Role of Turbine Testing Lab for overcoming the challenges related to hydropower development in Nepal

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Abstract. Repair/maintenance issue in power plants of Nepal is one of the major concerns, which has become an obstacle for smooth power generation. The rivers in Nepal contain excessive sediments, which is carried into the turbine causing erosion of several electromechanical components. The problem is more severe in wet season, when the concentration of sediment particles in rivers is maximum. The damaged turbines undergo repair and maintenance, which adds to the total cost, not only because of the cost of repair, but also because of the generation loss during the time of assembly/disassembly. Furthermore, turbines in Nepal are imported from companies outside Nepal, where the problems of sediment erosion are negligible. The turbines usually focus on better efficiency with optimization in cost and material. However, such turbines undergo erosion in short span of time, causing the efficiency to fall drastically. At this moment, Nepal needs to focus on research works related to sustainable turbine operations in power plants. Turbine Testing Lab (TTL) was established in Kathmandu University in 2011 to overcome the challenges of the hydropower plants in Nepal. In future, the lab is foreseen as a centre for turbine design, manufacturing and testing services for the Indian sub-continental countries. This paper presents the roles of TTL for dealing with current problems of hydropower plants in Nepal. The major components are efficiency measurements of the model turbines at the lab, as well as field measurements of the prototype turbines, design of the optimized turbines for sediment affected regions, exploring manufacturing techniques in the context of Nepal, handling problems of maintenance, refurbishment, and overall operation of power plants. The lab has implemented three strategic models to accomplish these activities. They are Foundation model, Co-operation model and Business model. This paper also presents the synergy of these three models and recent activities of the lab within these models. This paper gives an overview of the challenges of hydropower turbines in Nepal and initiation of TTL for overcoming those challenges.

1. Introduction
Sediment erosion of hydraulic turbines is one of the key challenges from the perspective of operation and maintenance in the power plants of Indian subcontinent. It was studied that out of 20 billion tons of global sediment flux from rivers to the oceans per year, around 6 billion tons is contributed from Asian rivers, particularly from Indian subcontinent [1]. Figure 1 shows the percentage of mineral content of sand present in various rivers of Nepal. It can be seen that the percentage of Quartz in most of the rivers is above 50%. The problem of excessive quartz particles in sand is also reported in power plants of India. A mineral study of the sediments in Northern India showed the quartz content of 77-79 % in Uri Power Plant and 52-55 % in Dulhasti Power Plant [2]. Quartz is one of the hardest minerals with Moh’s hardness of 7. When such fine suspended particles are carried into the turbine with the highly accelerated flow, these particles strike the surfaces having less hardness, leading to erosion.
Erosion degrades the surface morphology and performance of the turbine. This ultimately leads to various financial losses, which can be divided into three categories:

i) **Loss of efficiency**: Erosion reduces efficiency of turbines due to secondary flow induced from the deterioration of turbine surface. In Cahua Power Plant of Peru, efficiency drop of up to 2% was measured within 3 months of wet season [4]. Similarly, in Jhimruk Power Plant of Nepal, efficiency drop of up to 8% was measured within 2 months. As efficiency is directly related to the output power, it leads to the financial loss due to reduced production.

ii) **Repair and maintenance of turbines**: The frequency of repair and maintenance of turbines in sediment affected power plants is comparatively higher than normal. In Unit 1 of Kaligandaki ‘A’ Power Plant of Nepal, five major turbine maintenances have been carried out between 2002 to 2014, including a replacement of the runner [5]. Figure 2 shows the maintenance works of eroded Francis turbine components of Jhimruk HPP in Nepal carried out by a manufacturing company. The eroded sections commonly undergo cutting, welding and grinding process during the maintenance.

iii) **Unplanned outages of the plant**: Performance of a plant is measured according to its availability factor, which is the value indicating the availability of the machine for a specified period. It was reported that in the year 2012/2013, Modi Kholo HPP had the availability factor of 59%, due to the long shut down for maintenance of a cooling system failure caused by sediment [6].

