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RESEARCH ARTICLE

Importance of Real-Time Hydro Power Plant Condition Monitoring Systems and Contribution to Electricity Production

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ABSTRACT

In 2019, 16% of the world's total electricity generation was provided by hydroelectric power plants. Continuity of electricity production can be ensured by monitoring the status of these systems and timely maintenance without causing malfunctions. As hydro turbines typically rotate at a slower speed, they often have to operate at a partial load to meet the fluctuating electricity demands. This partial load process increases the potential for water pressure-related vibrations, turbulence, and cavitation. Continuous operating plant parts are prone to fatigue and damage owing to the excessive vibration caused by these fluctuations. It is possible to ensure that they work in harmony with each other from the smallest parts to large systems using online monitoring systems. This also extends life and increases performance of the power plants because of protected system integrity. In this study, we aimed to examine the importance of real-time hydroelectric power plant condition monitoring and its contribution to electricity generation in detail and presented suggestions for increasing system efficiency.

Keywords: Condition Monitoring, hydro power plant, electricity production, real-time system

Introduction

The use of fossil resources in the production of energy, which has become the main element of the maintenance of life, is high. In addition to increasing external dependency on energy, this brings along with it irreversible/long-lasting damages to the environment. Today, countries are making efforts to lower the use of fossil energy sources to reduce the global warming and greenhouse effect and develop strategies to increase the share of renewable energy sources.

More than 25% of energy needs of many countries worldwide are met from hydroelectric power plants (HEPP). Hydroelectric energy is an important source that provides 50% of the national electricity in 65 countries, 80% in 32 countries, and almost all electricity needs in 13 countries. As of 2019, the installed global hydroelectric capacity is at a level of 1,307 GW, and 16% of the world's total electricity generation in 2019 was provided by HEPPs [1]. In terms of renewable energy sources, Turkey's technical production potential is 216 billion kWh/year from hydropower resources. In addition, it is seen that in today's conditions, Turkey has a potential of 128 billion kWh/year that can be reached both technically and economically and has a great hydroelectric potential waiting to be evaluated. Turkey's 31.8% of the total installed capacity constitutes HEPPs with 29,916 MW installed capacity value [2]. It is notable that hydraulic power plants producing 88.8 billion kWh of electricity were operated efficiently with minimum failure for continuous production in 2019. This was achieved by monitoring the HEPPs properly and managing them efficiently.

Monitoring the operating condition of the bearings in a hydropower unit is a vitally important component of overall facility maintenance and reliability program. Direct monitoring and analysis of the power plant condition, especially the monitoring and analysis of the vibration condition, gives a good idea about the utilization status of hydraulic turbines and enables efficient maintenance operations [3]. In a condition monitoring (CM) system, only data recording and visual curve monitoring is not sufficient. It is necessary to increase the accuracy of diagnosis and predict anomalies using smart diagnostic methods. To achieve this goal, the application of artificial neural networks or the use of artificial intelligence methods increases the reliability of the diagnostic process.

In addition, a joint decision tree can be created for anomaly diagnosis between systems located in different geographical locations

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by remotely monitoring the status of different hydraulic power plant turbines. Thus, it is possible to increase the probability of diagnosing problems in remote monitoring of hydraulic power plant turbines [4].

In this study, the parameters and applications used in real-time HEPP condition monitoring were examined, and recommendations were made to increase the contribution of these systems to electricity generation and system efficiency.

Condition Monitoring Systems and Hydropower Plant (HPP) Applications

Today, it is imperative that operational safety of the machines and hydraulic turbines are protected against mechanical vibrations, and their reliability is high to ensure continuous production. CM systems have features, such as measuring mechanical vibrations of machines and determining different amplitudes of these vibrations.

The online monitoring systems include:

- Rotor, shaft, and behavior of rotating parts are monitored.
- Foundation, concrete structure, body, and physical changes that may occur in fixed parts are monitored.
- The frequency of malfunctions that may occur in a machine is detected and diagnosed and maintenance processes in terms of machine health are put in place.
- The EN 13306 maintenance management strategic approach ensures that maintenance activities are handled with predictive maintenance (PdM) approach.

CM serves to track changes in all parameters within a structure and provide specific detailed metrics on how far the unit is from optimum function. Machine health monitoring provides plant operators the information needed to predict when, where, and how to perform maintenance to keep the plant operational; and eventually increases efficiency and revenue and reduces downtime. Being aware in advance when a piece of equipment is approaching failure allows plant personnel to plan repair/replacement, order parts, and schedule manpower.

CM applications are widely used in wind turbines, power transformers, asynchronous motors, gas turbines, and HEPP units that generate electrical energy. The value of a HEPP depends on the successful operation and functionality of all of its connected parts. Each unit poses an element of manageable risk and requires some form of monitoring to reduce this risk and protect the welfare of the facility. To protect these components from future failures and keep them at optimum operating levels, it is essential to use systems that allow power plant operators to monitor the condition of their bearings, shafts, and other parts when the turbine-generator units are running. These systems are designed to monitor a variety of variables including vibration, lubrication and oil thickness, alignment, temperature, and more.

Main Points

- Online condition monitoring in hydropower plant operation can be improved, and significant savings in maintenance costs can be achieved.
- Online monitoring systems maintain system integrity in hydraulic power plants and ensure that they work in harmony with each other.
- It is possible to maintain the functionality of the plant by extending the life of the equipment using condition monitoring systems.
- If online condition monitoring system of a hydroelectric power plant is operated actively, machine downtime is decreased and profits increase.

Causes of Malfunctions in Hydroelectric Power Plants

During the production of electrical energy in HEPP, the turbines are exposed to constant stress caused by starting, stopping, and partial loading. These processes inevitably lead to material fatigue and equipment damage. A fully functional installed CM system helps prevent or at least reduce the damage caused by the daily operation of the machines.

HEPP turbines are sensitive to multiple parameters that continuously reduce their lifespan. Mechanical forces, material destruction, mechanical crushes, large differences in temperature, cavitation, corrosion, and chemical forces can cause various types of damage in power plants. Over the past decades, many HEPPs have switched from continuous base load operation to periodic and partial load operations. This periodic operation has proven to be more cost effective from an economic point of view; however, it adds additional burden to production units owing to the increased start/stop frequency.

