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Trends in Hydropower

1 Statements expressed in the paper are author's own opinions, they are not binding for the company/institution in which author is employed nor they necessarily coincide with the official company/institution's positions.

SUMMARY

With a global focus on reducing carbon dioxide emissions, hydro power has come to the fore as an effective means of balancing other forms of electricity production from renewable sources (wind, photovoltaics and biomass). The role of hydropower in the modern mix of energy has led to favorable climatic conditions for development in the construction of new plants and upgrading with the renovation of existing hydroelectric power plants. Especially reversible hydropower plants with modern equipment with the so-called variable speed technology have a special role, which enables stability in the primary and secondary energy regulation system. A noteworthy trend is the construction of new facilities with low falls with the installation of highly efficient Kaplan and Tubular turbines. The already built projects in the fifth and sixth decades of the previous century, especially in northern Europe, are rapidly revamped and prepared for use in the next 40 to 50 years. Modern and sustainable approach to designing and preparing documentation for the construction of new or renewable power plants requires the use of modern information technology with 3D design and BIM (Building information Modeling) approach. In this way, young generations of engineers and consultants are easier to communicate with each other and reduce the possibility of errors in all phases of project realization. Key to the realization is the contracting of projects, the big dilemma whether to have EPC (Engineering, Procurement, and Construction) contracts (turnkey) a responsibility in one place or to deal with separate lots and engage their employees to control realization in order to minimize risk. Special attention is given to model research and development of turbines with reciprocal tests both on the model and prototype turbines.

KEYWORDS

hydropower, pump storage, BIM, CFD, R&D.

1. HYDROPOWER KEY FACTS

Within many types of renewables technology nowadays, hydropower will undoubtedly play a vital role throughout the world. Hydropower provides around 16.4 % of the electricity throughout the world [1]. Indeed, it is the most important renewable energy source today. In 2017, hydropower development reached 21,9 GW as seen in Figure 1 due to the continued growth. Pure hydropower capacity placed into operation producing 1,267 GW worldwide including 153 GW of pumped hydro of the total installed capacity in the world as seen in Figure 1 and 2.

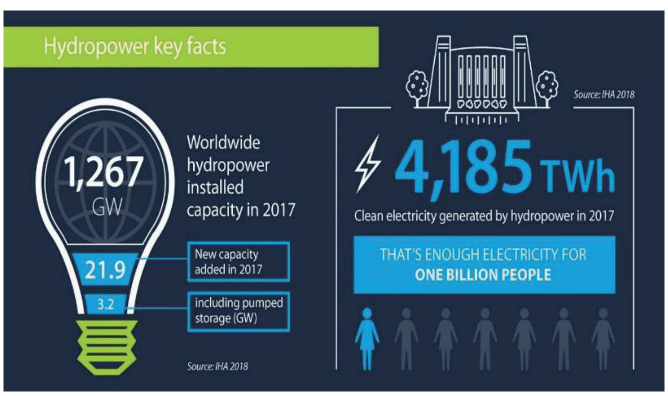

Figure 1. Hydropower key facts [1]

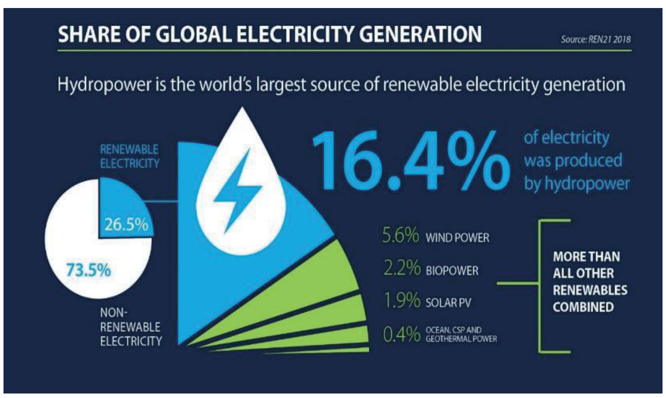

Figure 2. Share of global electricity generation [1]

Currently, many countries in the world have been using hydropower for their electricity supply. Moreover, more than 150 countries are reliant on hydropower to produce their electricity. For instance, Canada, China, Brazil, and the United States are the countries which utilized hydropower generation in a wide range because they have the largest hydropower production capacity as seen in Figure 3.

