Reduction of the development cost for SHPP utilizing a container-type mini hydropower plants

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Mini Hydropower Plant (MHP) Turija is a multipurpose infrastructure project (energy production, drinking water supply and irrigation) in Macedonia, which was originally designed as a conventional SHP. Historically, the dam of Turija was constructed in 1978 to supply drinking water for the town of Strumica. As the available water quantity collected in the dam was far above the needs for drinking water of the town of Strumica, with the construction of the dam it was predicted, especially during the summer period, to use part of the waters for irrigation. Also, a small hydropower plant of Turija with capacity of 2 units, each of 1 MW was constructed along with the construction of the dam; this power plant operates only during release of waters for irrigation, so not more than 3 months a year.

Since the construction of the whole complex, it was clear that there is remaining hydropower potential in the water that is used for drinking and goes with penstock to Strumica. However, due to the small size of this project, until 2010 it was not interesting for development.

In 2009, after the adaptation of the feed-in tariffs for small hydropower (in 2007) in Macedonia, this project became interesting one, and a private investor started to develop the project starting from a scratch.

1. The initial design

The investor started developing the design with renowned Macedonian designers in this field; however the task was not easy at all. The water concession was limited up to 200 l/s with vitiating net head between 32 m and 61 m, therefore a huge variation of net head for a very small installed capacity is to be expected.

Finally, the initial design concluded that it is possible to construct a MHP with installed capacity of only 150 kW and estimated annual energy generation of about 900 MWh, and estimated a budget for constructing the MHP of 500 k€. At with stage the investor was close to abandoning the project. However, at end of 2009 after proposing by the authors' alternative, not standard solutions to the owner, he decided to develop alternative design that should decrease the cost and make the project feasible.

As presented on Figure 1, the initial design of MHP Turija predicted the following facilities:

- Earth and stone excavation with blasting
- Standard Powerhouse with height of at least 5 meters (to permit a truck with mounting equipment to enter at site where the equipment can be taken by the crane).
- Crane
- Standard substation
- Space for mounting the equipment
- Governor
- Pelton runner with 4 jets

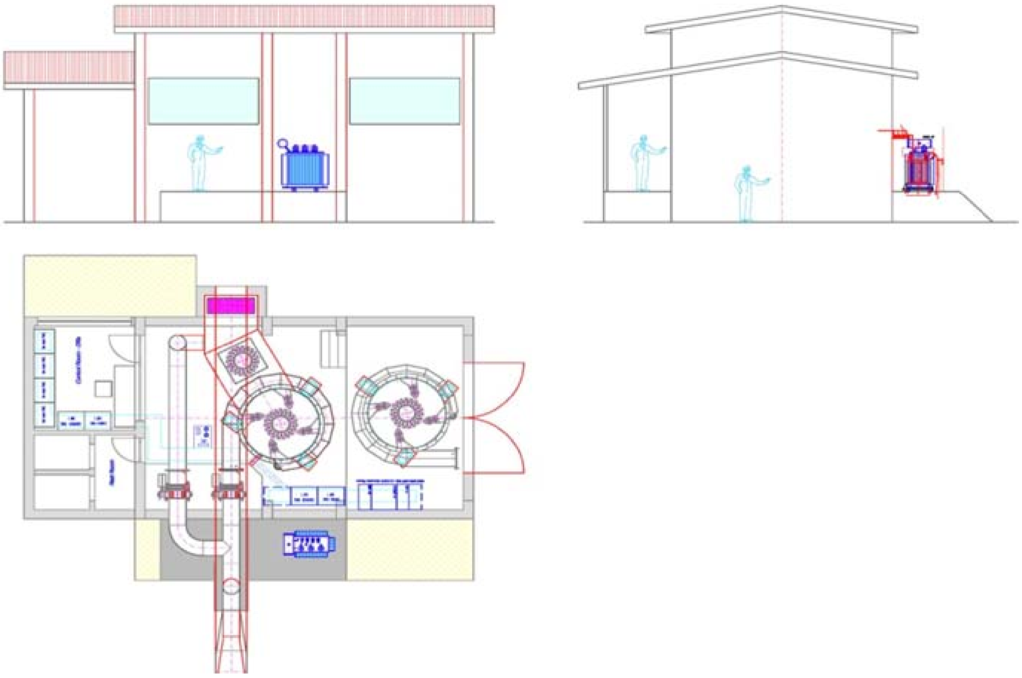


Figure 1: Initial design of MHP Turija

Photo 1 : Location predicted for excavation and powerhouse in the initial design

At a first glance, this was a very standard design, and not many improvements of the design were possible since all the things were interconnected. Accordingly, if any new spatial optimization was possible, there were only minor changes that could only aggravate the project feasibility.