As a result, there is a need to implement an effective CM solution to ensure that incipient faults are detected in a timely manner to avoid major damage and resulting downtime. In Figure 2, the most common malfunctions in the generators of hydraulic power plants and the root causes initiating these malfunctions are given [5].

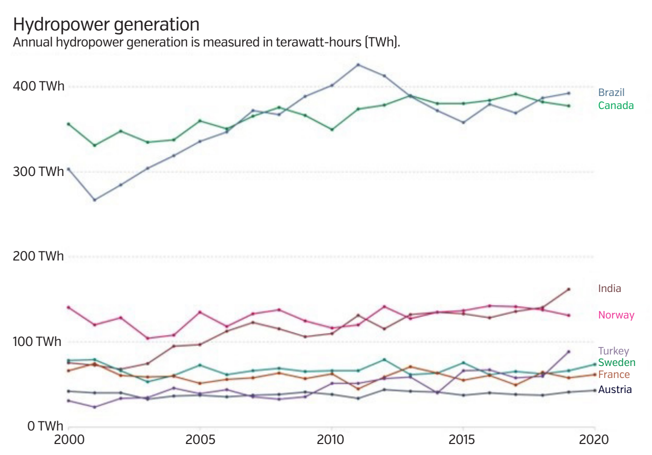


Figure 1. Annual production values of countries that produce the most hydroelectric power worldwide after China (Source: www.ourworldindata.org)

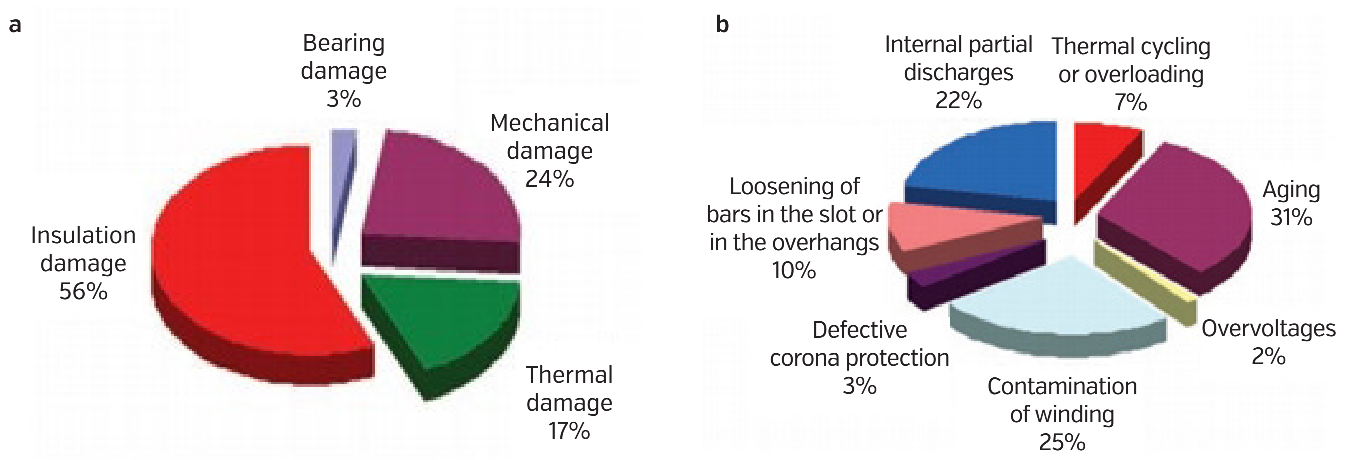


Figure 2. a, b. (a) Damages to hydro generators and (b) root causes of failures [5].

It should considered that all these failures in hydraulic power plants are generally of a slow developing nature. Faults in hydro power plants can be divided into rotor and stator problems.

Rotor problems:

- Change in the positions of the poles,
- Looseness in the rotor ring,
- Deformation in the rotor ring,
- Misalignment in the rotor rotation center.

Stator problems:

- Expansions in concrete (alkali aggregate reaction),
- Stator anchor bolts do not allow thermal expansion,
- Decomposition of stator core and frame.

As the total operating time of the plant increases, expansion and cracking owing to the reactions that may occur in the concrete to which the unit is attached will also cause static eccentricity as it will affect the shape of the stator. The magnetic imbalance in the generator because of static eccentricity causes the shaft to be pulled toward the side by magnetic forces where the air gap is low, together with increase in excitation voltage [10].

Therefore, excessive load can be placed on the bearings, and friction may occur owing to eccentricity in the warning part. Because of machine vibrations and because of the shaft sliding in one direction, the relative shaft vibration sensors in the generator bearings can also be damaged by rubbing against the shaft. As a result, the energy production efficiency of the unit decreases.

Condition Monitoring Systems in Hydroelectric Power Plants

The heart of a typical HEPP is the turbine. Water travels near the turbine runner when passing through the penstock on its way from the reservoir toward the outlet. The flow of water causes the slide blades to rotate and thus the turbine shaft to rotate. The turbine shaft then rotates the generator shaft, creating electricity. Using sensor data collected from turbine components (for example, gearbox, generator, bearings, blades, etc.) can enable predicting malfunctions and to resolve them before they happen as the maintenance program developed using these data ensures that the important components that make up the system are programmed to maintain their health. Furthermore, this will also ensure the implementation of an efficient maintenance strategy [6].

Continuous measurement and monitoring of important parameters gives the opportunity to set warning alarms beforehand. By controlling these parameters, part-specific, generator, and turbine-specific malfunctions can be prevented. Using CM systems in an HEPP, the plant management has an idea of the machine's condition and can make a proper plan or program for replacement. Vibrations are one of the most important values observed by monitoring systems. In all major unit parts, they are also traced in the form of radial relative movements of the shaft relative to the bearing housing in two axes that are rectangular to each other. Absolute vibrations are usually monitored by piezoelectric sensors. However, technological advancements have made optical measurement of vibrations possible**.**

The vibrations alone are indicative, but not sufficient for the exact assessment of the equipment's conditions. Therefore, it is necessary to monitor other parameters that are important in detecting faulty conditions in the machine, as follows [7]:

- **Vibration** in the form of radial relative movements of the shaft relative to the bearing housing in all major unit parts and in two axes that are rectangular to each other,
- **Rotational speed** measured by an inductive sensor and a marker used as a synchronization probe for individual measurement,
- **Clearance and magnetic induction in the stator core** to identify the eccentricity and asymmetry as well as short circuits between turns on the rotor and stator,
- **Shaft currents and voltages** that can damage the bearing,
- **Load angle** during operation because of control and maintenance of stability,

- **Partial discharges** to monitor winding insulation and detect related problems,
- **Optical measurement of temperature** in HV equipment as well as temperature in stator core and bearing,
- **Hydraulic values** in initial line pressures, levels, and flows that give data on turbine operating parameters as indicator of deviations in the reference operating parameters of the generator,
- **Cavitation** that can cause increased wear of machine parts.

