RESEARCH ARTICLE | FEBRUARY 14 2024

Analysis study of the influence of high vibration on Kaplan turbine generation capacity in Haditha plant FREE

Bashar Hassan Attiya ✉; Ahmed Ali Najeeb Alashaab; Abdulmuttalib A. Muhsen

AIP Conf. Proc. 3009, 030010 (2024)
https://doi.org/10.1063/5.0190424

Analysis Study of The Influence of High Vibration on Kaplan Turbine Generation Capacity in Haditha Plant

Bashar Hassan Attiya [1, a)], Ahmed Ali Najeeb Alashaab [2, b)] and Abdulmuttalib A. Muhsen [3, c)]

[1]*The State Company of Electricity Production, Ministry of Electricity, Haditha-Iraq.*
[2]*Mechanical Engineering Department College of Engineering, University of Anbar, Ramadi -Iraq.*
[3]*Faculty of Power and Aeronautical Engineering, Warsaw University of Technology, Warsaw-Poland*

[a)] *Corresponding author: bashar.attiya@alum.lehigh.edu*
[b] *ashaab_1977@uoanbar.edu.iq*
[c] *abdulmuttalib.muhsen.dokt@pw.edu.pl*

Abstract. Hydropower plant operation and load management have become very complex task in recent years. This is due to the increased load demand and the need to preserve the integrity of the plant structure from abnormal operational regimes impacts. Haditha power plant in Iraq is considered in this study. The aim is to investigate the influence of operating the plant units at different loads on the vibration levels generated in the unit structure. Vibration trends of two Kaplan turbine units within Haditha plant are collected and analyzed at upstream water level of 145.91m. In the first part, displacement signals for units four and six are collected at multiple load points at the turbine lower guide bearings. The peak to peak data of the displacement indicated that an increased level of vibration occurs between the loads 20 and 50 MW. In the second part of this study, rms data of the velocity signals are collected and analyzed for quality judgment. The trend of rms indicted that between 20 MW and 50 MW of unit's load, the unit exhibit vibration levels that is above the accepted levels according to the ISO 10816. Based on the above findings, the plant operation modified and was allowed to operate only for loads below 20 MW and loads equal to or larger than 50 MW.

INTRODUCTION

Conventional type hydropower plants are one of the oldest and most efficient renewable energy sources around the globe. It is still considered very essential in the sustainable development of many countries, and more importantly to developing countries. In 2021, the share of hydroelectricity production was 16% of the total generated electricity worldwide [1]. Although, the hydropower plant has a very high initial cost, its operational cost is very minimal and provides very flexible operational regimes. This type of renewable energy is considered to be the only renewable source which can supply an extended power range with immediate response to electrical grid sudden changes in demand. This make such plants operate in a very wide range of operational regime associated with different loads that sometimes can be very transient in nature [2][3]. This type of sudden load changes imposes adverse impact on the hydro unit multiple components (turbine, governor system, civil structure, etc.). The extent of such adverse effect may range from small concrete cracking up to complete loss of hydro unit due to damage in its mechanical structure. Such kind of operational regimes will increase the vibration level that is exerted on the unit and hence decreasing the generating unit availability and increases the maintenance costs [4].

Vibration happens in all hydropower plants. Typically, the vibration causes in such plants are primarily the direct consequences of three main sources: hydraulic, mechanical, and electric [5] [6]. The main source of vibration in hydro turbine units is typically the results of hydraulic instabilities within the water passage of the unit [7]. Sudden changes in flow conditions passing stay ring and runner with the associated cavitation, pressure fluctuation due to draft tube vortex rope, and the runner blade tip cavitation are among the uppermost hydraulic instabilities [8] [9]. To understand the extent of such issues on the hydro plant integrity it is imperative to investigate the effect of operational regimes on the vibration levels and hence the integrity of the plant.

