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Performance degradation mechanisms in small hydropower plants: Field evidence and rotor-bearing integrity analysis from Nepal

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Abstract

Hydropower represents nearly 70% of Nepal's installed capacity via small hydropower plants (SHPs), yet these facilities face an average 12% annual energy loss. While performance degradation is often attributed to hydrological variability, this study demonstrates that 50% of operational issues stem from mechanical degradation. The main aim of the research is to examine and evaluate the mechanical issues in SHPs, especially in shaft, bearing and runner with field based and onsite testing further validation with simulation. This research studies the current status of mechanical performance in SHPs of Nepal exploring its issues and possible causes. The field survey was done during the rainy season (August/September), when water flow is high, and most plants are operating fully. Status of 12 components of plants like bearing, flywheel, turbine, generator, guide valve, penstock, breaker, mechanical governor, transformer has been carried out in 12 plants. Therefore, we primarily focused on issue-oriented selection—narrowing the study from 12 samples to 4 for performance analysis, and then selecting 2 (different capacities) for detailed examination. Technical survey was performed on 12 SHPs with field diagnostics like thermography and vibration analysis along with Finite Element Method (FEM) simulations, this research evaluates mechanical integrity at the ageing Panauti (2.4 MW) and modern Chameliya (30 MW) facilities on issue-oriented basis. Results indicate that high-speed shafting at Panauti facilitates bearing temperatures exceeding 67°C and misalignments over 2 mm. At Chameliya, findings reveal 1.2 mm shaft erosion and significant grid frequency deviations of up to ±13.1%. FEM simulations validate field data, identifying 2X harmonic peaks as the primary diagnostic signature for shaft misalignment, resulting in a 40% vibration amplitude increase. The study concludes that irregular maintenance and systemic design flaws are critical bottlenecks. It recommends holistic rehabilitation and the adoption of robust, maintenance-free components to ensure operational reliability in developing regions.

1. Introduction

Hydropower is one of the most developed and productive renewable power resources that has served as an important source of electricity around the world [1]. Being a clean and economical source, it is especially crucial to developing countries in their quest to strengthen energy security and increase economic growth [2]. Its contribution to total global energy consumption, however, has been modest and is declining slightly, from 16.4 percent in 2012 to 15.1 percent in 2023. This trend is influenced by climate-induced variability in river flows [3]. SHP plants have resulted in increased accessibility in the use of electricity to under-developed and developing countries, and hence towards the realization of sustainable and developmental aims as well as empowerment of society in its social aspect [4]. SHP is a technology that is perceived to be the biggest density renewable resource that has a high degree of adaptation and minimal investment costs [5]. In this industry, small hydro power plants (SHPs), which are generally defined as facilities

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less than 10-30 MW, offer unconditional decentralized remedies [2]. They are also particularly essential in mountainous and rural areas because they are less expensive to invest in, can be developed in less time, and can be used to take advantage of the local water supply. Nepal is a good example of this vital reliance as SHPs take up almost three-quarters of the total installed hydropower capacity in the country, which is important in rural electrification and national power supply [6][7].

Despite its important role in energy supply, access to electricity remains a critical global challenge. While access has improved to around 91 percent globally as of 2022, an estimated 660 million people still lack electricity. This situation has been exacerbated by population growth and recent worldwide crises [8].

Hydropower today is regarded as one of the most important means of stabilizing electrical networks as well as plants are not immune to serious accidents resulting in widespread unavailability and expensive restoration [9]. Although the major causes of outages are natural disasters, such as floods, mechanical failures caused by the poor condition of equipment and other maintenance concerns constitute a considerable part of the reported severe incidents [9]. In other areas such as the Himalayas, the erosion, and cavitation of sediments are reported as the most common causes of destruction leading to surplus pressure variations and vibrations [10][11]. The vibrations tend to be enhanced when turbines work under off-design conditions or rapid load variability, and result in extreme wear of rotating components and surfaces [10]. To overcome these issues, the literature lays stress on transitioning to the model of sustainable maintenance management that would involve the use of condition-based monitoring, diagnostic instruments (including vibration and thermal inspection), and digitalization to identify the initial signs of failure and reduce production losses [11][12]. Moreover, the literature insinuates that whereas infrequent, yet critical events, typically, related to mechanical failures such as bearing failures, take up most of the total plant downtime, it is essential to pay attention to life cycle maintenance and massive design that guarantees long-term reliability [9].