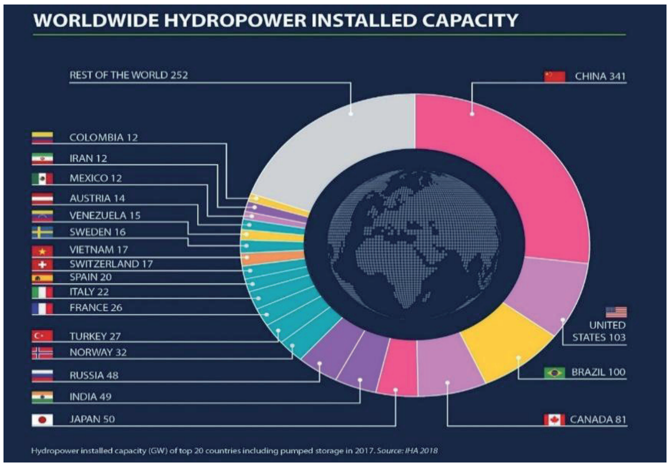

Figure 3. Worldwide hydropower' installed capacity [1]

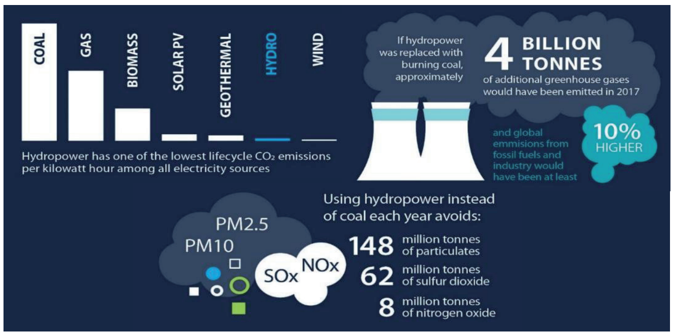

Figure 4. Hydropower versus coal [1]

Hydro energy represents the largest coefficient of energy recovery compared to other traditional and renewable energy sources as seen in Figure 4. The share of the total energy produced during the lifetime of the energy-sharing technology needed to build fuel is the true meaning of the energy return ratio. This is the most important benchmark when considering the efficiency and sustainability of the power plant. Therefore, a higher return ratio is required to achieve better ecological efficiency.

Due to the hydroelectric life span, the plant produces more than 100 times more energy. The extremely long life of hydropower systems and the short energy conversion processes are the reason for obtaining a high energy return ratio. For this reason, the life cycle assessment for hydropower gives a brilliant carbon footprint.

2. CURRENT TRENDS IN HYDROPOWER

2.1. TRADITIONAL HYDROPOWER GENERATING PLANTS

Traditional hydropower units have come a long way since they were introduced in the 19th century. With advances in all technical fields, all aspects of the operation of the hydropower units were greatly improved. Over the past few years by using the Computational Fluid Dynamics (CFD) modeling, especially large steps ahead concerning the efficiency and operating limits of new turbines were made. New runner designs were introduced with very high efficiency. In Fig. 5, some guidelines for model peak efficiencies for different turbine types and specific speeds are presented [3]. These values can lead to efficiencies of 96% in case of prototype Francis turbines.

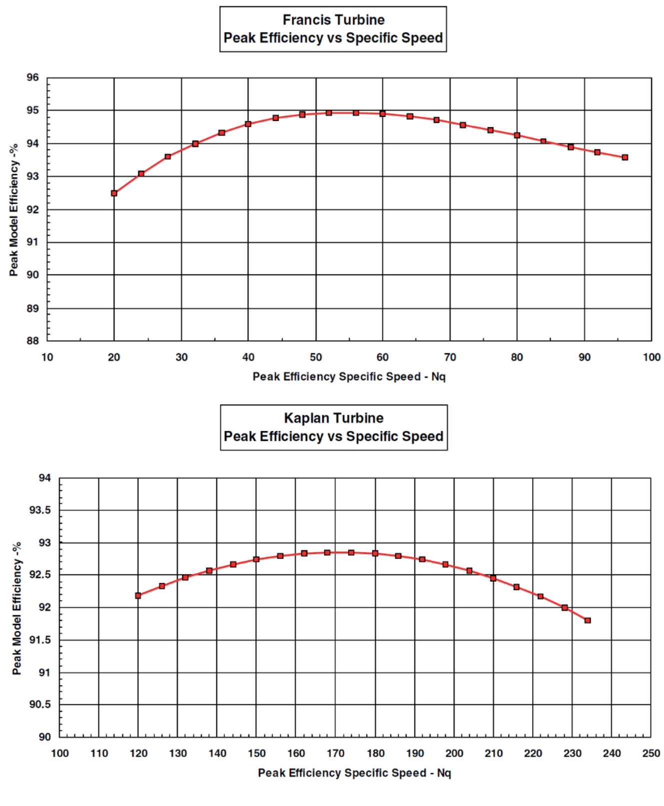

Figure 5. Francis and Kaplan turbines – peak model efficiency versus specific speed [3]

Standard scale-up procedures from model testing to prototype specified in the standard IEC 60193 [7] used for model testing, were complemented with a new standard IEC 62097 [8], which deals with performance conversion procedures from model to prototype in a much more detailed way.

