Opportunities and Challenges of introducing Francis Turbine in Nepalese Micro Hydropower Projects

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Abstract. Despite the initiation of the master plan, envisioned by the government of Nepal, complete electrification of rural Nepal still seems over ambitious for quite a long time. Thus Micro Hydropower Plants (MHP) can still be very effective for rural electrification. Decades of manufacturing of same type turbines have saturated the turbine manufacturing industries of Nepal, which demands for some new innovations and that could be the introduction of Francis turbine in Nepalese MHP. It’s undeniable that there are umpteen opportunities for the turbine manufacturers to manufacture and install the Francis turbines in Nepalese MHP. The feasibility studies performed by different institutions and the government policy strengthen the claim. In addition to that, data received from, NMHDA and a local turbine manufacturing industry suggest that there are abundant sites suitable for installation of Francis turbine. This paper illustrates the need of introducing the Francis turbine in Nepalese MHP and discusses about the opportunities available for the turbine manufacturers to enter into the market of Francis turbines for micro hydro and subsequently for larger hydropower projects in the near future. The challenges associated with the introduction of Francis turbine in MHP are highlighted.

Keywords: Micro Hydropower, Francis Turbines, Nepal, opportunities, challenges.

1. Introduction
Energy plays a vital role in the development of a country. Each country should find a balance between the demand and supply of energy based on the resources available [1]. R. Sharma and R. Awal[2] explain that increased awareness of the countries about their carbon footprint has motivated them to develop and promote sustainable and environmentally friendly resources. While the world is busy finding sustainable resources for energy production, Nepal still relies on traditional sources of energy; firewood, agricultural residue, and dry dung, for 69% of energy consumed [3]. With around 83,280 MW of potential concentrated in the river courses, Nepal can sustainably fulfil the energy demand for the foreseeable future, given that the available potential is exploited properly [4]. According to the annual report published by Nepal Electricity Authority, only 1,016MW electricity is being produced at present; which is less than 2.5% of the technically feasible 43,442MW [4,5]. The report also shows that, 1079.242MW more electricity would have been produced, had the projects under construction been finished as planned [5].
Integrated National Power System (INPS) is required to evacuate the power generated at the hydropower stations to the consumers. At present, the construction rate of high voltage transmission line, left out for Nepal Electricity Authority (NEA), is not on par with the construction rate of the hydropower projects. Thus, Shrestha claims that the power purchases above 20% of the planned generation of electricity would bankrupt NEA [6]. The Government of Nepal; Ministry of Energy, Water Resources and Irrigation has an ambitious Master Plan in action, planned based on the forecasted data on electricity generation and load scenario of the year 2040, for the development of Transmission system in Nepal. The estimated cost for the execution of the Master Plan, by the year 2035, is 6.07 billion USD, which is almost half of the total budget of the country for the year 2018/19[7]. Successful completion of the master plan would certainly eradicate the problem of electricity in most parts of the country, but it is unable to cover some of the regions in the northern part of the country, where extension of grid is financially and technically unfeasible. Even if the master plan were to facilitate the electrification of those areas in the long term, the population would still require a source of electricity until they were connected to the grid. The answer to the problem can be Micro Hydro; even for the long term in some regions [8].

Turbine manufacturing, for micro hydro, started almost 6 decades ago when, Balaju Yantra Shala Pvt. Ltd. (BYS) was established in 1960, manufactured and installed a 5kW propeller turbine for the first MHP of Nepal in 1962. Kathmandu Metal Industries Pvt. Ltd. (KMI), Nepal Yantra Shala Energy (NYSE), Nepal Hydro & Electric Pvt. Ltd. (NHE), Nepal Machine and Steel Structure (NMSS) and Thapa Engineering Industries Pvt. Ltd. (TEI) followed and excelled at manufacturing turbines in Nepal. They even started manufacturing and providing installation and maintenance services to foreign clients [8]. The success story of Micro Hydro in Nepal is often taken as an example throughout the world for sustainable development of developing countries, especially rural areas [9]. Swiss and German aid programs were crucial in the development of the manufacturing technology in Nepal. The participation of the private manufacturing companies was facilitated by publicizing the simplified designs of Cross flow and Pelton turbines [10]. The designs were exploited and a substantial number of turbines were manufactured for power plants within Nepal and beyond. Decades of manufacturing of the same types of turbines has saturated the turbine market; some of the manufacturers wish to expand their market by manufacturing Francis Turbines, but lack the knowledge and competence to design and manufacture it. Manufacturing Francis turbine could be an opportunity for Nepalese manufacturers to enter into the larger turbine market [9]. This paper describes the need of introducing Francis turbine; manufactured in Nepal; for Nepalese Micro Hydropower, the opportunities available and the challenges that one might come across to do so in detail.