There is an ongoing disparity between the projected and actual energy production of most SHPs despite the high investment and favorable policy frameworks [13]. Traditionally, the performance deficiencies have been significantly explained by the external forces like seasonal variations of flows, erosion of sediments, and grid constraints [14][15]. But operational experience shows that chronic mechanical failures and the effects of extended, unscheduled maintenance outages have an equally important and preventable impact on the reliability of the plant and the yearly generation [16]. Mechanical parts such as rotating shafts, bearings, turbines, and couplings are subject to continuous high cyclic loads and thermal stress [4][17]. In such environments as Nepal, where specialized expertise and regular preventive maintenance may be scarce, these parts become corroded and thus become less available, cost more to operate, and experience more rapid system failure [18].

Although the mechanical problems are well known in large-scale hydropower, systematic field-based research that has diagnosed mechanical problems in SHPs, especially in South Asia, is limited [16]. A strong research gap exists, which, in a quantifiable manner, can attribute mechanical failures, like shaft misalignment or overheating of bearings, to quantifiable generation losses, and can confirm these field observations with sound engineering arguments [19]. This paper fills this gap by providing a detailed assessment of the mechanical performance of SHPs in Nepal. It uses a combined approach that involves a combination of high field survey, in-situ diagnostic measurements (thermography, vibration analysis), and numerical rotor-dynamic analysis to establish and evaluate the underlying causes of mechanical underperformance and thus provide evidence-based solutions towards greater reliability and sustainability of small hydropower facilities [20].

1.1. Research gap and objectives

The past research on SHPs in Nepal as well as other countries has mainly concentrated on the hydrological limitation, erosion caused by silt and the inefficiency of the turbines. Such concentration tends to hold the underperformance as mainly due to both natural and hydraulic factors. There are however limited studies of integration of mechanical performance that has linked the direct field measurements, long term history of operation to the numerical simulation in order to help to diagnose the underlying causes of component failure. The available studies seldom measure the direct effect of the deterioration of the shaft-bearing system in terms of the annual energy loss, and they also do not explicitly test the field observation data in terms of predictive numerical models to determine the unambiguous cause-effect relationship.

There is a considerable gap in research between reporting generic electro-mechanical issues and creating a quantitative and systematic investigation of their effects. The most frequent problems are the lack of knowledge concerning the failure modes of the components, the absence of appropriate maintenance of the fast-moving parts, and high cost of the preventive actions is perceived. Although non-contact diagnostic tools such as thermography and vibration analysis are known, their usage in collaborative field research to diagnose SHP health is not very well recorded.

These gaps are going to be filled with the novel contributions in this study as follows:

1. **A nationwide mechanical performance assessment:** This paper will carry out a methodical survey of 12 SHPs in various capacity levels and ownership models in order to establish baseline of mechanical health and its relationship with the performance measure of the plant.
2. **Quantitative attribution of generation loss:** This study avoids qualitative evaluations in favor of quantitative attributions of energy loss due to a certain mechanical failure, in effect isolating the effects of mechanical integrity versus the effects of hydrological variability.
3. **Coupled experimental-numerical analysis:** A hybrid of on-site diagnostic testing (thermal, vibration, speed) and finite element rotor-dynamic tests. This kind of strategy validates field observations, most conspicuously in the form of working out a model of how a shaft misalignment is a direct cause of the vibration signature and bearing failures in plants like Chameliya SHP.
4. **Feasible, situated, recommendations:** Offering operational and economical implementation and design suggestions in response to the operational and economic constraints of SHPs in developing nations, where maintenance procedures can be non-regular and access to expert knowledge can be restricted.

2. Methodology

Mechanical performance of small hydropower plants (SHPs) was studied in a representative sample of Nepal hydropower plants. The method shifted from a wide survey to a narrow and detailed diagnostics and verification with numerical simulation as illustrated in Figure 1.

