

Strategic rehabilitation of the earthquake affected micro-hydropower plants in Nepal

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Abstract. Most people in the rural areas of Nepal rely on Micro-hydro Power Plants (MHPs) for their energy sources. With around four decade experiences in design and development of MHPs, Nepalese techno-entrepreneurs have gained wider reputation in the South Asian region and the beyond. However with the lack of competences in developing Francis turbines, majority of the MHPs are equipped with either Pelton or Cross Flow turbine, even though Francis units are suitable. With the devastating earthquake of a 7.6 magnitude that struck in the Gorkha district on Saturday, 25 April 2015, about 76 km northwest of the capital city Kathmandu, and the aftershocks followed claimed more than 8000 lives. It did not leave hydropower plants either. Many big plants have been affected and hundreds of MHPs were damaged, needing short to long term rehabilitation. The preliminary assessment of the 61 affected MHPs in the 6 earthquake affected districts shows more than 50% sites are suitable for Francis turbine. Hence the strategic rehabilitation plan has been developed in the present paper for the affected plants considering issues like geographical shift, dislocation of people and also with the focus on replacing the old turbine with Francis turbine in the suitable sites. The similar strategy can also be implemented in other developing countries with such situations.

1. Introduction

It is estimated around 43,000 MW of electricity could be harnessed economically from the rivers of Nepal, but only around 700 MW is trapped till 2013. The investors are seen to be interested in big hydro power development with the onset of ongoing political stability. However, the social value of Pico to Mini-hydro Power Plants is higher than big and small hydropower plants in Nepal, as it provides larger number of rural people per unit of electricity power compared to the grid connected urban people.

Plants with capacity up to 5 kW are referred as Pico, 5 kW to 100 kW as micro and from 100 kW to 1000 kW as mini-hydro power schemes. With the four decade experience in establishing Micro-hydro Power Plants (MHPs), the Nepalese techno-entrepreneurs have gained good praise and reputation in the South Asian region and the beyond. More than 3000 hydro schemes with capacity up to 1,000 kW have been installed in the country till date with a total capacity to produce more than 43,000 kW electricity, out of which around 24,000 from MHPs to electrify around 0.35 million rural households [1]. Most of these people are benefitted at least for lighting, and for some other secondary purposes to support subsistence economic development.

Figure 1 shows the total number of MHPs with their installed capacity from 1962 to 2013. Interestingly the MHPs are still increasing and projected to jump to a greater scale. Government of Nepal as well as private sectors are openly supporting for the agenda.



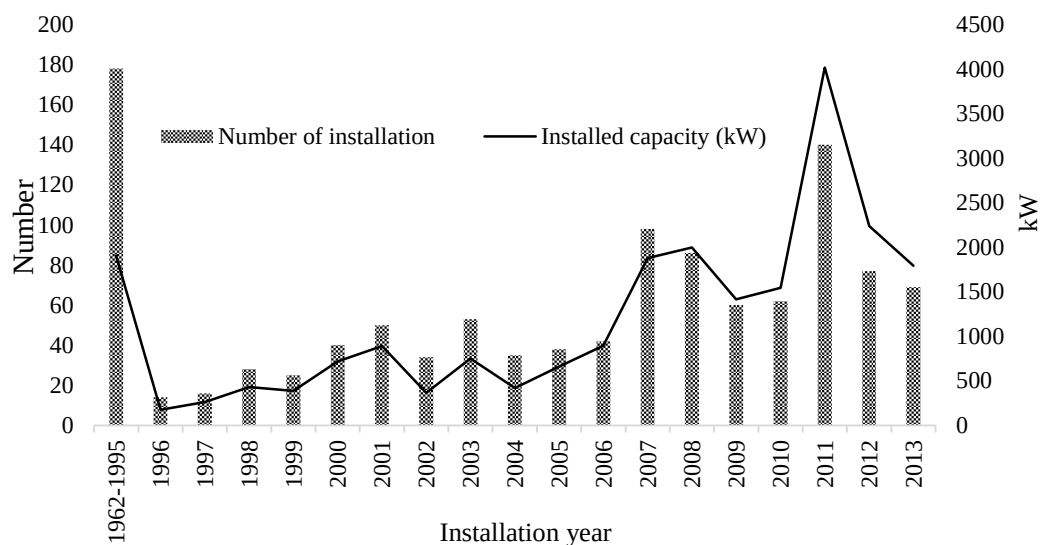


Figure 1. Total micro-hydropower plants installed in Nepal till 2013 [2]