However, latter on it the authors showed that is possible to make further optimization of the whole project but only with the change of concept and the whole idea of the MHP. Therefore, the initial design was cancelled and completely new optimized design was performed.

2. The new design concept

The most important conclusion was that it is possible to make the project attractive for investors and financially viable if and only if a complete redesign is undertaken adhere to the following constraints:

- Minimizing the amount of civil works,
- Having minor design modifications to the already existing structures that would results with insignificant changes on energy production/drinking/irrigation requirements,
- Design relatively simple equipment that could work under various working conditions with huge net head difference (from 30 to 60 m).
- In order to reduce the equipment cost, procurement of the equipment outside Europe was allowed as long as appropriate quality requirements are maintained.

No matter how simple it may look at a first glance, the above constrains were difficult to meet. First of all, it was unlikely to construct a powerhouse without the crane. The first question was how we will install the equipment without a crane? Initially, it was envisaged to construct it with temporary vehicle crane, which will disembark the equipment within the power house followed by construction of the powerhouse roof. With implementation of such construction procedure, the size of the building was decreased significantly, large savings were made, however still not enough to increase the feasibility of the whole project.

At the second instance, we came with the question: Why to construct a powerhouse at all, is it needed, does it brings any added value to our project? After a review, we concluded that site is not in the area with significant visual impact but it is rather in an industrial yard, i.e. in the environment is already located a substation and the existing old small hydropower plant. Accordingly, a new concept with container solution was adopted as the most appropriate one. With this concept, the need of crane, a powerhouse and additional land excavation were automatically discarded.

The basic requirements were defined as follows:

- ♦ All the equipment was included inside a container;
- ♦ Provide inputs for civil design needed before installation:
  - Concrete foundation
  - Diversion steel pipe
  - Transmission devices
- ♦ No control room needed;
- ♦ Unmanned operation.

Photo 2: Example of arrangement of the equipment in container SHPP

The re-design was performed and with replacement of the intended powerhouse with a container, the major civil and excavations works were eliminated. Moreover, as a result of the re-design, the environmental impact was also significantly reduced. In addition, the impact on the surrounding users and structures, constrain which previously was very important, now was significantly reduced and/or eliminated. The necessary construction area was reduced three times, and much of the standard equipment of the powerhouse (*such as hoists*) was eliminated.

2.1 Selection of appropriate machine

However, there were still some important issues to be resolved, particularly, the selection of the adequate turbine. What previously was considered as good solution, now it was very clear that the proposed Pelton turbine might not be the best solution for operation under given site conditions.

All historical data of flows for the drinking water for 20 years were found and analyzed, the conclusion was that the flow varies between night/day and winter/summer, but it is always within the limits of 150-220 liters per second. Regarding the net head, it was concluded that it has variation between 32 and 61 m, however with frequency of 90% it is between 42 and 58 m. Therefore, the decision was to concentrate on selection of a turbine that will have best performance under these working conditions (water discharge & net head).

After conclusion that the Francis turbine could provide best performances for this site (increases of the speed of the generator to 1000 min-1 compared to the 600 min-1 previously considered with the Pelton turbine) – we ended with generator almost at half price and two possible solutions were envisaged:

1. **Variable speed Francis turbine that will use asynchronous (induction) generator connected back-to-back converter-inverter and further to the main grid;**

The idea here was to use a simple low cost induction generator and two low cost commercial power electronic elements, a converter and an inverter. In this system, a converter is used for the excitation of generator and for transferring the generator's variable AC output as a DC power, and an inverter is used to convert the obtained DC power to the standard AC output. The control scheme used is a constant Voltage/Frequency (V/F) ratio scheme. For the variable speed system, the turbine and the generator can always be operated under the optimal condition despite the variation of the operating net head and the amount of water discarge. Consequently, the overall efficiency of the system at off-design head is improved much by using the variable speed system. However, the used electronic elements generates some additional loses which lead to decrease of the overall unit efficiency.

