Knowledge Transfer with Intention to Improve Design While Reducing Operational

Maricic Tihomir, Karney W. Bryan, Pejovic Stanislav[1]

Abstract--All experts face the dilemma about where to draw the line between the effort of achieving a better design and when to implement a project. Although premature implementation often leads to expensive maintenance and operational problems, seeking perfection leads to costly and delayed projects. The challenge of making such decisions in complex energy systems is further complicated by extensive overlap of technologies, by the broad design experience and knowledge requirements, and by the ever-present social and economic dimensions. The question of how to achieve the best balance between design and operation is specifically considered for several well-known hydroelectric plants, (Grand Coulee, Niagara Falls, Richard B Russell, Iron Gates 2, Jenpeg, Bajina Basta, Zvornik) along with reflections on how this knowledge can better be transferred to less experienced designers. Any hydroelectric installation, as a rule, should be designed using several stages. At each stage, entire project documentation should be reviewed by independent reviewers selected and nominated by official authorities. The organized multidisciplinary transfer of experience is a priority task to be undertaken by the universities and electricity sector in Ontario and Canada. There is a clear need to plan, finance and implement various long-term initiatives; it is urgent that decisions to address this be made now.

Keywords: Design, Guidelines, Expert, Experience, Maintenance, Project stage, Rehabilitation, Runaway, Knowledge, Hydroelectric, Review, Small / large hydro plants, Transfer, Wasting money.

1 INTRODUCTION

Over the past decade, there have been several instances where the performance of new hydro developments was compromised by unsatisfactory operation of some component associated with the hydraulic design of the facility [44], [63], [50], and cases described in Sections 9 Illustrative Systems and 14 Bibliography. Frequently one of the main reasons is the lack of transfer of knowledge. Companies and experts keep their knowledge for themselves to be competitive in the market. In North America as well as most countries all over the world Universities have not been involved in the teaching of the design of electric plants. Particularly hydroelectric plants design is very difficult because there are no two identical sites in the World. Terrain configuration and geology are different, river data varies as well.

In addition the continuity of experience and expertise have been largely lost in Canada and most parts of the world due to the slow pace of implementation. Canada has had more than 100 years of experience in the electricity sector but individual areas have lost valuable knowledge that accrued during this period. However, poorly coordinated transfer of practical and theoretical experience appears to be root cause of this loss. The consequences are an unstable energy market and investment climate, accidents, inefficiency and troubleshooting (of the same problems), which have all shown up regularly in recent years, will continue to occur if appropriate steps are not taken. The organized multidisciplinary transfer of experience is a priority task to be undertaken by the universities and electricity sector in Ontario and Canada, even in most countries over the world; it is urgent that decisions to address this be made now. There is a clear need to plan, finance and implement various long-term initiatives [33].

One of the greatest tasks facing the electricity sector is the design of new, and the urgent rehabilitation of existing generating units. Yet there are too few engineers with extensive experience and too few project managers who know how to cultivate the right skills from the market place [59].

The dilemma between smart design and less troubles is the question? At each stage, all project documentation should be reviewed by independent reviewers selected and nominated by official authorities. Reducing the amount of analyses, without justification, or worse yet, neglecting the design procedures puts the project at risk. Design, construction and operation of hydropower plants are complex tasks. A large number of details must be carefully considered, coordinated and executed in order that the projects achieve safe and economical operation.

What is the best way to protect consumers, taxpayers and investors (owners) wasting money? What is the best way to protect young inexperienced engineers and experts doing work not experienced and properly qualified to do[2]? A reply has been

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S. Pejovic is with Dept. of Civil Engineering, Univ. of Toronto, Canada (e-mail pejovics@asme.org)

B. W. Karney is with Dept. of Civil Engineering, Univ. of Toronto, Canada (karney@ecf.utoronto.ca)

T. Maricic is with Asset Management Dept. Niagara Plant Group, OPG (e-mail: tim.maricic@opg.com)

[2] PEO (Professional Engineers Ontario) law of Ethics; link:

proposed in the "Conclusions and Recommendations" submitted to participants and posted on the Conference website [33]:

1. *More than 50% hydroelectric plants have trouble in operation.*
2. *Continuity of knowledge and experience has been lost.*
3. *Organized multidisciplinary transfer of experience is a priority task.*
4. *Action should be undertaken all projects, including short-changing, correctly to be designed and reviewed.*
5. *Taking short cuts can lead – and indeed has often led – to large-scale problems*