1.1. Post-earthquake scenario in energy sector

A 7.6 magnitude earthquake hit Nepal with epicentre Gorkha district on Saturday, 25 April 2015. It was followed by more than 350 aftershocks greater than magnitude 4.0 (as of 31 July 2015) [3]. 31 districts of the country's 75 districts have been affected, out of which 14 districts were severely hit and also declared as 'crisis hits'. More than 8,500 people have been killed, above 22,000 were injured, many people became houseless and 2.8 million people were displaced [4]. Along with human casualties, it also seriously damaged national infrastructure, world heritage sites and natural tranquillity. Figure 2 shows the Laprak in Gorkha district, which is very near to the epicentre before and after earthquake. The place is completely destroyed resulting displacement of people.



Figure 2. Laprak in Gorkha district before (left) and after earthquake (right)

Many hydropowers ranging from Pico to big plants are also affected halting the energy sector of the nation. It adds energy crisis even more to what was ongoing in the nation and the investment policies and trend on investing in large hydropower projects are expected to be affected for a number of years. The earthquake affected regions are shown in Figure 3 and the Figure 4 show the corresponding mini/micro-hydro map of Nepal. The pictures show that the most of the micro-hydro plants are located in the affected regions, with Gorkha being highest number of MHPs installed. Other affected zones are Sindhupalchowk, Dolkha, Rasuwa, Nuwakot, Dhading and Ramechhap. As the MHPs are clustered

around the severely hit zones, it is certain that the most of the severe damages are located in the region. As the immediate relief, national and international organizations have distributed solar lanterns for lighting, but it is utmost necessary to repair and rehabilitate the damaged MHPs so that the local rural people can have their life back to normal.

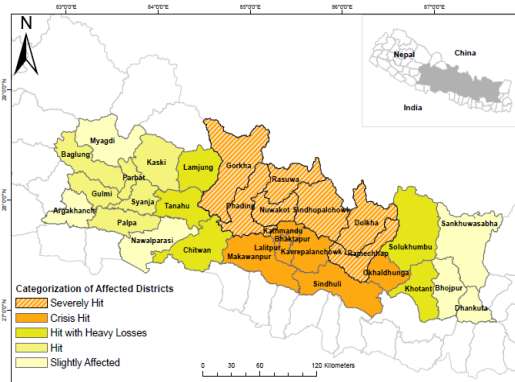


Figure 3. Earthquake affected districts [4]

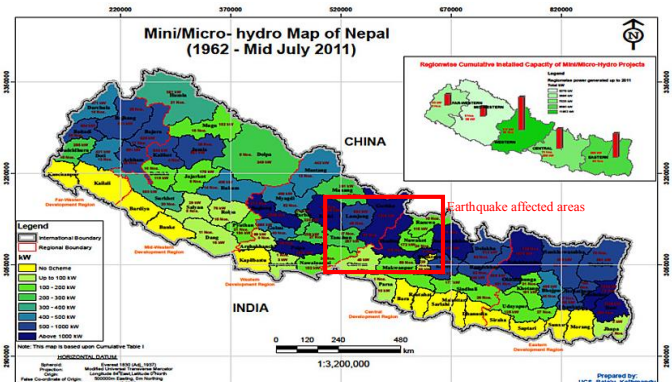


Figure 4. Mini/Micro-hydro map on Nepal [1]

It has been realized that the big power plants are highly susceptible to damage due to the earthquake. Serious damages were found in many plants of Nepal. Further, the situation had also created a threat around the local community for the catastrophe that could occur due to the structural failure of the plants. About 25% of the total hydropower electricity generation was also affected by the earthquake [4].

The lists of hydropower plants with its status after the earthquake are included in Table 1.