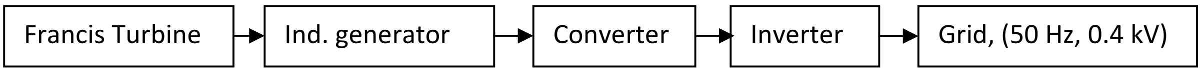


Figure 2: Concept of variable speed turbine

2. **Synchronous Francis turbine with optimal point of operation 248 l/s and nominal net head of 46 m, this was the point with greatest frequency of occurrence. It was specified that efficiency below 85% will be not acceptable for the turbine in this point.**

The second solution was classical solution where we tried to find optimum operation point of a standard Francis turbine, with a small additional study of the working conditions.

Queries were sent to manufacturers and comparison was done. It was concluded that the converter-inverter solution provides overall better efficiency (about 2% higher), and larger energy yield but, also this solution was technologically more complex, more subject to defects, and would require more maintenance. Additionally, the cost was approximately 30 k€ more, compared to the second solution, so after the payback period check and comparison between both solutions, the second one was retained.

2.2 Market investigation and fitting into the budget

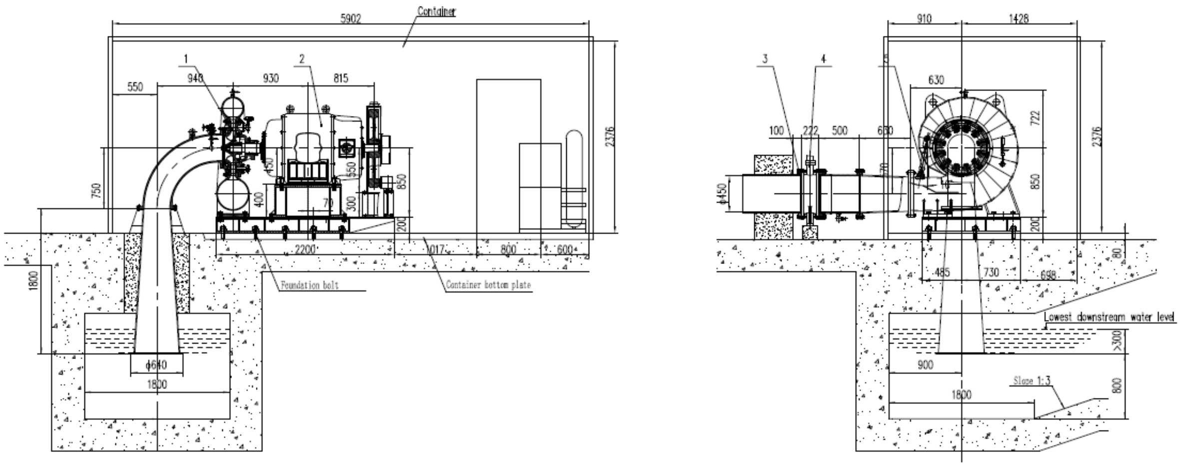
When in the previous step the queries were sent to manufacturers, it was concluded that the cheapest container solution available within Europe was estimated at around 250 k€. This amount already cut the previous budget in half, but yet, it was not enough feasible since it was still above the possible financial output of the project.

Then, as final solution to decrease the cost of the equipment, it was proposed to the project developer to procure all equipment from China where lower prices were expected, but however that the project management, procurement and all sourcing should be done by renowned Chinese company with adequate knowledge of the producers of the required equipment. The procurement of the equipment nevertheless was rather challenging. Not many companies are interested to provide an offer for equipment of such small installed capacities, and if they are interested, their offers are with unreasonably high prices. Furthermore, it was requested by the producer that the SHP should be delivered and assembled in a standard shipping container. After significant efforts, a renowned Chinese company was able to deliver the specified equipment within available budget. The complete construction time was fixed at 8 months (while with the conventional design, at least 12 months were necessary).

Finally, this concept resulted with decrease of the budget for the equipment to 100 k€, and the overall cost for construction and putting into operation of the power plant to 150 k€.

3. Final design and implementation

The previous step permitted to conclude a contract for the supply of equipment and to produce the final design. The final design was produced in one and half month after the contract signature and the equipment was to arrive in six months after the contract signature.