1.1. An Overview of Francis Turbines

After a series of experiments on Boyden’s inward flow turbine, James B. Francis; a British-American engineer, adopted the designs of Howd and Ponclet inward-flow wheels to develop his own model. He did experiments on his model and published his work in ‘Lowell Hydraulic Experiments’, which is considered one of the best contributions to hydraulic engineering by American society. Owing to the contributions he made, the modern Francis turbine is named after him even though it doesn’t resemble his model [11]. The modern Francis turbine is a mixed flow reaction turbine with numerous components, each having a specific function in the system. The main components of a Francis turbine are: runner, its blades, spiral casing, stay vanes, guide vanes, draft tube, etc. [12]. GE Hydro, a tech giant of Hydro turbines, claims that 60% of the world’s hydroelectricity is generated by Francis Turbines, making it the most used hydro-turbine in the world [13]. Francis turbine has a wide range of applicability, in terms of head, flow and power, as shown in the chart below thus its speed number lies in the range 0.2 to 1.25; speed number is dimensionless quantity, based on which turbine type can be selected for given characteristic parameters. The head requirement for this type of turbine can usually
range from 20m to 800m and the flow required is in the medium range [14]. Francis turbines are very well known for their efficiency and the predictability of the efficiency to a very high accuracy. It has been used for the extraction of huge amount of power with comparatively smaller size than other types of turbines. In spite of the outstanding performances, Francis turbines are often associated with the problems of cavitation and erosion. In addition to that its complex structure and number parts makes it difficult to design, manufacture and maintain. Moreover, Francis turbines are not preferred for the sites where there is high variation in the head and flow [14].

![Turbine application range chart of different turbine types](image)

**Figure 1.** Turbine application range chart of different turbine types [15]

2. **Development of MHP in Nepal**

Government of Nepal recognizes the hydropower plants ranging from 5kW to 100kW as micro hydropower plants. Mostly, micro hydro is of ‘run of river’ type plants; which means that the plant uses the flow of the river and there is almost no storage of water. Thus, this does not require construction of dams and other large civil structures. The civil structures, if present, contribute to conduct the water to the penstock and maintain the level of water at intake to the plant. Micro Hydro are considered to be one of the most environmentally benign energy technologies as they do not have any adverse effect on the surroundings, like the large hydropower projects do[10]. Nepal had been using hydropower through traditional water wheels called ‘Ghattas’ for mechanical power; food processing. Kathmandu Metal Industries had been manufacturing the Ghattas for grinding mills and other machines. The real journey of Micro Hydro, in terms of electricity generation, started in Nepal, in 1962, when a 5kW propeller turbine was manufactured and installed, at Godavari Fish Farm, by
BYS, a Swiss funded project. Swiss turbine manufacturers provided the drawings required for the manufacturing of the turbine as a part of Swiss Association for Technical Assistance. Development and Consulting Services (DCS), a joint venture company of then His Majesty’s government of Nepal (HMG/N) and United Mission to Nepal (UMN), had its fair share of contribution for the development micro hydro in Nepal [16]. Electrification alone was not enough to justify the need of installation of the micro hydro in rural areas and thus mechanical end uses for rice husking and flour milling was done, which increased the productivity of micro hydro [17]. Agricultural Development Bank of Nepal (ADBN) realized the impact micro hydro can make on agricultural and industrial production and started financing the traditional ‘Ghattas’ and their improvised versions since 1968. The initiative continued and the financial support was also provided to the water turbines with the electrification components. ADBN’s contribution for the development of micro hydro can be substantiated by the fact that it invested over 83 million Nrs in 685 micro hydro, until 1992 [18].

