The main objective of the research study is to identify the status and analyze the problems in Chameliya hydropower plants in Nepal. In this paper, the hydropower has been studied to identify some regularities of hydropower components on proper operation and generation through primary and secondary data. Further, it been analyzed by bottlenecking through mechanical components testing for the detail study to find the actual problems. Hydropower contributes about 86 % of total internal generation to available energy in Nepal with 93 % of people having access to electricity through the national grid. Small hydropower plants (less than 30 MW) are 90 % of the installed plants contributing the major electricity demands of nearly 50 % in the country. Though hydropower is one of the major export commodities in the past few years, it still has deficits in the dry season. Chameliya hydropower plant, 30 MW situated in the far-western part of Nepal, generates 670 MWh of energy in the wet season and which declines to 384 MWh in the dry season. Even though the plant does not have the problem of much erosion and has a sufficient flow in the dry season, the generation value is still below the design.

The issue of variation in shaft speed, misalignment of shaft bearing integrity and ultimately friction due to vibration, rises the temperature beyond the limit in the bearing Babbitt material result for failure in the plant with problematic shutdown. Thus, this research primarily focuses on the problem analysis in hydropower plants, concluding with the result that the developing countries need to have more focus on regular preventive maintenance and also schedule large maintenance on mechanical components like shafts, bearings, turbine etc. to avoid bigger damage in the long run. Hence, the study also suggests that mechanical failure in a hydropower is mostly common and therefore, a robust mechanical structure along with high safety factor components need to be encouraged where the possibilities of regular maintenance and smooth operation are reduced

Keywords: energy, generation, Chameliya hydropower, mechanical, problem, failure, operation, maintenance, thermal, component

UDC 338
DOI: 10.15587/1729-4061.2023.290012

IDENTIFYING SOME REGULARITIES OF HYDROPOWER COMPONENTS FUNCTIONING FOR PROPER OPERATION OF CHAMELIYA HYDROPOWER PLANT IN NEPAL

Roshan Pandey
PhD Scholar*
Rajendra Shrestha
PhD in Mechanical Engineering, Professor*
Nawraj Bhattarai
Corresponding author
PhD in Mechanical Engineering, Associate Professor*
*Department of Mechanical and Aerospace Engineering
Pulchowk Campus
Institute of Engineering
Tribhuvan University
Chakupat, Lalitpur, Nepal, 44600

Received date 09.08.2023
Accepted date 10.10.2023
Published date 30.10.2023

How to Cite: *Pandey, R., Shrestha, R., Bhattarai, N. (2023). Identifying some regularities of hydropower components functioning for proper operation of Chameliya hydropower plant in Nepal. Eastern-European Journal of Enterprise Technologies, 5 (8 (125)), 31–40. doi: https://doi.org/10.15587/1729-4061.2023.290012*

1. Introduction

Hydropower is the clean, sustainable renewable source of energy, ranking third in capacity wise after oil and gas [1]. Even though hydro power is sustainable and clean, Small Hydro Power (SHP) is considered a more renewable and green energy source than big hydro. The definition of the size of hydropower varies between countries. In China less than 50 MW is small, in the US less than 22 MW and in India less than 25 MW where, as in Nepal, less than 10 MW is considered to be small, unofficially [2]. The International Standardization Organization (ISO) has defined up to 30 MW as SHP in their guideline's documents in recent years. So, as green energy technology, SHP is growing its pace of installation in Asian region, having a huge potential of 38 GW in the region [3]. The role of SHP is very important in developing countries, like Asian nations. The electrification rate determines the pace of industrialization and urbanization, which is ultimately possible through sustainable, low-cost and reliable electricity obviously possible through SHP [4].

At present, there are 17 mini/micro plants and 84 SHP plants connected to the national grid [2]. The total installed hydropower plants of Nepal contribute 2185.543 MW of which nearly 23 % of its generation is contributed by SHP plants below 10 MW and 50 % by SHP plants below 30MW.

Having one of the mature technology and the biggest source of renewable electricity, Nepal utilizes less than 5 % of its country's generation potential and, globally, 28 % of technical and 46 % of economic potential is yet utilized, even though it contributes 17 % of the world's electricity consumption [2, 5, 6]. It uses the energy of naturally moving water to generate electricity and is a renewable source of energy.

Generation cost consistency, comparably minimal operation and maintenance cost, environmental acceptability, economic viability, and constant control make it to be a reliable and endless energy source.

The current status of global hydropower generation fulfills about nearly 16 % of global energy demand and it is estimated to increase by 3.1 % every year for the next 25 years [7]. Currently, nearly 17 % of the world's total power generation is based on hydro resources and its share of renewable power generation is 70 % [8]. Unlike other new and renewable energy sources, a Small Hydro Power (SHP) plant can also be considered as one of the robust, mature and reliable means of renewable energy generation which can be constructed with very less investment and fewer administrative procedures than medium and large hydropower plants [9].

Despite this amount of potential, there are major barriers in the region like investment, policies, technology, the market and many more. These barriers are even as they are in a country like ours. With the innovation in SHP technology, the growth rate has been increasing recently in central and south Asia.

The study on SHPs and their developments are more importance not only in the Asian region but in the whole world, as the people are rely more and more on sustainable and clean green source of energy rather than non-renewable sources nowadays.

So, the technical topic on identifying the issues for regularities of proper operation and functioning of such green SHPs could help in academic benefits and added the bricks on its research and development in future.

2. Literature review and problem statement

There are lots of opportunities as well as challenges in existing foreign investments for the large hydro sector. However, there are not many foreign investments in the SHP sector. Most of the SHP plants are owned and operated by local entrepreneurs and corporate in terms of investment. In recent days, SHP is considered as one of the most cost-effective energy technologies, considered for rural and community electrification in less developed countries [10].

SHPs are attractive renewable energy generation sources that are economically viable and require a short time for construction [11]. However, without proper installation procedures, good equipment, and proper operation and maintenance, performance evaluation practices can be the opposite of what was mentioned earlier.