Table 1: Damage in large hydro power plants due to earthquake [5]

No.	Project	Location (District)	Capacity (kW)	Project status
1	Bhotekoshi Khola	Sindhupalchowk	45,000	Penstock burst accompanied by submerging of power house
2	Indrawati-III	Sindhupalchowk	7,500	Significant damage, in operation
3	Sunkoshi Khola	Sindhupalchowk	2,500	Landslide at penstock alignment
4	Chaku Khola	Sindhupalchowk	3,000	Not in operation
5	Baramchi Khola	Sindhupalchowk	4,200	Penstock burst, not in operation
6	Upper Hadi Khola	Sindhupalchowk	991	Head race steel pipe cracks
7	Siuri Khola	Lamjung	4,950	Head race pipe deform
8	Sipring Khola	Dolkha	9,658	Expansion joint burst, Penstock alignment
9	Ankhu Khola-1	Dhading	8,400	Power house fully damage by landslide
10	Jiri Khola	Dolkha	2,200	Leakage from surge shaft
11	Radhi Khola	Lamjung	4,400	Broken bearing, cracks in penstock anchor blocks, deformation in headrace pipe

It has been noticed that a penstock is major vulnerable component in the plant. Apart from the hydro-mechanical components, distribution lines have also been affected. Table 1 suggests that the major hydropower plants in Nepal was affected, which take certain time and effort to get fixed. Some plants have tiny damages which were fixed with almost no time. Furthermore, the projects under construction are also affected by the earthquake.

1.2. Micro-hydropower plants in the earthquake affected regions

There are many rural areas in the earthquake affected zones where the national grid has still not been reached and people completely rely on the micro-hydro schemes for the electricity. Alternative Energy Promotion Centre (AEPCC) [2], a key driver of establishing renewable energy technology in Nepal has estimated around 262 MHPs in 15 districts are damaged with 91 shut down. The total number of households affected accounts around 54,541 households. The detail assessments of damaged micro-hydropower plants are still ongoing. Short term and long term relief measures for the damaged projects are urgent to be assessed. Figure 5 includes the total number of MHPs with its installed capacity in the most affected districts. The graph shows the maximum numbers of plants are located in the severely hit zone like Gorkha, Kavrepalanchowk, Sindhupalchowk, and Dhading.

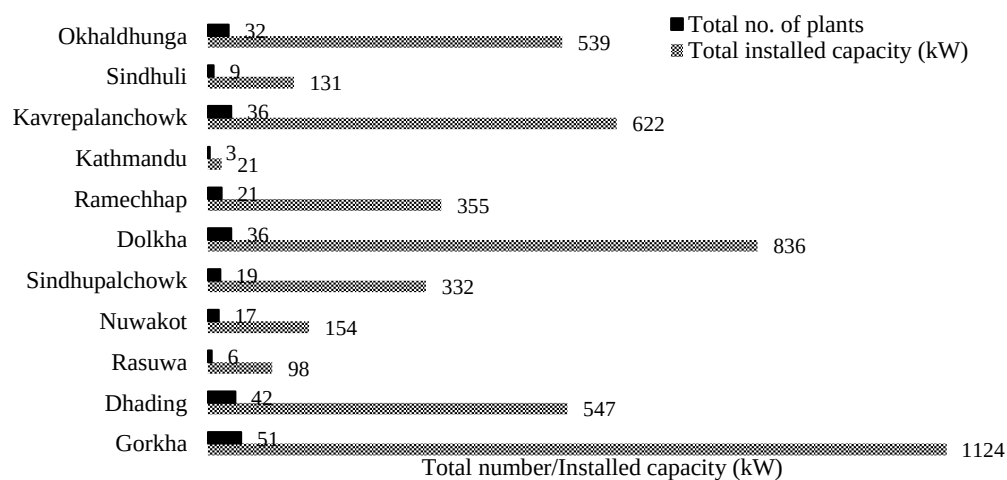


Figure 5. Total no. of microhydro power plants (5-100 kW) till 2011 with installed capacity in the most affected districts [1]



Figure 6. Micro-hydro plant damaged by the earthquake in Dolkha district in Nepal

Figure 6 shows a MHP completely damaged during the earthquake of 25th April, 2015. The penstock pipe has been burst due to the falling stones, the power house was completely destroyed, and the distribution line poles were broken. The rehabilitation of damaged MHPs needs strategic planning so that the power house runs in an optimal condition.

