Hydroelectric power plant with variable flow on drinking water adduction

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Abstract. The water feeding system of the urban and rural localities is mainly collected with feed pipes which can have different lengths and different levels. Before using, water must be treated. Since the treatment takes place in the tanks, the pressure in the inlet of the station must be diminished. Many times the pressure must be reduced with 5-15 Barr and this is possible using valves, cavils, and so on. The flow capacity of the water consumption is highly fluctuating during one day, depending on the season, etc. This paper presents a method to use the hydroelectric potential of the feed pipes using a hydraulic turbine instead of the classical methods for decreasing the pressure. To avoid the dissipation of water and a good behavior of the power parameters it is used an asynchronous generator (AG) which is coupled at the electrical distribution network through a static frequency converter (SFC). The turbine has a simple structure without the classical devices (used to regulate the turbine blades). The speed of rotation is variable, depending on the necessary flow capacity in the outlet of the treatment station. The most important element of the automation is the static frequency converter (SFC) which allows speeds between 0 and 1.5 of the rated speed of rotation and the flow capacity varies accordingly with it.

1. Introduction

Renewable sources will occupy an important share of energy production over the next decade.

The conversion of hydraulic energy into electricity is not polluting, involves relatively small maintenance costs, there are no problems with fuel and is a long-term solution [1-3].

The first hydroelectric power plant in Romania, Sadu I, was commissioned in 1896, having a vertical shaft turbine which was replaced in 1905 by a Francis turbine that operated until 1929 [4].

In setting up the hydropower micro-potential, both positive and negative effects on the environment must be taken into account.

Hydrotechnical constructions are non-polluting because they do not interact with the environment. On the contrary, some constructions are destined to water depollution, others increase natural self-purification capacity and others serve to dilute or annihilate some pollutants or substances.

Small hydropower plants placed on drinking water pipelines must comply with all regulations regarding pollution, and the conditions for choosing hydro-units are very strict [3], [5], [6].

The paper presents the stages of designing such plants starting from the hydraulic profile (Figures 1 and 2) and the average flows, taking into account the perspective of the increase in consumption [7], [8].
2. **Microhydro power plant design**

   The hydraulic profile of the feed is shown in Figure 3 where the portion A-B is made of metal pipe and the portion B-C of the asbocement. The height difference between the capture A and the pool C of the mixture at the entrance to the treatment plant is $\Delta H_{\text{geodetic}} = 103 \text{ m}$ [8].
Figure 3. Hydraulic profile of crude water supply

Location of the boiler will be at point B of the minimum supply level. Currently the inlet pressure of 9.5 - 10 bar is reduced to 0.5 - 1 bar using a butterfly valve. Output pressure is required to maintain the level in the mixing tank. At a pressure difference of 8.5 bar and a flow rate of 150-210 l / s, the relationship (1) results:

\[ P = \frac{Q \times h}{367} \quad [\text{KW}], \]

(1)
a power dissipated on a 90-140 kW valve (proportional to flow). Table 1 gives the statistical data recorded over the period 2009-2016, indicating an average capture flow rate in the range 150-270 l / s, variable (daily or seasonal) depending on the needs in the drinking water distribution network. Based on the expansion of the number of consumers in the future the required gross water flow will reach 350-400 l / s.

| Year | Flow Q\text{\,min} [l/s] | Q\text{\,average} [l/s] | Q\text{\,max} [l/s] |
|------|--------------------------|--------------------------|---------------------|
| 2009 | 165                      | 188                      | 206                 |
| 2010 | 148                      | 177                      | 210                 |
| 2011 | 155                      | 180                      | 201                 |
| 2012 | 152                      | 179                      | 205                 |
| 2013 | 160                      | 185                      | 215                 |
| 2014 | 165                      | 204                      | 240                 |
| 2015 | 182                      | 216                      | 252                 |
| 2016 | 195                      | 234                      | 270                 |
The proposed hydraulic functional scheme (which also includes the intervention pumping station) is shown in Figure 4 [8].