2.2. Modern energy storage plants

Hydropower plays a significant role in reaching Europe's climate and energy target. Notably, hydropower can accomplish the increased development of renewable technologies into the European power grid. The future energy systems in Europe of the wind and solar demands steady capacity and potentiality to stabilize unsteady generation over time varying from hours to several months. The only configuration of hydropower electricity storage that is convenient on a large scale is pumped storage. As a result, pumped storage hydropower provides additional Energy services. A lot of projects of pumped storage under construction such as in Switzerland and Portugal, more than 3,000 MW of new capacity was installed.

2.2.1. Avče pump storage plant

One typical example of modern energy storage plant with high head is project PSPP Avče in Slovenia which generates 426 GWh of electricity per year. The key advantage of this Power Plant is generating of the so-

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called peak energy from a renewable energy source. PSPP Avce with its advanced technology is one of the first reversible power plant in Europe with such type of variable speed technology in pumping and turbine mode. Due to adaptability to daily needs of consumers this Power Plant is of especially great importance at provision of stable supply of electricity to the Slovenian electric power system.

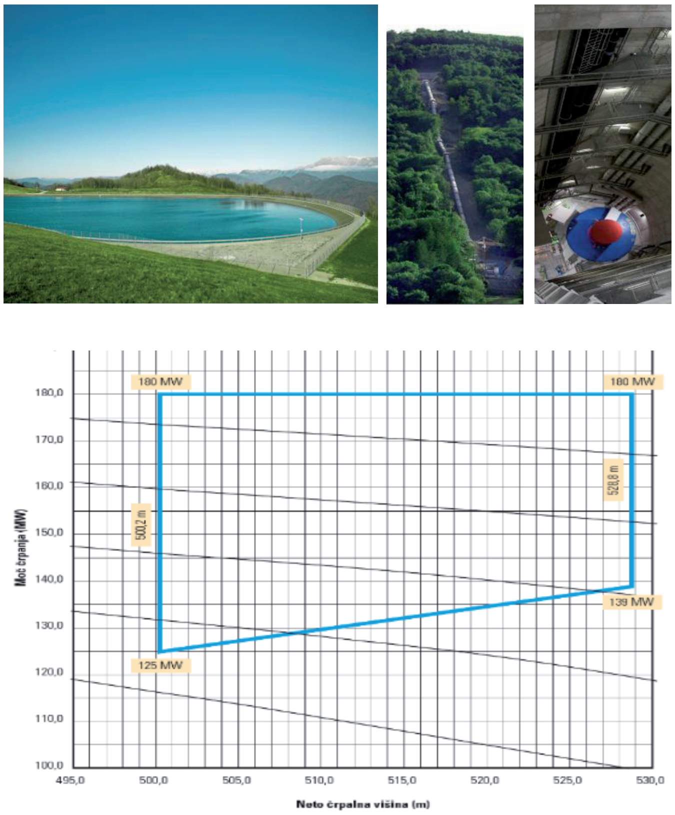

Figure 6. Avče pump storage plant [5]

2.3. CASE STUDY TURBINE REFURBISHMENT – DUBROVNIK HPP, CROATIA

HEP, National power producer is continuously working on refurbishment of units which operates more than 40 years. More than 5 hydro power plants were refurbished by using advanced approach defined by EPRI standard. All of them were very successfully refurbished and modernized and they are ready for continuous operation for next 40 to 50 years with minimum maintenance costs.

In the case of Dubrovnik HPP two turbines were upgraded with peak efficiency more than 95%, with more than 22% bigger power output and by increasing maximum flow more than 11,5 %, as seen in Figure 7.