Hydroelectric Power Plant Condition Monitoring Sensors and Parameters

The main task in a hydraulic turbine unit is monitoring the situation, protecting the facility, and early detection of a malfunction [8]. Advanced control systems found in hydraulic power plants typically include the control of the following sub-systems:

- Vibration,
- Partial discharge (PD: Partial discharge - monitoring),
- Magnetic flux generator,
- Air gap (between rotor and generator stator),
- Required temperature and process parameters.

CM standards, which are widely used in hydraulic power plants, include the following techniques:

1. Vibration
2. Infrared thermography
3. Acoustic emission
4. Ultrasonic
5. Tribology and oil sample analysis

The main parameters in the continuous monitoring of the turbine-generator group in HEPPs are given in Figure 3. The sensors and parameters commonly used for CM in hydraulic power plants are:

- Vibration in bearings,
- Bearing oil thickness,
- Cavitation,
- Vortex rope turbulence,
- Generator air gap and magnetic flux,
- Turbine speed and brake system,
- Temperature in high voltage areas.

Online CM software is used to measure mechanical vibrations in the machines with the PdM approach of maintenance activities and to monitor other condition analysis parameters and to evaluate these detected anomalies. Figure 4 gives a typical CM system program user interface.

Air Gap Sensor

The generator belonging to the hydroelectric unit has the components shown in Figure 5. Rotor poles rotate mounted on the rotor ring, which is connected to the shaft by means of the rotor. There is a circumferentially uniform "air gap" between the stator wall where the windings are located and the poles. Many systems are designed to monitor the condition of hydroelectric turbine-generators. The air gap, which is a measure of the distance between the rotor and the stator, is critical information for the life of a hydroelectric generator. A non-concentric rotor and stator can cause various problems in the generator that can lead to damage and inefficiencies to key components.

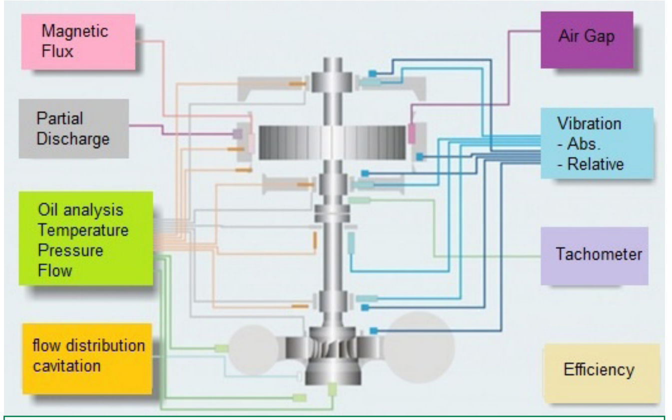


Figure 3. Parameters of the turbine-generator group in hydroelectric power plants.

Any change of the relative position between the rotor and the stator will cause the air gap to change, and this change will affect the mechanical, electrical, and thermal balance of the generator [10]. There are many types of malfunctions that can cause a change in the nominal air gap determined in the design of the unit. The air gap measurement allows operators to monitor rotor and stator shapes, positions, and minimum air gap dimensions. It provides operators with the information needed to shut down the machine before serious damage, such as magnetically induced overheating or rotor-to-stator friction.

Air gap sensors can be placed in the upper and lower levels of the generator (Figure 6). It is suggested that the upper-level air gap sensor should be mounted starting from the upper limit of the stator wall just below vent hole 2. In this way, the sensor will be deep enough to detect the smooth surface of the rotor pole. Generally, non-contact type sensors operating on the capacitive principle are used for the air gap measurement.

Vibration Monitoring Instrumentation

Hydro turbines typically rotate slowly at an operating speed of 75 to 1,000 rpm. Turbines often have to operate at partial load to meet fluctuating electricity demands. This partial load operation can increase the potential for water pressure related vibrations, turbulence, and cavitation. Prime mover components are prone to fatigue and damage owing to vibration caused by these fluctuations. In addition to bearing components, turbine and generator shafts and bearings are also prone to excessive vibration. These vibrations may be the result of imbalance, misalignment, bearing fatigue and/or overload, and insufficient bearing lubrication.

The main sources of vibrations occurring in hydro power plants are given below:

- Vibrations caused by electrical fluctuations,
- Mechanical vibrations,
- Vibrations based on hydraulic change.