![Figure 1. Mineral content of the sand in rivers of Nepal [3]](image)

| Mineral | Content (%) | Erosion rate (mg) |
|---------|-------------|-------------------|
| Amboide | 80.0        | 55.0              |
| Ilonite  | 75.0        | 50.0              |
| Hematite | 70.0        | 45.0              |
| Tourmaline| 65.0        | 40.0              |
| Gneiss   | 60.0        | 35.0              |
| Stilomante| 55.0        | 30.0              |
| Feldspar | 50.0        | 25.0              |
| Quartz   | 45.0        | 20.0              |
| Erosion | 40.0        | 15.0              |

| River   | Minerals | Erosion rate (mg) |
|---------|----------|-------------------|
| Narayi  | 80.0     | 55.0              |
| West Rapli| 75.0     | 50.0              |
| Modi    | 70.0     | 45.0              |
| Gadank | 65.0     | 40.0              |
| Pabasa  | 60.0     | 35.0              |
| Kali    | 55.0     | 30.0              |
| Bagmati | 50.0     | 25.0              |
| Bagmati | 45.0     | 20.0              |
In Nepal, the problem of sediments and large amount of quartz particles is aggravated by majority of run-off-river type power plants. Power plants with such schemes cease the deposition of the sand, making more particles to enter into the turbine. This paper presents the roles of an academic institution for uplifting the research standard in overcoming the challenges of hydropower development.

2. Concept of Turbine Testing Lab in Nepal
Turbine Testing Lab, under Kathmandu University of Nepal was established in 2011 with a vision of developing a centre for turbine design, testing and industry oriented applications inside Nepal. The lab was conceived as a body responsible for certifying turbines to be sold in Nepalese market, building competence and knowledge within hydropower sector in Nepal through teaching/learning facility and motivating research for the development of efficient and erosion-resistant hydro-turbines [7]. The capacity of the lab and strategic working models for prioritizing applied research in Universities and research-oriented production in industries have been explained in a previous study [8]. These strategic models have also been summarized in Figure 3. Out of these models, Foundation model includes the development of adequate facilities in the lab to be able to provide certifications of the turbines with international standards. Cooperation model emphasizes on stimulating collaborative research with national and international Universities and industries. Last model was Business model, which is directly related with creating employment opportunities and raise the socio-economic standard of the country.

This paper elaborates on how the lab can contribute in the aspect of research and development in hydropower sector. Primary roles focus on the direct contribution of the lab and secondary roles focus on the supplementary activities, which could be completed as collaborative activities between industries and other Universities.
3. Primary roles

Primary roles include fulfilling the major objectives of the lab. It can be divided into following sub-categories:

3.1. Laboratory testing of hydraulic turbines

TTL has a capacity to test up to 300 kW prototype turbines. For turbines larger than this size, model testing needs to be performed in a scaled down model. The scaling effect and procedures for testing such turbines is standardized by IEC [9]. An IEC standard test rig is currently being planned and installed at TTL. A model of the rig is shown in Figure 4. The objective of this rig is to certify the turbines before installation in the power plant. The rig will also give a possibility of testing various designs of the turbines, optimizing for efficiency, erosion, cavitation or structural integrity.

This lab should also encourage local manufacturers and developers to fabricate the turbines within their capacity and test the performance before installing in the site. Lab testing provides flexibility of testing the turbines in all the operating conditions. Performance curves of the turbines can be plotted in the form of hill diagram. This will assure the overall estimation of the output power from the turbines throughout the year.

Apart from the model testing, the lab also gives possibilities to test prototype scale micro hydro turbines. The turbines in the micro hydropower plants of Nepal are mostly being manufactured inside Nepal. It primarily includes cross-flow and Pelton type hydro turbines. TTL, in co-operation with Alternative Energy Promotion Centre (AEPC), Nepal has recently built testing facilities for turbines below 100 kW. This rig can be utilized to have a site independent turbine testing so as to reduce the disputes between manufacturers, installers and customers related to turbines.
3.2. Design of turbines for sediment laden projects

The turbines in the power plants of Nepal are exported from abroad. The design of these turbines is focused on higher efficiencies, but does not address the problems of sediment erosion. As a result, turbines erode reducing its life-span and also decreasing the efficiency after a short interval. If the turbines are designed addressing the problems of erosion by compromising on efficiency, the turbines would run longer at a uniform efficiency. Turbine Testing Lab can be the research centre for the new design philosophies of the turbines according to the local need.