1.3. Immediate solutions used for the power shortage

Rehabilitation of the large hydropower plants needed enormous time and effort; micro-hydropower also need some amount of time and strategic planning for the rehabilitation. Certain products stand as a good choice in the time of disaster. Portable solar lanterns were extensively distributed to the affected people during the earthquake. A small turbine with generator was also employed with minimal effort and money. As an immediate rehabilitation for the electricity, Turbine Testing Lab (TTL) Kathmandu University tested a Turgo turbine with 300 W capacities.

2. Rehabilitation of hydropower plants and some challenges in Nepal

Rehabilitation of hydropower plants is a comprehensive set of activities, which addresses from repairing and replacing components upgrading capacity of a plant, and restoring services to meet market requirements and opportunities to enhance ecosystems [6]. The broad concept of rehabilitation mainly concerns to maintain what is already functioning then only to think of possible improvements. Major components needed rehabilitation is turbines and electrical components. Figure 7 shows the energy production of a plant over time. Without rehabilitation the plant is seen losing its power production hence two ways are preferred: either to upgrade the plant by introducing efficient technologies or extending the life of the components generally by repairing existing components. Upgrading takes comparatively great amount of investment with strategic planning and come with greater energy production than life extending.

Rehabilitation of hydro power can be expensive because of the time consuming while dismantling the unit and temporary outage of power supply. The hydro power rehabilitation market scenario is different in developing countries than developed countries. The plants in the developed countries are generally routinely maintained, hence the market is lesser compared to the developing countries where the economic and other issues come into play. Turbine rehabilitation which is the major focus of the present paper also plays deterministic role in power production. Hence the affected MHPs in Nepal due to the earthquake should be rehabilitated for what was already functioning and then only to think to upgrade them.

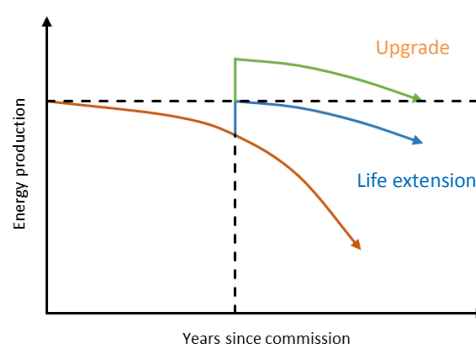


Figure 7. Energy production loss over time in hydro power plants [6]

2.1. Specific challenge of hydropower in the Himalayan regions

Nepal has been facing severe operational and maintenance issues related to hydraulic turbines caused by sediment particles. There are unique technical challenges observed in Nepalese hydropower plants like huge sediment transport in the rivers of Nepal, high quartz content in river sediment, thus high rate of erosion in hydro-mechanical components deteriorating the performance of turbines. Figure 8 shows the efficiency of the eroded turbine with and without coating. The efficiency of the turbine can be

improved by monitoring and periodical coatings. Quartz content is very high in Himalayan river sediments (almost 45% which reaches as high as 73% for some hydropower as shown in Figure 9), which is harder than the turbine materials ultimately resulting of turbine material erosion. Some research have been performed experimentally and computationally to make sediment friendly turbine, particularly Francis turbine. [7-10]

From the previous researches it has been recommended that to reduce the effect of the sediment erosion either the turbine material should be harder than the quartz or any other efficient method to reduce quartz content before reaching turbine should be employed. Since the performance degradation is severe due to sediment erosion problem in the hydro-power plants in Nepal, this issues should be addressed during rehabilitation as well.

