the following resulted:

- the variability of the river flows during one year required, in order to achieve a maximum energy output, the operation of the micro-hydro power

based on the principle of everything or nothing, with the application of a electromechanical action solution;

- installation coefficient, defined as the ratio between the installed flow and the average available energy flow rate (multiannual average decrease of the flow rate for the other uses) between 1 and 3;

- the equipment used in the construction of MHPs are generally typified, which, together with the technical and economical analysis of the design, has led to the choice of several variants regarding the river sector, the establishment of the installed flow, the diameter of the pipelines chosen in order to achieve the consistency with the arrangement;

- as these facilities do not have significant accumulations, the compensating basins being sized to a capacity that allows the operation of a turbine for 0.5 hours, the planned electricity production is not achieved;

- realization of the components of the arrangement according to simplified constructive solutions and type projects, having importance class IV (SHPP), respectively V (MHP);

- the use of standardized energy and hydromechanical equipment in domestic production (turbines, asynchronous generators, asynchronous motors in generator mode, etc.) [5];this was possible by making an internal production of micro-aggregates consisting mainly of two series of Francis turbine types (FO - Figure 2) and helicoidal (EOS - Figure 3), coupled with asynchronous generators, equipment that has been approved; the micro-aggregate range was further supplemented with groups equipped with a Kaplan horizontal hydraulic circuit turbine (KOS) hydraulic turbine, which allows either double-stroke or rotor-controlled, asynchronous / synchronous generator.
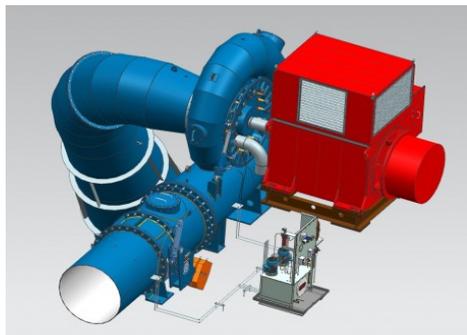

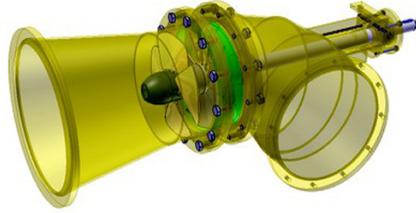Figure 2. Francis horizontal turbine (FO)

Figure 3. Horizontal turbine with S-shaped hydraulic circuit (EOS)

These framework normative criteria [4], with all their returns, have led to far-reaching outcomes, resulting in improvisational solutions, simplified design schemes, or design mistakes.

3. Characterization indicators for EOS And FO type turbines

For the characterization of low-energy hydro power installations equipped with EOS and FO turbines [6], a system of indicators is required that encompass all its component parts, but only a subjective arbitrary solution is possible. Taking into account the technical-economic design indicators (energy produced and the cost of energy), a series of indices can be detailed to show how much the arrangement is behaving. Thus, the energy produced in an average year is calculated with a relation:

$$E_n = K \times Q_m \times H \times 8760 \times \varepsilon_1 \times \varepsilon_2 \times 10^{-6} \text{ [GWh/year]} \qquad (1)$$

where:

K is a coefficient that depends on the efficiency of micro-hydro aggregate and takes 7 for EOS and FO turbines;

Q_m - multiannual average flow;

H – net head (gross head from which the load losses are reduced);

8760 - the number of hours in a year;

ε_1 - stock utilization coefficient;

ε_2 - availability coefficient (0.8 for a unit and 0.9 for multiple units).

Analyzing the factors that intervene in the aforementioned relation can be ascertained:

a) The coefficient K assumes a 70% hydro-aggregate efficiency, considered as cover if it reaches its installed power. From the performance measurements by ICEMENERG [7], [8], it is noted that at the nominal