Likewise much research on hydropower is carried out in terms of flow variation, erosion on turbine and optimization of plants. But, in last few decades, problem analysis and performance evaluation in plants has been the serious necessity for plants in developed and developing countries. The performance in the plants suffered from the problem of lower efficiency with time.

The previous study highlights the main reason for having operation problem are sediment erosion on turbines blades, valve, gates and the mechanical problem of vibration, cavitation and losses through leakage [12]. Other study suggested that generation loss is actual cause by erosion and followed by leakage of water from sealant, wicket gates, valves etc. [13]. Next paper gives the idea on turbine efficiency and optimization in overall as hydropower turbine can be monitored by a real-time monitoring system helps to give turbine efficiency for the optimization of the overall station as well [14].

Hence, it is found from earlier research and literature that the main reason for low generation in hydropower plant are generally the results of flow variation in rivers, erosion due to sand particles on turbines and valves and leakage in sealant but the recent development and research found that there are many other areas for improvement in generation and enhancing of performance of power plants. Similarly, a recent study of SHPs also shows the main reason for low generation to be mechanical issue not always the low flow rate of water in rivers [15].

Even, looking at the practices from other developing countries, evaluating the performance and analysis of mechanical components and design consideration for SHP systems is always a matter of great importance for the reasons like energy security, incentive, etc. [16]. Other previous studies, also suggests that the major failures in hydropower are occur in mechanical and electrical components due to the negligence and ignorance in proper operation use of them. The scheduled and plan maintenance and operation of any plants with standard instruction can reduce such failures [17].

Many plants suffered with problematic shutdown time and again due to ignorance and improper repair and maintenance system. Though, very less research and study has been done till date on the performance evaluation and problem analysis of hydropower components but the value of such study has much importance in terms of economical suitability. And the management of risk and failure could help in reducing the cost of operation and maintenance sustainably [18].

In Nepal SHP are in high risk of operation after its installation. The earlier study on few SHP like Panauti and Fewa small hydropower plants also shows the issues of reliability of the systems due to schedule maintenance and repairs [19, 20].

Therefore, further study with more details, need to be necessary in the fast moving components for problems analysis of plants is high necessity. Since, it is impractical to stopped the running plants for testing and analyzing problems so, the non-touch test like speed measurement of shaft, temperature measurement of components, vibration and alignment test with secondary data and observation images could be one of the fruitful methods in other plants as well for evaluating and analyzing the issues in SHP. Though, many researchers had done thermal measurement methods and some has done alignment measurement but the combination of the study is almost the first time practice. Similarly, testing of these three important parameters speed, thermal, vibration and alignment for any fast moving components and comparing it to observe data would give the detail history of operation and maintenance practices.

Hence, in this regards, study of Chameliya hydro power plant, 30 MW located in far-western Nepal is taken as the study site for detail problem evaluation and analysis. Therefore, being one of the largest SHP, lying in farthest region from central has definitely reflected the actual problems in the SHP during operation and generation.

3. The aim and objectives of the study

The aim of the study is identifying some regularities of hydropower components functioning that effect the operation and generation for proper operation of Chameliya hydropower plant in Nepal.

To achieve this aim, the following objectives are accomplished:

– to identify the actual status of Chameliya hydropower plant using primary and secondary data;

– to analyze the different problems and issues in Chameliya hydropower plant;

– to have detail study of the problems in Chameliya hydropower plant that effects the operation and generation;

– to recommend the best suggestions with findings results.

4. Materials and methods

4. 1. Object and hypothesis of the study

The object of the study is actual status of Chameliya hydropower plant and analyzing the different problems that effects the operation and generation in it.

The basic assumption on the status and problems of the plant is as usual like in other plants in Nepal having issue of erosion in runners and low energy generation due to flow variation.

The methods process adopted for this research starts with literature review with on-desk study of abnormalities observed in the Chameliya SHP of Nepal which includes hydrological data, secondary data from reports and papers on generation and operation. After then, bottlenecking the study with problems identification, with collection of actual field based data through questionnaire methods. Then, detail studied of the SHP plant was done to collect genuine data by conducting field based survey for a week, which includes real-time monitoring of various components, recording the on-time data with external testing equipment and valid it with data log. Then analysis of these data and validation of them gives the required results. The conclusion and recommendation are drawn with the results. The detail methodology process adopted has been illustrated in Fig. 1.

