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A SHORT OVERVIEW ON INDUSTRY 4.0 IN MAINTENANCE OF HYDROPOWER PLANTS

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***Abstract**. Energy generation in hydropower plants is becoming of greater importance with the introduction of other renewable energy technologies because of its ability to stabilize the grid. The arising issues are that hydropower units are often operated in unfavorable conditions, away from their optimal design domain, and the need for updated hydropower scheduling for optimal water management. With the modern technologies brought by Industry 4.0, potential answers arise to resolve the mentioned issues and to optimize hydropower generation as well as to offer greater reliability. This paper gives a short overview on these technologies and their benefits on maintenance in the field of hydropower.*

Key words: Hydropower plants, Industry 4.0, Digitalization

1. INTRODUCTION

The primary goal of Industry 4.0 was to enhance manufacturing processes by achieving a higher level of automatization. Larger amounts of sensors are implemented to obtain more data for better and thoroughly analyses. Digitalization and implementation of IT and modern technologies such as 5G communication, Machine Learning, Big Data, Cloud Computing, Internet of Things and other, enable efficient gathering, storing, processing and analyzing acquired sensor data.

Connecting sensors, devices and other things on the internet and enabling their mutual communication over fast 5G networks laid the foundation for Internet of Things. This gives the possibility of sending and receiving data continuously and remotely, in almost real time. Communication technologies that are internet based allow sensors and other devices to store and acquire data, for example, on a cloud. The cloud consists of hardware and software resources that are remotely accessible. This stored data, historical and real time, can represent a digital model of the technical system of interest. Cloud Computing services, Big Data Analytics and Machine Learning algorithms are then employed to assist evaluating information and act or help in decision-making (Figure 1).

Big Data represents a large quantity of gathered structured and unstructured data with certain complexity. Big Data Analytics are used to process and determine patterns, correlations and other quantities in the data. Statistical techniques and Machine Learning algorithms are also employed for this analysis. Machine Learning algorithms are used on gathered data for their classification, regression, clustering, anomaly detection, feature selection, prognosis and optimization.

Eventually, Industry 4.0 has reached the field of hydropower – Hydropower 4.0, implementing its ideas and new technologies to optimize and offer higher reliability and safe operation along with cost reduction. This is very beneficial, as hydropower is a renewable and relatively green energy source, and can also be used to balance the production and demand of the electrical grid. The advances that were brought are mainly in the area of maintenance, but also in hydropower scheduling, as indicated in [14].

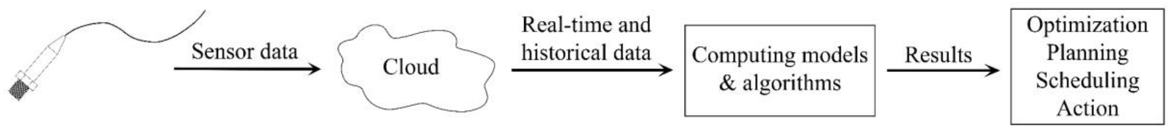

Figure 1 – Utilization of sensor data using contemporary technologies

2. MAINTENANCE

Maintenance of machinery and equipment is very important in order to ensure their reliability and safe operation. Excessive wear and destruction of components can lead to an unplanned shutdown, or even a disaster, compromising safety and usually leading to large costs. A maintenance management conceptual framework for a hydropower plant, that assess the impact of maintenance management on economic, social and environmental performances is presented in [17].

Due to the fluctuating production of energy, hydropower units often work in unfavorable conditions, with frequent starts/stops and away from their optimal design domain, in order to balance the grid. These conditions impose higher dynamic loads and stresses in the hydro unit's components [5,18,20], drastically decreasing their lifetime. Some of the cracks, that can appear under these unfavorable conditions, can go unnoticed by the monitoring equipment. The reason for this is that most monitoring systems measure vibration values and that there is little to no correlation between vibration and crack occurrence and propagation. More details regarding this issue is presented in [10] and a mitigating solution is proposed.

Depending on the reliability and safety importance of the equipment being maintained, several maintenance strategies have been developed: reactive (corrective) maintenance, preventive maintenance, condition-based maintenance and prognostic (predictive) maintenance.