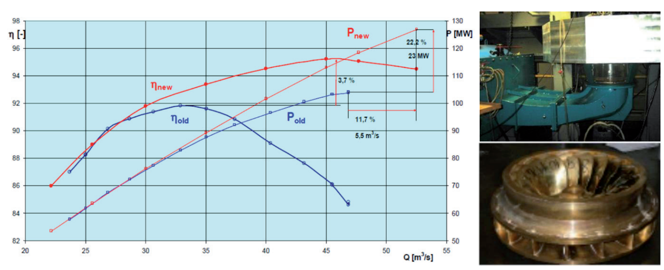

Figure 7. Case study turbine refurbishment – Dubrovnik HPP, Croatia [6]

2.4. CASE STUDY TURBINE REFURBISHMENT – HPP ZAKUČAC, CROATIA

In the case of HPP Zakučac, special approach was implemented by performing so called independent competitive tests by two of biggest turbine manufacturers, Alstom Hydro now GE Hydro and Voith Hydro. The winner of the model tests competition performed in laboratory of Turboinštitut was Voith Hydro. As a result of such approach turbines at units A&B units were upgraded with peak efficiency more than 95,7% with weighted prototype efficiency more than 95%. These are extraordinary results of turbine refurbishment, unique in this part of Europe. Some moments from model tests are given in Figure 8.

Figure 8. Case study turbine refurbishment – Zakučac HPP, Croatia [6]

2.5.MODERN APPROACH TO DIGITAL PROJECT MANAGEMENT - BIM

In a modern and sustainable approach to designing and preparing documentation for the construction of new or renewal of existing power plants, it is necessary to use modern information technology with 3D design and access to Building Information Modeling (BIM). In this way, the younger generations of engineers and consultants communicate with each other and reduces the possibility of errors in all phases of project implementation.

Different BIM levels can be achieved for different types of projects. Each level represents a different set of criteria that show a certain level of »maturity«. BIM levels start with 0 and go to 4D, 5D, and even 6D BIM. The purpose of these levels is to determine how effective, or how much information is shared and managed throughout the process.

Level 0 BIM does not apply to co-operation at all. If you are using 2D CAD and working with drawings and / or digital prints, you can say that you are at level 0.

Using 3D CAD for conceptual work, but 2D for producing production information and other documentation, probably means you are working at level 1 BIM. At this level, CAD standards are managed in accordance with BS 1192: 2007, and electronic data sharing is performed by the common

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data environment (CDE) commonly run by the performer. Many companies are at BIM level 1, which does not involve much collaboration, and each participant publishes and manages their own data.

Level 2 BIM begins with the addition of documentation in a collaborative environment. Level 2 of the BIM became a mandatory requirement in April 2016 on all publicly announced projects in the UK. At Level 2, all team members use 3D CAD models, but sometimes not in the same model. However, the way in which information is exchanged distinguishes it from other levels. The information about the design of the built-in environment is shared through the normal file format. When companies combine this with their own data, they save time, reduce costs and eliminate the need for processing. Because data is shared in this way, CAD software must be able to export to the usual file format, such as IFC (Industry Foundation Class) or COBI (Building Operations Build Information).

BIM level 3 is still collaborative. Instead of each team member working in their own 3D model, level 3 means that everyone is using one, common project model. The model exists in a »central« environment and everyone can access it and change. This is called Open BIM, which means that another layer of protection is added against the conflict, adding value to the project at each stage. The UK Government has even pledged that level 3 of BIM would be a prerequisite for all projects in the coming years.

Because of the clear advantages, it is certain that BIM will remain. It has defined goals that are obviously beneficial for all those who work their way through the levels. Without a doubt, the future of construction will be even more collaborative and digital. As BIM is becoming more and more sophisticated, 4D (add-on time component), 5D (added component costs), and even 6D (maintenance and running of already-built projects), BIM will play a leading role in this construction process. Furthermore, worldwide there is an attempt to reduce waste in construction. Much is attributed to the inefficiency of the supply chain, conflicts and processing. Cooperating in the BIM environment, it all becomes less likely, setting the stage for a better tomorrow.

2.5.1. Smisto hydropower – Norway

Experience from Smisto Hydropower project in Norway shows the possibility of construction of a hydroelectric power plant without 2D drawings – documentation.