2 GOALS AND BEST PRACTICES

A. *Organizing multidisciplinary transfer of experience and knowledge - a major task that needs to be undertaken.*
B. *Creating experts to form future teams for designing hydroelectric plants with at least ten years of combined hands-on training in the classroom, design office and on-site.*
C. *Smart design - less troubles*
D. *Protecting inexperienced engineers and experts of doing work beyond qualifications[2].*
E. *Minimizing inefficiency and assist troubleshooting through lessons learned from past experience.*
F. *Protecting consumers and taxpayers.*
G. *Protecting environment.*
H. *Protecting owners' investments.*

3 PROJECT DEVELOPMENT

Any hydroelectric installation and other hydraulic projects[3], as a rule, should be designed using the following stages:

(i) Feasibility study,
(ii) General design,
(iii) Detailed design (after bidding),
(iv) Commissioning and running-in process,
(v) Trouble-shooting investigations, and
(vi) Reconstruction, redesign, adjustment or enlargement.

(vii) Review at each stage.

Ideally, all project documentation should be reviewed at each critical stage by independent reviewers selected and nominated by official authorities. Short-changing the analyses, without justification, or worse yet, neglecting any design stage or its associated review, puts the project at risk. At stake here is the economical and efficient functioning of the whole project; taking short cuts can lead – and indeed has often led [10] – to large-scale problems. The point here is that the design team, the project documentation, and the review process all play an interconnected role in anticipating and resolving difficulties before they are implemented in the field, and thus solving them when they are relatively simply addressed [8], [17], [19], [25]. At the same time reviewers as high experienced experts transfer their knowledge and experience to the designers and to the all present and responsible for the project proper and adequate review, construction and operation.

There is no a single hydroelectric project running through the commissioning and trial operation without troubles and troubleshooting; thus a higher degree of review and documentation through project stages could pinpoint problems earlier and more effectively than later [39], [45], [50], [61], [62], [63]. Furthermore, this process, while costing only a small premium, would decrease troubleshooting and maintenance costs over the project's life time.

Hydroelectric plant's equipment may have been designed in accordance with the highest standards and produced using the finest manufacturing practices, but this does not necessarily guarantee that equipment will operate properly when integrated in a system. Every hydropower project has unique design criteria. Unique characteristics of a particular installation can result in unknown and unexpected events during plant operation. For this reason, designs, reviews, construction, erection, start-up testing should be a carefully planned, step-by-step procedure that provides adequate projects, drawings, in short all documentation and data, for a thorough analysis of all operating conditions. All parts of the design should be reviewed to determine which items require analyses and to what extent. This is not only important for new designs that lack proven operating records, but similarly, when a system is expanded and up-rated, since these improvements must be predicted and verified with accuracy.

(viii) Construction and inspection is an extra (obvious) stage.

Although this is an obvious step, an experienced and qualified eye during the construction process duly documenting details would be of importance for future troubleshooting and maintenance activities, as well as to proactively deal with issues which may impact schedule and performance of the installation.

As an example, Canadian team of experts in Iranian company reviewing manufacturers drawings and booklet submitted reports [34], [35], [37] to protect the units from the water column separation as it was done designing pump storage plant successfully operating for decades [27], [12]. Owners' young inexperienced engineers having not

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http://www.peo.on.ca//publications/code_of_ethics.html
[3] Nuclear plants have, for instance, up to 25 pumping hydraulic systems of different types.

chance to be educated on the subject rejected to follow recommendations and the 2000 MW plant is running at risk. For the similar reason the reviewers rejected printing of the article [68] describing some phenomena not published in Western publications. New, longer article is under review [6].

4 STANDARDS, GUIDELINES, BOOKS,

Many important experiences and knowledge accumulated in last century are not yet introduced into the publications [8], [19], [18], [25], [21], [14] and many other standards, guidelines and recommendations such as IEC, ASMA, ASCE, IEEE, EPRI, IEA, USBR,[4] etc. The young experts therefore have nowhere to read and learn about phenomena very important for the safety of electric plants. In addition the Design of Hydro and Wind Electric Plants is thought at the University of Toronto for the first time in Winter 2009; so far this is the first time that the Design of Hydroelectric Plants is presented to the students in North America.

5 COMPUTERS' APPLICATION

These problems are perhaps further magnified by the use of computers and readily available programs. Overall, the practice of professional engineering has become increasingly reliant on computers, and engineers use many programs that incorporate technical principles for design and simulation. Ultimately these programs are used as tools for baseline installations and in some cases their applicability can be seriously questioned. Invariably, such programs are based upon assumptions, limitations, interpretations and judgments on engineering criteria that were made by or on behalf of an engineer when the program was first developed. Therefore, it is often difficult to determine, simply by using a program or studying its manual, the inherent assumptions, coding algorithms employed and their limitations. When using computer programs to assist in this work, engineers should not only be aware of the engineering principles and incorporated assumptions but must independently verify the results and are thus responsible for the interpretation and correct application of the analyses the programs provide [7].