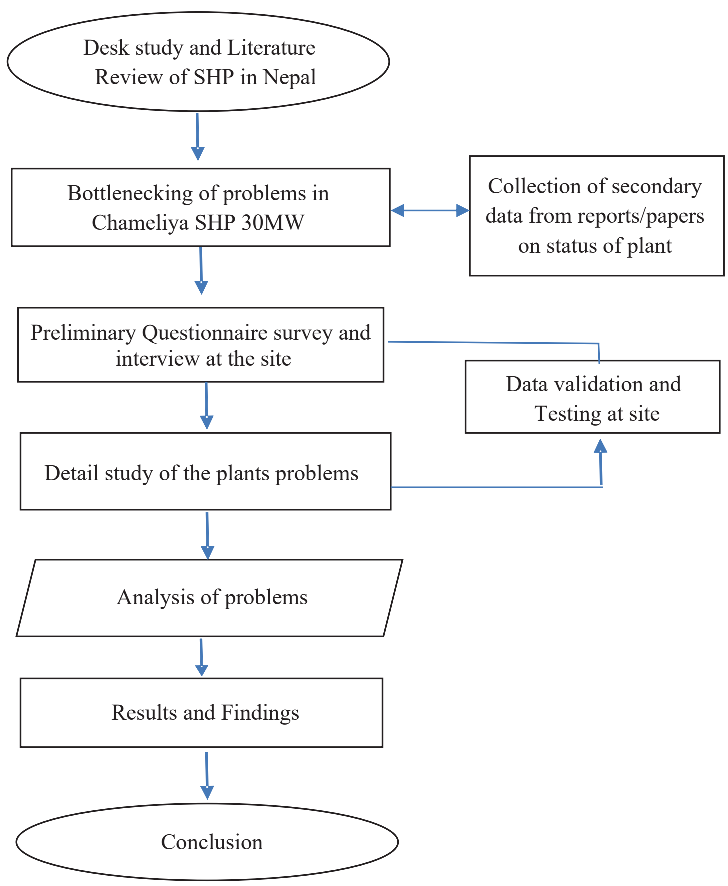


Fig. 1. Activities during Field Research at Chameliya Hydropower Plant

The research study was started with the literature review of various publications and reports on small hydropower plants. The study was further concise and bottle neck with status study and the problem identification of Chameliya small hydro power plant 30 MW of installed capacity as per the International Standardization Organization (ISO) definition on SHP. Then, secondary data on discharge of flow, generation of the hydro power has been taken for preliminary study. Primary data was developed from questionnaires and interviews in the site plant. Later, on the basis of these preliminary data, detail study of the plant has been carried to analysis the actual problems in details. The detail study of the plant's problems, especially physical inspection, temperature measurement, frequency measurement and vibration measurement methods in mechanical component (shaft, bearing and turbine) integrity has be done to verify the results and findings. The main analysis method adopted to sort out the issues and problems are thermodynamic and physical methods using some of the testing equipment and valid it with the inbuilt system generated data, interview with the power plant authorized personals and published reports. Further preliminary parameters, like flow measurement, generation, plant loss and other information were also analyzed. The material and methods for the detail study has been summarized in the sections.

4. 2. General observation of plant

Chameliya hydropower plant is one of the latest installed hydropower plants in Nepal located in Sikhar, Darchula district. It is a peak run-off river type of project with 30 MW of installed capacity. The silent features of Chameliya hydropower is mentioned in the Table 1.

Table 1

Silent features of Chameliya Hydro Power Station

Parameters	Value/Features
Installed capacity	30 MW
Maximum head	101.8 m
Rated head	94 m
Minimum head	89 m
Rated discharge	17.73 m^3/sec
Rated output	15.3 MW (2 units)
Rated speed	428.6 rpm
Runaway speed	800 rpm
Type of turbine	Francis (HLA678-L-J-160)
Direction of rotation	Clockwise viewed from above
Specific speed	210
Rated voltage	11 kV

Some of the major problems in the mechanical components observed in Unit-1 of the station have been mention in details:

a) Shaft: the shaft is one of the main components that have been observed to deviate from data of the last two years. The length of the shaft is short as compared to its 400 mm diameter of it so, the deviation observed is also not much overall besides wear on it.

The vibration on turbine shaft at different load condition has been observed in the site as illustrate in Table 2.

Table 2

Load versus vibration in each turbine

Load (MW)	Vibration (mm/s)
6	0.022
12	0.018
14	0.017
15	0.012

Depending on the load, the runner is subjected to vibrations. More vibration was observed for fewer loads, with observing machine running hours to be 11,100 hours. Similarly, permissible skewness and eccentricity up to 750 rpm is 0.1 mm as standards but was observed as 0.5 mm at 428.6 rpm in 2020 March and 1.2 mm in 2021 August [21]. This wear value has been observed from 0.05 in 2019 to 0.5 in 2020 and finally 1.2 in 2021 as shown in the Fig. 2.

Since, Vibration Condition Monitoring (VCM) is one of the important supervision mechanisms in Hydro Power System (HPS) that enhances and increases the efficiency of the plant's generation. The rotational and non-rotational components both need to diagnosis through VCM for proper operation and maintenance in the HPS [22];

b) Bearing: the bearing used in the turbine guide part has an issue. It has a cooling mechanism through oil lining layer and water on other parts. The lining layers of bearing has been illustrate in Fig. 3;

c) Runner: Francis runner are used in both the units having no major erosion problem till 20,000 hours of effective running. Cavitation zone for the system is observed from 6 to 8 MW only so, no operation below 6 MW was practiced to date. Fig. 4 illustrates the runner dissembled for maintenance in one of the unit of HPS.

Fig. 2. Shaft wear in the bearing section

Fig. 3. Bearing with inner lining [23]

Fig. 4. Francis runner of Chameliya plant [23]

The integrity parts of gates and turbine in Fig. 5 along with leakage in the elbow of the balance pipe in Fig. 6 have been illustrated below.

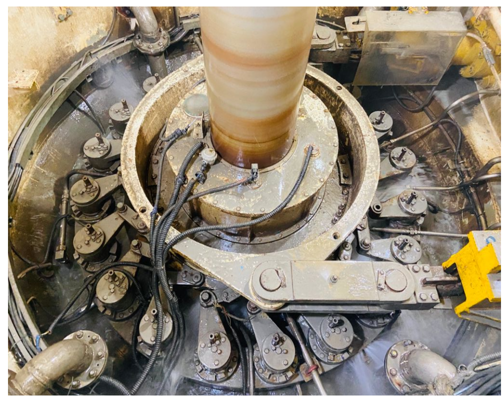


Fig. 5. Shaft, guide vane system

Fig. 6. Elbow inside the balance pipe of the head cover [23]

Visual inspection of bearing like cracks, lining is important part to be monitored along with temperature measurement as the increasing temperature in bearing gives the indication on bearing failure during monitoring [24]. So, the display reading of temperature on the components has been taken for analysis in future.

4. 3. Energy generation pattern observed throughout the year

Nepal has constant peak power supply deficit due to low power generation from run-of-river hydropower plants during the dry season, when river flow decreases.

The minimum energy was generated in Magh (January/February) and maximum energy was generated on Ashwin (September/October) is about 670 MWh daily as in Fig. 7. The energy generation pattern of Chaitra (March/April), during study period is shown in Fig. 8. These patterns help to study the generation of plants season wise comparing designed and targeted one.