2.1. Plant selection and survey framework

A stratified cluster sampling method was used to sample (12SHPs out of 120) to represent a national outlook; therefore, 12SHPs having a capacity of 1 to 30 MW were sampled. The sample was intended to be representative of the major variables of operation: it had plants of the public utility (NEA) and the independent power producers (IPPs) and it covered the geographical areas from the east to the west of Nepal. It encompassed the whole range of operational ages: old and newly established plants. Information gathering in these locations was done through a structured walk-through survey involving the use of a comprehensive checklist and questionnaire for the engineers and the plant operators. The test collated vital primary information on the history of maintenance, frequency and reason of failures, qualitative and quantitative condition evaluation of key components, and long-term generation performance history which were in turn compared to design and target energy outputs.

2.2. Field measurements

Based on the preliminary survey, two plants were selected to undergo an on-site diagnostic of critical profiles in the SHP fleet, including the old design of plants, the smaller-capacity plant, and the new, larger-capacity plant. These consisted of 2.4 MW Panauti SHP (commissioned in 1965) and the 30 MW Chameliya SHP (commissioned less than 10 years ago). In order to assess the integrity of the fast-moving components without interrupting the operation of the plant, a set of non-invasive measurements was implemented. The shaft rotational speed and change of speed under load was measured on calibrated laser tachometers. To measure the amplitude and frequency spectrums and detect imbalances and misalignments, vibration analysis was carried out. More importantly, surface temperatures of bearings, shafts and couplings were mapped using infrared thermography, identifying hotspots that were a sign of friction, lack of lubrication and insufficient cooling. The empirical data required to diagnose the prevailing failure modes and set boundary conditions in the event of further numerical modelling were obtained by these field measurements.

2.3. Numerical simulation

To diagnose the root cause of the observed vibrations and wear at Chameliya SHP, a finite element rotor-bearing system model of the hydro-turbine shaft was developed. The simulation aimed to isolate and quantify the impact of shaft misalignment, a fault identified from field measurements.

2.4. Model and methodology

A 3D model of the shaft-bearing assembly was created, incorporating bearing stiffness values ($k_{xx}, k_{yy} = 5 \times 10^6$ N/m) and an elastic support to represent the thrust bearing. Operational loads of a 3000 N vertical force and an 80 Nm moment were applied, with a rotational velocity of 450 RPM. The analysis involved two steps namely, a static pre-stress analysis in order to determine the baseline stresses and a complete transient dynamic analysis. The frequency domain conversion

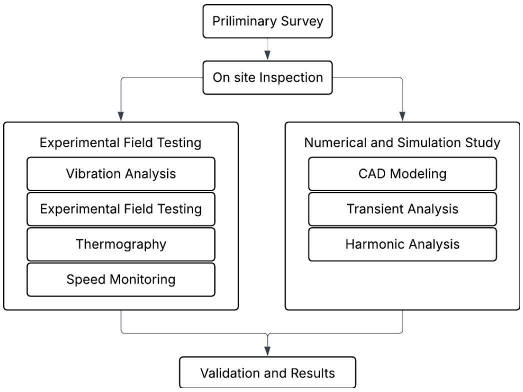

Figure 1: Methodology

of the system response to harmonic analysis was done with Fast Fourier Transform (FFT).

2.5. Simulation scenarios and results

Three alignment conditions were simulated and compared.

Perfect alignment (Baseline)

In the model where there was no misalignment, there was a stable and damp response. Frequency spectra were clean with the fundamental rotational frequency (7.5 Hz) prevailing and with little harmonic content which is a sign of a mechanically stable system under ideal conditions.

Parallel and angular misalignment

A combined fault case of 0.5 mm parallel and 1° angular misalignment was modeled to replicate suspected field conditions. The results were radically dissimilar. The time-domain plots exhibited sustained sinusoidal oscillations in displacement, velocity and acceleration that indicated a persistent undamped vibrational force.

Vibration signature and amplification:

The analysis of the misaligned case in the frequency-domain indicated a conclusive diagnostic signature. The most dominant peaks appeared at the 2X harmonic (14-15 Hz) with major energy sources also at the high harmonics (3X, 4X) as well. More importantly, the amplitudes of vibration of displacement, velocity and acceleration in the misaligned model had increased more than 40 percent of the perfectly aligned baseline. This is mathematically shown to create significant cyclic forces even when there is the slightest misalignment.

Conclusion from simulation

The field observations at Chameliya SHP are substantiated using conclusive mechanistic validation through the simulation. It establishes that quantifiable shaft wear, overheating of bearings and high vibration levels are direct outcomes of misalignment. The acceleration in the degradation cycle is the excited 2X harmonic and the root cause (misalignment) is directly connected to the failure modes found on-site. This model can now be used as an anticipatory version of design tolerances and maintenance interventions.