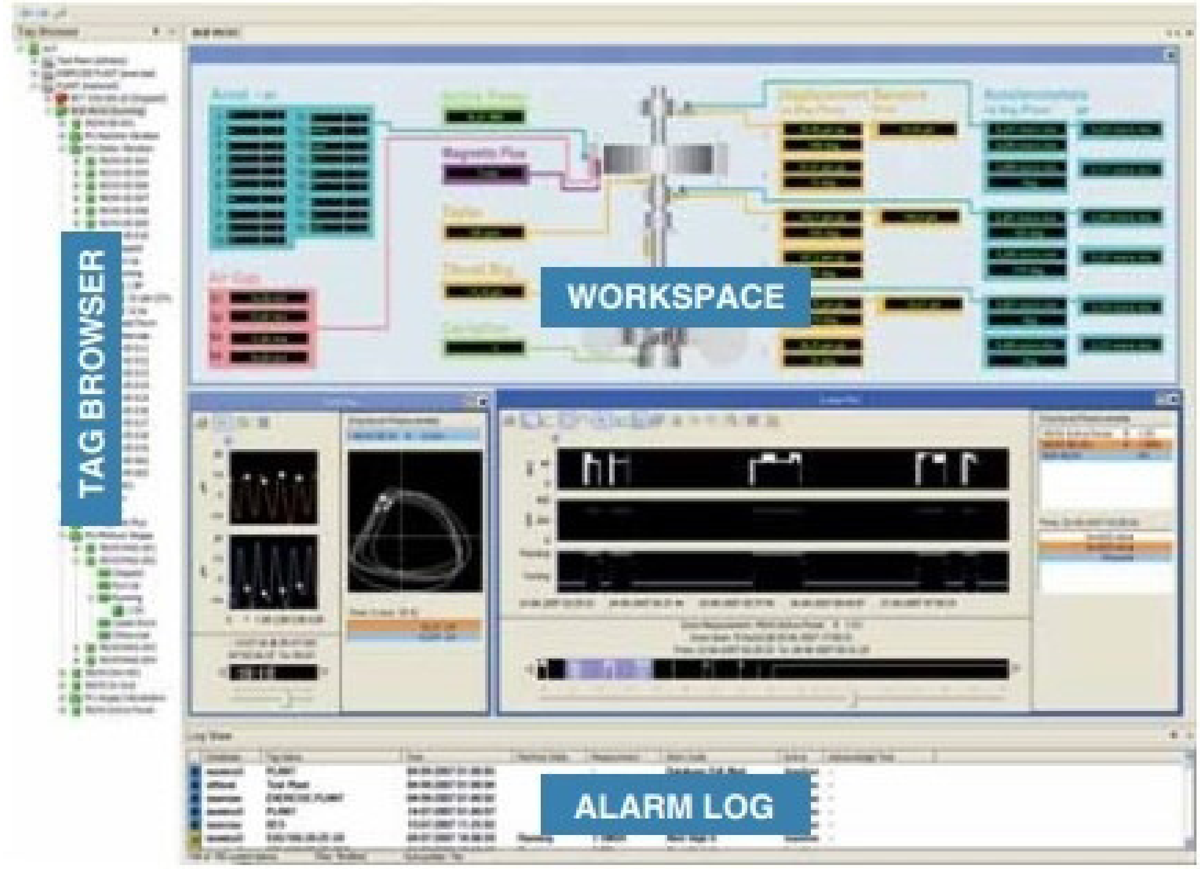


Figure 4. A typical condition monitoring system program user interface.

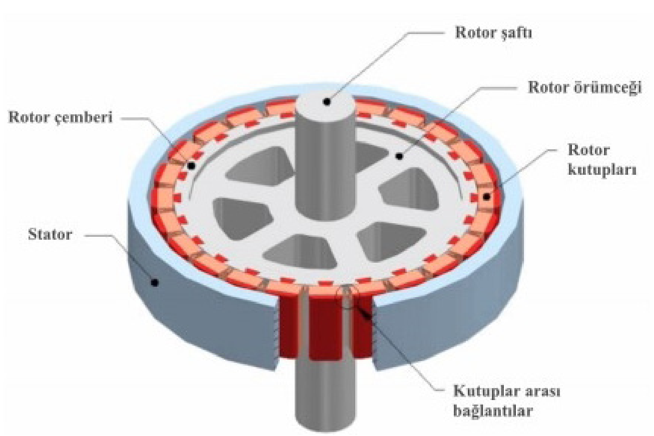


Figure 5. Hydroelectric generator components [9].

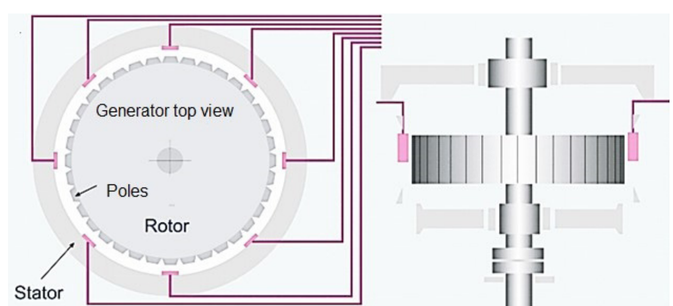


Figure 6. Layout of air gap sensors on the generator [11].

The vibrations occur not only in rotating equipment but also in equipment that do not rotate because of its spreading nature. The vibrations of the hydraulic turbine are caused by excessive force fluctuations caused by cavitation [12].

Bearings play a complex but integral role in the operation of an HEPP and are found in a variety of locations, including:

- Guide bearings both above and below the generator,
- Thrust bearings under the generator,
- Guide bearings in the turbine unit.

Although relatively small in size, a malfunctioning bearing can cause plant shutdown and damage to other valuable components of the plant, including the turbine unit. Defective bearings are caused by normal erosion during use. Machine speed affects the process of finding bearing faults using vibration signals as bearing condition deteriorates. Vibrations in bearing housings may decrease as the failure approaches.

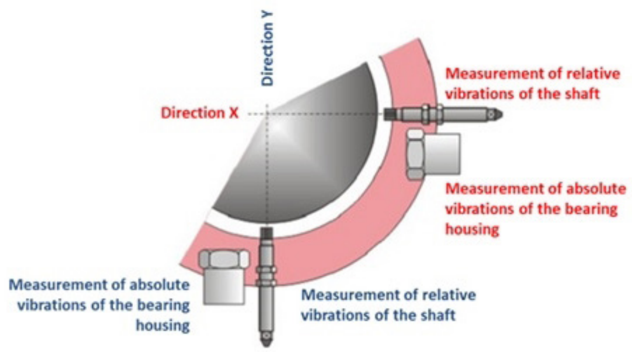


Figure 7. Typical arrangement of vibration sensors

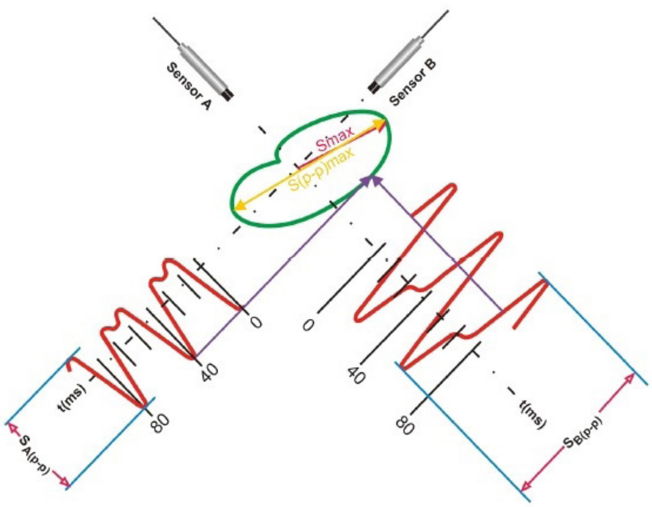


Figure 8. S(p-p) and Smax measurements with double displacement sensor.