Drawing 1: Final layout of MHP Turija

<u>Basic parameters and structure of turbine:</u>

Type	Francis type
Rated water head	46m
Max. net water head	58m
Min. net water head	30m
Max. Discharge at the rated water head	0.31m3/s
Max. Discharge at the maximum net water head	0.35 m3/s
Rated output	117kW
Max. Prototype efficiency under the rated operating condition	86.7% (turbine)
Rated speed	1000r/min
Runway speed	1700r/min
Rotating direction (viewed from generator end)	clockwise
Coupling mode between turbine and generator	Direct
Suction head (Hs) at the turbine centreline	+2.1m
Max. Hydraulic thrust of bearing at the Max. Head of 58m	0.8t

Basic parameters and structure of generator:

Type	SFW150-6/590
Rated capacity	183kVA
Rated power	150kW
Guarantee output	146kW
Rated voltage	400V
Rated current	270A
Power factor	0.8 (lagging)
Frequency	50Hz
Number of phase	Three (3)
Rated speed	1000r/min
Runway speed	1700r/min
Coupling	Direct
Insulation grade	F
Rotating direction (viewed from the turbine end)	Anti-clockwise
Efficiency (at full load – 80K temperature rise)	90.0%
Ventilation	Air cooled

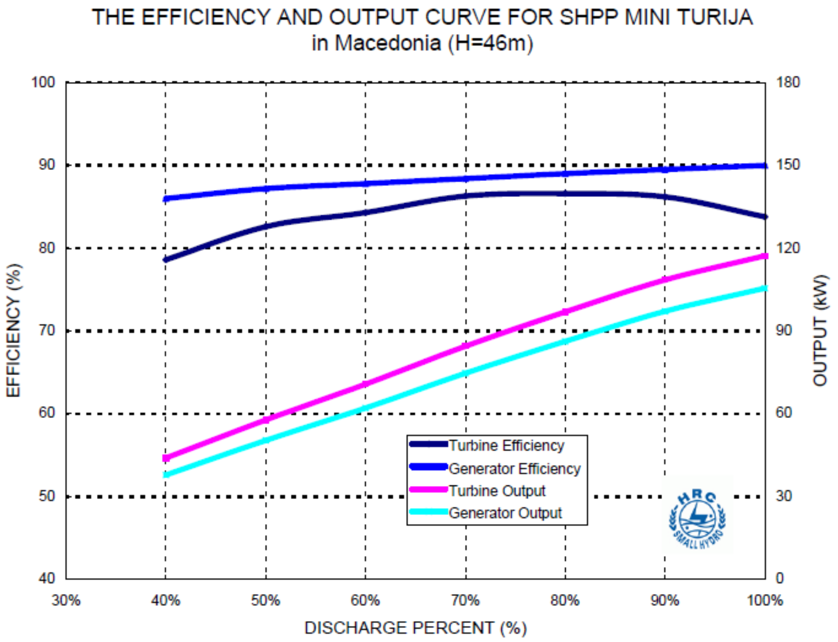


Figure 2: Turbine and Generator Efficiency & Output curves

Mayor implementation milestones of project MHP Turija (month 1 corresponds to Feb. 2012).