3. Results

3.1. Performance trends across SHPs

The twelve sampled SHPs analysis demonstrated that there was a huge national trend whereby mechanical health was put in relation to the performance of the plants. The data shows that every one of three SHPs (33.33 percent) has chronic problems in its operations. Most importantly, forced outages are caused by mechanical failures, which is the leading cause of about 75 percent of all problematic shutdowns. Components such as bearings, shafts, and cooling systems were identified as the major culprits as they amounted to about 50 percent of overall losses in generation. There was a close association found between long periods of large machinery maintenance (average of about five years) with lower plant performance values, such as reduced plant factors and also higher levels of vibration. Further comparative analysis of generation data indicated that plants with low mechanical condition ratings never achieved their designs or target energy output even in high flow seasons, and so the point has been made that not all losses are related to hydrological constraints.

The brief findings of the selected SHPs are illustrated in Table 1.

Table 1: Observations in 12 SHPs

S.N.	Name of SHPs	Capacity in MW	Major Issues	Years duration for major repair	Level of Problems	Measured Parameters in Runner, Shaft and Bearing				
						Shaft Vibration	Thermal effect in shaft and bearing	Variation in speed of Shaft	Shaft and bearing alignment	Condition of runner
1	Trishuli	24	Lack of sufficient water and erosion problems	1	High	Moderate	Less	None	Less	Moderate
2	Chameliya	30	Technical glitches in shaft, bearing and runner integrity	3	Very High	High	High (> 700°C)	High (up to ±13%)	High (> 1.2 mm)	Poor
3	Panauti	2.4	Lack of sufficient water and mechanical issues in moving components	5	Very High	High	High (up to 680°C)	Less	High (> 2 mm)	Moderate
4	Fewa	1	Silting problem, valve, generator, and penstock problems	1	Medium	Moderate	Moderate	—	Less	Poor
5	Radhi	4.4	Bearing, Turbine	1	Medium	Less	None	None	None	Moderate
6	Jiri Khola	2.4	Bearing, Butterfly valve, and Governor	1	Medium	Less	None	None	Less	Moderate
7	Khudi	4	Turbine control and monitoring, Excitation system	3	Medium	Less	None	Less	None	Moderate
8	Mai Khola	4.5	Bearing, Control panel, Bus bar	0.5	Medium	Less	None	None	None	Good
9	Modi Khola	14.8	Intake, cooling system, trash rack	1	High	Moderate	Moderate	None	None	Moderate
10	Puwa Khola 1	4	Governor, Turbine	1	None	Less	None	None	None	Moderate
11	Upper Puwa Khola	3	Current Transformer/Potential Transformer damage	0.5	None	Less	None	None	None	Good
12	Lower Modi	10	Runner silting, Cooler jam in winter	1	Medium	Less	None	Less	None	Moderate

3.2. Case study I: Panauti SHP

A traditional example of mechanical degradation of hydropower infrastructure is the Panauti SHP, a 2.4 MW plant that was commissioned in 1965. The traditional mechanical design has caused the problem of incessant reliability, despite a strong civil structure. The plant has a long horizontal shaft (1000 RPM) attached by five bearings and three couplings so that its design is susceptible to inherent instability.

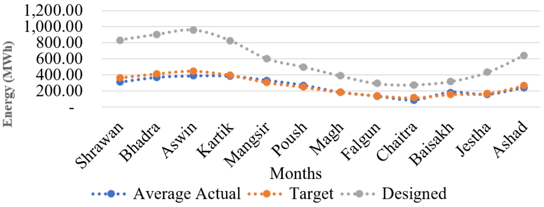

Figure 2: Actual generation vs target generation vs designed capacity of Panauti SHP since 2076/077

The figure above shows the actual, target, and designed capacities for the electricity generation of Panauti SHP. The average data generated for 5 years is the generated data which is very low in comparison to the designed value. It has a massive influence on the financial and energy security dimension.

Mechanical failures and thermal diagnostics

Field inspection and thermal imaging diagnosed severe faults in the rotor-bearing system.