Incorrect lubrication of mechanical parts with improper lubrication system parameters causes turbulence of the oil film and results in destruction. According to the statistics given in the literature, approximately 60% of bearing damages are because of improper lubrication. In the lubrication of bearings; suitable oil, suitable lubrication method, appropriate amount, appropriate re-lubrication, and clean oil are factors of great importance [13].

The safe operating condition of HEPPs is based mainly on vibration monitoring. Permanently installed equipment is used to measure overall vibration values at all measurement points at the same time. This type of monitoring equipment creates an alarm and shuts down the machine before a catastrophic failure occurs. As most hydropower equipment has plain bearings, the most effective way to monitor the machine is to measure the vibration relative to the shaft via two displacement probes per bearing plane [Figure 7].

The ISO 7919-5 standard provides recommendations for equipment type, what to measure, where to measure, and acceptable vibration levels for evaluation. The ISO 20816-1:2016 standard specifies the general conditions and procedures for measuring and evaluating vibration using measurements made on rotating, non-rotating, and non-reciprocating parts of all machines. First, when minimizing the negative effects of vibration on the relevant equipment, the aim is to ensure reliable, safe, and long-term operation of the machine [14]. ISO 10816-5 covers Mechanical Vibration - Evaluation of machine vibration with measurements made on non-rotating parts - Part 5: Machine tools in hydraulic power generation and pumping plants [15].

Methods

HPP Condition Monitoring Applications

Application of Relative Shaft Vibrations

The method to monitor and evaluate vibrations in turbines in HEPPs and machine groups in pump stations is described in ISO 7919–5 and ISO 10816–5 international standards. In the measurement of relative shaft vibration, vibration displacement sensors mounted between the shaft and bearing are used in radial bearings; whereas in absolute bearing vibration, sensors that measure vibration acceleration (or velocity) are mounted on the machine block [Figure 8].

The evaluation of the vibrations of hydroelectric machines using relative measurements taken in the radial direction between the bearing and shaft is performed according to the ISO 7919–5 standard. Measurements made within the scope of this standard are called "relative shaft vibrations" and are measured in terms of displacement. Relative shaft vibrations defined in the standard as measured using displacement sensors that are placed radially at an angle of 90° to each other and measure the relative displacement between the bearing and shaft. These sensors do not come into contact with the shaft, and they work on the basis of the eddy-current principle.

Evaluation Zones for Relative Shaft Vibration Measurements

With the standard, the recommended vibration-rating zones for the nominal rotation speed of the machine and stable operating conditions are defined as follows:

- *A-B Major Zone:* Machines whose vibration levels fall in this major zone are considered suitable for long-term operation without restriction.
- *C-D Major Region:* Machines falling in this major region have high vibration levels. The measured values should be checked for their suitability for long-term continuous operation, considering the machine-specific design and operating conditions.

In all cases, relative shaft vibrations should be evaluated by comparing parameters of the bearing diametric clearance and oil film thickness during operation. Tables showing vibration evaluation zones in the standard are given separately for Sp-p (Peak-Peak) and Smax measurements [Table 1]. The standard also mentions the factors to be considered when determining "ALARM" values and "TRIP" values.

- *ALARM (warning):* It was stated that values may vary from machine to machine and that the ALARM level could be deter-