Taking into account the need for a variable flow rate (150–400 l/s) for the water treatment plant, a water drop of 85 m (assumed constant) requires the use of turbines that allow continuous flow control, without sensitive decrease of conversion efficiency on the required flowrate range. In this respect, it is proposed to permanently adjust the speed of hydro-aggregates so that they can generate the flow transmitted by the transducer placed at the exit of the treatment plant. In this way the reserve of drinking water in the storage tanks is always kept.

\[ \text{Figure 4. Functional situation with the use of micro-hydro aggregates} \]

The generators will be asynchronous cage rotor with high efficiency. Hydraulic cutting accessories will be electrically controlled. When a turbine fault occurs, it will operate on the existing circuit without endangering the availability of the water resource necessary for the normal operation of the treatment plant [8].

All cutting elements (electrically controlled valves) will be provided with UPS (uninterruptible power supply) so that the return to the classic hydraulic circuit can also be achieved when the supply voltage drops. The switching of the flow between the two schemes must avoid hydraulic shocks (rake shot) [8].

The SCADA system (Figure 5) must ensure: controlled start-up and shutdown of the generators, generators tripping, no load and load of the generators, measure and protection of the generators, controlled output at loss of the grid, avoidance hydraulic shocks, communication with the hierarchically superior dispatcher or PLC, monitoring, controlling and controlling all dispatchable items, making real-time energy calculations for operating in an optimal area, providing screens as a communication interface with the human operator, automatic maintenance of imposed climatic parameters (temperature, ventilation) in various station compartments [8].
Static frequencies converters 1 + 2
Temperatures - generator - turbine
Pressure transducers Flowmeters Electrovalves position
Comands: Close / open electrovalves
Supply - electrovalves - flowmeters
RS 485/232/MOBUS
P, 100
PLC
Relays
Sources 3×380V
1×220V
UPC 3~ 3 kVA, 15 min
Local display
Radio
GSM
Modem Dispatcher
PC + SCADA

**Figure 5.** Block diagram of the PLC and SCADA system at micro-hydro power plant with variable speed

The yield curves are shown in Figure 6 (220 l / s and 350 l / s), and the turbine upstream pressure calculation calculates the value of 0.07 bar [7].

**Figure 6.** Adduction flow curve

Two generators, with 200 kVA power (called the main MA) and 132 kVA (called auxiliary unit AA) and the associated turbines were selected. For reasons related to the pressure drop and the limited
physical space allocated, it is necessary to use irregular Francis turbines (without directing apparatus),
characterized by reduced radial dimensions, the turbine speed being achieved by electric means.

Since the application requires that variable flow (prescribed online by the user) be obtained by speed adjustment, Figure 7 shows the variations in power and flow rate at constant pressure drop and different speeds [8].

![Figure 7. Variation of power and flow depending on speed, at constant drop](image)

The failure flow rate, when dropping the load, is

$$Q_f = 0.7Q_n,$$  \hspace{1cm} (2)

and the crash speed

$$n_c = 0.7n_N,$$  \hspace{1cm} (3)

for the chosen turbines.

To prevent the occurrence of the hydraulic shock, it is necessary to handle the hydraulic cutting elements in a time greater than $T = 9.4\, s$ calculated for the hydraulic network characteristics. Total drainage times were chosen for $150\, s$ (2.5 min). An overpressure valve mounted on the main duct or in the suction manifold is to be opened from 100 mca to take the calculated maximum pressure (126 mca).

### 3. Technical and economic calculation

With the help of a specialized program [7] in the calculation of micro-hydropower plants, based on the data previously calculated and the input quantities, the data on the value of the investment, the production of the electricity obtained and the duration of the investment recovery are obtained. The simulations have been made for the average flow of the last 3 years of $220\, l/s$ and for the expected average flow rate of $350\, l/s$ in the future. The results are presented in a comparative manner [7].
Figure 8. Calculation of micro-hydropower plants

4. Conclusions

Variable speed MHC operation implies significant advantages: there is no need for a constant speed maintenance system that involves a turbine stator directing device, the flow rate of the turbine adjusts the required flow rate, replaces the pressure reducing valve and the flow adjustment with a hydro-filling unit. From the economic calculations it is noted that due to the high pressure drop and the circulation flow, the duration of recovery of the investment of 2 years is very low, so the investment deserves to be done.

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