2nd International Conference for Engineering Sciences and Information Technology (ESIT 2022)
AIP Conf. Proc. 3009, 030010-1–030010-8; https://doi.org/10.1063/5.0190424
Published by AIP Publishing. 978-0-7354-4835-3/$30.00

In order to maintain the integrity of the hydropower plant it is essential to detect any fault within the hydroelectric units in the plant. Recently, early fault detection based on monitoring hydroelectric unit vibration signal has gained a lot of attention from researchers. The reasons for such recent attention are due to the fact that such approaches is associated with high levels of sensitivity, online and offline continuous monitoring capabilities, and ease of implementation in different operational environments [10]. Vibration monitoring and analysis is very essential in minimizing unnecessary hydropower plant outage through early detection of any irregularities in the vibration levels. These hydroelectric unit failures can be associated with a very high cost in emergency repairs and also in the loss of power generation. Lei et al. [11] reported that machine health approaches based on vibration monitoring is very attractive to both academic researches and industrial operators in the recent years. Such techniques can aid in early detections of structural problems within the hydropower plant which can cause damage to several components.

Several studies have been conducted to understand the influence of vibration levels on the hydropower units and its subsystems. Sridharan and Kuppuswamy [12] conducted an experimental vibration analysis using vibration-monitoring techniques on bulb type hydro turbine. The aim was to understand the sources of the vibration and its influence on the plant and propose mitigation techniques. The authors reported high levels of vibration during different stages of the unit load profile. Such high levels of vibration have been a severs problem in conventional hydropower plants for many years [13][14]. It is crucial for the policy makers and the technical staff in such a plant to have an early indication of such issues and how to mitigate the adverse effects of it. Vibration analysis within the general condition monitoring approaches is very crucial to give an early warning and save money in emergency maintenances. Mohanta et al. [15] reviewed the different sources of vibration in hydropower plants and the different approaches to mitigate it. The authors reported that one of the key aspects of any solution of this issue is the vibration condition monitoring and analysis of the investigated case. According to the study vibration data of different components, rotating and stationary, within the plant is crucial in the understanding of the extent of the problem and hence the correct approach to be used in the mitigation process.

Lian et al. [16] investigated the effect of vibration on the powerhouse of a plant with bulb turbine. The authors reported that due to the unit operation and the flow patterns within the unit vibration excitation occurs in the powerhouse structure of the plant under investigation. Dorji and Ghomashchi [17] reported the different aspects related to hydro turbines failure and its impact on the operational activities of the plant. They concluded that vibration monitoring gives an early warning that can be very crucial in saving the integrity of the mechanical components of the hydro unit. This way any up normal vibration levels can be detected and then, through prespecified control system, reducing the operational activities of the unit or even completely shutting down the turbine to preserve it from any damages.

The main objective of this study is to examine the relation between unit’s load pattern and the associated vibration levels measured at a non-rotating part in Haditha plant hydroelectric units. The aim is to provide the technical staff at Haditha plant and the higher management with the optimal load regimes that can be considered safe to operate the plant within it. The physical aspects of the vibrations sources and remedies to suppress it, in the critical load ranges, are out of the scope of the present work. Future work will include frequency analysis of the vibration signals at different locations in the plant aiming to precisely identify the sources of such high level of vibration. Moreover, experimental, and numerical approaches will be used in the future work to identify the vibration sources and the proper approaches to mitigate such its influence.

CASE STUDY

Haditha hydropower plant is situated on the Euphrates River to the west of Iraq within Anbar province. The plant was put into operation in 1986 with six type Kaplan turbines with design capacity of 110 MW per unit. The units are of the vertical type with each turbine having six movable blades directly coupled to a three-phase generator with an 8.976 m long vertical shaft. Flow from the spiral case into each unit is directed by 12 fixed blades and is controlled by à wicket gate consisting of 24 movable gates. A general layout of Haditha hydropower plant cross section is depicted in Fig. 1 showing a single Kaplan turbine unit with the water passage indicated by arrows starting from the intake radial gate and ending in the draft tube. The rotating parts of the unit are supported by a thrust bearing near the generator and aligned by two guide bearings, upper guide bearing near the generator, and lower guide bearing near the turbine. The manufacturer data of the turbine and generator are reported in Table 1.