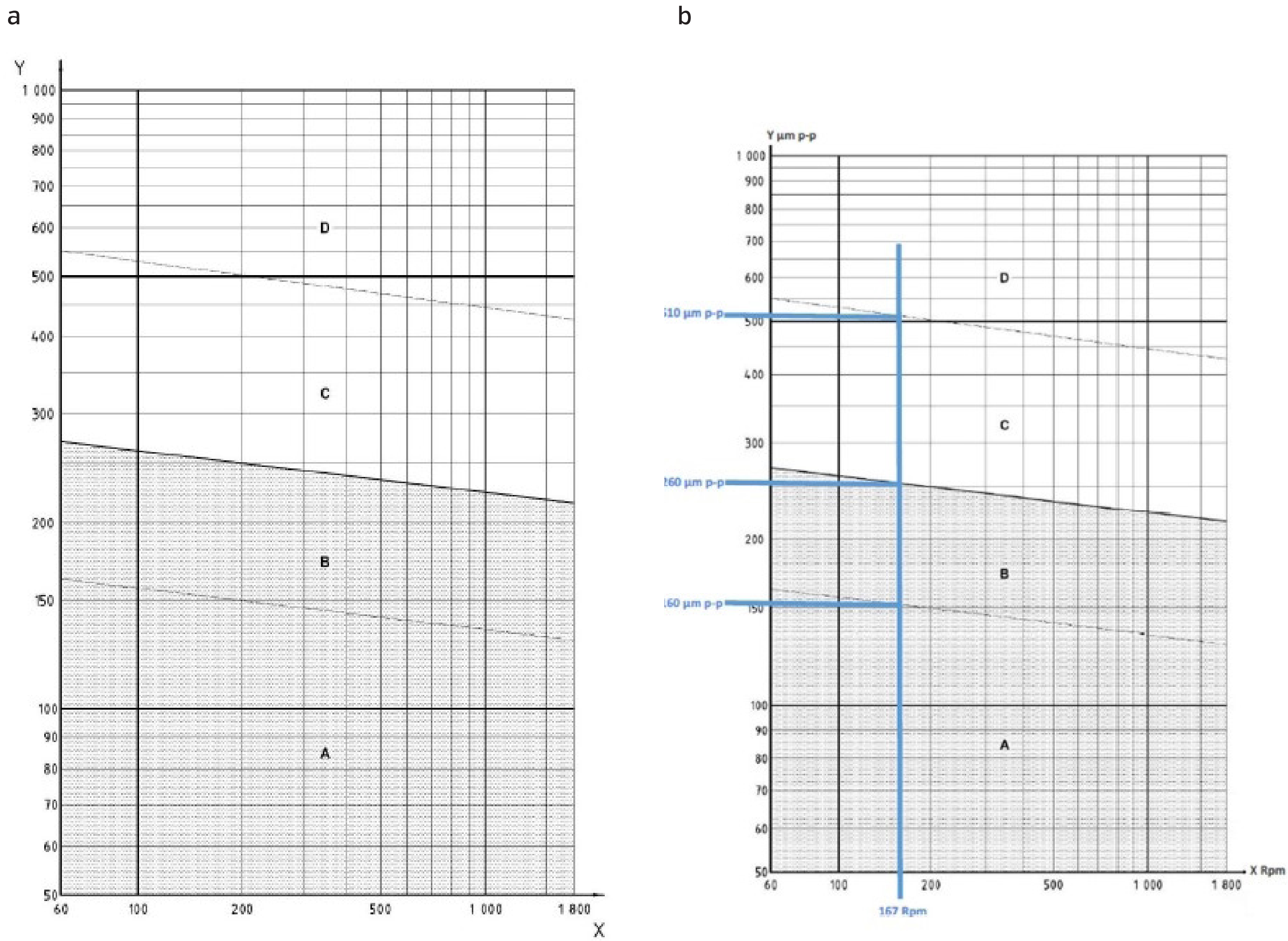


Figure 9. a, b. (a) Table of vibration-rating zones in standard (b) table equivalents of the measurements made in hydro power plant (X: Speed of rotation [rpm], Y: Relative vibration level [µm peak-peak])

Table 1. S(p-p) Vibration evaluation zones included in the standard

Limit values ISO 7919-5		
Limit Name	**Region Definition**	**S_{p-p}(µm)**
Limit A/B	Green Region	160
Limit B/C	Yellow Region	260
Limit C/D	Red Region	510

mined by adding up to 25% of the upper limit value of the A-B major region on the baseline observed under normal operating conditions of the machine. The alarm level determined should not be more than 1.25 times the upper limit value of A-B major region. Depending on the dynamic load condition and bearing stiffness, different alarm levels can be determined in different measurement points and directions in the same machine.

- *TRIP (danger)*: It is stated in the standard that the values will generally be in the C-D major region and should not be more than 2 times the upper limit value of the A-B major region. Considering the experienced data, the µm Smax TRIP level to be determined in the radial bearings should not exceed 85% of the radial bearing clearance value of the bearing to prevent the oil film from being distorted and the shaft from rubbing against the bearing.

In the measurements made in ABC-1 HEPP, the relative shaft vibration assessment has been compared according to the shaft rotation speed of 167 rpm, and the corresponding limit values are shown in Figure 9 and Tables 2 and 3.

When the displacement, orbit, and FFT graphics taken from unit 1 are evaluated, it is seen that the unit operates below the limit value of the A-B major region from the peak-peak vibration evaluation zones given in ISO 7919–5; therefore, in the A region. There were no drawbacks in the long-term operation of this unit, which works in Zone A. Results from the measurements made in hydro power plant are shown in Figure 10.

Table 2. Absolute bearing vibration measurement values taken from Unit 1

Absolute Bearing Vibration Measurement Values

Unit load status	Vibration measurement unit	Combined bearing		Turbine guide bearing	
147.54 MW	mm/s RMS	CH 1 X	CH 2 Y	CH 1 X	CH 2 Y
		0.234	0.271	0.317	0.289

Table 3. Relative shaft oscillation values taken from Unit 1

Relative Shaft Oscillation Values

Unit load status	Vibration measurement unit	Combined bearing		Turbine guide bearing	
		CH 1 X	**CH 2 Y**	**CH 1 X**	**CH 2 Y**
147.54 MW	µm (p-p)	149.7	112.9	124.7	98.61
	1X (So-p)	62.56	29.64	35.81	29.82

Condition Monitoring System Hydroelectric Power Plant Application Results

In this section, information is given about the CM system applied in ABC-1 HEPP with an installed capacity of 600 MW. In this system, relative displacement sensors, which can be used in the frequency range of 0–10,000 Hz and temperatures up to 110°C, and vibration speed sensors that can measure up to 2,000 Hz are used. The location, types, and placement of the sensors used in the system are given in Figures 11-13.

When the units of the applied power plant have a power of around 60 MW, the values taken from the CM system used are shown in Figure 14. The measurement parameters displayed in the CM system used in this application are given below:

- Relative shaft vibration, Smax (µm)
- Absolute bearing vibration (mm/s RMS)
- Relative displacement sensor spacing (gap) (mm)
- Relative displacement sensor gap voltage (V)
- Amplitude and phase values for first, second, third, and fourth harmonics of the vibration
- Cycle speed (r/min)

Contribution of Condition Monitoring to HPP Electricity Production

The advantages of real-time monitoring of production equipment in HEPPs can be listed as follows:

- Operation and maintenance costs are reduced.
- Risks to personnel are reduced.
- Equipment can be changed on the basis of system parameters.
- Major malfunctions that cause downtime can be minimized.
- The life and efficiency of the equipment can be improved.

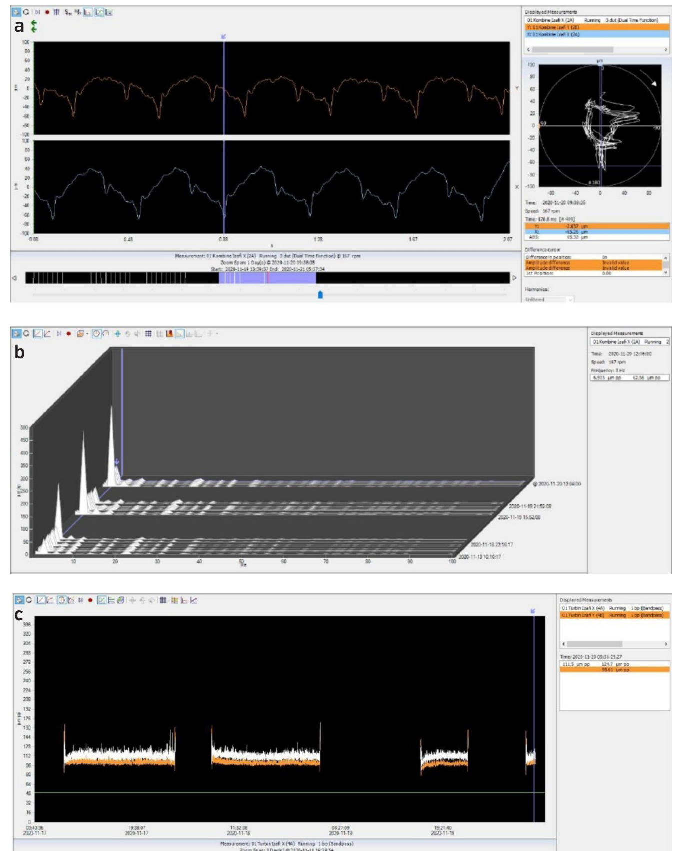


Figure 10. a-c. Display of the results from the measurements made; (a) Relative vibration level in X-Y directions (µm peak-peak) and Orbit plot; (b) Relative shaft spectra in X-Y-Z direction; (c) Relative vibration level changes

- The frequency of downtime can be minimized.
- The machine can be operated within vibration limits.