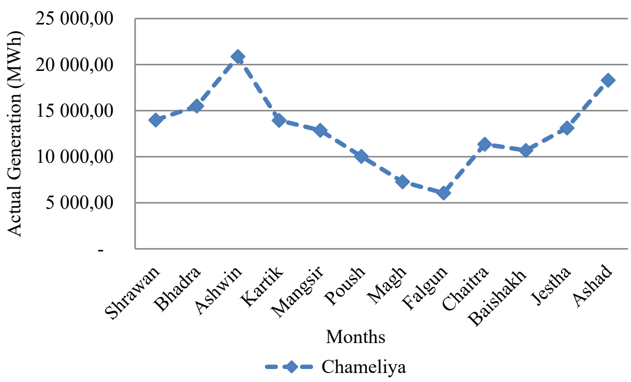


Fig. 7. Monthly Actual Generated from Chameliya HPP [25]

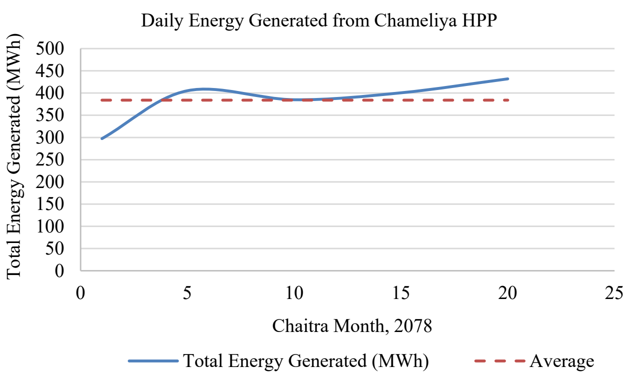


Fig. 8. Daily Energy Generated from Chameliya HPP [25]

The last five fiscal years generation also shows the lowing value of actual generation as compare to design generation. The fiscal year 2075/76 has higher generation than in fiscal years 2076/77, 2077/79 and 2078/79 whereas the fiscal year 2074/75 has the minimum generation with starting year after commissioning as in Fig. 9.

The actual generation curves from fiscal year 2076/77 to 2078/79 shows the decrease in generation annually and then remain constant. These decrease in generation value can be further analyze to find the frequency of maintenance and repairs of plants.

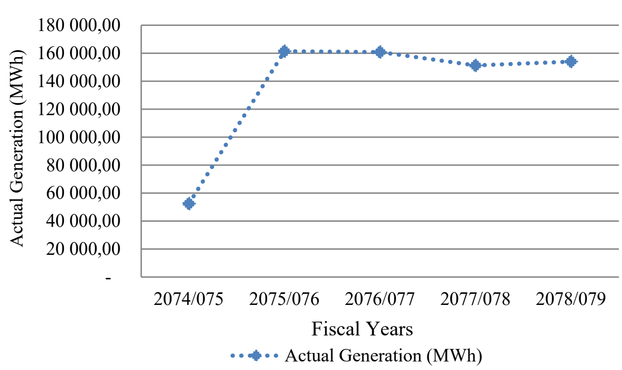


Fig. 9. Five Fiscal Year Actual Generated from Chameliya HPP [25]

4. 4. Thermal image data of mechanical components

The temperature at various points and the thermal images are taken by Fluke TiS10 Infrared Camera with 80×60 resolutions (4,800 pixels) which measure temperature from −20 °C to 250 °C. Since, thermodynamic method is one of the important and approved methods to observed the status of mechanical components in dynamic system, authors has study the temperature of the components in different ways:

a) generator: the temperature around the generator section recorded was 28–45 °C, which is comparatively high observed at the shaft speed of 500 rpm. Fig. 10 shows the temperature gradient around the generator which is recorded through Fluke TiS10 Infrared Thermal Imaging Camera. This temperature dropped to 25 °C near the shaft section;

b) shaft: the temperature distribution is found 20–25 °C at around the turbine-generator shaft section, which is good for the normal working of the shaft. The temperature variation graph of the shaft section observed and tested at Chameliya hydropower plants have been illustrated in Fig. 11;

c) turbine: the temperature distribution is found at 15–21 °C around the outside of the turbine section. The temperature of the shaft near the turbine has been measured with a lower value relative to other components shown in Fig. 12.

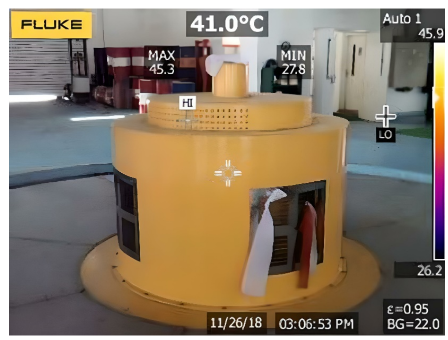


Fig. 10. Thermal data around the generator section

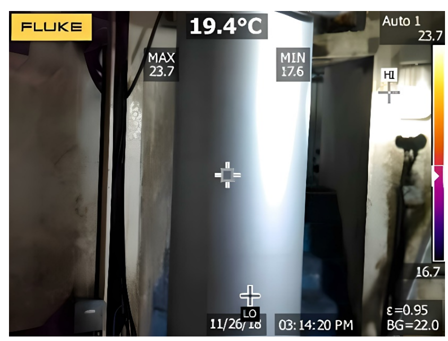


Fig. 11. Thermal data around the shaft section

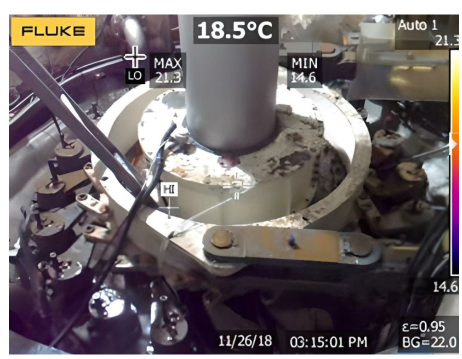


Fig. 12. Thermal data around the turbine surrounding

4. 5. Measure of speed of fast moving components

The speed of the turbine-generator shaft is recorded using the DT-2234A+ Digital Professional Automatically Switchover Non-Contact Laser Photoelectric Photo Type Tachometer which measures the rotational speed of a shaft in RPM (revolution per minute). The tachometer is calibrated in Small Hydropower Equipment Testing and Research Laboratory, NAST.

At last, concrete outcome as finding has been drawn from the detail study and then analysis was done from the collected primary and secondary data to conclude and to discuss about the overall performance and abnormalities of the plant. Finally, conclusion has been drawn with analysis of results with some suggested recommendation.

