SMART REHABILITATION PROJECT OF 7 SMALL HPP'S

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INTRODUCTION

In order to modernize, improve and enhance the capacity of the electric power system of Macedonia and to further promote clean power production from renewable resources, the Government of the Republic of Macedonia authorized JP Elektrostopanstvo na Makedonija (ESM) / Electric Power Company of Macedonia – to prepare and award the Project of Rehabilitation, Operation and Transfer of Seven Small Hydro-Power Plants.

The scope of the Project shall include performance and execution by HYDROPOL Project & Management A.S. of all design, engineering, procurement and rehabilitation of the HPPs, operation and maintenance of the HPPs, and financing of the entire Project, including rehabilitation in accordance with the specifications and standards set forth in ROT contract.

Finally, it might be summarised that the construction and rehabilitation of the hydropower stations Matka, Zrnovci, Dosnica, Pena, Pesocani, Kalimanci and Sapuncica means a demanding but feasible project. The production of the power stations was increased as well as their automation, material and component modernisation took place, they become environment friendly and their efficiency was increased in such a manner that operation is efficient, under the conditions of best practice maintenance and operation, for the next 50-80 years.

The effective date of ROT contract was 1st of February 2002, by this date so called pre-rehab period started. Currently HYDROPOL operates all Seven Small Hydro-Power Plants and the rehabilitatin works was done.

Small hydro power plants are located all over the country. Some of them are multipurpose and some of them are in generation purpose only. Given below is plants short description:

Tab. 1 – Short description of ROT HPPs

SHPP	***Dosnica***	***Kalimanci***	***Matka***	***Pena***	***Pesocani***	***Sapuncica***	***Zrnovci***
Commissioning Year	1952	1970	1938	1926/84	1951	1952	1950
Installed Capacity [MW]	4.08	12.00	4.21	2.50	2.74	2.91	1.40
No. of Units	3	2	3	2	2	2	2
Turbine type	Pelton horizontal	Francis vertical	Francis vertical	Francis horizontal	Pelton horizontal	Pelton horizontal	Pelton horizontal
Discharge [m^3/sec]	2.1	18.0	19.5	4.0	1.2	0.8	0.8
Head [m]	232.7	80.0	24.5	72.0	291.1	412.0	215.0
Year of rehabilitation	2008	2005	2005-2008	2006	2007	2007	2009

1. PERFORMANCE TESTS BEFORE REHABILITATION.

Performance tests at all Power Plants were carried out before rehabilitation process (except for HPP Kalimanci). These tests had more purposes. They served as basic data for design of new installed units and also for evaluation of future benefits. Some of them are presented in following subchapters.

Gibson method was used as the physical discharge measurement method before and also after rehabilitation. This method has minimal instrumentation requirements in comparison with other ways of flow measurement. Use of this method is inexpensive and does not require to stop the measured device for a long time and to drain away the penstock. Also accuracy of this method is very good, if correct penstock dimensions are available. Because all ROT HPPs are equipped with well accessible penstock, with good possibility to install pressure transducers, other requirements of this method were fulfilled.

The basic formula for flow calculation is derived from Newton's laws of motion and is described in standards IEC 41/1991 and IEC 62006.

$$Q_G = \frac{1}{\rho \cdot c_{pst}} \cdot \int (\Delta p + \xi) \cdot dt + Q_0$$

where: ρ = water density

c_{pst} = penstock factor

$$c_{pst} = \int_{l=0}^{L} \frac{1}{A(l)} dl \qquad \text{or} \qquad c_{pst} = \sum_{i=1}^{n} \frac{L_i}{A_i}$$

L_i = length of i^{th} penstock part

A_i = cross section area of i^{th} penstock part

Δp = pressure difference on measuring section $\Delta p = p_{2G} - p_{1G} - p_{offset}$

p_{offset} = difference of static pressures $p_{2G} - p_{1G}$

ξ = sum of friction losses at measuring section and velocity heads difference in both measuring profiles G1 and G2

$$\xi(t) = k * Q(t)^2$$

Q_0 = residual discharge after spherical valve closing (after rehabilitation $Q_0 = 0$)

Experience and problems which occurred during test, their evaluation and also recommendation how to avoid this trouble are mentioned.