Engineers are responsible for verifying that results obtained by using software are accurate and acceptable. Given the increasing flexibility of computer software, the engineer should ensure that professional engineering verification of the software's performance exists. In the absence of such verification, the engineer should establish and conduct suitable tests to determine whether the software performs what it is required to do and at the required level of accuracy.

Clearly, the engineer must be alert to the possibility that errors may exist in design software and, as for any design data or design aid, must perform independent checks to ensure the validity of such design assistance. It is not acceptable professional practice to assume that computer output is accurate unless the user has independently verified both the program and the output. Briefly, the engineer must ensure that the program is appropriate for the application, that it is accurate when used properly (as established by validation tests), and that it is correctly used by properly trained personnel. Most importantly, remember the old adage in engineering that an engineer should never base a really important decision on a single calculation (or invalidated computer output). Alternative and independent computations must be made to validate the original results. Reviews should be done to reduce the probability of troubles and incidents

It is the manager's responsibility to ensure that this is done consistently. Ontario professional engineering (PEO) Ethics and Law enforce managers and professionals [71] to verify the computer programs and results of calculations.

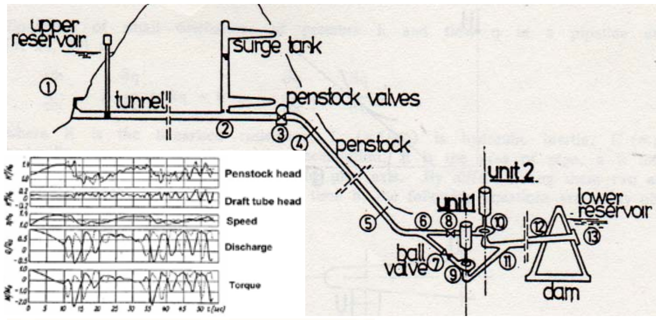
As an important, typical example for computer applications and difficulties with understanding the fluid flow in the hydroelectric and all other hydraulic systems[3] is the analysis of the computed results. Outputs are numbers, tables and diagrams but users have to understand, analyze, and make decisions. Our software [75], [76], [77], [78], [79], and other commercial software we have used [74], [80] as most other programs do, are printing results but analyses and decisions must be made by users.

For instance in the case Figure 1 the water column separation in the draft tube and pressure jump up to 10 bar when separated water columns rejoined has not been noticed by designers and manufacturers. As the system runs into the "S" form instability the results of calculation and measurements are unpredictable and unrepeatable.

6 HYDRAULIC TRANSIENTS

Transients in hydraulic networks and infrastructure can become critical constraints during design and operation. Vibrations produce the highest pressures in the waterways and associated conduits. They cause critical stresses in the overall hydraulic, civil, and mechanical structure and therefore cannot be neglected during design. This aspect is independent of the size of the conduits or hydraulic machinery and is thus recommended for all installations including mini and small hydro. Many books have been published on modeling and calculations of hydraulic transients ([24] and many other books and

[4] IEC - International Electrotechnical Commission, ASME – American Society for Mechanical Engineering, ASCE American Society for Civil Engineering - , IEEE - Institute of Electrical and Electronics Engineers, , EPRI - Electric Power Research Institute, IEA – International Energy Agency



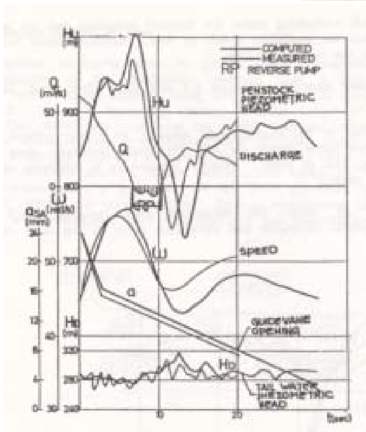


Figure 1 Bajina Basta pumped-storage plant; two pump-turbines each 315 MW output and pump discharge 51 m^3/s at speed 428.6 rpm; head 600 m. Low specific speed unstable "S" form four-quadrant curves are the source of severe transients even at one unit load rejection. Penstock pressure prevented to exceed designing pressure but water column separation in the draft tube and pressure jump up to 10 bar when separated water columns rejoined has not been noticed by designers and manufacturers.

articles) and vibrations (few books [15], [22] and many articles) but only two guidelines for transient and vibration analysis, [8], [19] based on the books [12], [17], [20]. [5] Transient analysis of hydraulic auxiliary systems in hydro, thermal and nuclear plants has been analyzed in [19] based on the book [16] and related research project. It is important to repeat that these books do not cover phenomena casing dangerous hydraulic accidents if not prevented. Some of those are scanned in Section 9 Illustrative Systems. The costs associated with cavitation, transient conditions, vibrations and stress analysis for mini, small and big hydroelectric plants are often quite comparable in absolute terms; however, the relative cost as a fraction of the total investment is obviously much greater. Bigger plants usually entail such costs less than one percent of the total whereas smaller installations may well see these costs as being nearly equal to overall initial expenses.