Haditha plant has been under the influence of vibration at the electro-mechanical parts and at the civil structures. Such vibration was reported by the plant technical staff during certain periods of unit’s operation. This is usually associated with off design operational conditions that is the direct results of the high demand on electrical power in Iraq. Such operational conditions will result in hydrodynamic instabilities in the hydroelectric unit which will manifest itself to structural vibration. This results in multiple fatigue type failure at many civil, electrical, and mechanical components in the plant. Evidence of adverse impact of vibration was clearly observable at the upstream gantry crane deck. The steel guard rail of this deck was sheared at several locations due to fatigue. Concrete cracking was also noticed on the main powerhouse floor and also near the gantry crane deck, the bridge deck, and several other locations.Fig.2depicts several types of structural and mechanical failure in Haditha plant. In order to ensure the integrity and the safety of the power plant, vibration analysis related to the load regime is critical in the understanding of such problems.

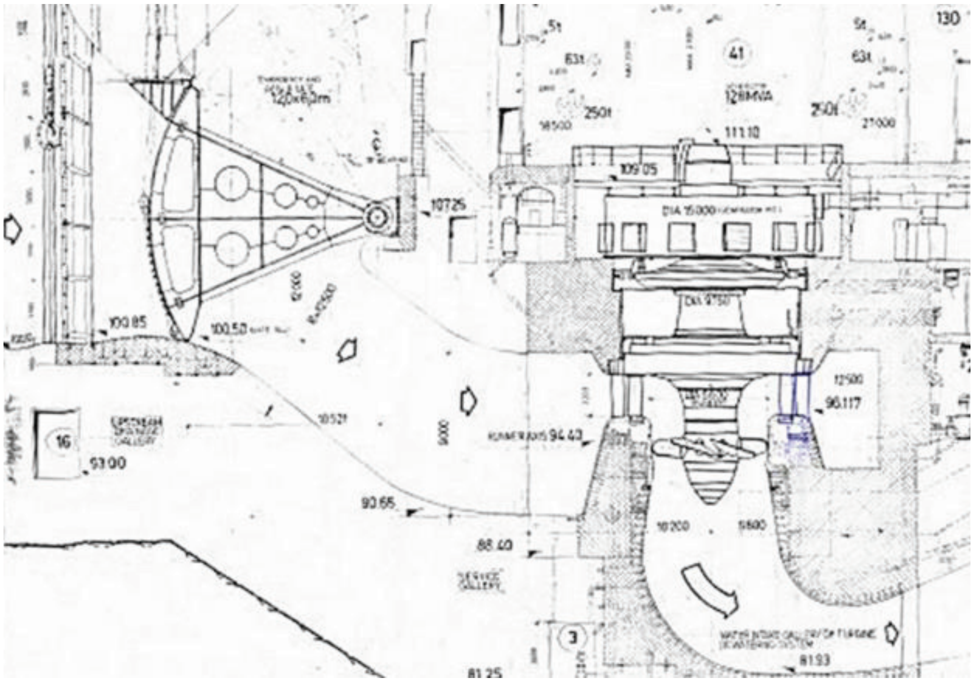

FIGURE 1. As-Built drawing of Haditha hydropower plant. Image courtesy of Ministry of Electricity\Iraq.

TABLE 1: Haditha Plant Turbine – Generator Data.

TURBINE	
Manufacturer	**Litostroj**
Type	Kaplan 6 K 50
Rated Head	36.0 m
Max. Head	46 6 m
Min. Head	18.0 m
Rated Discharge	335.5 m
Rated Power	110 MW
Rated Speed	100 rpm
Runner Diameter	6.6 m
GENERATOR	
Manufacturer	**R. Koncar**
Type	S 9786-60
Dimensions	
Stator External Diameter	11.5 m
Stator Inner Diameter	9.1 m
Weights	
Total	820 Tons
Rotor	405 Tons

FIGURE 2. Runner blade damage (top row), and structural cracks in Haditha plant (bottom row). Image courtesy of Ministry of Electricity\Iraq.