1.1 HPP Sapuncica – Penstock Loss Determination

HPP Sapuncica is equipped with 2 Pelton turbines and long penstock (about 2 km) with small diameter (500 ÷ 600 mm). After 50 years of operation large-scale incrustation developed on the inside surface of whole penstock.

Fig. 1 – Penstock inside incrustation

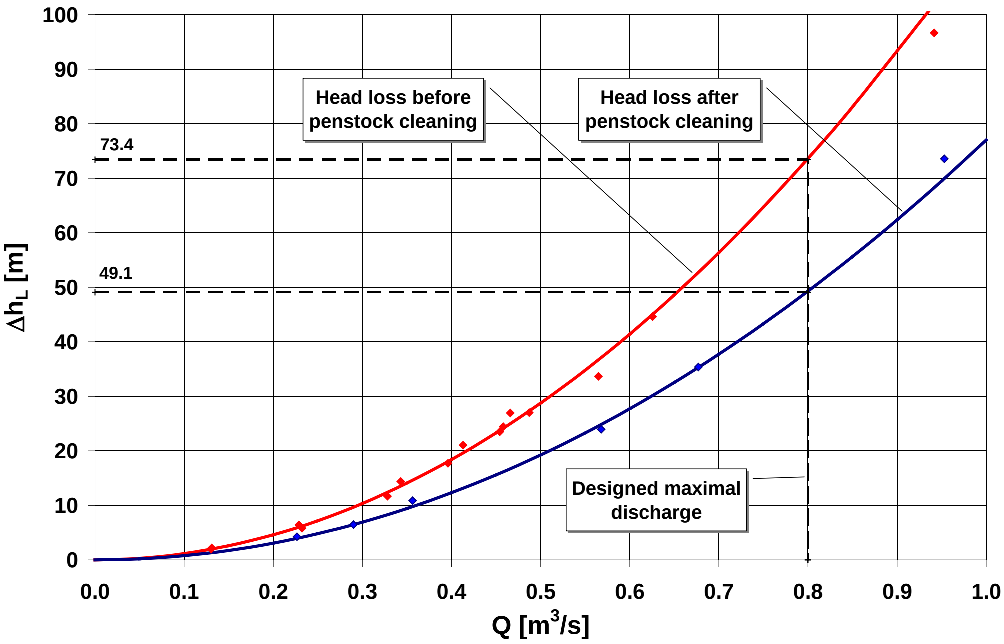

Fig. 2 – Head losses before and after penstock cleaning

The friction losses were determined by measurement, where discharge was measured by Gibson method – see ***Fig. 2***. Because head loss for designed maximal discharge reached about 20% of geodetic head, the special cleaning of penstock was implemented. New measurement was arranged after cleaning. Its results are also presented in ***Fig. 2***. Losses after cleaning correspond very well with theoretical calculation and they were used as basic data for design of new Pelton turbine runners. During this measurement turbine efficiency for future comparison with efficiency of upgraded units were also determined.

1.2 HPP Matka – Data for Surge Tank Improvement

Performance tests before rehabilitation provide not only static parameters such as efficiency, max. power and stable discharge, but as well records of dynamic behaviour of whole hydraulic circuit.