The pressures stemming from private sector design and accounting are certainly now upon us in a big way. The result is a rapid movement to minimal staff or no site staff. Extensive use of numerical simulation for the performance of hydraulic machinery is remarkable these days, but a shortage of qualified specialists and engineers is often aggravated as a result. New staff, whose number will have to grow again in the light of initiatives, will rely on the new guidelines and upon up-to-date standards and technical literature.

Small hydro power plants often suffer from the same problems as the large ones. The analyses of transient regimes are actually more complicated, due to complex boundary conditions. Despite this, there is a general tendency to decrease the design costs and to simplify analysis.

Thus, in general, the smaller the hydroelectric plant, the higher the risk of having troubles as the result of reduced project costs. Saving money by reducing reviewing costs further increases the risk.

7 RISK AND RUNAWAY PROTECTION

In designing a hydraulic machine unit, the runaway operating condition has to be considered. The balance between safety and costs for manufacturing components and maintenance must be recognized and allowed for. Excluding very small size units, all generator / motors are at risk at full runaway [63].

Some books [14], [21] and articles [61], [55], [63] discuss the issue.

Units must withstand the full runaway speed for a short time, as stipulated in the delivery specifications of the order. According to the experience hydro plants actual runaway occurs only very seldom.

Another alternative is economically preferable, since the probability of runaway occurrence is small enough that the damage and repair costs are less than the savings obtained by eliminating the costly protective devices[6].

In the example [61], [63] the client's designers identified the dangerous phenomenon of the unstable "S" form pump-turbine characteristics and water column separation. The manufacturer verified the instability and the control system were altered to prevent catastrophic runaway and pressure surges in the long penstock (Figure 1). But, in another case hydraulic resonance accident occurred operating in trial operation in the unstable "S" zone [32].

8 VIBRATION SEVERITY

Excited forces in the hydro generator unit include those from hydraulic, mechanical and electrical sources. The test value is compared with standard or permitted values. Some nations and organizations suggest standards based upon the test material. When the unit vibration satisfies these standards, normal operation and safety are usually ensured. Two books, [15], [22], are the highest level scientific,

[5] Research projects at the University of Belgrade supported by electricity sector

[6] Contrary to practice with thermal turbo generators, the hydro turbo set in general has to withstand the runaway speed of its turbine. This is a multiple (1.4 to 3.3) of the rated speed, depending on the design. The first safety precaution is the speed governor of the set (if any at all). At least each set has an emergency shutdown device for the case a certain overspeed (about 1.3 of the rated one) is surpassed.

theoretical, and practical site and laboratory analyses of hydraulic and hydraulic machines vibrations; knowledge crucial for high level hydraulic design. The phenomenon that hydraulic resonance sometimes occurring when increasing submergence and sometimes when decreasing submergence is explained in the articles [3] and [56]. Model test results confirmed the odd phenomenon for hydraulic waterways resonance excited by the draft tube vortex core [35].

At the present time international vibration standards do not exist. Some important draft tube phenomena [2], [3] are not yet included into standards, guides and books.

8.1 Vibration and hydro unit lifetime

Hydro units should provide a service life of at least 4 years and/or 25000 hours before requiring a general overhaul. The average service life before requiring a major rehabilitation should be not less than 30 years. Actual lifetime will depend upon the maintenance performed and mode of operation (e.g. a unit start may be considered equivalent to 8-15 operating hours; a runaway event could be much higher depending on the duration of the event).

Investigations on many units have shown that vibrations experienced by hydro units increase with operating hours. This is caused by gradual erosion and corrosion of the unit and its bearings (generator supports, spider, bearing inserts, etc.), and also by abrasive and cavitation destruction of the runner and associated turbine components, which disturbs runner balance. As the result vibration of the unit reaches boundary "trip values", and the unit must be removed from service and overhauled. Several methods and formulae for the calculation (estimation) of average lifetime between overhauls [4], [15], [22], [38], [64] are based on measured vibration of the unit.

The vibration standards should take into account vibration severity as the main source of crack's propagation. Severity of vibrations directly influences the rate of crack propagation which in turn correlates to increased maintenance requirements and operational risk [31].