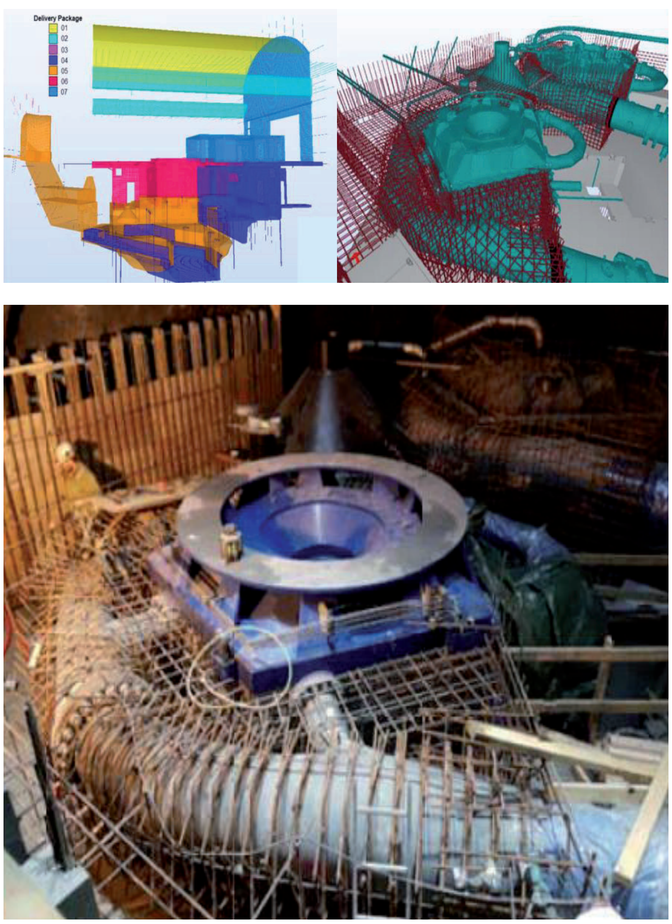

Figure 9. Case study turbine refurbishment, Smisto, Norway [4]

The experience of the Smisto Hydropower (Fig. 9) project shows that the construction of a site without 2D drawings benefits from improved interaction of all parties in the project. By overcoming not only technical challenges, but also challenges with changed working methods, implementation and adoption of a process based on 3D models, it is seen that the project has a better design, mutual understanding between the parties, flexibility and economy compared to the work with conventional 2D documentation.

2.6. CONTRACTING THE HYDROPOWER PROJECTS

Key for successful realization of the hydropower projects is the contracting of projects. The big dilemma is whether to have EPC (Engineering, Procurement, and Construction) contracts (turnkey) a responsibility in one place (single point of responsibility) or to deal with separate lots of the contracts and to engage their employees to control realization in order to minimize risk.

EPC contracts are effective but also sensitive subjects that require high level of consulting and adequate risk management methods. It is the most commonly used contract process for the development of large hydro power projects.

EPC contracting is a chance for projects mainly because of its ability to minimize the duration of a project when is properly managed.

In that sense, the use of FIDIC's (International Federation of Consulting Engineers) so-called "standard package" (e.g. Red, Yellow, Silver, Gold, Green Paper) offers the following advantages:

- internationally recognized,
- provides a standard framework, hence a common language for contractors, employers and engineers,
- determines the general design, supply and quality commitments,
- fair distribution of risk,
- updated practices for dispute resolution mechanisms.

2.7. VT TURBO EXAMPLE OF NEW TURBINE DEVELOPMENT

In 2018 VT Turbo worked extensively on developing a new turbine for a large powerplant with 8 generating units. Powerplant was built in the 1950s and is now in the process of modernization. Modern research and development methods were applied during the development phase. New turbine runner is a 6-blade non-adjustable Kaplan type with fixed blade angle (propeller) having a diameter of 7,2 m (Fig. 10). Rated power of newly developed turbine is 106,15 MW with peak prototype efficiency exceeding 95%.

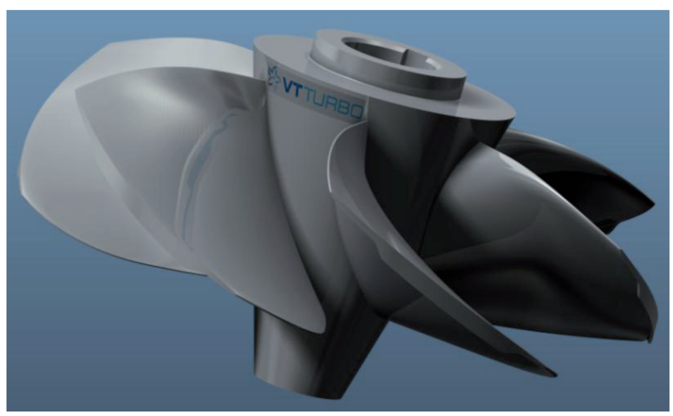

Figure 10. Newly developed runner, D = 7,2 m

During the initial stage of the project a new shape of the runner was proposed, with quite different approach to blade design as the existing ones. Comparison between the two is shown in Fig. 11.