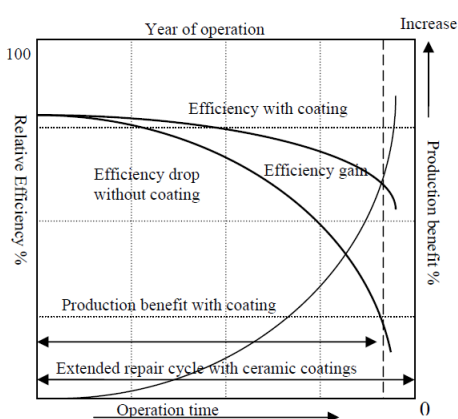


Figure 8. Efficiency gain and increase of life due to coating [12]

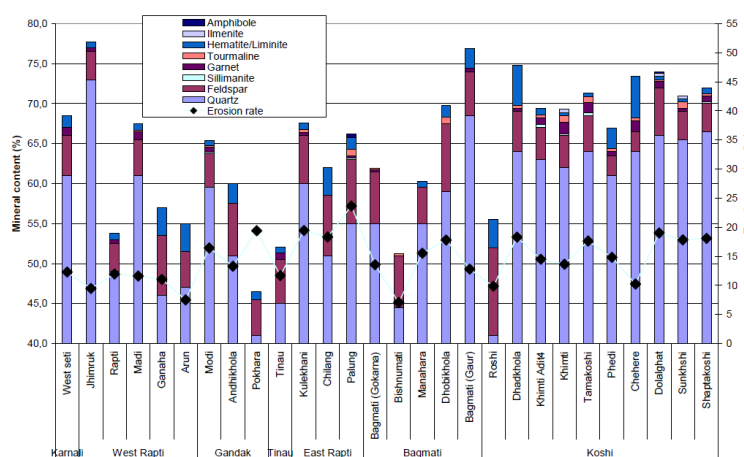


Figure 9. Mineral content with quartz dominance in hydropower of Nepal [12]

3. Rehabilitation of the earthquake affected MHPs

3.1. Rapid analysis of the earthquake affected MHPs

A preliminary analysis was conducted for the earthquake affected micro-hydro sites. The data collected from these plants show that most of the power plants are running within the best efficiency of 50-60%. The results on the basis of the available head and discharge showed that more than 50% of the sites are suitable for Francis type turbines whereas the rest are suitable for the other types (Cross-flow and Pelton). Figure 10 shows the preliminary assessment of the 61 MHPs located in the 7 earthquake affected districts. 71% of the total MHPs i.e. 43 out of 61 plants are from the range 5-30 kW installed capacity. Only 13% plants have installed capacity ranges from are 61-100 kW. From the hydraulic parameters available at these sites, it has been found that most of the plants are running with low installed capacity; Figure 10(a) and (b). Most of the plants are seen to have been using Pelton Turbine (PT) and Cross Flow Turbine (CFT), Francis turbine is very limited. As discussed earlier, it is not because of the unavailability of suitable sites for Francis turbine but with the lack of competence in design and development of the turbine.

Pelton turbine is impulse type of hydro turbine where one or more jets impinge on a wheel with number of buckets. It is generally operated from medium to high head sites even with more than 1000m head. In case of Cross flow turbine, the water passes through the turbine transversely, firstly from the periphery towards the centre and then after crossing the open space inside the runner the water flows from the inside outwards. This type of turbine is suitable for high discharge conditions and low head. Whereas, Francis turbine are compact and efficient type of turbine with flow entering radially and exiting axially. Francis turbines are suitable in the wide range of flow and discharge conditions and often selected on the basis of speed number. The speed number Ω is defined with the following relations.

$$\Omega = \underline{\omega}^* \times \sqrt{\underline{Q}^*} \quad (1)$$

Where, reduced angular speed $\underline{\omega}^*$ and reduced discharge $\underline{Q}^*$ are given by relation 2-4.

$$\underline{\omega}^* = \frac{\omega}{\sqrt{2 \times g \times h}} \quad (2)$$

$$\underline{Q}^* = \frac{Q}{\sqrt{2 \times g \times h}} \quad (3)$$

$$\omega = \frac{2 \times \pi \times N}{60} \quad (4)$$

Where, ω is angular velocity in [rad/s], N is the rotational speed of turbine in rpm, g is gravity, h is the available head in [m] and Q is the available discharge [m³/s].