METHEDOLOGY

The condition monitoring approaches implemented in hydro turbines typically measure the different components of vibration at multiple locations. Offline vibration measurement was chosen in this study to assemble a data set concerning the vibration levels in the unit. The Vibrotest 60 from BrüelandKjaer Co. was used in this study. The device was implemented as an offline vibration data logger. In this study, three sets of vibration measurement are executed. The first set of vibration measurement (displacement) were collected at nine different locations within Haditha plant. These nine locations span the entire water passage through the unit, starting from the upstream level at the top of the dam reaching to the lowest point at the turbine guide bearing. The aim of this set is to determine the point with the highest vibration measurement. This point was then used to collect the two remaining vibration measurements sets(displacement and velocity), which then will be used in the quality judgment for the entire unit's load range. In this study, the quality judgment of vibration severity is based on ISO 10816 [18]. All measurements are conducted at fixed upstream water level which is 145.91m. Hence, the effect of water level in the lake is not considered in this study. The data reported in this study is for two units in Haditha plant; unit four and unit six. Only two unit's data are reported here because the data for the remaining four units will be presented separately in future work. Cumulative vibration and the transmission between the six units will be investigated in future work but it is not included in the present work.

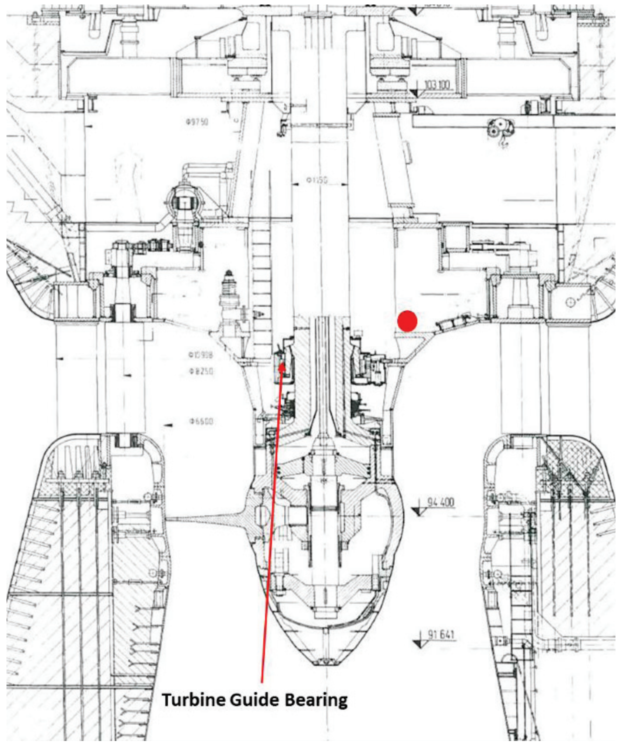

FIGURE 3. As- built diagram of Haditha plant Kaplan turbine cross section, showing the point of vibration measurement (red circle) in relation to the turbine guide bearing location.

VIBRATION MEASURMENT AND ANALYSIS

Vibration measurements for two units, four and six, were chosen to be presented in this study. The first set of measurement were conducted at both civil structure and electro-mechanical systems. In this set the vibration measurements were consisted of displacement measurement collected by using the data logger Vibrotest 60. The data indicated that the point with the highest vibration readings for both units was at the turbine guide bearing structure with peak-to-peak value of 0.15 mm. This can be attributed to the fact that this point is the closest point to the Kaplan turbine runner, which is usually under the influence of very high hydraulic forces within the turbine and draft tube. Flow separation on the runner blades, vortex rope formation within the draft tube and the associated flow cavitation are among the sources of such vibration level in this point.

Figure 4 and 5 show the peak-to-peak displacement measurements for unit four and six attained at the turbine guide bearing. The data were collected for loads from 20 to 100 MW at 10 MW intervals. Examining the two figures indicates that the two units show similar patterns with unit number six having a higher vibration amplitude. Both figures indicated an increase in the level of vibration at loads above 20 MW with a peak value of 1.28 mm for unit four, and 1.9 mm for unit six at 40 MW. The vibration readings start decreasing rapidly at load 50 MW and continue until they reach the lowest values around 70 MW. This indicates a high vibration sensitivity in relation to the unit power between load ranges from 20 to 50 MW. This can be related to the fact that high hydrodynamic interaction and instabilities are increases during this range. This can be seen when investigating the level of sound emitting from the turbine in this range which is related to the cavitation phenomenon caused by pressure pulsation due to flow instabilities.