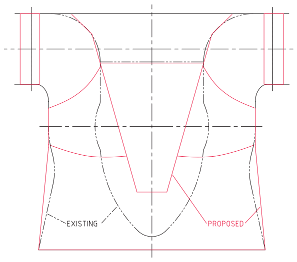

Figure 11. Existing and proposed runner chamber and hub shape

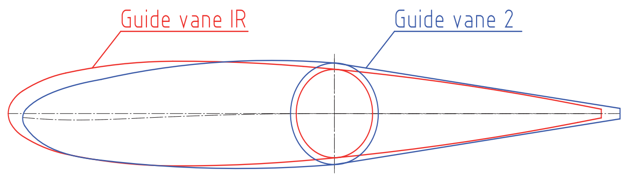

Figure 12. Existing and proposed guide vane shape

When real development began, the first stage was to set the new guide vane shape (Fig. 12). Furthermore, the influence of the wicket gate assembly rotation was examined, and final position was set as pointed in Fig. 13.

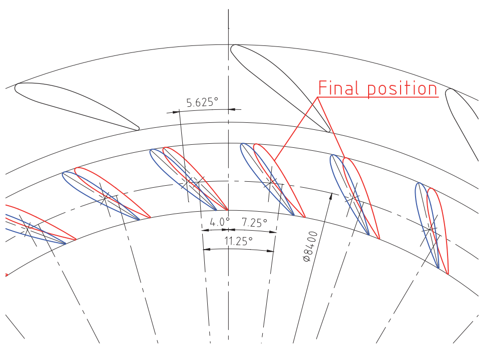

Figure 13. Optimization of guide vanes position

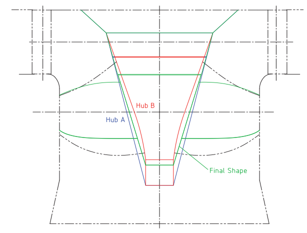

Figure 14. Optimization of runner hub and inner cone

Following the wicket gate optimization, the final shape of the runner hub together with blade profiles were determined as seen in Fig. 13. During this phase numerous variants and combinations were considered and tested with the goal of achieving the best possible outcome according to the specified guaranteed values.

Numerical analysis (CFD) was used extensively during the development phase (Fig. 15, 16) using NUMECA software. HEXPRESS and AutoGrid modules were used for generating hexagonal mesh with excellent mesh metrics and low element count. FINE/Open software was used for solver with k-ω SST turbulence model. Total number of CFD checked designs were 39. For all 39 geometries, efficiency curve for nominal head from low to high discharge was calculated, to ensure optimal curve shape. After confirming the final geometry, additional calculations for multiple heads were done. At the initial development phase, the calculations were done using the steady state approach. Final geometry was then checked by the unsteady analysis with a few revolutions of runner at a very small rotation step. Pressure fluctuations and cavitation phenomena were also analyzed in several operational regimes using the unsteady flow model.