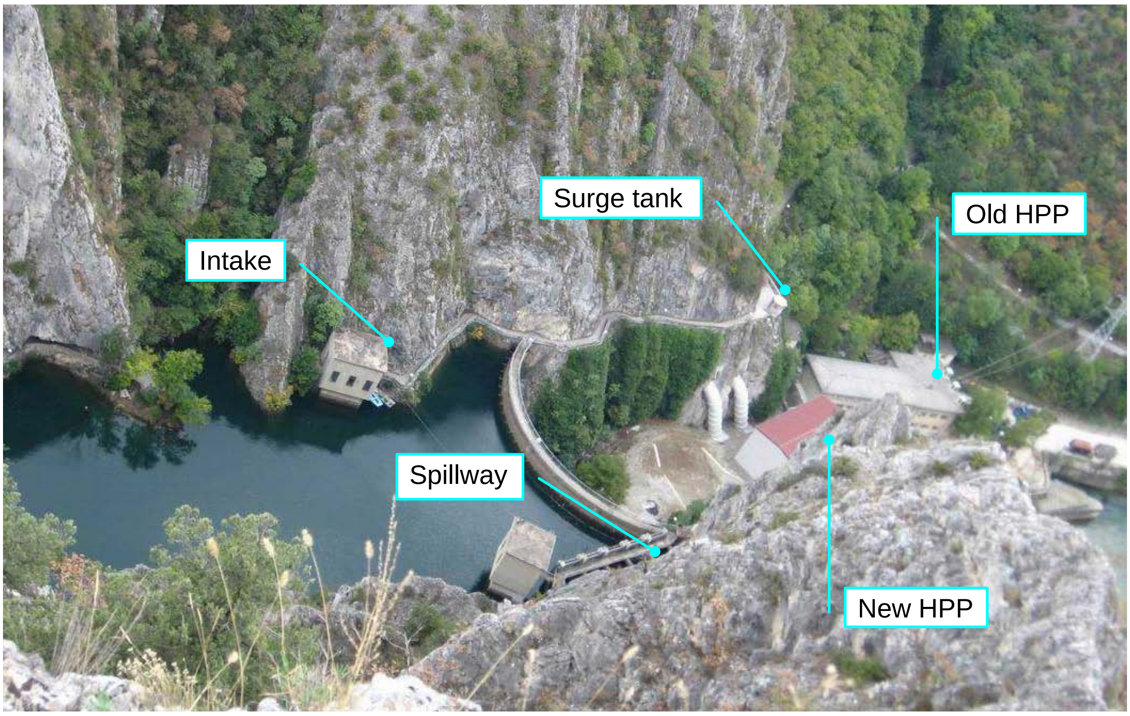

Fig. 3 - Perspective view of HPP Matka with main parts description

The HPP Matka is presented in *Fig. 3*. The old Power Plant was substituted by a new one with double capacity, but the intake with tunnel and surge tank remained the original ones. Several performance tests were carried out before the HPP upgrade started. Waveforms of pressures and discharges were used for calibration of mathematical model, which was used for new hydraulic circuit design (company HYDROPOL Project & Management a.s. + Brno University of Technology). There is no other method of flow measurement than Gibson that can offer discharge waveform with full dynamics reconcilable with pressure dynamics. The rehabilitation results are follows:

- Discharge doubled
- Surge tank with unchanged volume never overspills (it was happening during old turbines emergency shut down from full load)
- Higher efficiency, more than double the power and production.

2. EFFICIENCY MEASUREMENT

Efficiency measurement before and after rehabilitation was carried out at each HPP. Two interested examples are mentioned in following subchapters.

1.3 HPP Pesočani

HPP Pesočani is a characteristic example, which allows to present typical process of performance tests before rehabilitation and afterwards acceptance tests of upgraded HPP.

The HPP Pesocani is located on the River Pesocani near to the town of Ohrid. A derivation 4.9 km long channel collects water from the main intake and two smaller side intakes to an open water reservoir. Then, 900 m long, DN 600 steel penstock leads to the powerhouse, where two synchronous 2.2 MVA generators are driven by 4 Pelton single jet turbines (two turbines per one generator on each side).

One important experience was obtained during our activities at HPP Pesočani: The overhead penstock is very good accessible, but for performance tests before rehabilitation the penstock factor was based on documentation provided by investor without its verification on the spot. The reason was time and cost minimization. The commissional dimension measurement was carried out only before acceptance tests of new turbines – see Fig. 5. Length of constituent sections, outer circumference and wall thickness were exactly determined. Especially difference of penstock length comparing with provided data was discovered.