8.2 Reliability

The value of energy produced depends on the mode of production. Of course, the goal is to achieve high rate of production with low cost of operation and maintenance for as long as possible. On the other hand, life of the unit is dependent upon the operating conditions. There are some ranges and conditions which reduce the life of the unit. Characteristics of these zones are higher levels of vibrations, cavitation, and flow speed.

It is well known that oscillations of the unit are indicators for operating qualities (cavitation characteristic of turbine, resonance in any component). During unit commissioning the characteristics of oscillation may be used to determine the degree of success for the installation or overhaul. Finally, this data may be used to determine the best technical / economical operating strategy for the unit [3], [4], [15], [64].

Every unit problem may be predicted [4], [15], [22] [53]. Proper investigation and analyses of the results provide information. Developing systems for diagnosing potential problems is the most effective method for increasing reliability and maximizing time between overhauls.

The guidelines for determination of vibration conditions have been developed based upon numerous experiments [10], [15], [22]. There have also been some international attempts for standardization of allowable vibration [15].

8.3 Fatigue

Fatigue is the progressive and localised structural damage that occurs when a material is subjected to cyclic or fluctuating strains at nominal stresses that lead to structural failure. The maximum values of stress that result in fatigue failure are often significantly less than the ultimate tensile stress, and also below the yield stress of the material [41], [50], [65].

The problems associated with cavitation erosion, transient states and vibrations may arise in operational installations, sometimes after several years of seemingly normal operation. These problems usually relate to emergency or catastrophic cases, damage to the plant due to breakdown of equipment, excessive vibrations or other similar situations.

Figure 5 and Figure 6 show the consequences of excess vibrations and fatigue.

8.4 Protection

To determine the root cause of the problem and develop an effective remedy, a very detailed and precise study must be undertaken at all designed stages as specified in paragraph Section 3 Project Development.

9 ILLUSTRATIVE SYSTEMS

9.1 Layout and Methodology

To illustrate the possible causes and origins of specific systems, several cases studies are introduced. Many others cited in the Sections 13 References, 14 Bibliography[7], and 12 Appendix.

The goal is to simply illustrate the range of issues and challenges that so quickly arise in practice, and is not intended to apportion fault or blame on any party or developer because the experts dilemma

[7] The bibliography at the end lists general references containing material describing some of many accidents, incidents and troubleshooting.

always present has been: smart design/low costs of investments and expensive maintenance/short life span or the best expensive design and construction versus low maintenance costs and long lifespan. Rather, it is presented to advocate a renewal of collaborative ties and a sharing of expertise across the field. In all cases, the role of the design process, its connection to operation, and the specific role of hydraulics (and particularly transients) will be illustrated, and comments are made about the possible value and role of the review process. Space limitations prohibit doing justice to the details of these designs.

9.2 Grand Coulee Hydroelectric Plant

Grand Coulee is a typical example of smart design. Peak energy has been needed and the new 700 MW units have been built. There was no space. Therefore turbulent 90^0 bending inflow into the intake structure and outflow into the tailrace has been the “only acceptable and reasonable solution.” High maintenance costs, expensive plant deliver clean “cheap” peak hydro energy into the electrical grid (Figure 2).

Figure 2 Grand Coulee hydroelectric Plant

9.3 Sir Adam Back Hydroelectric Plant

Sir Adam Back. (Figure 3) has similar inflow hydraulic conditions into the turbines on the right side of the dam as the previous Grand Coulee case but more severe inflow having twice 90^0 bending of the water stream once into the inflow canal and then into the turbine intakes. Really an “S” type bending is known as the source of increased turbulence. Saved investments yet increased maintenance costs. Post factum comparison of investments, maintenance costs and energy losses could give data for future analyses.

Figure 3 Sir Adam Back 2 (Satellite photo)

9.4 Richard B. Rustle Pump-Turbines

Figure 4 shows Richard B. Rustle Plant with four turbines and four insufficiently submerged pump-turbines. Based on the available data describing troubles (identified sources listed in the figure) a bid was submitted. The final solution is unknown as the bid failed.