Chronic overheating

Infrared thermography revealed critical temperature excursions. Temperatures around the generator and excitation system were 51-67 °C, and there were hotspots of 68 °C. Conversely, the turbine bearing temperatures were low (36-40 °C) yet exceeded the limit of safe operating temperature of Babbitt material. Such asymmetry in the axial temperature indicated a lack of alignment and lubrication or cooling.

Shaft and bearing integrity

The long shaft span became prone to deflection and vibration, resulting in historical misalignment of over 2 mm and even shaft failure. The high interfacial temperatures led to the welding of the shaft to the sleeve bearings, and broke inner races and linings. This was a system failure due to the bearing design being under thermal and misalignment stress.

The illustrated Figure 5 represents the machining of the shaft for adjusting the replacement bearing to overcome the issue mentioned.

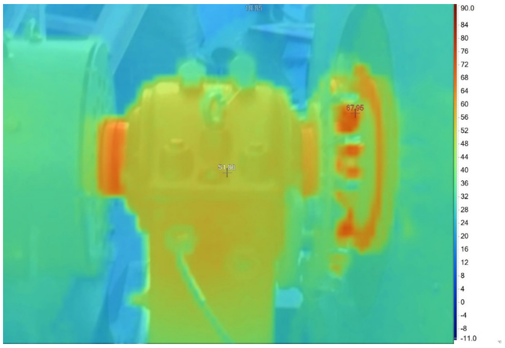

Figure 3: Thermal image near the excitation bearing at Panauti SHP

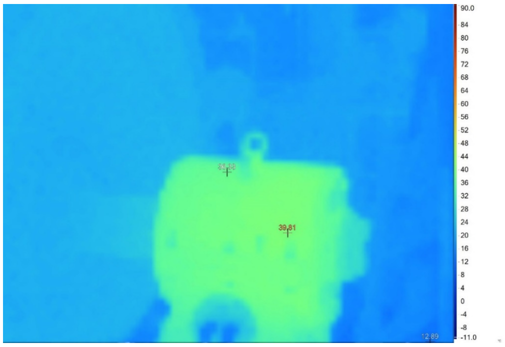

Figure 4: Thermal image around the runner bearing at Panauti SHP

Figure 5: Bearing holding the shaft with the flywheel

Systemic design limitations

The original designs of the governor and the turbine casing were mechanical in nature and thus leaked and were inefficient. Although the control system was subsequently modernized, the basic mechanical drive train was one of its weaknesses.

Operational impact

The cumulative mechanical degradation directly impacted plant performance. Operational data confirm a steady decline in generation output before rehabilitation efforts. Two of the three original units have been inoperative for years, reducing the plant's operational capacity. The persistent mechanical issues, evidenced by severe thermal signatures and component failures, validate that deferred and inadequate maintenance of the mechanical system was a primary factor in the plant's declining energy yield, separate from hydrological variability. This case underscores that aging SHPs with obsolete mechanical designs require holistic rehabilitation, as piecemeal component repairs fail to address systemic root causes.

3.3. Case study II: Chameliya SHP

The examination of the relatively new, 30 MW Chameliya SHP showed that the major mechanical degradation does not only affect aging plants. The field diagnostics showed that there are a set of interconnected problems that start with the rotor-bearing system.

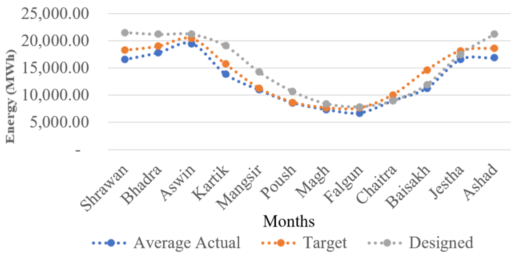

Figure 6: Actual generation vs target generation vs designed capacity of Chameliya SHP since 2076/077

The Figure 6 represents the actual vs target vs designed capacity of electricity generation of Chameliya SHP. The generation data is the average of 5 years generated data which is mostly low compared to designed value. It has significant impact on financial as well as energy security aspect.

The Figure 7 represents the average vibration observed from 2076 to 2078. The vibration seems to be increasing and the rotor RPM doesn't seem to be stable.