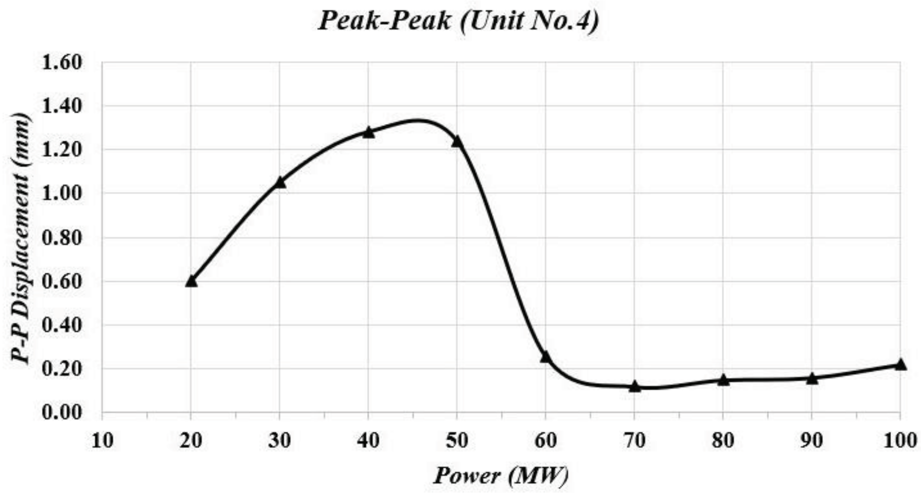

FIGURE 4. Displacement variation with power for unit number four.

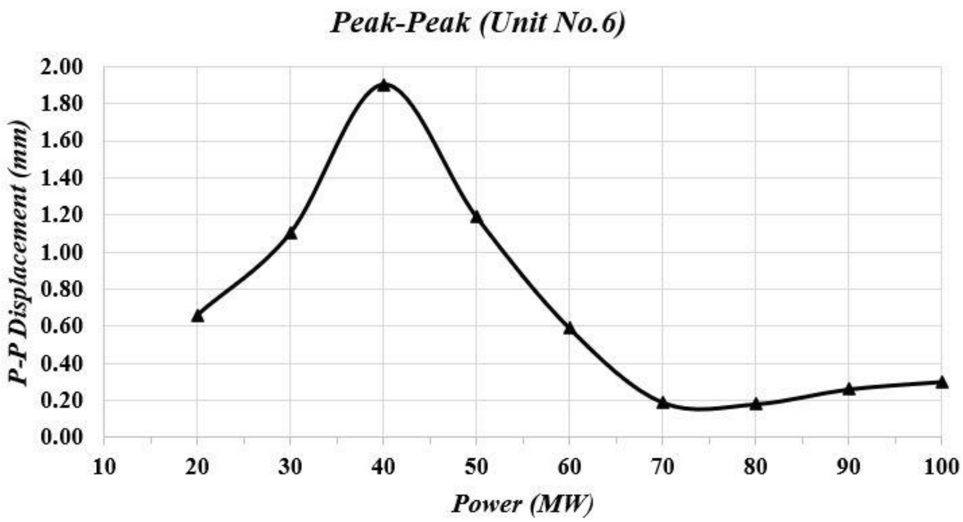

FIGURE 5. Displacement variation with power for unit number six.

In order to make a judgment regarding the severity of the vibration measurements that were reported in Fig.4 and Fig. 5, a quality judgment must be conducted. For this purpose, the ISO 10816 standard was adopted in this study to achieve this goal. This standard defines the rules for evaluating the vibration performance of large prime movers and other large machines with rotating masses only, with a power of more than 300 KW and speeds from 10 to 200 r/s. In this standard and for large turbomachines, the vibration levels, rms of velocity signal, below 2.8 mm/sec considered to be good. Levels between 2.8 and 7.1 mm/sec are allowable. Finally, rms of velocity readings above 7.1 mm/sec is unacceptable.