5. Results of problem analysis in Chameliya hydropower plant

5. 1. Result analysis of general observation data of plant

Shaft actual rotational speed is 428.6 rpm and which has been exceeded with varying in load up to 450 rpm in some instant with vibration and deflections. Due to this circumferential 30 % of the turbine guide part has been observed to have worn with large eccentricity in alignment.

Damage in tin rich bearing Babbitt parts is due to the continuous vibration in the system caused by the increasing rpm of the shaft. The temperature of the Babbitt material (ZSnSb11Cu6) also fluctuates from 30-34 °C normal temperature to 45 °C with increasing in vibration.

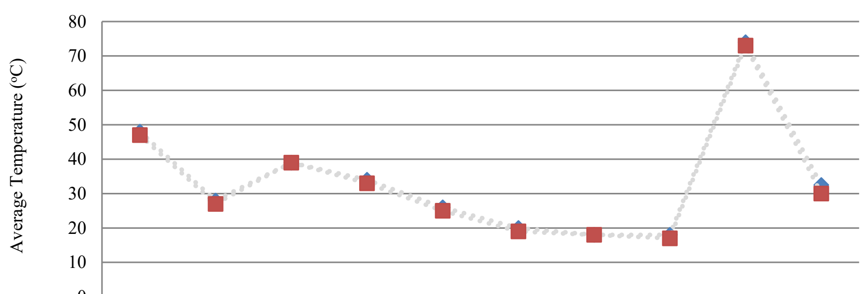
The leakage of water from the balance pipe of the head cover region causes the replacing of oil in the oil tank with water leading to damage to the oil lining layer in the turbine guide bearing and ultimately leading to friction in shaft bearing integrity.

Similarly, the average temperature variation in components of unit-1 and unit-2 of Chameliya plants also has a similar trend of rising in temperature. The rise in temperature in turbine bearing parts and the average variation of temperature of upper guide and lower guide bearing as presents in Fig. 13, 14 are the results of vibration due to increase in rpm of shaft and friction with bearing Babbitt material.

These graph results shows the maximum range of working for the bearings are from 48–74 °C for unit-1 and 50–87 °C for unit-2 for thrust bearing and bearing at stator core, which is above the normal rage for the bearing with tin based Babbitt with constant working load. It also leads to damage in Babbitt materials results in vibration and misalignment mentioned above.

5. 2. Results analysis of energy generated on actual versus designed

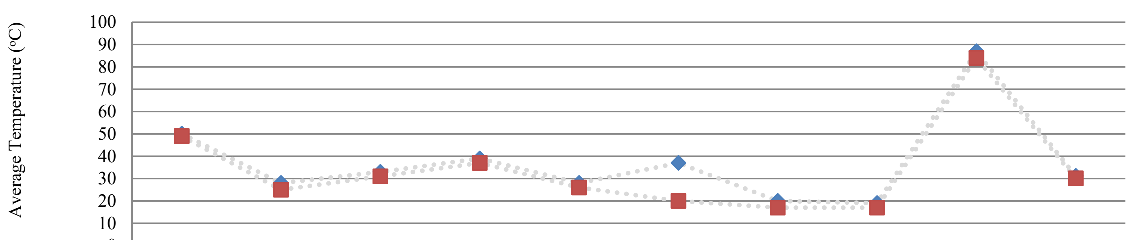
The Chameliya hydropower produces the daily average energy of 384 MWh in the month of the dry season, which is about 45 % less than in the wet season. The minimum energy was generated in Magh (January/February) and maximum energy was generated on Ashwin (September/October) which is about 670 MWh daily as in Fig. 9–11.



	Thrust Bearing	Thrust Bearing Oil Resevior	Upper Guide Bearing	Lower Bearing	Lower Bearing oil Resevior	Turbine Bearing	Thrust Cooling water	Lower Bearing Cooling	Stator Core	Sump Oil Tank Oil
Maximum-Temperature (°C)	48	28	39	34	26	20	18	18	74	32.5
Minimum-Temperature (°C)	47	27	39	33	25	19	18	17	73	30

Components

Fig. 13. Average temperature variation in Unit-1 components of Chameliya plant



	Thrust Bearing	Thrust Bearing Oil Resevior	Upper Guide Bearing	Lower Bearing	Lower Bearing oil Resevior	Turbine Bearing	Thrust Cooling water	Lower Bearing Cooling	Stator Core	Sump Oil Tank Oil
Maximum-Temperature (°C)	50.1	28	33	39	28	37	20	19	87	31.2
Minimum-Temperature (°C)	49	25	31	37	26	20	17	17	84	30.1

Components

Fig. 14. Average temperature variation in Unit-2 components of Chameliya plant

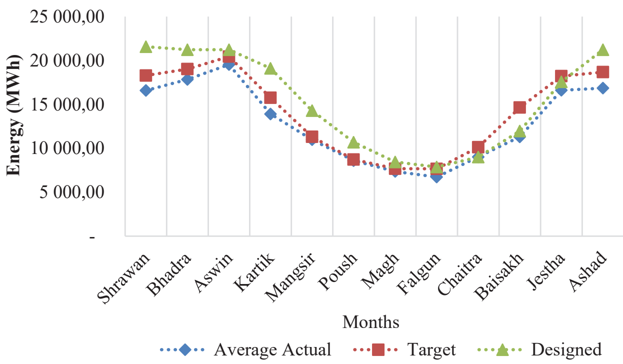


Fig. 15. Actual generation versus target and design generation of last three year

The average actual generation value is always below the designed and targeted generation value in last three years as in Fig. 15 additionally supports results of observation data on 5. 1 sub-section which shows the mechanical issues in the components rather than monthly flow variation.

5. 3. Thermal images data of mechanical components on testing

The average temperature variation graph measured in each component in the Fig. 16 with both minimum and maximum values:

a) external surface of generator measured to have 28–45 °C temperature variation, which is even high as compare to temperature at internal surface measured by sensor at 428 rpm;

b) shaft surface temperature taken externally measured to be 20–25 °C and this variation in temperature from thrust bearing to surface of shaft results critical lead to damages the Babbitt materials or pads causing deflection and failures in such hydro turbines;

c) though, the temperature in the turbine section has little lowered in temperature 15–21 °C, the leakage of water from the elbow of the balance pipe inside the head case causes the oil layer to wash out with water and also replaced the oil level in the oil tank leading to adding issues for wear in the bearing and shaft.

