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Hybridization in Kaplan turbines. Wear and tear assessment

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Hybridization in Kaplan turbines. Wear and tear assessment

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Abstract. In the current energy market, hydraulic turbines are increasingly demanded to work in Frequency containment reserve (FCR) mode to compensate the constant frequency fluctuations in the electrical grid. To do so, hydraulic turbines change their generating power continuously which implies to regulate the flow rate. Kaplan turbines are double regulated machines that change the position of both guide vanes and runner blades to regulate the flow rate maximizing their efficiency. Therefore, guide vanes and runner blades are continuously moving when they provide FCR, leading to high wear and tear of the regulation system components.

Within the frame of the European project XFLEX Hydro, a new technology to reduce the wear and tear of the regulation system in FRC have been implemented. This technology consists in the hybridization of the unit with a battery system. In that way, the battery is the one in charge of providing part of the power fluctuations to the grid, reducing the movements of guide vanes and runner blades of the turbine. The battery system was successfully installed in August 2021 in one unit of the Vogelgrun powerplant, in France. Since that moment, the unit has been working in hybrid mode.
A monitoring system was installed in the power plant in two different units, the one hybridized and another without hybrid system. Several sensors were installed and different parameters were measured simultaneously to calculate the wear and tear of the different components. In this paper, a comparison between the hybrid mode and the standard mode (non-hybrid) is performed in terms of mileage and wear and tear of the guide vanes and runner blades servomotors.

Keywords: Kaplan turbine, hybridization, wear, fatigue

1. Introduction

Hydropower is nowadays very important in the role of providing fast Frequency Containment Reserve (FCR) into the electrical grid [1]. Therefore, hydro units are in charge to compensate frequency deviations in the grid when they are working in FCR mode. They can do that by regulating their output power: they increase the power when the grid frequency decreases and they decrease power when the grid frequency increases. Kaplan turbines are the most used to provide FCR since they can regulate their power by adjusting both guide vanes and runner blades angle maximizing their efficiency.

Therefore, when Kaplan turbines are providing FCR, their regulating systems are continuously moving to regulate the power as needed. This fact could lead to wear and tear problems in the components of the regulation system [2,3]. The regulation system in Kaplan turbines is generally based on oil-powered servomotors which move the guide vanes and runner blades through different links and levers. The components that are prone to have wear are therefore the bearings or bushings of the guide vanes and runner blades and the servomotor pistons themselves. The wear rate for this kind of components is dependent on the distance moved, the contact pressure and the friction material [4,5]. The tear or fatigue in the different components depend on the stress and number of cycles [6] and the stress is consequence of the servomotors forces. Thus, to quantify the wear and tear, it is important to know the total distance travelled by the servomotors, which is also called mileage, the forces done by the servomotors and the number and duration of the movements.

To reduce this wear and tear in the regulating systems, the hybridization of hydraulic turbines has recently been proposed [7,8]. It is based on installing a battery in parallel with the unit which is in charge of infecting or subtracting power from the grid to provide FCR. In that way, the unit has to regulate less its power since the battery is doing this task. Furthermore, the reaction of the battery is almost instantaneous, which helps the stabilize the grid faster.

In this paper, the benefits in terms of wear and tear of the regulating system of a Kaplan turbine prototype are presented. This is part of the scope of the European project XFLEX Hydro [9]. A Kaplan turbine prototype is used as demonstrator to provide FCR and flexibility to the grid. This turbine is located in the power plant of Vogelgrun in France. A battery system was installed and commissioned in August 2021. Since that moment, the unit has been working in hybrid mode. A monitoring system to measure different parameters of the unit was installed. With the experimental data obtained with the monitoring system, the wear and tear of the regulating systems can be estimated by comparing the hybrid operation with the non-hybrid operation of another unit in the power plant. In that way, the benefits of hybridizing a Kaplan turbine can be quantified.

2. Experiment

2.1. Prototype selected

The unit selected for the study is a Kaplan turbine with a maximum power of 35 MW an a rated head of 12 m. The unit has the availability of 4 MW to provide FCR to the grid. The turbine has 24 guide vanes and 4 blades. The guide vanes are regulated using two servomotors located at 180 degrees between them that move a ring where all the guide vanes are connected through levers and links. The regulating system of the runner uses a single piston inside a rotating shaft where the blades are connected. The oil in the servomotors is pumped using a constant speed pump and a proportional valve. Controlling the position of the proportional valve, the position of the servomotors can be controlled. Two units will be studied, one with the hybrid system and another one without.