Quality judgment of vibration severity of unit number four and six are depicted in Fig.6 and Fig.7. In both figures, the rms of the velocity data are plotted as a function of the unit power for both units. Superimposed on the two figures are the vibration severity limits according to ISO 10816. Examining Fig.6, it is clear that when the unit operates at loads smaller than 20 MW or loads equal to or larger than 50 MW the resulted vibration levels are classified as good with few points under the satisfactory condition. In Fig. 7 for unit number six all loading points are within the good limits for the same power ranges. However, for loads higher than 20 MW and lower than 50 MW the vibration severity will be unsatisfactory according to the limits of the ISO 10816 and the units must not be operated under such conditions. As mentioned earlier, this can be related to the increased level of pressure pulsation caused by cavitation during this range. The effect of such up normal levels can be clearly seen during annual maintenance of the unit as sever erosion in the turbine and sometimes even a complete damage of blade, (see Fig. 2).

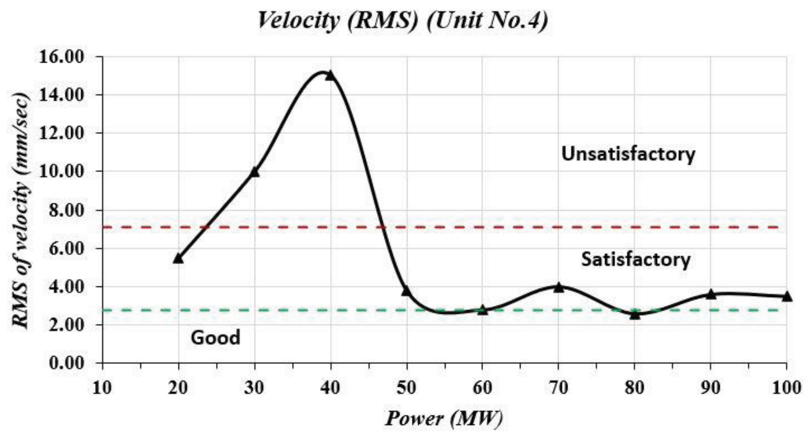

FIGURE 6. Vibration severity judgment for unit number 4.

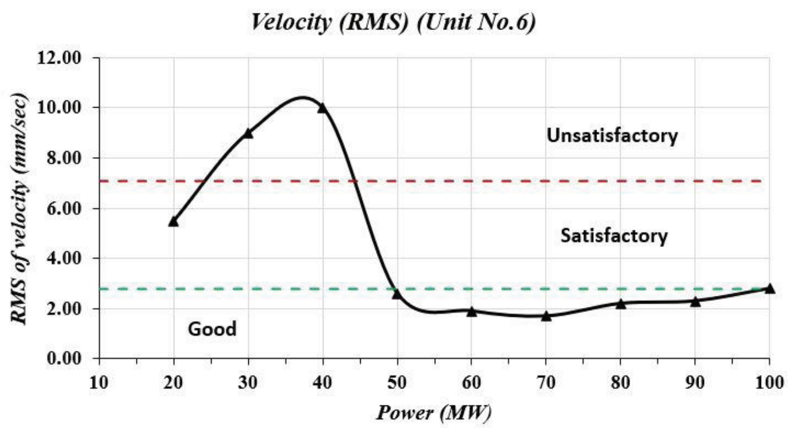

FIGURE 7. Vibration severity judgment for unit number 6.