TTL has been conducting some research activities related to the change of the guide vane and runner blade shapes of Francis turbines to reduce the erosion. It has been found that the estimation of erosion in turbines can be done through simulations and hence, different combinations of the blade design parameters can be tested for the optimum design without much investment [10]. Figure 5 shows a CFD simulated runner blade showing the erosion rate density pattern on the blade due to sediment particles.

![Figure 5. Simulation of erosion in a Francis turbine’s runner blades [11]](image)

Some new findings also relates to the change in the shape of the guide vanes in Francis turbines for minimizing the secondary flow after erosion [12-14]. The secondary flows are associated with formation of vortex filaments from the clearance gaps of guide vanes. Figure 6 shows the flow through the clearance gap of guide vanes having NACA0012 and NACA4412 profiles. The clearance gap in this figure represents the eroded section, which causes the gap to increase in size. It can be seen that in NACA0012, which is the reference profile in the plant, induces leakage flow due to the pressure difference between the two sides of the guide vane. In NACA4412, the leakage flow is reduced, which
consequently decreases the intensity of the secondary flow. Reduction in the leakage flow was seen to increase the performance of the turbine, in terms of higher efficiency and lower erosion of runner.

![Figure 6. Simulation of erosion in a Francis turbine’s runner blades [12]](image-url)

Apart from the study of different designs of the turbine, some studies have also focused on materials and coatings for minimizing the effect of the impact of sediment particles on turbines. The most common erosion resistant coating material in hydraulic turbines is thermal sprayed tungsten carbide cobalt chromium, WC-CoCr [15]. A tungsten carbide coated turbine in Cahua HPP was found to increase the energy production significantly compared to the production by the uncoated turbine during the same time period [4].

4. Secondary roles
These roles are associated with other research activities and academic contributions. Some of the secondary roles are explained below:

4.1. Addressing the maintenance issues in power plants
As explained in section 1 of this paper, a significant amount of revenue is lost due to outage time spent during overhauling of turbines. Some research activities of TTL have been focusing on optimizing the turbine design assembly to reduce the outage time. One of the works proposed on optimizing the head cover of vertical Francis turbine. The comparison of the outage time between 3 designs was compared, as shown in Figure 7. It showed that the modified design reduces the outage time because the new designs do not require dismantling of intermediate shaft and generator assemblies to have the repair and maintenance of turbine components [16]. Some other research works also included maintaining quality during the welding repair of Pelton runner [17].
4.2. Promote manufacturing turbines in Nepal
TTL has been promoting the fabrication of turbines within the capacity of local manufacturers. Figure 8 shows some examples of the turbines designed by TTL and manufactured in the companies of Nepal. Considering the complexity of manufacturing the blades of Francis turbines, TTL has also been using a 3D Rapid Prototyping machine. This 3D printer replicates the blade model in a plastic form, which can be casted into metal. The lab has also designed a tool for designing the blades of Francis turbine for high head applications. Endeavours such as these help to encourage the companies in Nepal to manufacture larger scale turbines other than micro-hydro.

4.3. Training/Workshops
TTL has been conducting several interaction programs to build a network between industrial and academic sector. TTL emphasizes on participating and conducting trainings and workshops to share the knowledge in the sector of hydropower. TTL has also been regularly conducting symposiums and seminars to create a platform for national and international researchers to share their works.

5. Conclusion
A turbine testing unit in Nepal is identified as an essential entity for overcoming the challenges of hydropower development. The major roles of the lab include testing of the turbines with international standard, such that the lab is capable to certify the turbines that are manufactured locally. Additionally, the lab is foreseen as a hub for turbine design, manufacturing and testing services. Design of the turbine emphasizes new philosophies, such that the problems of sediment erosion in turbines are
addressed. This requires research facilities, including experimental and numerical setups. Apart from the research works for erosion-resistant turbines, the lab is also targeting on other challenges of hydropower plants, such as maintenance issues, materials and coatings, manufacturing and measurements. Finally, TTL being an academic institution, it also has a role in disseminating the knowledge to industries and academics through workshops and training.

6. References

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