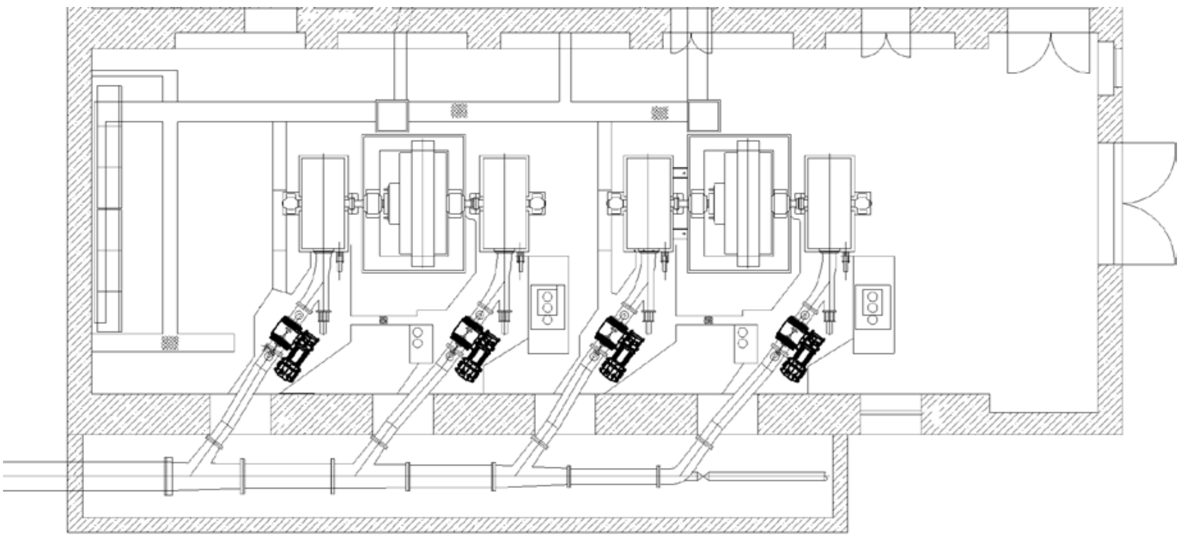

Fig. 4 – The groundplan of HHP Pesočani

Fig. 5 – Penstock outer circumference and wall thickness measurement

Results of both measurements on unit TG2 is presented in Fig. 6. Efficiency of unit TG1 is practically identical with TG2.

It is evident, the units were extensively amortized before rehabilitation. Significant efficiency increase of about 20 % ensures good profit rate of HPP rehabilitation. Calculated efficiency before rehabilitation according to original penstock dimension data was significantly higher (more than 10%). After discharge recalculation with correct penstock factor, the real profit did appear.