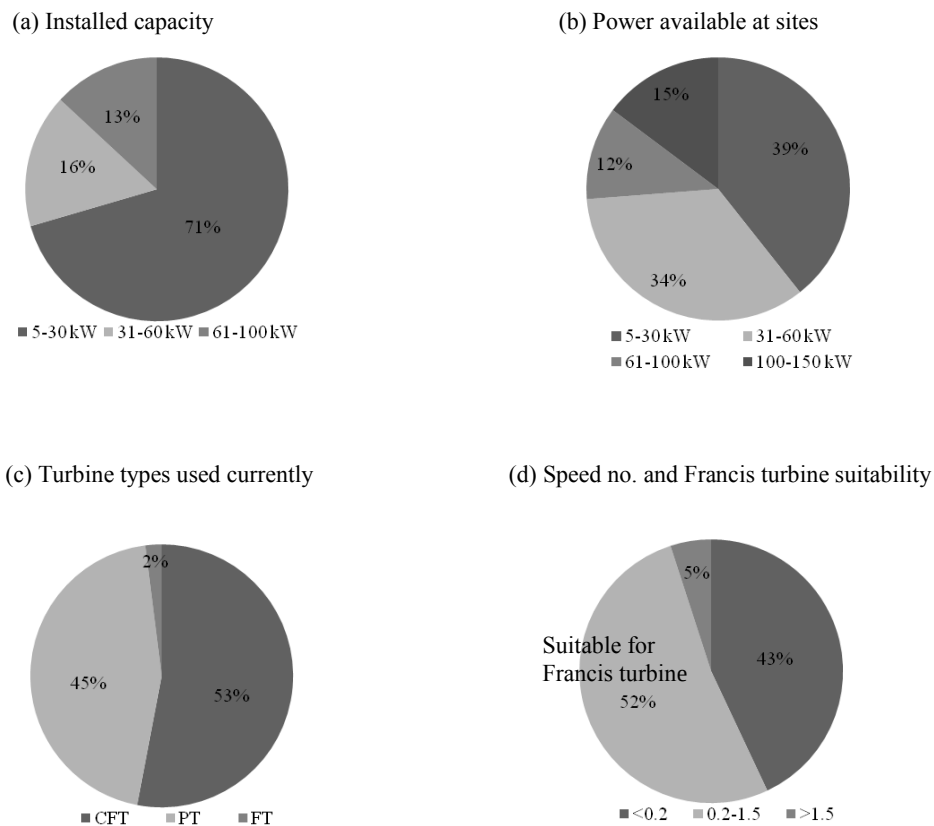


Figure 10. Preliminary assessment of 61 micro hydropower plants in 7 districts

On the basis of speed number, the available site can be identified as suitable for a particular turbine type. Speed number with 0.2 to 1.5 corresponds to the suitability of Francis turbine in that site. As presented in Figure 10(d), it has been found that 52% of the sites are suitable for Francis turbine. It means 34 out of 61 sites are suitable for the compact, economical and highly efficient Francis units. However, only 1 site at the moment is using Francis turbine. Replacing the other types of turbine in these sites may not be economical and feasible. Unfortunately there are certain challenges in Nepal in designing Francis turbines. The turbines are tailor-made design i.e. site specific and further comes to

manufacturing challenges inside Nepal. However the good part is that Turbine Testing Lab (TTL) at Kathmandu University has developed competences in Francis turbine design and successfully demonstrated with various previous projects. The development of 92 kW model Francis turbine was the initial project commenced during 2010-2013 from the financial support of Norwegian Agency for Development Cooperation (NORAD). An in-house design code with cooperation with Norwegian University of Science and Technology (NTNU) was developed to facilitate the hydraulic and mechanical design of the turbines [9, 13, 14]. The development method utilizes this in-house code for preliminary design, optimizing through computational methods (CFD), plastic model development from rapid prototyping machine and finally manufacturing the metal runner with the help of casting (generally lost wax casting). This method of Francis turbine development has been shown in Figure 11 and also elaborated in [15].