Field-measured degradation

Operational instability & wear

The shaft had speeds of 428-500 RPM as opposed to the design speed of 428.6 RPM. This was coupled with misalignment and caused gradual and deep wear at the shaft-guide bearing interface. There was an increase in measured wear, which went up to 0.05 mm (2019) and 1.2 mm (2021), and vibration amplitude peaked at 0.023 mm. Load versus vibration was non-linear: at lower loads (e.g., 0.022 mm with 6 MW and 0.012 mm with 15 MW) it was often found that higher vibrations occurred, suggesting more complex dynamics at work.

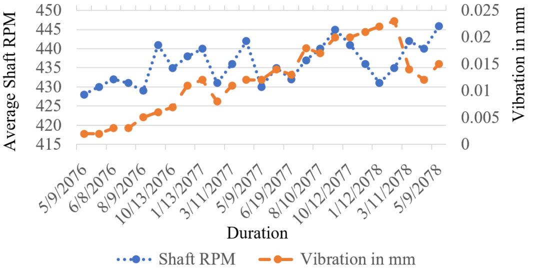

Figure 7: Monthly average vibration amplitude with shaft rpm

Bearing overheating and failure

Sensor data and Infrared thermography indicated that thrust and guide bearings have been experiencing chronic overheating. The Babbitt-lined bearings had a temperature that was average varying between 30 °C-45 °C with higher peaks recorded at the time of increased vibration. This heat strain corroded the Babbitt substance resulting in lining breakdown. It was made worse by the fact that the balance pipe was leaking water into the lubricating oil, thus compromising its efficiency even further and increasing the speed at which the metals met each other.

System synchronization issues

The examination of the shaft speed identified a severe lack of connection between the shown and the real working conditions. Although the control systems came up with a constant frequency (approximately 50 Hz), the RPM-calculated grid frequency error was up to ±13.1% with a standard deviation of 2.536 Hz. This institutional instability was a danger to grid synchronization and indicated mechanical imbalances.

Simulation results

The boundary condition assumed as similar to the field condition bearing stiffness value k_{xx} and k_{yy} value of 5×10^6 N/m was applied to the two faces and an elastic support of 1×10^{10} N/m^2 was applied to account for the effect of the thrust bearing. A moment of 80 Nm and a force of 3000 N were applied assuming that the shaft accelerates to 0–450 rpm in 15 secs and there is a vertical force equivalent to 300 kg of load. A joint rotational velocity load of 450 rpm was applied to the shaft. The mesh size of 0.06 mm was chosen as a compromise between accuracy and computational time. The analysis was run for a single step with a step end time of

3 secs and the number of sub steps 1024. The selected mesh size of 0.06 mm is small (approximately 1/10th of parallel misalignment) relative to the shaft diameter and misalignment magnitude (0.5 mm parallel), ensuring accurate representation for contact, coupling deformation, and bending behavior.

Global dynamic responses (displacement, velocity, acceleration, and frequency) are the key products of interest in this work and not the local stress concentration. The mesh size chosen of 0.06 mm is small (around 1/10th of parallel misalignment) compared to the shaft diameter and magnitude of misalignment (0.5 mm parallel) and will be accurate when it comes to contact, coupling deformation, and bending behavior representation.

The internal check was first done by local refining of the mesh in areas of concern like the coupling and bearing points and the difference between the dominant frequency peaks and the amplitude of displacement results was found to be insignificant. Although no formal mesh convergence study is presented, the selected mesh is fine enough to capture both global dynamic response and frequency content, which are largely controlled by system stiffness, mass and time-step resolution (selected as 1024 sub-steps in 3 seconds) instead of local mesh refinement (which controls localized stress).

Time history plots of acceleration were obtained as the desired location and the Fast Fourier Transform (FFT) was performed to obtain the frequency response plots. The time history and frequency response plots of acceleration plots in the radial directions along the z directions were as illustrated in Figure 8 and Figure 9.

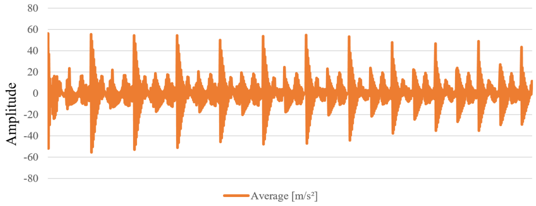

Figure 8: Time history plot of acceleration in z direction

The above acceleration curve represents the acceleration of the shaft in z direction. This data shall be converted into frequency domain in order to identify the exact frequency effect.