power for the EOS 500 turbine the efficiency was 66÷68%, and for EOS 1100 the efficiency was 74÷77%. At partial loads, efficiency falls rapidly, as can be seen from the graph in Figure 4.
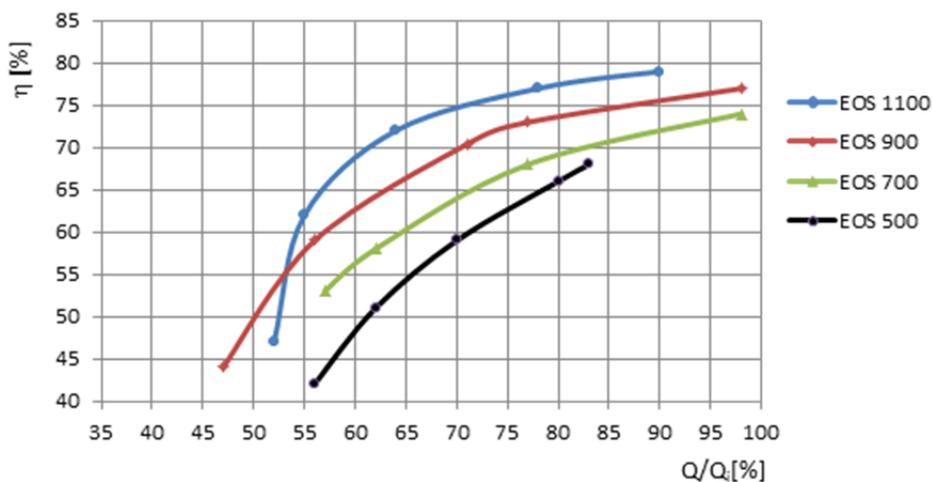

Figure 4. Efficiency variation by type EOS turbines flow

b) The average flow rate Q_m seen as a water flow constant based on multi-yearly measurements, gives indications of leakage volume over a long period of time. From the point of view of exploitation, it is essential to capitalize the daily flow of tributary, which is characterized by a pronounced variability, a measure of which is the coefficient of variation, having values between 0,3 - 0,74, for monthly average flows, its value rising far more for daily average flows.

c) Net head H, is the difference between the gross fall and the loss of the load. The loss of the calculated load in the design phase is underestimated, being mainly dependent on the pipe or adduction channel (large roughness due to poor executions) and the exploitation with a higher degree of clogging of the grids or the deposition of material alluvial on the hydraulic circuit.

d) Coefficient ε_1 , defined as the ratio between the stock of water and the annual stock, is difficult to estimate because the capacity of such arrangements is reduced. During the flood, a large amount of water is lost and, at the same time, during these periods the hydrotechnical boats have a faulty behavior.In order to determine this coefficient, it is necessary to have a system of measuring the volumes transited during the high water periods

and to make a hydraulic balance of an appropriate accuracy (less than 10%). During the small waters, the share of servitude, which in some cases reaches up to 50% of the tributary flow, takes an important share.

e) The stock availability coefficient ε_2, determined by design according to the frame norm [4], has the values: 0,8 for a hydro aggregate and 0,9 for several hydro aggregates.

From the behavioral study for SHPPs and MHPs it ranges from 0.85 to 0.98, but in this indicator there is no indication of downtime including repair and maintenance times at various ovens and equipment.

In line with the existing design, construction, and operating deficiencies of MHPs, it is inevitable that much less electricity production than projected in the project will be. In most cases, energy in one year represents between 1÷80% of the project energy, and this interval does not allow for a pertinent conclusion, and can not be correlated with the hydraulicity of the year, the type of turbine or other factors.

4. Operation MHPs based on the ″Everything or nothing″ principle

4.1. ″Everything or nothing″ principle

In order to be exploited with optimum efficiency, micro-aggregates that equip low-energy hydropower were designed to operate on the principle of everything or nothing.

This type of operation involves the periodic operation of micro-aggregates by performing a number of start-stop cycles in one day, which has the following consequences:
- the occurrence of overpressures in the induction line at start and stop;
- packaging of micro-aggregates at the time of stopping;
- clogging of the compressor outlet and compartment;
- blocking intake butterfly valves in the turbine;
- the occurrence of frequent stresses of electromechanical installations (switch, actuator of the REGMO type instrument).

These stresses have a negative effect, such as breakage of the conduit through the sealing of the seals, the destruction of the bearings, etc.

In case of operation according to the all or nothing principle, the energy obtained is determined on the basis of the analysis of the operating cycle.

A working cycle has a duration tc composed of a running time (t_f) and a fill time you (a pause period).