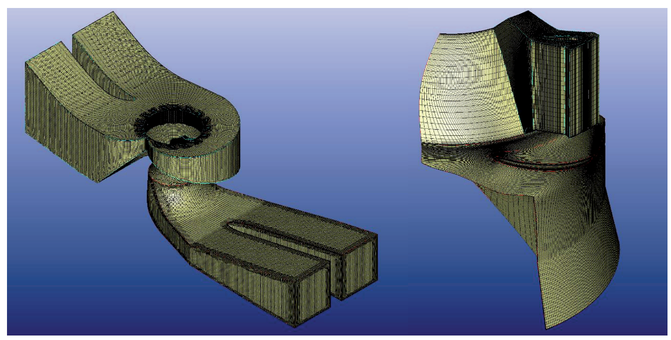

Figure 15. CFD Model – NUMECA, 20 M elements

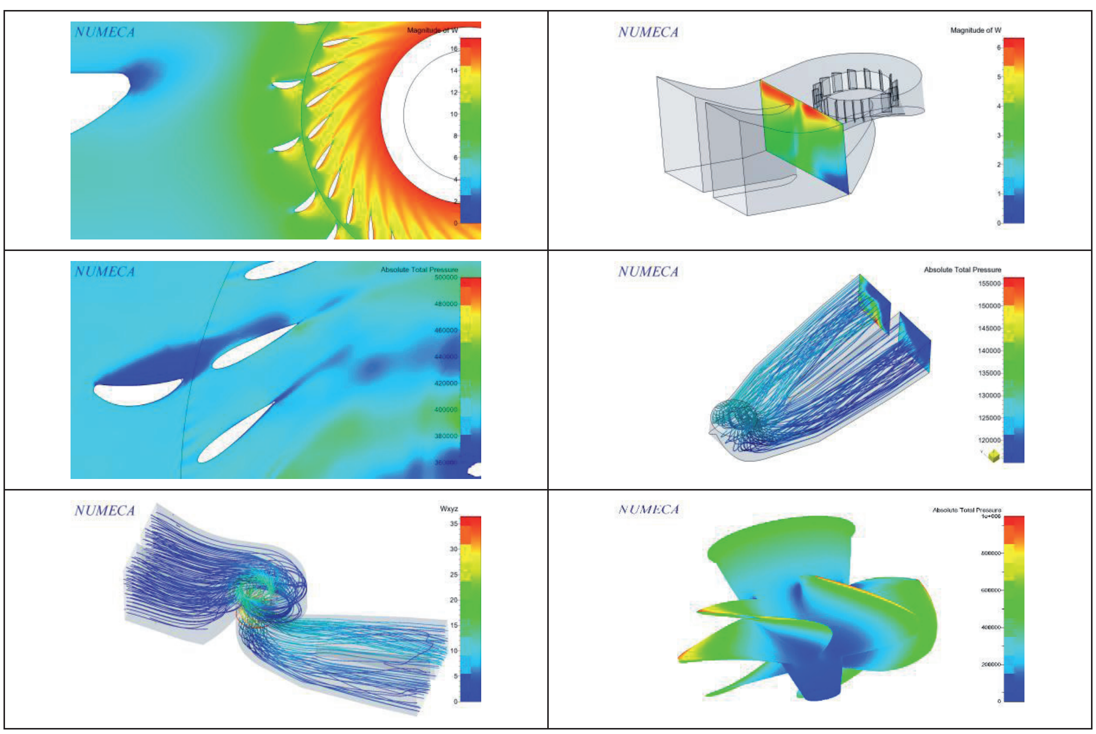

Figure 16. Results of CFD calculation

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Model testing was performed in the hydraulic laboratory of ČKD in Blansko, Czech Republic (Fig. 17) on the new upgraded vertical test rig. Testing was carried out with high accuracy and repeatability, also in compliance with all the requirements, stated in the IEC 60193 standard.

Based on the results of this measurements, the properties of the prototype may therefore be determined quite accurately with appropriate scale-up procedures for all the parameters where the similarity conditions are valid. As shown on Fig. 18, measured efficiency is well above the guarantees. Values have also been confirmed during the acceptance testing.