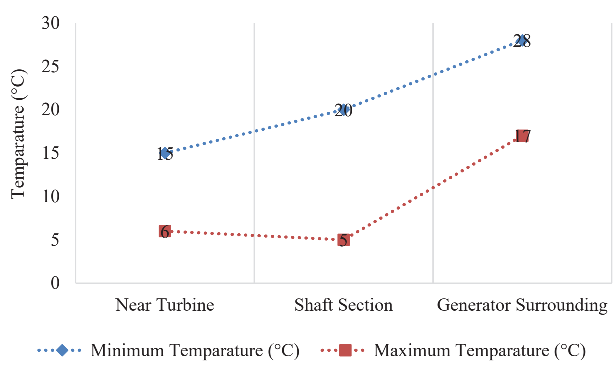


Fig. 16. Temperature variation in different components of the Chameliya Hydropower Plant

These values in graph, further supports the data observed from inbuilt testing equipment's sensor data on display panel. The variation inside the components has the similar trend and correlation profile of temperature outside the body parts results in critical damages in bearing and shaft materials if expose for long run.

5. 4. Testing result of fast moving component

The rated speed of the shaft is 428.6 rpm. The actual average speed recorded by the tachometer is quite high around 450 rpm in average which is about +/–15 % more than the rated speed and it is above the tolerable limit. When the speed varies, the frequency of the system also varies accordingly, and hence equipment within the areas would lose synchronicity in grid connection. The rpm of the shafts along with actual and display frequency of system in an hour of time interval for a week has been illustrated in Fig. 17, 18 for unit-1.

The hydropower faces the heating problem in the bearing section many times, and higher rpm might be one of the reasons for that. Similarly, Fig. 19, the average RPM of the shaft in Unit 1 (only running that time) and average thrust bearing temperature in each week from 15 January–14 February 2022 shows the rise in temperature of shaft thrust bearing in average with rise in speed of the shaft further supports the increasing in temperature of bearing due to the variation on shaft speed.

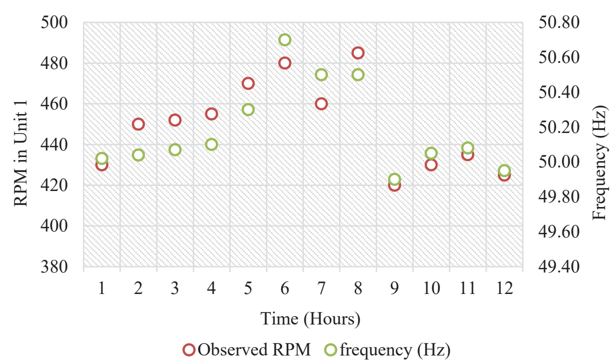


Fig. 17. Observed RPM of shaft with display frequency in each hour in Unit 1

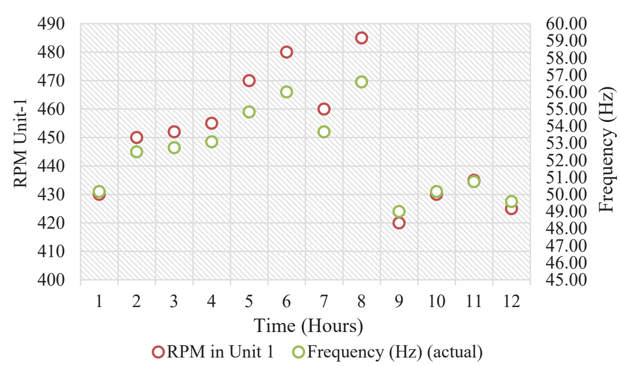


Fig. 18. Observed RPM of shaft with actual frequency in each hour in Unit 1

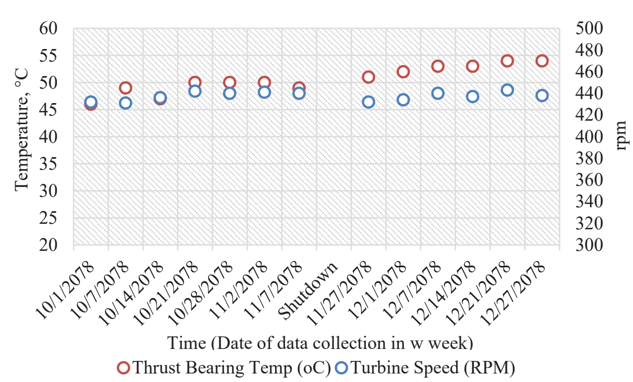


Fig. 19. Average RPM of shaft and average thrust bearing temperature of each week

The analysis of the general observation data is further valid with thermal measurement data, and speed measurement of the shaft showing the results of damages in shaft circumferential and Babbitt of bearing due to over speeding and vibration and prolonging the effect by losses in lubrication due to leakage of water to sweep water from upper head cover in overall.

And these problems are not even affected by season variation as shows from actual energy generation versus design generation value for the periods.

6. Discussion of the result of problem analysis in Chameliya hydropower plant

Chameliya hydropower 30 MW, in farthest from Nepal represent the overall hydropower problems in Nepal. It is not operating satisfactory with two units each of 15 MW at the moment. Being farthest, there is a problem with continuous repair and maintenance. The result of observation section reveals that the problems were observed in the shaft with eroding in 30 % of the circumferential part from 0.05 mm to 1.2 mm in three years. Leakage in turbine manifold parts near the turbine is the other problem. The vibration in the system is due to the high rpm in the shaft causing variations in load from 6–15MW, and some cavitation in the turbines during the dry season. Moreover, the curve of vibration depends upon the machine's previous loading and rotating history above 50 % of the load and as the speed of the machine varies beyond the default value, obviously the bearing moves from good to poor and sometimes the machine starts suffering vibration in other hand [26].