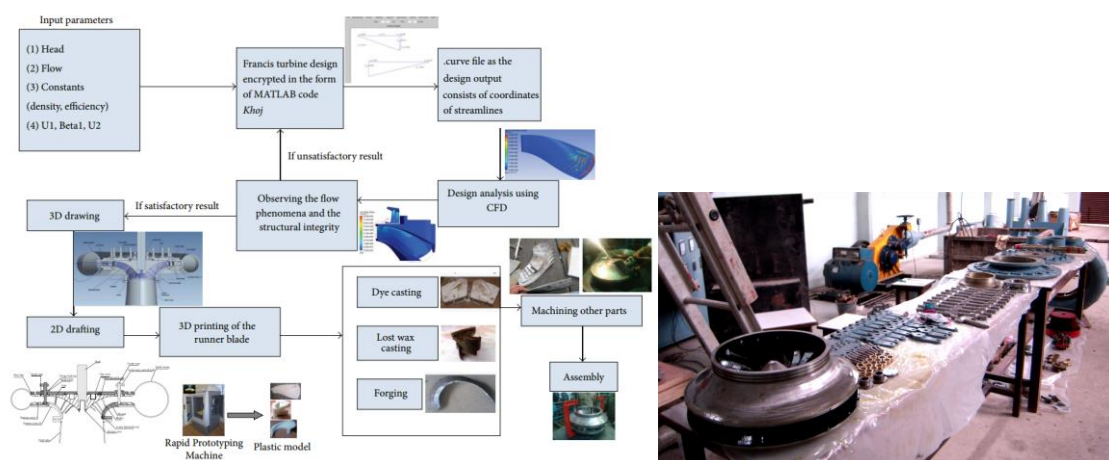


Figure 11. Francis turbine development process, *left* [15] and turbine manufactured by a Nepalese company from the process, *right* [14]

Similarly, TTL also completed 1.6 kW reversible pump turbine project [16, 17] and 7 kW low head Francis turbine from the support of NORAD recently [18].

3.2. Strategic implementation of the rehabilitation plan

The detail assessment of the affected MHPs needs a rigorous approach. Governmental organizations have been assessing and addressing the issue. The present work mainly focuses on the strategic way to make a rehabilitation plan. The work flows are as follows: Database of earthquake affected micro-hydro plants is filtered to know their status. MHPs that are not in operation condition are further assessed to find the status of its components. Those with potential for rehabilitation will be further assessed to investigate if Francis turbine could be a better option.

A lot of rural people have been dislocated due to the earthquake. Therefore, it may not be feasible to rehabilitate the affected MHPs in the same region. There is very low chance that the displaced people are relocated in the place with no electricity. Thus strategic plan is necessary to rehabilitate the MHPs in this scenario. Further, there are several issues in this rehabilitation programme. Some of them are highlighted here:

- Most importantly, site should not be immediately connected by the national grid. Proper assessment and immediate and future plans of the utility, Nepal Electricity Authority NEA, should be carried out. Rehabilitation investment may not be attractive if there is possibility of connection to the national grid.
- If people are displaced to a new place with no grid connected, then the existing MHP of this location, if any, could either be upgraded with other units or make cluster system for mini-grid. The up gradation could be done with the help of Francis turbine if the site is suitable.

- Proper assessment of the geological and climatic condition should be done. Lack of knowledge on these matters has brought negative consequence like flooding and landslides. This also makes an investment futile.
- Other issues like local politics, end-users scheme are to be determined. It is also better to make a scheme profit-oriented rather than service-oriented. It helps in sustainability of the plants.

The rehabilitation of the damaged micro hydropower plants can be illustrated in the flow chart shown in Figure 12.