CONCLUSION

Vibration data analysis for Haditha hydropower plant are collected and evaluated. The aim is to explore the influence of different hydro unit loading levels on the vibration severity within the plant. Inspecting the vibration measurements patterns collected in Haditha plant, it is clear that there is a need to restrict the plant units' operational range, which historically been affected by multiple failure in civil and mechanical components. This is due to the adverse effects of operating these units in their full operation range on the unit structure and the plant integrity in general. According to the findings, the units load should be restricted to loads smaller than 20 MW or to loads that is equal to or greater than 50 MW. In this allowable range the rms values of the measured velocities of units four and six lie in the "Good' to "Satisfactory" regions of vibration levels according to ISO 10816 standards. Further investigation of water level variation in the reservoir is needed to investigate the effects of these aspects on the vibration behavior of the investigated units.

REFERENCES

1. IEA, "World Energy Statistics, 2021," International Energy Agency,(2021).
2. C. Trivedi, B. Gandhi and C. Michel, "Effect of transients on Francis turbine runner life: a review," *Journal of Hydraulic Research,* **51**(2),121-132,(2013).
3. X. Liu, Y. Luo and Z. Wang, A review on fatigue damage mechanism in hydro turbines, Renewable and Sustainable Energy Reviews, **54**, 1-14, (2016).

4. J. Vialle, P. France, F. Grenoble and M. Sabourin, "Prediction of natural frequencies in water Application to a Kaplan runner," in *Proceedings of the HydroVision*, Sacremento, USA, (2008).
5. S. Wei and L. Zhang, "Vibration analysis of hydropower house based on fluid-structure coupling numerical method," Water Science and Engineering, **3**(1), 75-84,(2010).
6. Y. Guo, X. Liang, Z. Niu, Z. Cao, L. Lei, H. Xiong and D. Chen, "Vibration Characteristics of a Hydroelectric Generating System with Different Hydraulic-Mechanical-Electric Parameters in a Sudden Load Increasing Process,**14**(21), 7319, (2021).
7. A. Shen, Y. Chen, J. Zhou, F. Yang, H. Sun and F. Cai, Hydraulic Vibration and Possible Exciting Sources Analysis in a Hydropower System, Applied Sciences, **11**(12), 5529, (2021).
8. L. Zhang, Q. Wu, Z. Ma and X. Wang, Transient vibration analysis of unit-plant structure for hydropower station in sudden load increasing process, Mechanical Systems and Signal Processing, **120**, 486-504, (2019).
9. A. Yu, Q. Tang, X. Wang, D. Zhou and J. Liu, Investigation of the pressure fluctuation alleviation in a hydraulic turbine by runner modification, Water, **11**(7), 1332, (2019).
10. F. Dao, Y. Zeng, Y. Zou, X. Li and J. Qian, Acoustic Vibration Approach for Detecting Faults in Hydroelectric Units: A Review, Energies, **14**(23), 7840, (2021).
11. Y. Lei, N. G. Li, L. N. L., T. Yan and J. Lin, Machinery health prognostics: A systematic review from data acquisition to RUL prediction, Mechanical Systems and Signal Processing, **104**, 799-834, (2018).
12. P. Sridharan and N. Kuppuswamy, "Vibration and cavitation prediction and control of turbine alternator in hydro electric power plants, Australian Journal of Basic and Applied Sciences, **7**(8), 9-28, (2013).
13. S. Nandi, H. Toliyat and X. Li, Condition monitoring and fault diagnosis of electrical motors - a review, Energy Convers., (2005).
14. K. Kumar and R. Saini, A review on operation and maintenance of hydropower plants, Sustainable Energy Technologies and Assessments, **49**, (2022).
15. R. Mohanta, T. Chelliah, S. Allamsetty, A. Akula and R. Ghosh, Sources of vibration and their treatment in hydro power stations-A review, Engineering science and Technology, an international journal, **20**(2), 637-648,(2017).
16. J. Lian, Y. Zhang, F. Liu and X. Yu, Vibration source characteristics of a roof overflow hydropower station, Journal of Vibration and Shock, **32**, (2013).
17. U. Dorji and R. Ghomashchi, Hydro turbine failure mechanisms: An overview, Engineering Failure Analysis, **44**, 136-147,(2014).
18. ISO 10816-1. Mechanical Vibration—Evaluation of Machine Vibration by Measurements on Non-Rotating Parts—Part 1: General Guidelines; ISO: Geneva, Switzerland, (1995).