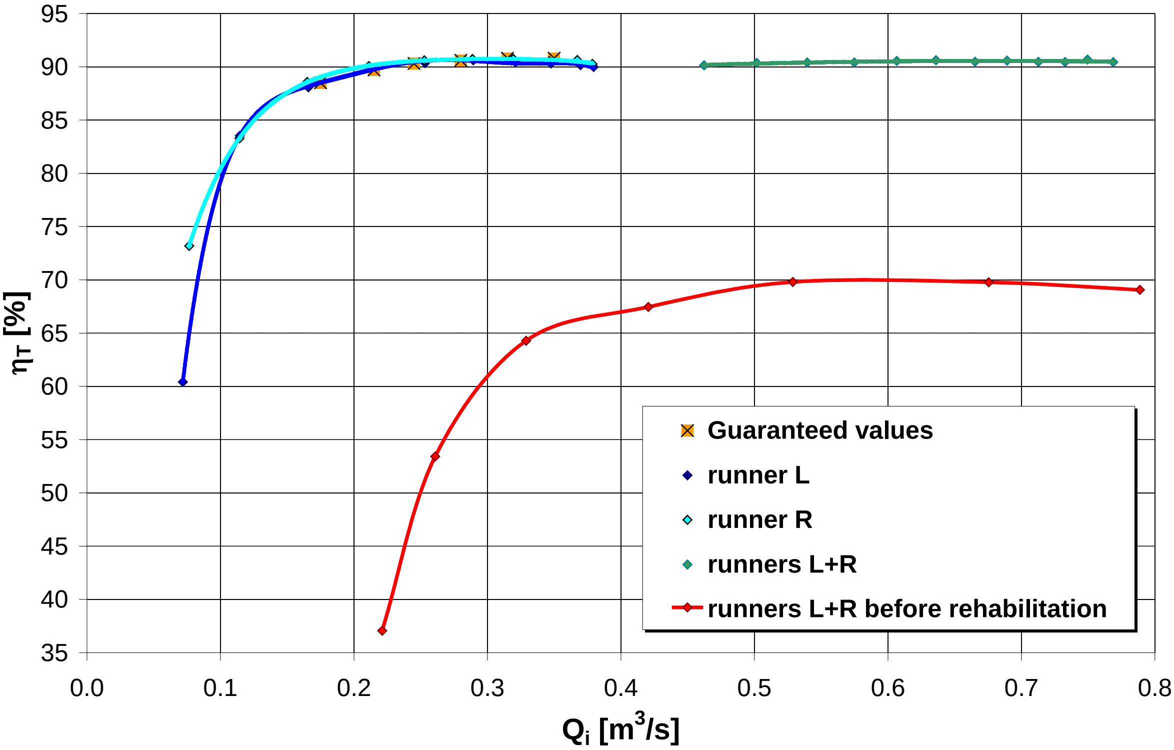

Fig. 6 – Resulting turbine efficiency of unit TG2 HPP Pesočani before and after rehabilitation

1.4 HPP Sapuncica

HPP Sapuncica was mentioned in subchapter 0. The efficiency measurement was carried out twice before rehabilitation together with friction losses measurement and three times after rehabilitation by different methods and different test groups.

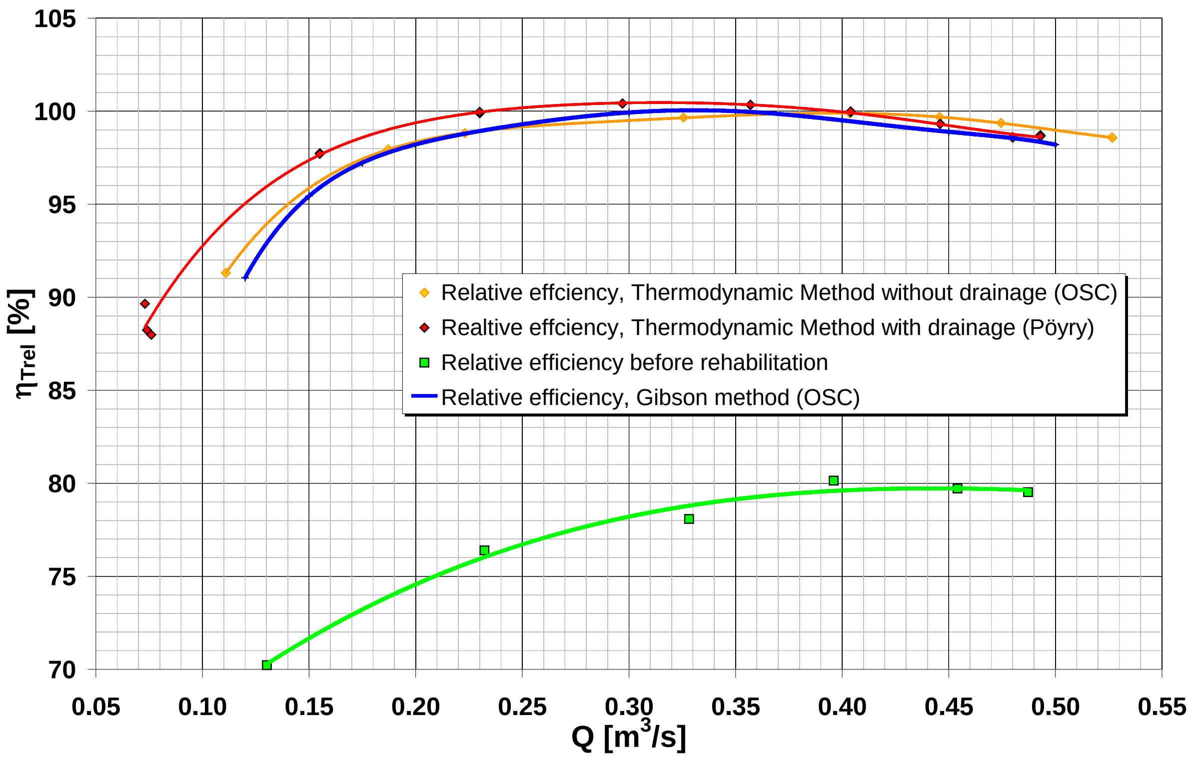

Fig. 7 – Comparison of different efficiency measurements at HPP Dosnica

The tests before rehabilitation was based on flow measurement by Gibson method combined with index measurement using calibrated Pelton nozzle. Tests after rehabilitation used both the primary methods (Gibson, Thermodynamic) and also ultrasonic flowmeter callibrated by mentioned primary methods. In ***Fig. 7*** there are presented results of unit TG1 of HPP Sapuncica. TG2 was practically identical. The correlation among all used methods is very good for discharge higher than 30% of full range. The higher uncertainty of generator efficiency causes higher mutual deviation for efficiency based on Gibson method for low power. Also inaccurate power reading from operational power meter by Pöyry group has similar effect.