After realizing the need of a versatile turbine which could adapt to the different heads and flows, BYS decided to manufacture and install cross flow turbine in 1974. One of the main reasons for the selection was the simplicity of the manufacturing process compared to other sophisticated turbines; Manufacturing of the whole machine was possible with just welding process and some bending for the blades. It was important back then as welding was one technique Nepalese manufacturers were competent at, due to the training programs initiated by Norwegian aids. They made different modifications in the initial model and have reached to ‘T15’ model from their first model, ‘T1’ [19]. Pelton Turbine was manufactured subsequently, in 1975, by Butwal Technical Institute; established in 1963 as a project of UMN with the initiations of an Norwegian Engineer, Odd Hofftun[9][20]. International Agencies like SKAT, from Switzerland; ITDG, from U.K.; GATE/GTZ, from Germany and FAKT, from Germany have played vital roles in R&D, promotion, installation and monitoring & evaluation of MHP. These agencies were crucial in the introduction of different turbines currently being manufactured in Nepal [21]. There are other private and government companies which cannot go unmentioned when it’s about the development of Micro Hydro in Nepal; Kathmandu Metal Industries Pvt. Ltd., Nepal Yantra Shala Energy Pvt. Ltd., Thapa Engineering Industries are often mentioned as the pioneers of turbine manufacturing; within Nepal and abroad[9].

The number of entrepreneurs investing in the new, on demand, technology increased greatly during the mid-1980s, when the micro hydro could compete with the diesel driven milling systems, in terms of quality and cost [22]. The manufacturers who were actively involved in the development of micro hydro decided to come under a common umbrella organization called Nepal Micro Hydro Development Association (NMHDA), in December 1992. NMHDA has been accelerating the development of the Micro Hydro in Nepal since its inception by providing technical assistance to the entrepreneurs and representing the private sector in the development of policies collaborating with the government agencies [23]. AEPC is another government agency; established in November 1996, under then Ministry of Science and Technology of the Government of Nepal which has been promoting the renewable energy in Nepal, including Micro Hydro. The establishment of these agencies facilitated the development of micro hydro in Nepal and the progress has been substantial; there are more than 3300 Micro Hydro in Nepal electrifying more than 350,000 households in the rural areas [24]. The argument that micro hydro has been successful in Nepal can be solidified by the fact that the percentage of population having access to electricity in the rural areas has gone up whooping 85% from just 17% in 15 years[25].

2.1 Relevance and status of the use of micro Francis turbines in Nepal

Even though Nepalese industries made some attempts to manufacture and use the Francis turbines in micro hydro in the past, expected success could not be achieved [9]. Annual progress report of AEPC,
2009, reports that introduction of a 33kW Micro Francis turbine, which was much smaller than the original cross-flow turbine, increased the production by 6kW [26]. With the aim to develop the micro hydro sector, NMHDA has established a model MHP near Kathmandu, which will be a dedicated technical center for the research, development and training in relation to the micro hydro. A separate space has been left for the installation of Francis turbine. The Francis turbine to be installed is being designed and manufactured as a part of the research study at KU [24]. A 92kW Francis turbine, scale down model of 4.2MW Francis turbine of Jhimruk Hydropower Project, has been manufactured by NHE, Butwal. The turbine was designed at TTL, KU with the aim to evaluate its performance in terms of efficiency and erosion against the conventionally designed models [27]. This shows the competence of Nepalese manufacturers in manufacturing the Francis turbine of micro scale. Nepalese manufacturers also have experiences of repair and maintenance of imported Francis turbines, installed at different hydropower projects in Nepal. A feasibility study done as a project at KU concludes that the Nepalese manufacturers have bright future in the field of Francis turbine manufacturing [28]. Another more detailed feasibility study performed by TTL, KU; submitted to NORAD, concluded that the technology and knowledge available at the time was adequate for the manufacturing of Francis turbines up to 5MW [29]. Despite this fact, there has not been enough progress in the manufacturing of the Francis turbines, even in the micro hydro range. Lack of knowledge about the design and manufacturing procedure could be the reason for the manufacturers not to attempt the feat. Thus, realizing the need of introducing the Francis turbine in the Micro hydro range; this research project, funded by RenewableNepal, was proposed by TTL, KU.