Reactive maintenance strategy involves replacing or repairing the equipment once it failed. This maintenance strategy is considered primitive and it is only used on equipment which failure does not affect safety and costs while it is out of order. A typical example would be a light bulb.

Preventive maintenance is based on scheduling routine checking of the equipment's health and their maintenance. In [2], a failure risk assessment analysis is conducted, based on statistics and staff experience, to enforce inspection priority on certain Kaplan turbine components. In [3] a similar failure risk assessment analysis was carried it for Francis turbine components. Even though this maintenance strategy may not offer the best efficiency in terms of reliability, it is widely used on some hydropower plants.

Condition-based maintenance is based on monitoring certain parameters that reflect the condition of the equipment. These parameters could be temperatures, pressures, vibrations, wear debris in oil, fluid flow, and so on. Condition-based monitoring can be performed online – continuous data inflow and analysis, or offline – gathering data using portable equipment. This type of maintenance is mainly present on large hydropower plants. Topics covering condition-based maintenance of hydropower equipment can be found in [15,16]. IoT facilitates online condition monitoring, as sensor data can be accessed and processed remotely. This means that service engineers, which are valuable and in high demand, can work from a centralized location [6].

Proactive or predictive maintenance is used to estimate the equipment's residual lifetime using statistical methods or Machine Learning algorithms. By acquiring and analyzing sensor data, it is possible to determine an estimate of when a certain component might fail. This enables scheduling in advance so that the component can be timely replaced or repaired.

Vibrations are the most frequently used indicator for estimating a machine's condition. It is because they are the consequence of dynamic force imbalance. In hydraulic turbines, dynamic forces that occur have mechanical (e.g. misalignment, mass imbalance), hydrodynamic (e.g. deviation of geometry and flow angles, hydrodynamic instability in bearings) and electromagnetic (rotor-stator interaction – air gap eccentricity) origin. An extensive analysis on the sources of vibration and their treatment in hydropower stations is given in [12].

Many hydropower monitoring systems store values only of the vibration's intensity and compare it to some prescribed threshold value to alarm if undesirable conditions occur. This data does not provide enough information for a thoroughly analysis. However, gathering vibration data as vector values and plotting vector diagrams gives more information for analyzing the change in vibration and trying to determine its cause [11].

Hydropower 4.0 involves the use of Artificial Intelligence with sensor data to make predictions, anomaly detections and digital twins. Acquired data, such as temperature, pressure, vibrations, is analyzed using contemporary Machine Learning algorithms. Machine learning algorithms used in general for predictive maintenance are described in [7] along with their issues in integration. Identifying patterns, trends and unusual uncorrelated anomalies in data, it is possible to detect even sensor error, as it was done in a case study in [1]. Practical cases of hydropower system maintenance using Machine Learning for data analysis and fault diagnostics is conducted in a join industry project MonitorX [19]. The project mainly focuses on models for condition monitoring and fault diagnosis based on machine learning and artificial intelligence. It includes cases of rotor fault detection, pump condition monitoring and Kaplan turbine hydraulic system monitoring. In the last case, an Artificial Neural Network was first trained and used to make a prediction of the normal state of oil tank level using power, oil tank temperature and oil level in the accumulators. Amorality detection is then possible by determining state deviations from the normal state.

The latest topic of full scale digitalization is utilizing Digital Twins for maintenance, optimization and control. However, as indicated in [14], a small amount of published cases in the field of hydropower are available, probably due to the challenges in mode-rnizing existing hydropower plants. Nevertheless, it is also used in prognostic and condition monitoring of equipment such as bearings [13]. A digital twin for penstock monitoring of a hydropower plant is given in [9], utilizing measured values and analytical formulas for fatigue assessment. Optimization of a cooling system in a power plant using digital twins based on fuzzy logic theory and automatic rules extraction algorithm is given in [4]. A general overview of predictive maintenance using Digital Twins in provided in [8].

3. CONCLUSION

Industry 4.0 and the technologies associated with it have given potential answers for advanced hydro-power maintenance, offering greater reliability. Machine Learning, Digital Twins and analytical models for data analysis, combined with Big Data and IoT seem to give promising results for online remote condition-based and prognostic monitoring of vital hydropower equipment. However, for the widespread implementation of these technologies, more extensive research with practical cases is needed, especially on the topic of hydropower Digital Twin.

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