2.2. Battery parameters.

The battery is provided by Entech with a total power of 650 kW and a total capacity of 376 kWh. The battery size represents de 16.25% of the power available for providing FCR (4 MW). Therefore, the battery is in charge of providing part of the power fluctuations due to FCR but not all of them.

2.3. Sensors and monitoring system

To monitor the units, two MVX Oneprod monitoring systems were installed in two different units (the one with battery and the one without). A total of 32 channels are used in every unit. Vibration, pressure, displacement and operating signals are acquired simultaneously. For this study, the most important signals used are the opening of guide vanes and runner blades, the pressure in the pistons, the active power, the head, the grid frequency and the battery power.

2.4. Testing

The prototype of study is not only providing FCR to the grid while in operation but it is also proving flow regulation. This means that many of the servomotor’s movements are due to the flow regulation and not to FCR. Therefore, it is difficult to separate those manoeuvres that are due flow regulation and due FCR. For that, special tests were carried out in the power plant. The hybrid unit was operating at the same time that the non-hybrid unit for 4 hours with a constant flow-rate setpoint and head. This means that all the changes in the opening would be due to FCR. Figure 1 shows some parameters recorded during the tests for both units.

3. Wear and tear estimation

The wear of bushings of the regulation systems can be studied by analysing the total distance travelled by the servomotors. This total distance has been called mileage (M) and it is calculated as in Eq (1):

$$M = \sum_{t=t_1}^{t=t_2} abs(x_t - x_{t-1}) \quad (1)$$

where x is the guide vane or runner blade servomotor position at time t. This position is calculated with the opening of both servomotors.

The tear of the regulation system has been studied by performing a rainflow analysis of the forces in the servomotors. Thus, it is assumed that the forces are proportional to the stresses in the different components of the regulation system. The forces in the servomotors are calculated with the pressures at both sides of the pistons and with the corresponding area of contact.

4. Results

The servomotors mileage during the tests has been calculated as in Eq.(1) and it is shown in Figure 2. It is observed that there is an important reduction of the mileage for both servomotors in the runner and in the guide vanes. However, it should be noted, that the non-hybrid unit reacts faster than the hybrid unit since the governor set up is different for the two units. Anyway, for these tests where the flow-rate set point was almost constant, the differences in mileage are to be due to the frequency regulation.