![Figure 2. 92kW Francis turbine Test rig at TTL, KU](image1)

![Figure 3. 92kW Francis turbine designed and manufactured in Nepal](image2)

2.2. Prospects of utilizing Francis turbines

6000 rivers and rivulets flowing through the country have bestowed Nepal with 83,000MW of theoretical hydroelectric potential, of which very few have been exploited. The difficulty of grid extension in the hilly and Himalayan region of Nepal makes micro hydro the best option for rural electrification in Nepal [22]. Afore mentioned potential does not include the micro hydro potential of Nepal, as Dr. H. M. Shrestha, in his dissertation, considered only those rivers which had more than 300 sq. km of catchment area, this leaves rivers with less catchment area but still having potential to generate electricity. Thus, it is estimated that more than 1000MW electricity can be generated by installing the micro hydropower plants at those rivers [31]. A study done at TTL on the prediction of turbine needed for the Future Hydropower concluded that 75% of the turbines required for the future hydropower will be Francis turbine [32]. A preliminary analysis of the earthquake affected MHP showed that more than 50% of the sites were suitable for Francis turbine, but other turbines were used with the efficiency of 50%-60% [30]. Data from 27 Micro hydro power projects, for which turbines were manufactured by Thapa Engineering Industries Pvt. Ltd., Butwal, were analyzed to determine the
type of the turbine used at each site and it was found that 18 out of 27 sites were suitable for Francis turbine. While, these sites used cross flow turbines and had average efficiency of 65% with maximum efficiency 71%. In addition to that, the data received from NMHDA, on the micro hydro sites of Taplejung district showed that 13 out of 34 sites were suitable for installation of Francis turbines. But, most of these sites used Cross flow turbines and had average efficiency of just 61%. These data illustrates that the sites suitable for Francis turbine are abundantly available in Nepal. Use of Francis turbines in these sites could have generated more power than the current generation of power, which was the case at Handi Khola, Sindhupalchok, as mentioned above [26]. The policy of Nepal Electricity Authority for purchasing the electricity from micro hydro has motivated developers to select more efficient turbines.

2.3 Challenges
There are numerous challenges in using the Francis turbine, starting from the design itself. The modern design process of the Francis turbine involves the optimization of blade shape using Computational Fluid Dynamics, competence in which is lacking with Nepalese manufacturers at present. In addition to that, the accuracy of the blade profile matters a lot in the energy conversion process and the advanced manufacturing technique required to manufacture runner with high accuracy is not available with Nepalese turbine manufacturers at present. While designing a Francis turbine for micro scale, controlling the vortex shedding can be a challenge for the designers [33]. The reluctance of Nepalese manufacturers to take the risks and invest on research for new product or technology is often mentioned as one of the reasons for not being able to manufacture Francis turbines till date. Lack of skilled manpower at the power plant has been a problem in Nepalese micro hydropower since the beginning and it’s going to be troublesome to have unskilled plant operator at a plant with Francis turbine as it requires continuous condition controlling [14][34].