Similarly, the vibration in the bearing parts connected with the shaft leads to the failure in the lining of the inner race and multilayer's of Babbitt parts. The damage to the Babbitt parts of the bearing due to increase in temperature above normal as observed in Fig. 13, 14 makes the edges in the lining sharp and the rotating shaft connected with it causes wear by 30 %. The Fig. 13, 14 also results the high temperature observed in stator core parts in both units to lower temperature at turbine bearing parts and this variation in shafts also results in critical temperature difference to flow the heat with irregularities. The literature also shows that in high-speed turbo machinery, constant viscosity is supposed over the complete film thickness and that thermoelastic bearing deformation is neglected and has led to inconsistency in many of the calculations. A study done on some turbine bearings shows a phenomenon called «temperature leap». In which constant load and increasing shaft speed, bearing temperature rises to maximum but afterward drops suddenly. Bearing surface temperature is not reduced in the whole bearing but the section near the minimum gap width [27].

The main problem currently is the wear on the shaft, creating vibration in the shaft, and bearing integrity. The vibration is not that much but it led to damage to the Babbitt material in bearing causing misalignment and leakage of oil. Besides, the sharp edges of the Babbitt lining of the bearing, the layers of oil in the lining have been washed away by leakage of water from the elbow inside of the balance pipe of a head case to the washing of headset, causing the two metal parts to rub continuously.

The discussion on the results of low generation on wet season by the plants below design generation clears the other issue in plants. It also make the assumption of authors, to be wrong that low generation of plant is likely to be by flow variation and the issue like erosion in runner like in other plants. The variation of the daily generation curve with design generation from the analysis section can be further discussed as results of other factor like mechanical issues and failures as shown in result of Fig. 15.

Similarly, discussion on the results of the temperature measurement of the thrust bearing that found to be increasing with the increase in rpm of shaft and runner caused damage to Babbitt materials, later causing misalignment in the system as measured in Fig. 16 showing the similar pattern as observed in temperature sensor in Fig. 13, 14. This is also supported by one of the oldest studies, which explains the monitoring of temperature across the radial and circumferential surface in the high-tin-content Babbitt used on the working surface of the bearing pad loses its strength, and is subject to creep at high temperatures and pressure [28].

Another major issue found in results is calibration of the inbuilt measuring sensor whose reading varies many times, like the speed of the shaft and the temperature of the surface. The high water flow in the wet season causes the pressure on the rpm of the system with +/–15 %, causing the variation in display frequency with +/–1.5 % and +/13 % ultimately with actual frequency illustrate in Fig. 17, 18. But the inbuilt sensor at site shows the variation in data, which is also the reason for ignorance and not notice by technicians for causing vibration and results increase in temperature in thrust bearing illustrate in Fig. 19.

Further, a study results concluded that upcoming SHPs need to have robust mechanical components with high safety factors in them, which can the design consideration points of view for a country like ours where the regular preventive maintenance practices in SHPs is almost zero.

7. Conclusions

1. The preliminary study and observation concludes that the status of the plants is quite below satisfactory with decrease in the actual generation as compare to designed and targeted generation not actually due to the variation of flow in rivers, but with the case of improper maintenance and irregular monitoring of important parameters in the moving components viz shaft, bearings, generator, runner etc.

2. On analyzing the problems, issue of erosion in runner blades was found much less as compare to other plants but the mechanical problems in the shaft, bearing and runner integrity was much high. Shaft were much more erode in circumferential part by 30 % from 0.05 mm to 1.2 mm in last three years (2019–2022). Leakage in runner manifold parts near runner is the other problem leading to leakage of water that sweeps away the lubrication from bearing at head cover. The temperature reading in moving components, mostly in different bearing also results the problems analysis of the plants.

3. Similarly, on detail problem analysis, the vibration in the bearing parts connected with the shaft leads to the failure in the lining of the inner race and multilayer's of Babbitt parts was concluded. The damage to the Babbitt parts of the bearing due to an increase in temperature above standard (50 °C) makes the edges in the lining sharp and the rotating shaft connected with it causes wear by 30 %. Deviation in design rpm by +/–15 % on average also led to vibration in the shaft and an increase in temperature of various components like the thrust bearing. The variation in frequency by +/–1.5 % in inbuilt display and +/–13 % in actual due to increase in rpm also led to synchronization issues with the grid. Further, on testing, ignorance and untimely calibration of monitoring equipment led to misguiding value of rpm and temperature

was found. And this method could be implemented in other SHPs as well where the problems analysis in mechanical components is higher than the other hydrological analysis.

4. Likewise, two types of solutions can be recommended for the resulted issues. One the short term solution, as the wear part is just 30 %, the increase in bearing lining, aligning the shaft properly and cleaning the shaft seal with adding oil in oil tank. This solution can lead to maintain the system for some days as a temporary solution. As long as the oil layer will be there, no further deviation and wear will be observed. The second is the long-term solution with machining the shaft by >1.3 mm depth and then increasing the bearing lining enough to fix the alignment properly. Along with that the shaft and head case seal need to be properly checked with more packing material to maintain the lining of the oil layer.

Conflict of Interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

University Grants Commission (UGC), Nepal has financed this research as the PhD fellowship; grant number PHD 75/76 Engg3.

Data Availability

Data will be made available on reasonable request.

Acknowledgement

Authors would like to thank University Grants Commission (UGC), Nepal for providing funds for the fellowship and also Nepal Academy of Science and Technology (NAST) for a laboratory facility for research. Similarly, the authors would also like to thank Chameliya Hydropower Project, NEA for helping in the study with valuable data and survey facilities. We would also like to thank Department of Mechanical and Aerospace Engineering, Pulchowk Campus, IOE for work space and guidance.