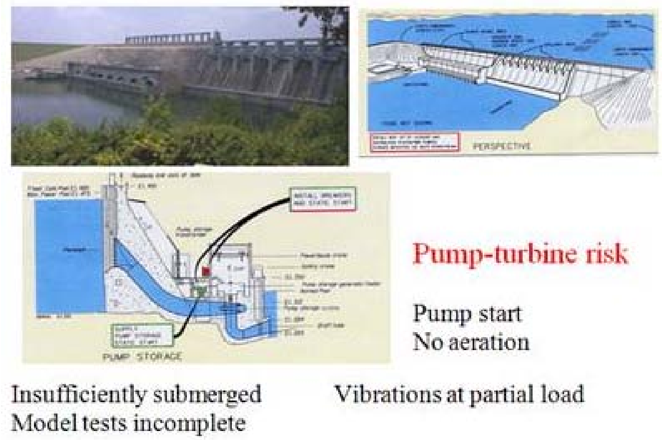


Figure 4 Four turbines each 78 MW.
and four pump-turbines each 76 MW

9.5 *Iron Gates 2 / Jenpeg*

Figure 5 and Figure 6 show the consequences of excess vibrations and fatigue. Figure 5 portrays sixteen bulb Iron Gates 2 turbines each rated at 28 MW. Large vibrations at high heads starting at the rated head have been measured. To reduce investments, the turbine specific speed (type of the turbine) is not properly selected increasing vibrations [46], [50]. After 20 years of operation, shaft failure occurred (Figure 6), and frequently runner blades cracks have had to be repaired.

Jenpeg Hydroelectric plant has identical units but no data available.

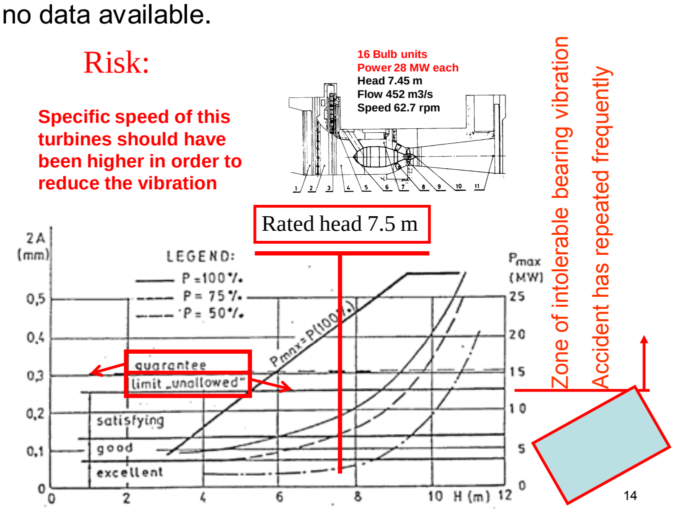


Figure 5 Sixteen units each 28 MW

A detailed technical, technological and economic analysis should take place prior to redesign, reconstruction and adjustment, considering the balance between manufacturing and maintenance costs [31].

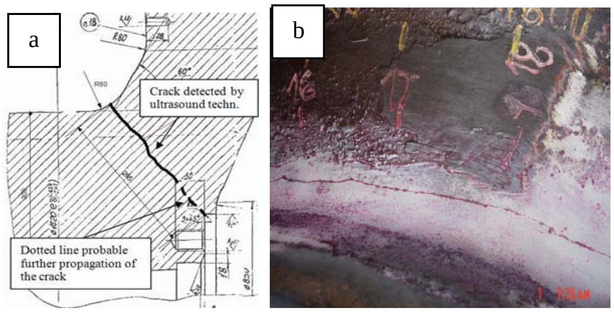


Figure 6 a Horizontal shaft crack; b Shaft to flange transition radius; damaged protective coating and shaft material crack along the perimeter

9.6 Masjed-e-Soleyman hydroelectric plant

In this example [62] the client's designers identified the dangerous phenomenon of water column separation, as described at the end of Section 3Project Development.

The Masjed-e-Soleyman plant is a big 2000 MW underground structure with eight equal turbines having long tailrace tunnels (Figure 7). An air injection system designed to prevent the rejoining of the separated water columns in the draft tubes occurring in most transient regimes. The submergence must have been increased at no additional costs to prevent reverse waterhammer [30], [34], [35], [36], [39], [45], [62]. A better organized design, reviews and involvement of experienced expert could have made the project at lower risk and costs.

Powerplant designed by inadequately trained and inexperienced engineers has been put in danger by water column separation in the turbine draft tube. Insufficiently submerged to prevent water column separation in trial operation excessive pressure surges measured; air injection system added to mitigate pressure peaks [30], [34], [35], [36], [37], [39], [45]. Complete excessive transient analyses should have been done [17], [8], [25] and the system appropriately protected. At partial loads vibrations are present as well [3].

The panel of experts nominated to solve the problem verified during commissioning and trial operation also has not protected adequately the system and controversial articles were published [30], [45], [62], [63], [68], [6].