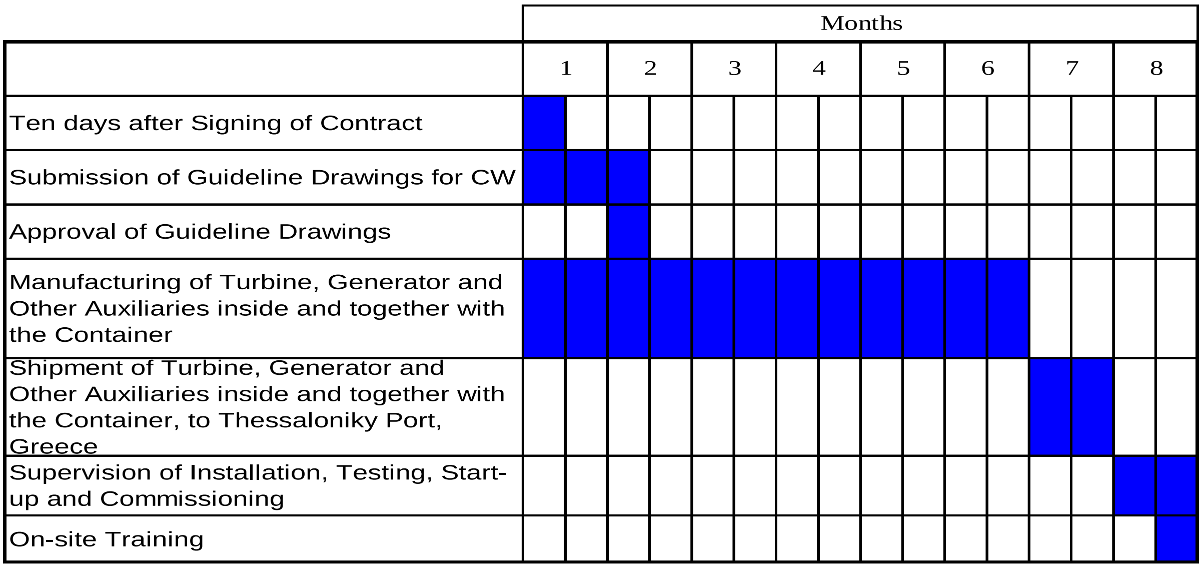


Figure 3: Implementation schedule of MHP Turija (contracted and executed)

3.1 Transportation, Installation and Commissioning

The schedule was very ambitious one and was fully respected by Investor and the Contractor. The transportation of the container from Shanghai to Thessaloniki port took one month as predicted, and in one day was dispatched to Strumica (90 km from Thessaloniki). The installation started the same day that the turbine arrived and in 5 days was finished. However, prior to the installation of the container, there was approximately one month of civil works for constructing the foundations, welding the intake pipes, installing a security butterfly valve (second one) and providing all links to the existing water drinking system of the town of Strumica. With the installation of the MHP Turija the existing piping system for water supply became bypass which now operates only when the turbine is out of operation. The project was successfully commissioned (unfortunately only with dump load) in mid-December 2012, a half-month ahead of the schedule. Ironically, the connection of the plant to the grid due to administrative and bureaucratic issues within the country waited for another 7 months and caused damages to the investor of loss of production of approximately 25 k€.

Photo 3: Inside the container during commissioning of MHP Turija 27.06.2013 (177 kVA, 168 kW with 58 m of head and 420 l/sec, it can be seen on the control panel that MHP Turija provided 22 kW more than the guaranteed value of 146 kW at max flow and max head)

4. Conclusions

The main conclusions from this small but challenging project are:

1. Each time a power plant is designed the concept should be investigated; entering into design without examining the concept may end in no go for the project.
2. For installed powers below 300 kW and at sites with medium and high net head, the container concept should be examined since it can significantly decrease the costs.
3. Good team of engineers can reduce the cost with building up a good procurement concept and fixing necessary technical guarantees.
4. The state bureaucracy can always endanger the deadlines and budgets of the projects, therefore significant risk provisions should be provided in order to be sure to close the project as a profitable one.

The Authors

Dr. Vlatko Cingoski, graduated from the Faculty of Electrical Engineering and Information Technologies - Industrial Electric Power and Automation Department, from Sts. Cyril and Methodius University in Skopje, Macedonia in 1986, and obtained Master's Degree in Technical Sciences (Electrical Engineering) in 1990 from the same University. Dr. Cingoski obtained his Doctoral Degree from the Faculty of Engineering at the University in Hiroshima, Japan in 1996. He worked as a university Lecturer, Assistant professor and Associate professor at several state and private Universities in Macedonia and Japan.
In 1999, Dr. Cingoski joined the state utility company "Elektrostopanstvo na Makedonija", where he had held several professional and managerial positions such as Project Manager (EBRD & the World Bank projects), Assistant General Manager for Development & Investments. In 2006 he was appointed as the General Manager of the JSC Macedonian Power Plants - the largest electricity production utility within R. Macedonia. In January 2013, Dr. Cingoski joined the State Univeristy "Goce Delcev" in Stip as an Associate Professor. Dr. Cingoski is a member of several professional and scientific national and international societies. His main scientific and professional interests are in the fields of electricity generation, energy policy, renewable energy resources and electromagnetic fields modeling and analysis. Dr. Cingoski is author or co-author of more than 60 papers in various professional and scientific journals and magazines.

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