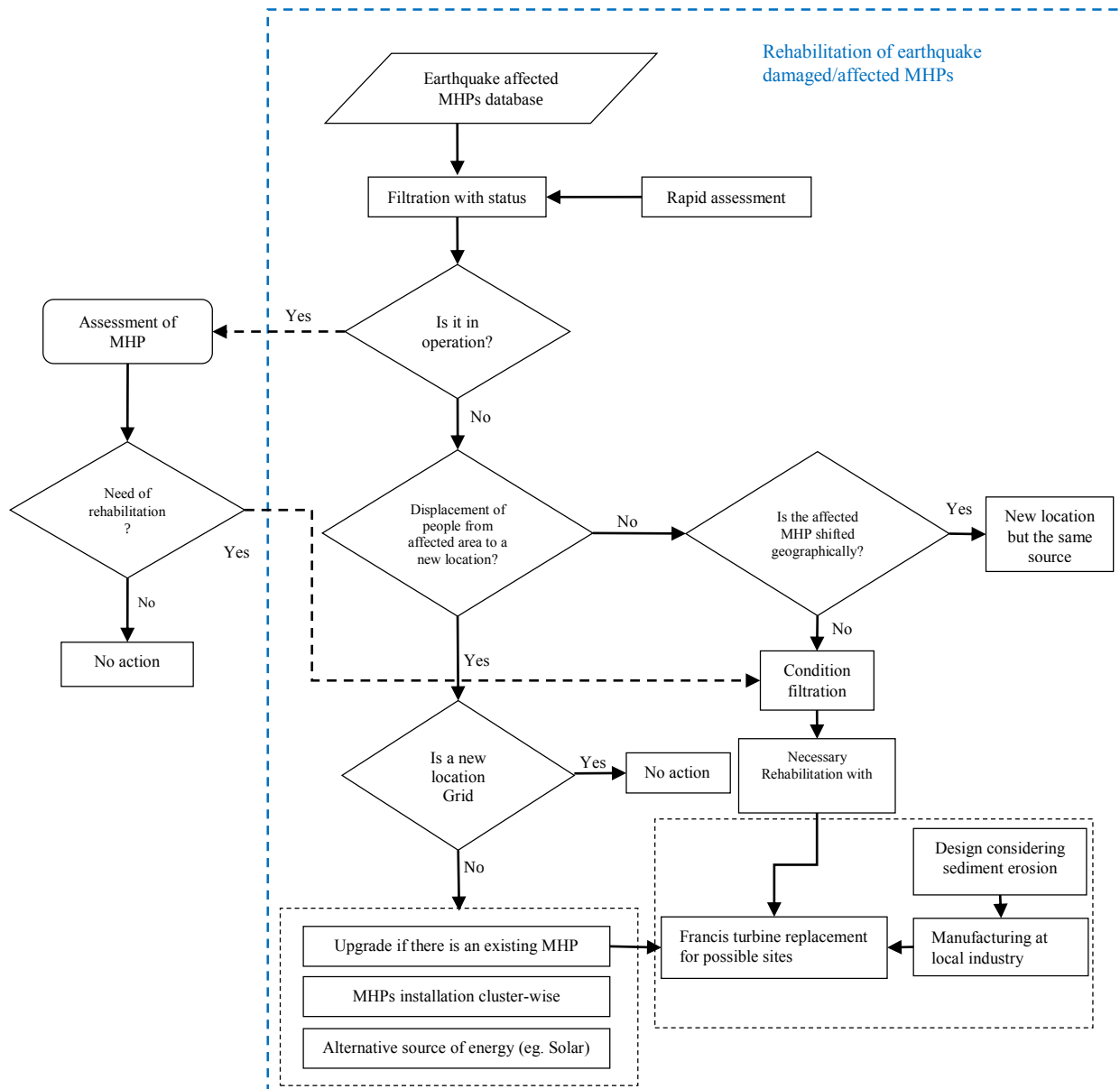


Figure 12. Strategic plan for the earthquake affected MHPs rehabilitation

4. Conclusions

Quick rehabilitation of the earthquake affected micro-hydro plants is seen necessary to bring the lives of affected people back to normal. Rehabilitation could take huge effort and hence strategic plan has

been developed in the present study with a preliminary assessment of the MHPs in the earthquake affected districts of Nepal. It is revealed that most of the plants are equipped with Pelton and Cross Flow turbine, although Francis turbine is suitable for the site. It is mainly because Nepalese turbine designers and manufacturers have developed matured competences in these turbines, but with limited knowledge in design of Francis turbine since these turbines need tailor-made design and special considerations. Among 61 MHPs surveyed, 52% of the site is found to be suitable for Francis turbine. Francis turbines are compact and efficient than other types of turbines, so the rehabilitation of the damaged MHPs with Francis turbine compatibility should be equipped with the Francis turbine. For this, Turbine Testing Lab (TTL) at Kathmandu University has gained and demonstrated competence in Francis turbine design and assistance in manufacturing. Many earthquake affected people have been dislocated so the rehabilitation of MHPs in Nepal needs certain consideration and hence strategic plan for the earthquake affected MHPs have been developed in the present study.

Acknowledgments

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