If the online CM system of an HEPP is operated actively, the cost benefits listed below can be taken according to the reliability of the system [16]:

- Maintenance cost decreases by 50%–80%,
- Equipment failure decreases by 50%–80%,
- Machine downtime decreases by 50%–80%,
- Overtime cost decreases by 20%–50%,
- Machine life increases by 20%–40%,
- Profit increases by 25%–30%.

As an example of the contribution of CM systems to electricity generation in hydraulic power plants, the results of a study carried out in a hydraulic power plant within EUAS can be given. In the hydraulic power plant belonging to Elektrik Üretim A.Ş, which has four vertical axis Francis type turbines with a capacity of 167.4 MW each, a failure of the unit to be kept not available owing to the generator oscillations occurred. The behavior of the generator shaft caused magnetic unbalance because of variable magnetic charge interactions when the current unit was operating.

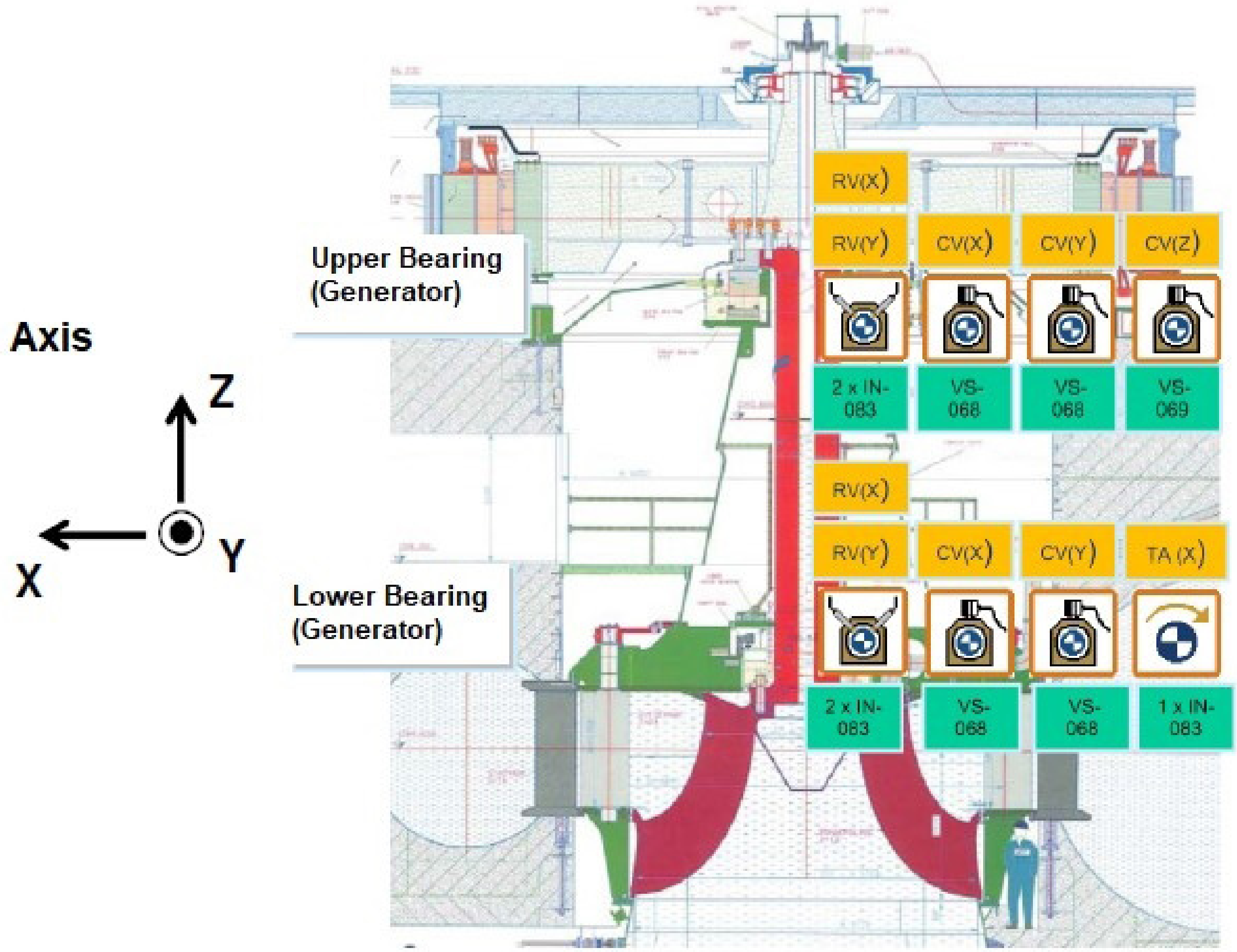
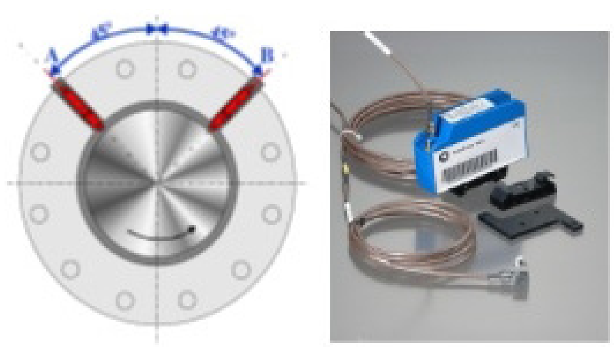


Figure 11. Placement of sensors used in the system.

a



b

Figure 12. a, b. Relative displacement and vibration speed sensors used in the system. (a) Relative displacement sensor, (b) vibration speed sensor.