The fill type of the compensating basin depends on the tributary flow (Q_a), the loss through the directing device (Q_{ad}) and the volume of the compensating basin (V), which has the expression:

$$t_u = \frac{V}{Q_a - Q_{ad}} \quad .$$

(2)

Runtime is a sum of partial times

$$t_f = t_0' + t_0'' + t_{exp} + t_1'' + t_1' = A + t_{exp} \quad .$$

(3)

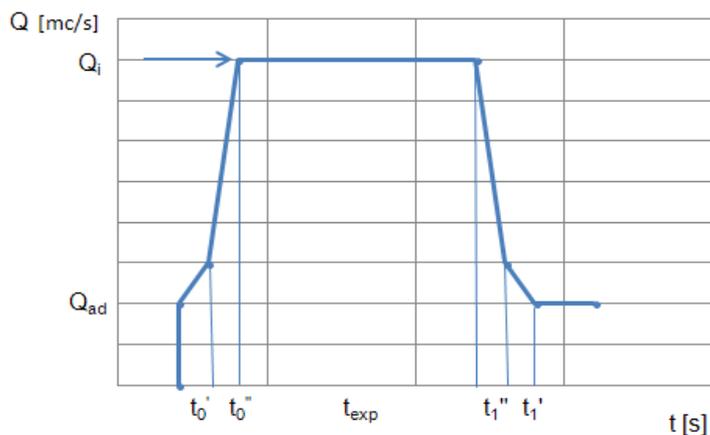The allure of time of operation (3) is shown graphically in Figure 5.

Figure 5. Operation chart based on everything or nothing

where:

t_0' - is the start time until the MHP connects to the network;

t_0'' - the time needed for the MHP to reach the nominal regime;

t_{exp} - the operating time to the nominal regime;

t_1'' - the shutdown time up to the trigger limit from the system

t_1' - stop time of the MHP;

A - a constant that depends on the turbine and the nominal regime imposed on it, namely the steering apparatus stroke and the shut-off speed of the REGMO,

Q_i - installed MHP flow rate.

To determine the operating time of the MHP, the equation of the volume balance of the arrangement is written:

$$(t'_0 + t''_0)\frac{Q_i+Q_{ad}}{2} + t_{exp}Q_i + (t''_1 + t'_1)\frac{Q_i+Q_{ad}}{2} = V + Q_a t_f \ . \qquad (4)$$

If it is marked with:

V_0 the volume of water required to start the turbine

$$V_0 = (t'_0 + t''_0)\frac{Q_i+Q_{ad}}{2} \ ,$$

V_1 the volume of water lost in stopping the turbine

$$V_1 = (t'_1 + t''_1)\frac{Q_i+Q_{ad}}{2} \ ,$$

then the MHP time equation becomes:

$$t_f = \frac{Q_i A + V - V_0 - V_1}{Q_i - Q_a} \ . \qquad (5)$$

Taking into account that tc is the duration of a start-stop cycle, the number of start-stop cycles (*n*) of a day is

$$n = \frac{24}{t_c} \ . \qquad (6)$$

The electrical energy produced in a start-stop cycle E_c is given by the relationship

$$E_c = 9{,}81 Q_i H(Q_i) \eta_{T+G}[Q_i, H(Q_i)] t_{exp} + 2E''_c \qquad (7)$$

where E''_c is the energy produced during t''_0 and t''_1 is calculated with the relationship:

$$E''_c = 9{,}81 \int_{t'}^{t''} Q(t)H(Q)\eta_{T+G}(Q, H)dt = \text{const.} \qquad (8)$$

Electricity produced in a day working on the totality or nothing principle is calculated by the relationship:

$$E_{TSN} = n \, E_c \qquad (9)$$

4.2. Advantages and disadvantages of operation according to the principle of ″everything or nothing″

Operation based on the principle of ″everything or nothing″ has the advantage of obtaining a maximum yield by choosing such a nature of the turbine (Q_i installed flow rate, *H* calculation), but also by efficiently using

the water stock if the tributary flow is more smaller than the installed flow ($Q_a < Q_i$).

The disadvantage of this mode of operation of MHPs materializes through a large number of start-stop cycles; this number depends on the affluent Q_a flow and leads to: load of the electric circuit breaker bearings, shocks in the power transmission lines, blocking of the drive mechanisms of the steering apparatus and damage to the electric motors, erosion of the concrete basin and the escape channel, the fluctuating flow downstream of MHP, a fluctuation that makes it almost impossible to maintain an aquatic life.