References

1. World Energy Outlook 2019. IEA. Available at: https://www.iea.org/reports/world-energy-outlook-2019
2. Power Plants :: Hydro (More than 1MW). Department of Electricity Development. Available at: http://doed.gov.np/license/54
3. Liu, D., Liu, H., Wang, X., Kremere, E. (Eds.) (2019). World Small Hydropower Development Report 2019. United Nations Industrial Development Organization. Available at: https://www.unido.org/sites/default/files/files/2020-02/WSHPDR%202019%20Case%20Studies.pdf
4. Bhutto, A. W., Bazmi, A. A., Zahedi, G. (2012). Greener energy: Issues and challenges for Pakistan-hydel power prospective. Renewable and Sustainable Energy Reviews, 16 (5), 2732–2746. doi: https://doi.org/10.1016/j.rser.2012.02.034
5. Killingtveit, Å. (2022). Hydropower Resources Assessment-Potential for Further Development. Comprehensive Renewable Energy, 14–29. doi: https://doi.org/10.1016/b978-0-12-819727-1.00069-8
6. Gunatilake, H., Wijayatunga, P., Roland-Holst, D. (2020). Hydropower Development and Economic Growth in Nepal. ADB South Asia Working Paper Series. doi: https://doi.org/10.22617/wps200161-2
7. Use and Capacity of Global Hydropower. World Watch Institute. Available at: http://www.worldwatch.org/node/9527
8. Alam, F., Alam, Q., Reza, S., Khurshid-ul-Alam, S. M., Saleque, K., Chowdhury, H. (2017). A Review of Hydropower Projects in Nepal. Energy Procedia, 110, 581–585. doi: https://doi.org/10.1016/j.egypro.2017.03.188
9. Final Report, Evaluation of Small Hydro Power (SHP) Programme of MNRE (2017). Ministry of New & Renewable Energy (MNRE), 90.
10. Paish, O. (2002). Small hydro power: technology and current status. Renewable and Sustainable Energy Reviews, 6 (6), 537–556. doi: https://doi.org/10.1016/s1364-0321(02)00006-0
11. Ghosh A, M. S. K. A. (2012). Steady growth in small hydropower in India. ICRA rating feature, New Dehli.
12. Sapkota, P., Chitrakar, S., Neopane, H. P., Thapa, B. (2022). Problem Identification and Condition Monitoring status of Nepalese Power Plants. IOP Conference Series: Earth and Environmental Science, 1079 (1), 012064. doi: https://doi.org/10.1088/1755-1315/1079/1/012064
13. Thapa, S. K., Poudel, L. (2017). Performance Evaluation of Francis Turbine using thermodynamics analysis: A Case Study of Kali Gandaki A Hydropower Plant-144 MW. Proceedings of IOE Graduate Conference.
14. Feng, D., Wang, Z., Ma, P., Wang, W. (2013). Analysis and Application of Hydropower Real-time Performance Calculation. Energy and Power Engineering, 05 (04), 63–67. doi: https://doi.org/10.4236/epe.2013.54b012
15. Pandey, R., Shrestha, R., Bhattarai, N., Dhakal, R. (2023). Problems identification and performance analysis in small hydropower plants in Nepal. International Journal of Low-Carbon Technologies, 18, 561–569. doi: https://doi.org/10.1093/ijlct/ctad043
16. Verma, H., Kumar, A. (2007). Performance Testing and Evaluation of Small Hydropower Plants. International Conference on Small Hydropower. Sri Lanka. Available at: https://www.yumpu.com/en/document/read/33482849/-performance-testing-and-evaluation-of-small-hydropower-ahec
17. Zegarac, N. (2017). Improving technical maintenance of systems of mini hydropower plants: Analysis of causes of malfunctions, faults, failures and system failures. Vojnotehnicki Glasnik, 65 (3), 673–702. doi: https://doi.org/10.5937/vojtehg65-13246

18. Yaseen, Z. M., Ameen, A. M. S., Aldlemy, M. S., Ali, M., Abdulmohsin Afan, H., Zhu, S. et al. (2020). State-of-the Art-Powerhouse, Dam Structure, and Turbine Operation and Vibrations. Sustainability, 12 (4), 1676. doi: https://doi.org/10.3390/su12041676
19. Bashyal, M., Poudel, L. (2021). Performance analysis and rehabilitation prospective of aged Small Hydropower Plant – A Case Study of Fewa Hydropower Plant (1 MW). Proceedings of 10th IOE Graduate Conference. Lalitpur, 161–169.
20. Prajapati, R. N., Deo, K., Rauniyar, N., Shrestha, J., Neupane, P. (2017). Identification of Reduction of Power Production in 50 Years Old Panauti Hydropower Plant in Nepal. Journals of Recent Activities in Infrastructure Science, 2 (2). Available at: https://www.researchgate.net/publication/324138661_Identification_of_Reduction_of_Power_Production_in_50_Years_Old_Panauti_Hydropower_Plant_in_Nepal
21. Singh, P. (2020). Interview, Performance of Small Hydro Power.
22. Mohanta, R. K., Chelliah, T. R., Allamsetty, S., Akula, A., Ghosh, R. (2017). Sources of vibration and their treatment in hydro power stations-A review. Engineering Science and Technology, an International Journal, 20 (2), 637–648. doi: https://doi.org/10.1016/j.jestch.2016.11.004
23. Sob, P. (2021). Interview, Performance Analysis of Small Hydro Power.
24. Iliev, H. (1999). Failure analysis of hydro-generator thrust bearing. Wear, 225–229, 913–917. doi: https://doi.org/10.1016/s0043-1648(98)00410-4
25. NEA, Generation Magzine 14th Issue (2022). Generation Directorate, Nepal Electricity Authority. Available at: https://www.nea.org.np/admin/assets/uploads/annual_publications/Generation_2021-22.pdf
26. Stack, J. R., Habetler, T. G., Harley, R. G. (2003). Effects of machine speed on the development and detection of rolling element bearing faults. IEEE Power Electronics Letters, 1 (1), 19–21. doi: https://doi.org/10.1109/lpel.2003.814607
27. Hopf, G., Schüler, D. (1989). Investigations on Large Turbine Bearings Working Under Transitional Conditions Between Laminar and Turbulent Flow. Journal of Tribology, 111 (4), 628–634. doi: https://doi.org/10.1115/1.3261987
28. Mikula, A. M. (1986). Evaluating Tilting-Pad Thrust Bearing Operating Temperatures. A S L E Transactions, 29 (2), 173–178. doi: https://doi.org/10.1080/05698198608981675