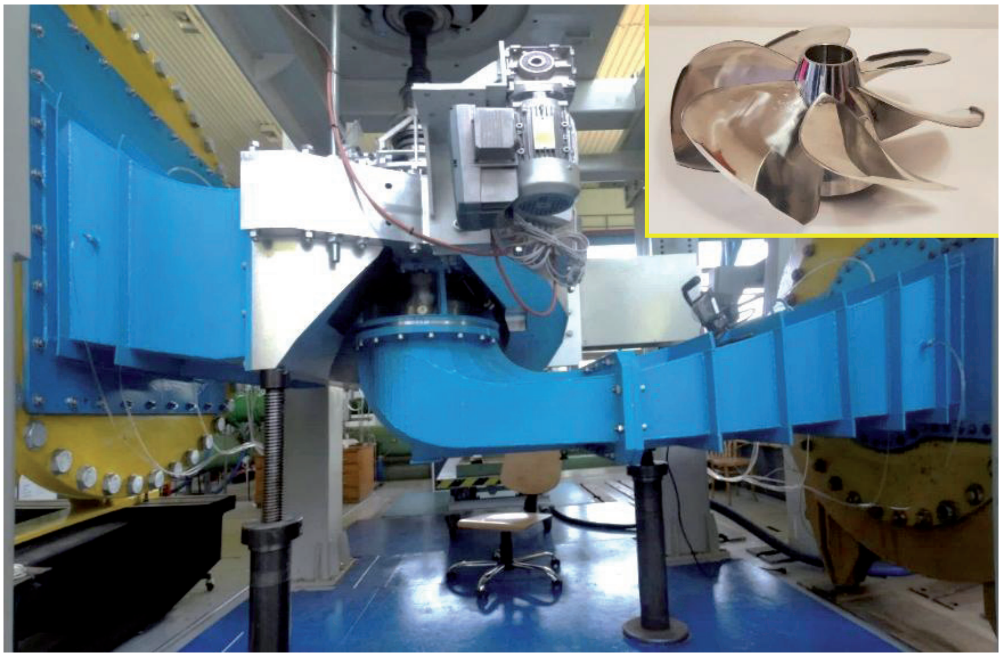

Figure 17. Turbine model installed on the test rig

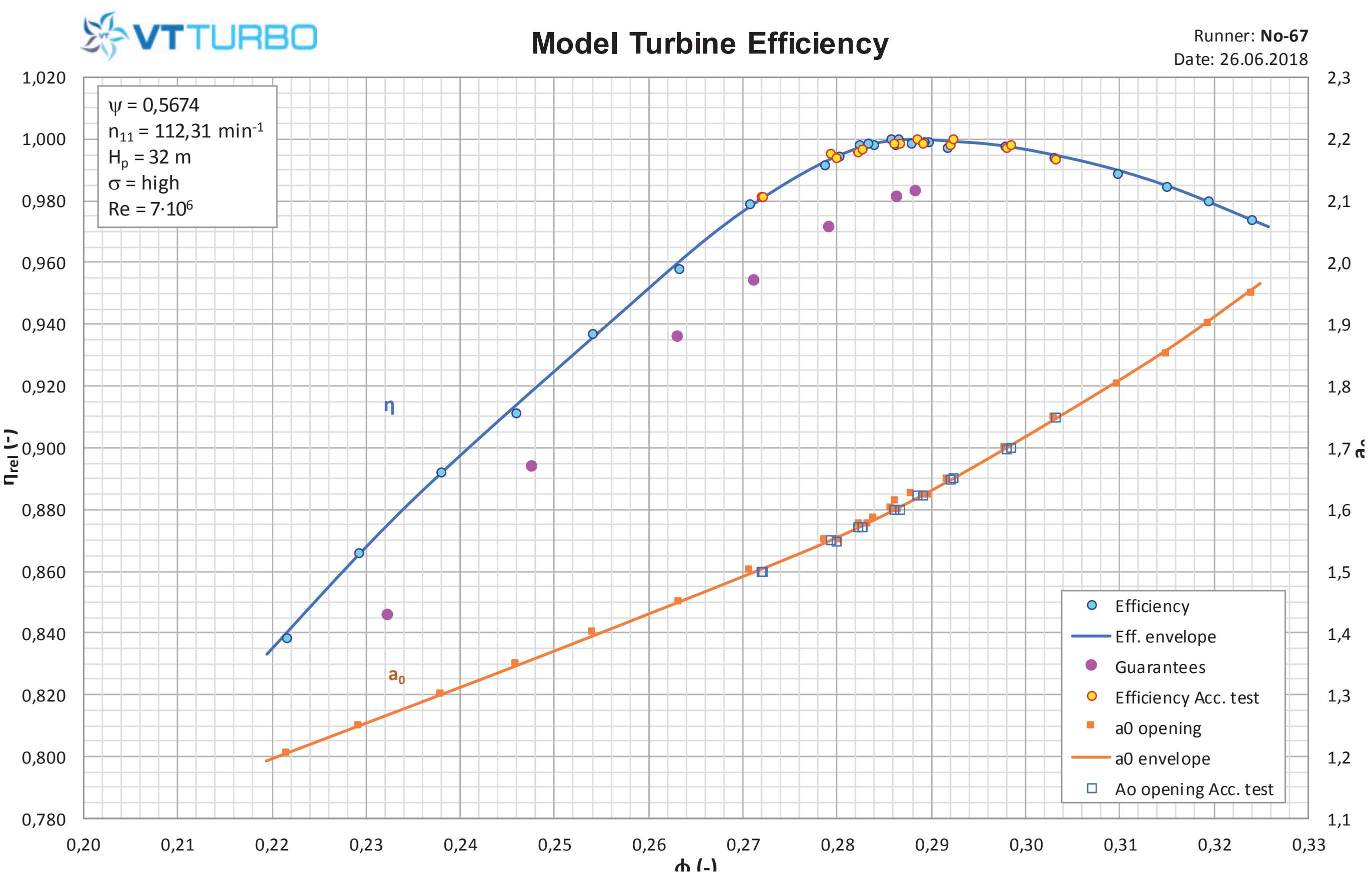

Figure 18. Turbine relative efficiency results from the model testing

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3. CONCLUSION

Hydropower is the most important renewable energy source today.

Recently, the investment is focusing on low head projects, pumped storage projects, refurbishment and modernization projects to boost the lifespan and the efficiency.

Experience from Smisto Hydropower project in Norway and many current projects in Europe shows the possibility of construction of a hydroelectric power plant without 2D drawings – documentation.

EPC contracts by using of FIDIC's so-called "standard package" are the most commonly used contract processes for the development of large hydro power projects.

Advanced tools as CFD simulation, integrated with model testing should be used in order to achieve up to date performances with turbine peak efficiency over 95%, smooth running with acceptable pressure fluctuations and cavitation free operation.

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