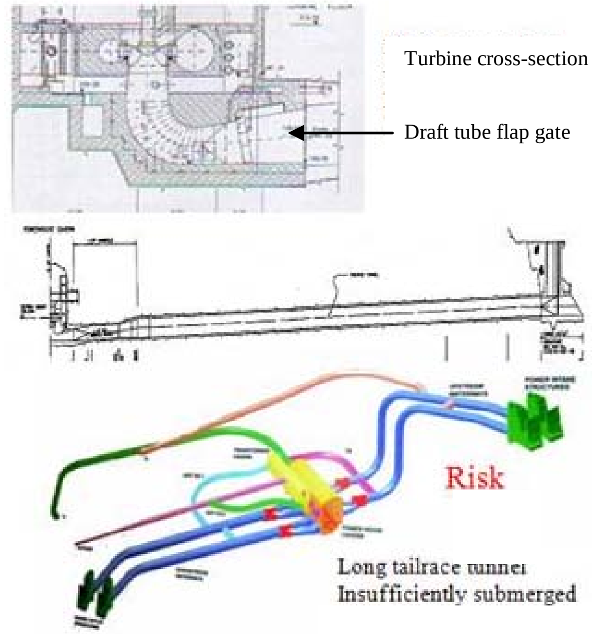


Figure 7 Power plant under construction; eight unit each 250 MW

9.7 Hydroelectric plant Zvornik

A 22 MW generating unit was operating during the night with an output of 8 MW. Because of the governor failure the guide-vanes opened very quickly and the power output increased; oscillations between 20 and 25 MW registered, and then roaring sounds were heard from the turbine. Emergency shut-off button pressed. A banging noise was heard; water was leaking out through the turbine head cover. One of the runner blades was broken at the root (Figure 8) [5].

A year later in another plant a turbine having the identical runner had catastrophic accident as well.

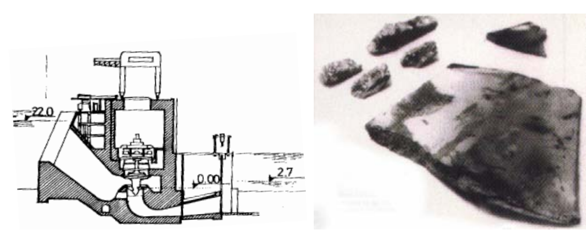


Figure 8 Hydroelectric plant Zvornik Runner Blade Broken in the Accident

9.8 Hydroelectric plant under construction

The next example is a small 20 MW plant (Figure 9) under construction which could be at risk. Based on figures and data originally posted on internet the cause might be high head, big diameter, bulb unit sensitivity to vibrations and/or bend disturbing the inflow into the turbine. We are lead to believe that designers have verified and corrected all issues, highlighting again the value and role of a review process.

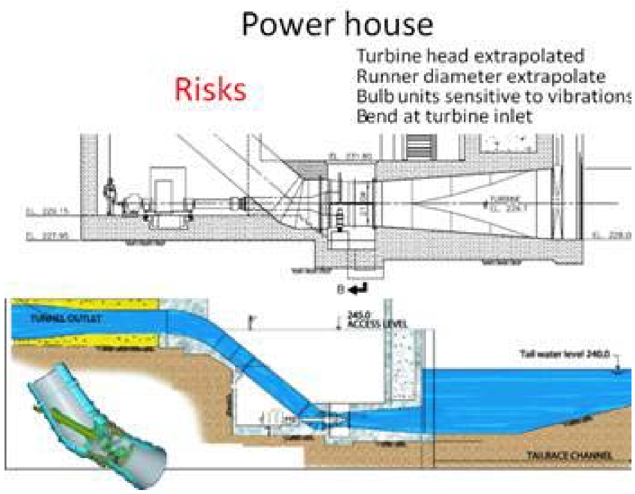


Figure 9 Small powerplant under construction: two units each 10 MW. Hydraulic constraints must be verified.

9.9 At the end of Illustrative Systems

As has been illustrated from the above case examples, troubleshooting of both large and small hydro installations will almost certainly occur in the field and would thus require experts to provide solutions. Many of these problems, particularly for mini-hydro, are due to incompatible approaches to the design as opposed to large installations. Such a process is thus encouraged for smaller installations, perhaps with the aid of codes or guidelines for standard, contemporary or replicable design.

10 ACTION AT THE UNIVERSITY OF TORONTO

10.1 Case studies

The Division of Environmental Engineering and Energy Systems at the University of Toronto has decided to support editing and writing a book tentatively titled *The Current State of Technology in Hydraulic Machinery and Cases in Hydraulic Plants Design, Construction, Maintenance and Operation* to provide important examples to project team members and reviewers.

All interested to collaborate and coauthor are invited to join the team. We are very excited about the idea of including a section on "Smart Designing – Less Troubles" as a key component of this endeavour and within the near future.