Rehabilitation of HPP Sapuncica brought significant parameter improvement which causes production increase and appropriate financial benefit.

3. OPERATIONAL FLOWMETERS CALIBRATION

Operational ultrasonic flowmeters were installed at all ROT HPPs in terms of rehabilitation. Factory calibration was corrected during acceptance test. In following **Tab. 2** systematic errors of output data from ultrasonic flowmeters at all ROT HPPS are presented. Typical relationship between US flowmeter output and real discharge measured by physical method (Gibson or Thermodynamic) is presented in **Fig. 8**. Then the recalibration is easy by implementing of correction constant to flowmeter acquisition unit.

Tab. 2 – Ultrasonic flowmeter's errors with factory calibration

HPP	Type of US transducers	US flowmeter systematic error
Kalimanci	built in, 2 paths	2.90%
Matka	built in, 4 paths	- *)
Pena	built in, 2 paths	3.30%
Pesočani	clamp on, 1 path with reflection	1.50%
Sapunčica	clamp on, 1 path with reflection	2.70%
Došnica	built in, 2 paths	7.80%
Zrnovci	built in, 1 path	10.20%

*) not ready to use during acceptance tests

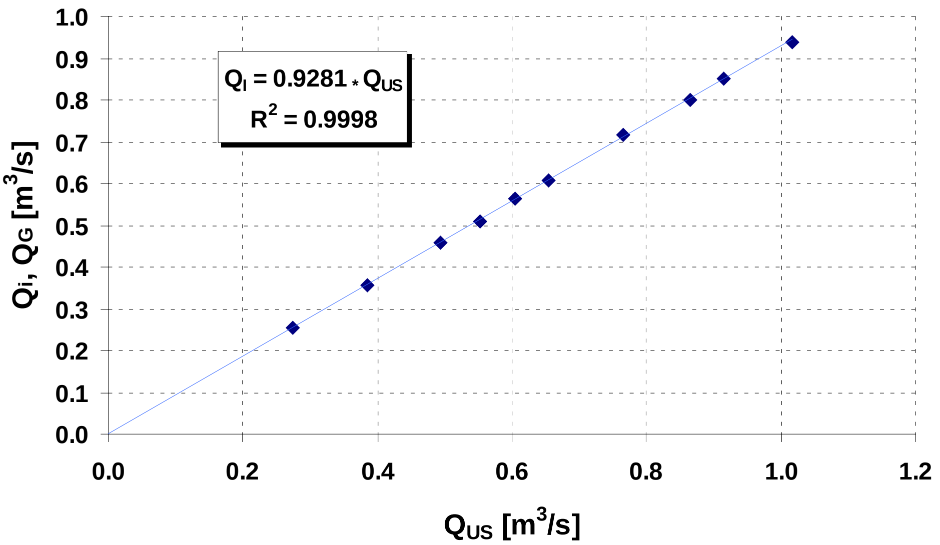

Fig. 8 – Typical relationship between ultrasonic flow reading and real flow – HPP Dosnica

According to our experience the reason of this bad factory setup is mechanic application of installation principles for ultrasonic transducers on pipe. The axis line of HPP's penstocks including elbows is situated in vertical plane. Offset of streaming centre after elbows is vertical, but the ray paths is usually situated horizontal.

4. CONCLUSION

ROT in Macedonia is a large project where was lack of technical information to find the optimal solution at the very beginning.

Performance test before rehabilitation brought important information which allowed to determine the optimal technical solution and to precise the economical benefits.

Gibson method was used as the basic physical method for flow determination because it is a cost effective and non-invasive method. As it is presented above, this method reaches very good accuracy, when its application is based on correct dates and is realized by skilled experts. Very important is to verify provided data. In the case of higher uncertainty of the provided documents correctness it is better to arrange own dimension measurement.

Acceptance tests proved significant parameters improvement at all HPPs.

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