3. State of the art in MHP
Francis turbine is famous for being used in some of the largest hydropower in the world. Even though it is not very popular in the micro hydro, as the efficiency achieved in the large scale turbines cannot be achieved in smaller turbines due to manufacturing constraints, Francis turbine has been found being used in numerous micro hydropower plants around the world as its efficiency would still be better than other types of turbines. Francis turbines were the go to turbines for the micro hydro and low head sites in the first quarter of the 20th century even after the development of Kaplan turbine. Lately, the modern CFD methods have been used to improve the efficiency of the micro Francis turbines [35]. The northern neighbor of Nepal, China, deserves a special mention when it’s about micro hydro development with Francis Turbines. Moreover, Chinese are very well known for their manufacturing capability and have been manufacturing standardized micro Francis turbine generators in large scale for some time now [10]. There are some mentions of the Francis turbines being used in micro hydro in India as well [36]. Myanmar doesn’t have a long and profound history of MHP like Nepal does, but the development of the MHP sector has been exemplary in the recent years. Even without the proper technical trainings, international funding and the support of the government, initiations from Myanmar’s social entrepreneurs have successfully alleviated the sector. The local manufacturers in Myanmar are motivated and have been manufacturing Francis turbines for micro hydro applications, with much less experience in the field [37]. Recently, the 3D scanning technology has been used to get a 3D model of the micro Francis runner, which is optimized to improve the efficiency, and new runner is manufactured.

4. Future directions
It is clear that being dependent on the foreign manufacturers for turbines would make Nepalese hydropower industry unsustainable. And according to the need, manufacturing Francis turbines locally
can surely sustain the industry. As Nepalese manufacturers lack experience in manufacturing Francis turbines, extensive research is required before jumping into manufacturing the turbines for the actual hydropower. The center of excellence at TTL has been performing research to solve the problems of hydraulic turbines and certify the turbine designs after doing model tests on an IEC standard test rig [38]. TTL is also envisioned as a testing facility for newly designed micro Francis turbines and has been working closely with AEPC and NMHDA to motivate the turbine manufacturers to test their turbines before installing them at site. At present, research is going on to develop a design of a simplified Francis turbine which can be manufactured using the locally available manufacturing technology. Bovet approach will be used to develop the meridional flow channel and the complete runner will be created using the conformal mapping. This approach of designing Francis turbine has never been used in Nepal as ‘Khoj’ software is very convenient in designing high head Francis turbines, but fails to design low head Francis turbines. The current research will focus in creating a similar software which can create a 3D geometry of a Francis turbine for low head applications. The designs will be optimized using the modern optimization techniques and the results obtained from CFD will be validated by tests at TTL or the installation site. The project aims to manufacture the different components of the turbine by using the local technologies such as casting, forging and machining. One such attempt is already being made at TTL, KU as a MS project of Mr. D.R. Dahal. The turbine manufactured will be tested at TTL and installed at the technical center established by NMHDA at Dhamile Khola MHP. The design methodology for the turbine will be made available to the local manufacturers so that they can start manufacturing the Francis turbines for MHP. The manufacturers should keep building their manufacturing capacity and competence to scale up from micro to mini and subsequently larger hydropower projects. In addition to that, researchers and manufacturers should collaborate continuously to develop more advanced turbines in Nepal.

5. Conclusions
Micro hydro has been very effective in rural electrification of Nepal. Private sector; turbine manufacturers have had their fair share of contribution in the development of Nepalese MHP. For more than 60 years Nepalese turbine manufacturers have been manufacturing the cross flow and Pelton turbines of different models. Some consider the manufacturing of the conventional turbines, in Nepalese industries, has been saturated and that its time to start manufacturing Francis turbines in Nepal. Cross-flow and Pelton turbines are being used at efficiency of 50%-70%, even when the site conditions favored Francis Turbines. Feasibility studies has suggested that the manufacturing technology available in Nepal is adequate to manufacture the Francis turbines up to 5MW but turbine manufacturers do not seem motivated enough to initiate the manufacturing. The current research aims to motivate the turbine manufacturers by installing a Francis turbine, designed considering the local
manufacturing technology and manufactured by a local manufacturer, at an MHP in Nepal. This work elucidates the opportunities for Nepalese manufacturers to start manufacturing Francis turbines in Nepal. In addition to that, it also identifies the challenges that come along, while considering the Francis turbines for Nepalese micro hydro. The manufacturing of Francis turbines for Micro hydropower projects should be taken as a learning step to manufacture the Francis turbines for larger applications on the long run.

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