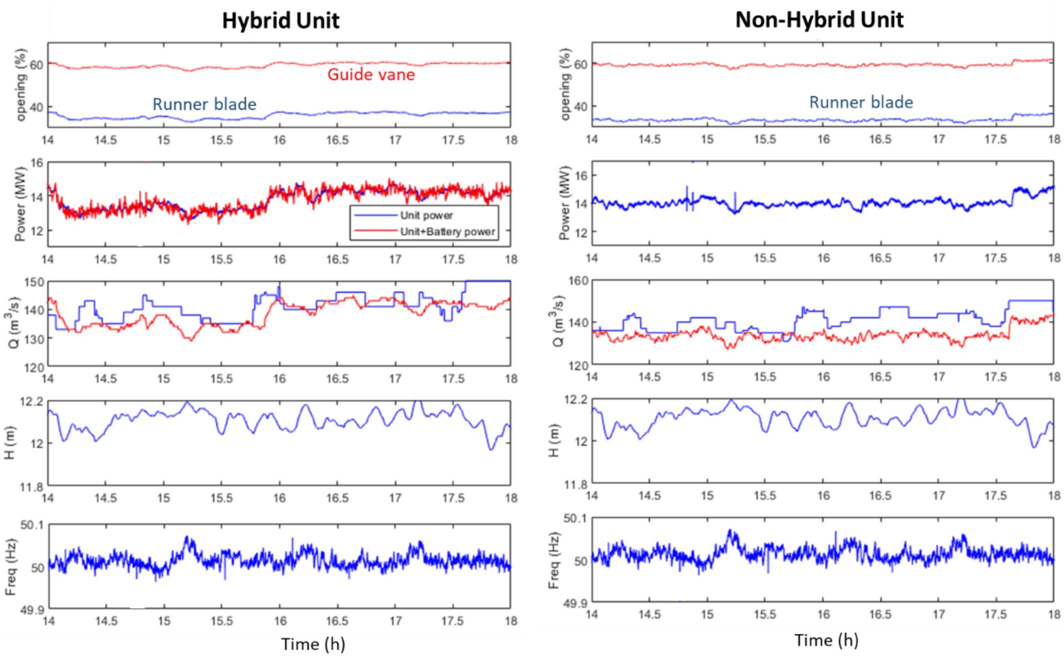

Figure 1. Testing procedure: From up to down: Guide Vane, runner blade openings, unit power, flow rate (red), flow-rate set point (blue), gross head and grid frequency.

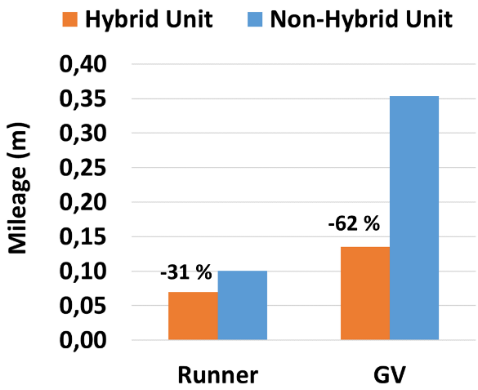

Figure 2. Servomotors mileage for the hybrid and non-hybrid units.

The servomotor forces during the tests are plotted in Figure 3. In this graph, the forces are plotted versus the opening. It is seen that the range of forces in the two units is not exactly the same. This could be due to the different status of the friction materials in the regulation system of the two groups. To better analyse the influence of the hybridization in the fatigue of the regulation systems, a rainflow analysis of the forces is performed. Figure 4 show this rainflow analysis for both units and regulation systems. It is observed that in the hybrid unit, the amplitudes are smaller and less concentrated in a single value, as it is the case of the non-hybrid unit. From the point of view of fatigue, this will reduce the accumulated damage of the components in the hybrid system. However, to quantify this damage, the relationship between the forces and the stress in the components should be used together with a SN curve of the material. At the moment this is not yet done since it will require from numerical simulations.

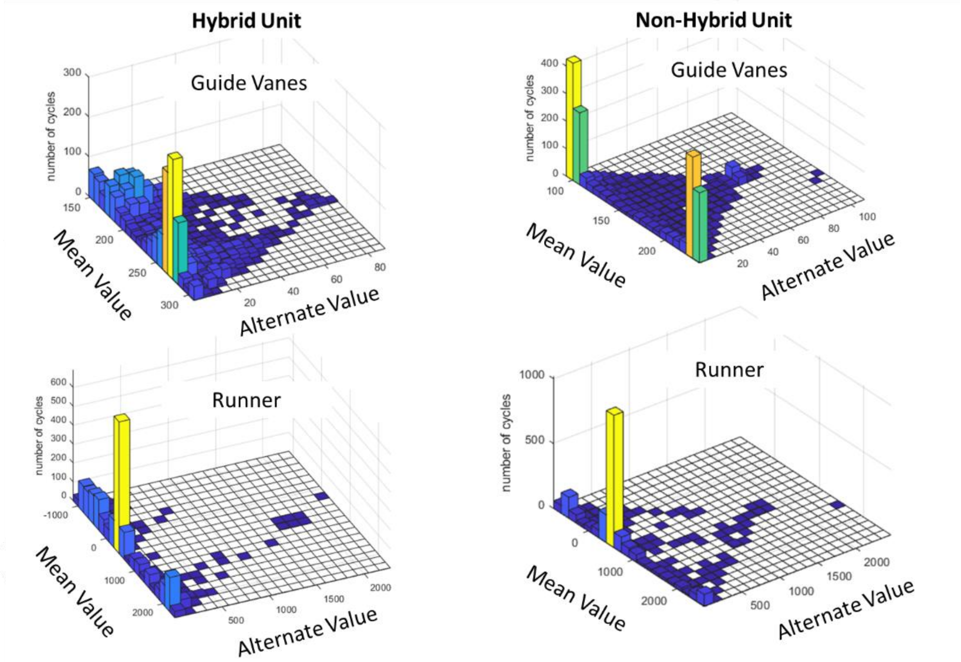

Figure 3. Servomotor forces during the tests.