To eliminate the main problem causing high emissions, the absolute and relative shaft behaviors of the generator have been demonstrated by monitoring the vibration measurements and relative shaft measurements from the fourth unit generator upper guide-bearing areas. Balancing studies have been conducted to dampen the centrifugal forces that cause magnetic unbalance and cause the unit to oscillate excessively. The unit was loaded at 140 MW from the warning position and operated for 6 h from 9:00 to 15:00 (hot position). Oscillation was observed to be at the level of X 185, Y 211 microns. To eliminate the main problem causing high emissions, bed vibration measurements, and balancing application studies have been carried out. Relative shaft oscillations have been brought to the transition zone from the good to the sufficient machinery zone in the quality class in ISO 7919-5 international standards. To evaluate the results of the work carried out, the unit was kept available for six months and operated according

Figure 13. Placement of the sensors used in generator and turbine bearings

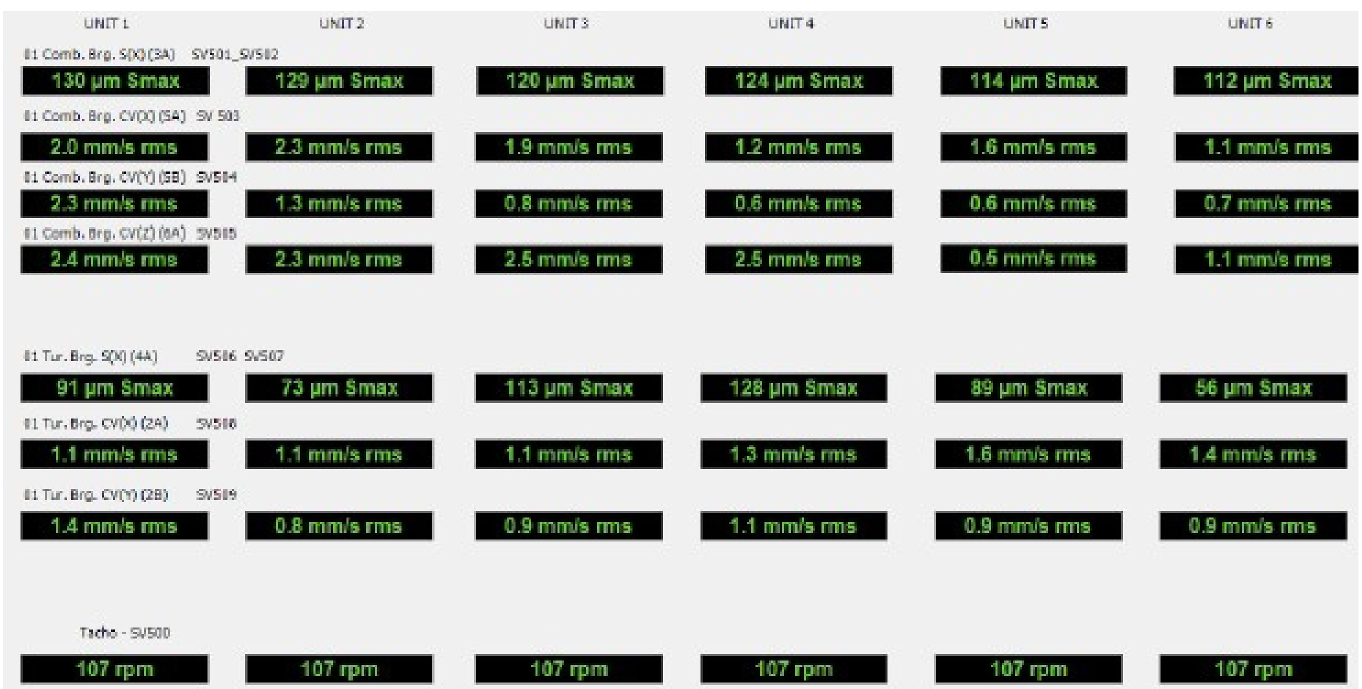


Figure 14. User interface of the information from the condition monitoring system used in the system.

to the daily production schedule consistent with the needs of the system.

The vibration was monitored from the online system for predictive maintenance operations while the unit was running. Because of the unit being on hold for a long time of vibration, it caused both production and discharge of water from the spillway during the flood period. As a result of determining the problem in the generator using CM method and solving the problem, a total of 245.3 million kWh electricity was generated from the fourth unit of the hydraulic power plant between May 28-May 30 and December 20, 2019.

Discussion

Online monitoring systems, which are widely used in the industry, especially in critical equipment, are of great importance in reducing maintenance costs, minimizing machine downtime, and preventing disruptions in production. In particular, online monitoring systems powered by artificial intelligence modules play a major role in making diagnosis of machine faults faster. With the integration of Enterprise Resource Planning software, it provides support for important inputs of maintenance planning at the point of tracking stocks of machine spare parts and faster procurement.

There has been a huge amount of application of cloud technologies in recent times. It provides rapid access to online monitoring data and the establishment of data infrastructure. It helps experts from different centers to analyze data required for fault diagnosis. Similarly, with the use of modern technologies and innovative methods for the maintenance of HEPPs, the cost can be reduced, the plant's reliable production can be increased, and long-term interruptions can be minimized. Turbine wheel and generator are the most important equipment in an HEPP. CM system, which includes parameters such as real-time online vibration monitoring, continuous air gap measurement, online partial discharge measurements and stator-winding isolation facilitates the abovementioned benefits.

In this study, the structure of a real-time HEPP CM system was examined, and its contribution to electricity generation was presented through an example by giving their applications in hydraulic power plants. It is concluded that if the operation and maintenance are optimized according to the actual characteristics of the turbine, generator, and other important equipment of the plant; the profitability and reliability of the hydropower plant operation can be improved, and significant savings in maintenance costs can be achieved. Online monitoring systems maintains the system integrity in hydraulic power plants and ensures that they work in harmony with each other, from the smallest component of the power plant to the largest components such as turbines and generators. Thus, it is possible to maintain the functionality of the plant by extending the life of the equipment.

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Conflict of Interest: The authors have no conflicts of interest to declare.

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