The harmonics analysis represented the 1X, 2X, 3X and so on frequency effect in the shaft vibration. This finding concluded that the large vibration of the system that was measured as part of the experimental testing was 2X frequency that was confirmed by comparing its data on experimental result.

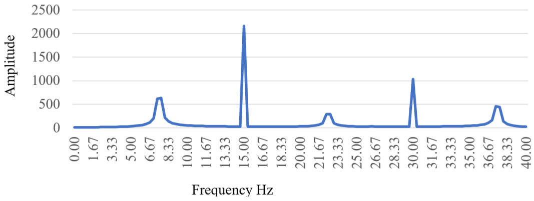

Figure 9: Frequency plot of acceleration in z direction

4. Discussion

The combined results of this research essentially put in question the existing belief that seasonal hydrology is the controlling factor of SHP performance. Although the low flow in rivers is a cause of dry-season deficit, it has been shown that mechanical integrity is a major, and in most instances, a more controllable factor in long-term reliability and energy production.

Key insights emerge from the convergence of field surveys, diagnostics, and numerical simulation.

- **New SHPs are not immune:** The example of Chameliya SHP (30 MW, less than 10 years old) demonstrates that mechanical deterioration is not the problem of aging infrastructure only. Poor design margins of bearing stiffness, cooling and shaft sealing along with operational misalignment can cause a high rate of degradation (misalignment, vibration, overheating, wear) in even a modern plant.
- **System-level rehabilitation is essential for aging SHPs:** The long-term ineffectiveness of Panauti SHP (2.4 MW, over 50 years old) is rooted in the old systemic design, with a long, high-speed shaft, inadequately cooled. Modernization of individual parts (e.g., the governor) was not enough. The case highlights that an interdisciplinary redesign or replacement of mechanical systems, but not individual repairs are necessary to achieve sustainable operation.
- **The high cost of neglect:** The relationship between long maintenance times, low component ratings and low plant factors determines that the overall cost of lost generation and major corrective overhaul is much greater than the investments in regular and preventive maintenance.

The combination of empirical and modelled data is a strong point that enhances the strength of these conclusions. Chameliya field measurements of RPM fluctuations, temperature rises, progressive wear, etc., are directly described and confirmed by the rotor-dynamic simulation. The model provides that the recorded 2X harmonic vibration signature and the ensuing amplification of more than 40 percent are diagnostic of misalignment, which provides a mechanistic connection between the root cause and the resulting failures. This synergistic approach between the evidence on the ground and theoretical review establishes the increased applicability of the research finding to a wider range of settings other than the ones conducted by the researcher in the study and provides a trustworthy model of diagnosis and prevention of mechanical degradation in SHPs in similar situations.

5. Conclusions

This paper shows that among the major causes of underperformance that is chronic in small hydropower plants is mechanical degradation of rotating components. It uses integrated field diagnostics and numerical modelling to give actionable evidence that restoration of much lost generation could be offered by increasing the mechanical integrity, even when hydrological conditions remain the same. A nationwide survey of twelve SHPs determined that 75% of is caused by mechanical failures which are mostly in bearings, shafts, and cooling systems. Extensive case studies of aging Panauti SHP and newer Chameliya SHP indicate the same degradation mechanism. Problems such as shaft misalignment, detected through thermal imaging, vibration analysis and simulations confirm that misalignment results in increased vibration (which, according to simulations, magnifies the amplitudes up to more than 40%), which in turn result in bearing overheating, accelerated wear of Babbitt linings, and erosion of the shaft. This cycle has a direct impact on weakening the reliability and energy production of plants.

This study evidences the impact of the poor maintenance in the hydropower plants. The study identifies the significance of maintenance in the SHPs and suggests that frequent monitoring and undertaking preventive maintenance to reduce a massive loss of money and improve energy security and reliability. The overlap of empirical field findings and computer results has given an approved model of diagnosis and intervention. These lessons provide a vivid, well-grounded avenue for operators, developers, and policy makers in Nepal and other areas to augment the stability, productivity, as well as sustainability of their small but very crucial hydropower infrastructure.

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References

[1] Luis J, Sidek L M, Desa M N M, et al. Sustainability of hydropower as source of renewable and clean energy[J/OL]. IOP Conference Series: Earth and Environmental Science, 2013, 16 (1). DOI: 10.1088/1755-1315/16/1/012050.