10.2 *Cooperation in preparing the new ASME Guide*

Cooperation with ASME (American Society of Mechanical Engineers) Hydro Power Technical Committee is editing and reviewing The Guide to Hydropower Mechanical Design, planned for 2009 [8], [25].

10.3 *New courses*

New courses related to the Electric Plant Design at graduate and undergraduate level are scheduled to start for the first time in the next years.

Courses already started:

1. Design of Hydro and Wind Electric Plants (S. Pejovic: Winter 2008 – graduate, B.W. Karney and S. Pejovic: 2009 undergraduate students),
2. Energy Transformation Systems (S. Pejovic: Winter 2006).

11 CONCLUSIONS

The growth of both electricity demand and subsequent production and supply, and particularly the related interest in hydropower, is of world wide scope and significance. It is a growth and interest that shows no sign of decreasing or letting up [26], [28], [40], [70].

And yet there is also no doubt that hydropower plant design, construction and operation are complex tasks. Such an undertaking requires, among other things, competent environmental and hydrological assessments, careful planning and design, visionary financing, long-sighted political planning, demanding construction and supervision, painstaking commissioning and trouble shooting, and meticulous operation and control. Tens of thousands of details must be accurate, well conceived and executed, and carefully coordinated for a project to achieve safe and economical operation that can be judged a social, technical and environmental success. Yet, when only a few of these myriad details are overlooked, under-estimated or improperly linked to each other, great complications can quickly arise. It has not been uncommon to have major investments in hydro projects to under-perform and forced to run at much lower than design loads due to failures in the review process, particularly associated with the poorly understood issues of system hydraulics. The purpose of this paper is to review such issues and bring them strongly to the attention of the larger energy community.

For large-scale projects, even minor performance improvements deserve consideration during development and testing. Similarly, when a system is expanded and up-rated, since most of the investment is justified by the performance improvements alone, these improvements must be predicted and verified with accuracy. The effectiveness of incentives for performance achievement has many examples to date.

Yet small developers are seldom as well equipped, financed or experienced as those working on larger units. As a result, they are exposed to face greater risks and complications. Special standards to provide comprehensive rules and guidelines for smaller units and new developers would largely alleviate some of the inherent, yet avoidable risk.

The issues and concerns associated with developing special manuals for hydroelectric plants, particularly smaller plants, should be effectively engaged and controlled by a public committee or task force, including possible solutions. The main purpose of reviews is to protect consumers, taxpayers, environment, and owners from unqualified designers, manufacturers, managers and other complications and thus to avert avoidable risks and expenses during operation [25].

12 APPENDIX

It is impossible in a limited lengths paper to include all important and relevant details about the cases studies. To begin to provide reference resources, the authors are collecting together a set of examples and case studies on the following web site: (to be determined).

This site includes more details about the examples presented here, and also information about additional cases. Comments on this collection are welcomed.

13 REFERENCES

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15 BIOGRAPHIES

Tihomir Maricic graduated in Mechanical Engineering from University of Nis, Yugoslavia, in 1981. After the graduation he joined the crew of the builders of Iron Gates 2 Hydroelectric Development Project. For more than 10 years, through the variety of positions he has gained substantial and wide experience in hydro equipment design, manufacturing and installation. After moving to Canada, he has used this experience in international and domestic hydro projects as a design engineer, consultant and project engineer for service and rehabilitation. 2006 Tim has joined Ontario Power Generation as a Senior Plant Engineer with Asset Management Department of Niagara Plant Group. Tihomir (Tim) Maricic is a licensed Professional Engineer in the Province of Ontario.

Dr. Bryan W Karney is a Professor of Civil Engineer and Chair of the Division of Environmental Engineering and Energy Systems at the University of Toronto, where he has worked since 1987. Dr Karney has spoken and written widely on subjects related to water resource systems, energy issues, hydrology, climate change, engineering education and ethics. He was Associate Editor for the ASCE's J of Hydraulic Engineering from 1993 to 2005 and has been a principle of Hydratek and Associates since 1988.

Dr. Stanislav Pejovic was a Professor of Mechanical Engineering at the University of Belgrade, visiting Professor at the University of Singapore, Hong Kong, Sarajevo, Skoplje, Nis, to name a few. He is teaching at the University of Toronto and Ryerson University and has lectured on subjects related to energy, thermodynamics, physics, fluid mechanics, power plants, hydraulic transients, vibrations, stability, and resonance. He specializes in design, construction, commissioning, maintenance, troubleshooting and review of electric plants, hydraulic systems, pumps, turbines, and complex systems of thermal and nuclear plants. He is the author of several books. He was designing and consulting engineer at "Energoprojekt", Belgrade. Dr Stanislv (Cane / Stan) Pejovic is a licensed Professional Engineer in the Province of Ontario.