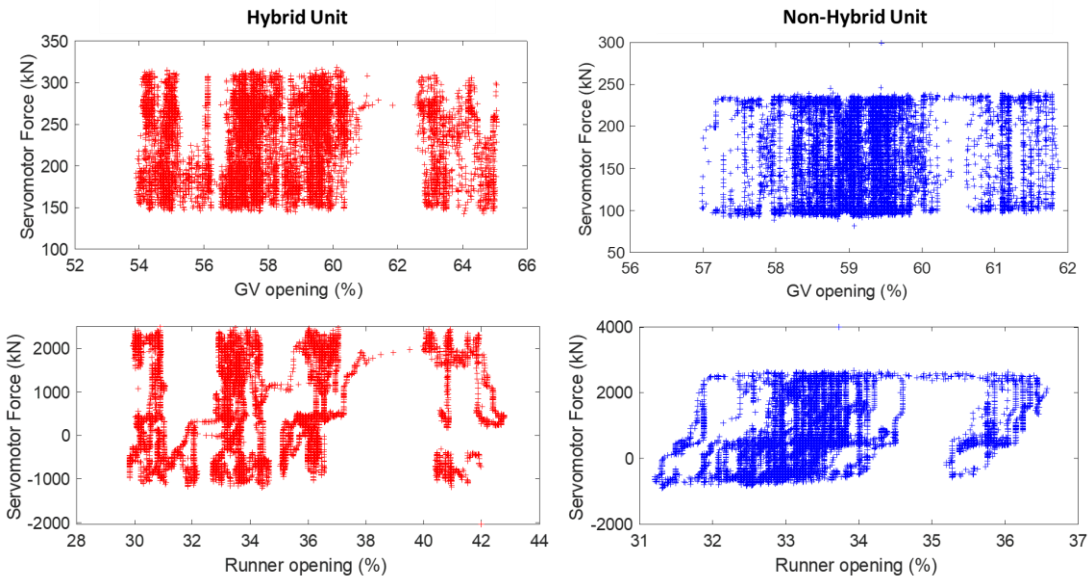

Figure 4. Rainflow matrix of the servomotor forces.

5. Benefits evaluation

To evaluate the overall benefits of hybridizing Kaplan units, the cost of the battery and its life expectancy should be considered. For this case, the battery cells have been selected to have a useful life from 8 to 12 years, considering the end of their life when the energy capacity is down the 60% the original capacity. The total cost of the full battery equipment, including battery cells, inverter, transformer and cabling is about 500.000 €. The battery provides faster response to FCR regulation, which can be also translated into economical savings, plus the maintenance savings of having less wear and tear in the regulating system components.

6. Conclusions

A battery system was installed in a Kaplan unit to evaluate the benefits of hybridization of hydraulic turbines from the point of view of wear and tear. Two units are used to compare these benefits, one hybrid and one standalone hydro (non-hybrid). When hydraulic turbines are working in FCR, they constantly regulate their power to compensate the frequency deviations in the grid. With a battery in parallel, the units can provide this service without regulating that much the power since this task is done by the battery. This hypothetically reduces the number of manoeuvres in the regulation systems and therefore reducing their wear and tear.

Tests with constant flow rate set point were done in the power plant to be able to compare both units under similar conditions. In that way, the servomotors movements are only due to the frequency fluctuations in the grid. The mileage for both units has been analysed, obtaining a reduction of 31% in the runner servomotor and 62% in the guide vanes. Furthermore, the forces of the servomotors have been compared by using a rainflow counting method, obtaining less amplitude values in the hybrid unit than in the non-hybrid, which also leads to a reduce in fatigue.

The unit is working in hybrid mode since August 2021, so the benefits the hybridization will be observed at long time. For the moment, the data is being analysed and compared, and further results about this topic will be evaluated at the end of the XFLEX project.

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