5. Techniques to increase the performance of MHPs

By abandoning the exploitation based on the principle of ″everything or nothing″ and the adoption of continuous operation at the Qa tributary flow, the coverage of the long-lasting average daily flow curve is no longer optimal, resulting in significant energy losses.

Given that the continued operation of MHPs is more appropriate when $Q_a \geq Q_i$, but usually $Q_a \leq Q_i$, which requires intermittent operation based on the principle ″everything or nothing″, consideration should be given to replacing existing MHAs with other MHAs with lower powers.

This also results from the fact that the vast majority of cases of energy-power hydropower with more MHAs offer a much more elastic seasonal flow adjustment scheme.

Based on the design on the same criteria according to the frame norm [4], the fragmentation of the flow is done in equal mode resulting in a number of identical MHAs.

However, the question of the opportunity of replacing an MHA with another available, with a lower nominal flow, requires a careful study, choosing the optimal variant is a decision-making problem that is solved on the basis of the multicriterial analysis due to the divergent tendencies in maximizing the energy obtained and minimizing spending.

One of the technical solutions that could be applied to the principle of " everything or nothing" in order to reduce the number of start-stops of an MHP equipped with a single MHA is to use a regulator to operate on the REGMO device to close the device director of the turbine according to the affluent Q_a flow, ensuring continuous operation of the MHA. It should be borne in mind that in the case of an MHP equipped with a single MHA it is

possible to operate at a minimum flow rate of 50% of the nominal flow, which means that the number of days of continuous operation in one year could also be about 100 for the low power hydro power plant located on rivers in the mountain range.The remaining 265 days The MHA must be intermittent. Thus, by reducing the value of the flow rate used from the maximum turbulent flow rate to 50% of the nominal flow, by closing the turbine guide vane, during periods when the flow rate of the tributary flow is lower, an increase in the duration of operation of the MHA acquis.

Another way to increase the efficiency of running MHAs can be to change the installation angle of the rhetoric blades.This solution involves removing the rotor blades and placing them at a lower angle than the one corresponding to the nominal flow.

The optimal angle setting is based on turbine characteristics and is generally lower by 5^0, which corresponds to a 30% reduction in flow rate and an 8.5% increase in efficiency compared to the original one.

In this case, the main drawback is that run blades are welded, seasonal adjustment is difficult to achieve, requiring specific devices and skilled personnel.

Another option may be to purchase a spare run with the installation angle at the desired value.

This variant is warranted if each run has a service life of approx. 3000 hours per year.

The above solution is viable if you can easily adjust the installation angle. For a seasonal adjustment, a mechanical device can be adapted to change and lock the installation angle to a certain value. The use of KOS type turbines is too demanding to be used in this case.

6. Conclusions

By efficiently capitalizing the Romanian hydropower potential, the use of fossil fuels for energy purposes is reduced, for which important funds are spent annually; reducing energy loss on transport lines; an important number of localities are supplied with energy; eliminates voltage drops in distant areas of electrical networks; reduce the number of floods of localities and lands; a large number of jobs are created.

According to the analyzes presented in the article, we note the following ways of adapting EOS type turbines for their optimal efficiency in the case of the reduction of the turbulent flow at the value of the tributary flow:

- changing the angle of rotor blade installation, which requires studies to achieve a technical solution for seasonal adjustment;

- reducing the number of start-up cycles of an MHA by using a regulator that acts on the REGMO device to close the turbine directing device according to the tributary flow;

- replacing the existing MHA with a smaller MHA with a lower power corresponding to the tributary flow. The features of the new MHP are derived from a pertinent technical and economic analysis.

These solutions can be applied during retrofitting, following a feasibility study.

For a real optimization of the operation of small hydropower developments, an in-situ [9] verification of exploitation characteristics and technical / economic indices resulting from the project is required. In addition to the performance of MHAs (as compared to the service topographies guaranteed by the equipment provider) in the performance tests [10], the actual MHA consumption (power-to-flow) characteristic is also being developed.

This allows for the efficient use of water available in a hydropower facility and the premises for a pertinent analysis of how MHA works.

In order to make a visible progress in the micro-hydro power field, the efforts made so far (setting up a MHP realization concept, training the personnel needed for MHP exploitation, creating an internal MHP production) should be continued;this is in line with the current micro-hydro policy in other countries where rivers with energy parameters similar to those of the Romanian water courses frequently build hydro power plants of low energy.

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