[2] Paish O. Small hydro power: technology and current status[J/OL]. Renewable and Sustainable Energy Reviews, 2002, 6(6): 537-556. DOI: 10.1016/S1364-0321(02/00006-0.

[3] Zaiets R. Renewables 2023 global status report energy supply collection[R]. 2023.

[4] Yah N F, Oumer A N, Idris M S. Small scale hydro-power as a source of renewable energy in Malaysia: A review[J/OL]. Renewable and Sustainable Energy Reviews, 2017, 72: 228-239. DOI: 10.1016/J.RSER.2017.01.068.

[5] Kishore T S, Patro E R, Harish V S K V, et al. A comprehensive study on the recent progress and trends in development of small hydropower projects[J/OL]. Energies, 2021, 14(10): 2882. DOI: 10.3390/EN14102882.

[6] Aryal S, Ghimire S, Tiwari S, et al. Evolution and future prospects of hydropower sector in Nepal: A review[J/OL]. Heliyon, 2024, 10(10): e31139. DOI: 10.1016/J.HELIYON.2024.E31139.

[7] Adhikari D. Hydropower development in Nepal[J/OL]. NRB Economic Review, 2006: 70-94. DOI: 10.3126/NRBER.V18I1.53048.

[8] United Nations. The sustainable development goals report[Z].

[9] Yasuda M, Watanabe S. How to avoid severe incidents at hydropower plants[J/OL]. International Journal of Fluid Machinery and Systems, 2017, 10(3): 296-306. DOI: 10.5293/IJFMS.2017.10.3.296.

[10] Shrestha R, Pradhan S S, Gurung P, et al. A review on erosion and erosion induced vibrations in Francis turbine[J/OL]. IOP Conference Series: Earth and Environmental Science, 2022, 1037(1): 012028. DOI: 10.1088/1755-1315/1037/1/012028.

[11] Kumar K, Saini R P. A review on operation and maintenance of hydropower plants[J/OL]. Sustainable Energy Technologies and Assessments, 2022, 49: 101704. DOI: 10.1016/j.seta.2021.101704.

[12] Singh P, Singh S, Vardhan S, et al. Sustainability of maintenance management practices in hydropower plant: A conceptual framework[J/OL]. Materials Today: Proceedings, 2020, 28: 1569-1574. DOI: 10.1016/j.matpr.2020.04.842.

[13] United Nations Industrial Development Organization (UNIDO). World small hydropower development report 2022[R/OL]. 2022. https://www.unido.org/WSHPDR2022.

[14] Singh R, Bhattarai N, Prajapati A, et al. Impact of variation in climatic parameters on hydropower generation: A case of hydropower project in Nepal[J/OL]. Heliyon, 2022, 8(12): e12240. DOI: 10.1016/J.HELIYON.2022.E12240.

[15] Sapkota P, Chitrakar S, Neopane H P, et al. Problem identification and condition monitoring status of Nepalese power plants[J/OL]. IOP Conference Series: Earth and Environmental Science, 2022, 1079(1): 012064. DOI: 10.1088/1755-1315/1079/1/012064.

[16] Pandey R, Shrestha R, Bhattarai N. Identifying some regularities of hydropower components functioning for proper operation of

Chameliya hydropower plant in Nepal[J/OL]. Eastern-European Journal of Enterprise Technologies, 2023, 5(8): 31-40. DOI: 10.15587/1729-4061.2023.290012.

[17] Hopf G, Schuler D. Investigations on large turbine bearings working under transitional conditions between laminar and turbulent flow[J/OL]. Journal of Tribology, 1989, 111(4): 628-634. DOI: 10.1115/1.3261987.

[18] Department of Electricity Development, Government of Nepal, Ministry of Energy. Guidelines for operation and maintenance of hydropower plants, substations and transmission lines[R]. Government of Nepal, 2017.

[19] Hariharan V, Srinivasan P S S. Vibration analysis of misaligned shaft–ball bearing system[J/OL]. Indian Journal of Science and Technology, 2009, 2(9). DOI: 10.17485/IJST/2009/V2I9/2952144.

[20] Hassan L M, Ali J K. Diagnosing the effect of misalignment on a rotating system using simulation and experimental study[J/OL]. Al-Kitab Journal for Pure Sciences, 2023, 6(2): 46-64. DOI: 10.32441/KJPS.06.02.P5.