EFFICIENCY MONITORING
IN THE HYDRO POWER PLANT OF FILISUR

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The power plant of Filisur has recently been equipped with a condition monitoring system to survey the real time efficiency as well as its history. In addition, a large number of site specific characteristics are acquired and stored to a database with a sampling rate of 1 Hz. All these data can be analysed on demand over a period of at least three years. For the real time evaluation of efficiency complex stability criteria were developed. With this data base the history of a damage event with an efficiency loss of 1.6 percent within a short time duration could be retrieved and analysed in detail.

1 Introduction

Monitoring of the operation of hydraulic machinery and of hydro power plants has multiple purposes. Since decades vibration monitoring is standard in all larger hydro power plants. Also monitoring of generator, e.g. partial flux or air gap monitoring, is well established. These devices allow early failure detection of electro-mechanical equipment.

With today’s digital storage and data processing possibilities long time monitoring of operating conditions and of stress patterns becomes possible (condition monitoring). Based on such data the life span of machine components can be estimated based on measured data (predictive maintenance). The more detailed data are available, the better the prediction of the life expectancy becomes, e.g. pressure pulsation measurements allow a better estimation of unsteady loads.

In the context of the accumulated start and stops and part load operation since recent years, such a monitoring becomes increasingly significant.

Efficiency monitoring on the other hand focusses on the quality of energy conversion.

Goals of efficiency monitoring are:
- Energetically optimized plant operation
- Optimized operation of machine groups
- Detection of long-term efficiency decay due to wear of components
- Quantification of efficiency increase due to repair works
- Detection of short term efficiency decay due to damaged or blocked elements
- Quantification of energy losses due to frequent start and stops
- Quantification of energy losses due to no load operation

Once energy losses are quantified, they easily can be converted into financial income losses.

Based on the information on efficiency losses due to wear, repair works can be scheduled in the best possible manner. Also the return of invest of eventual
refurbishment projects can be much better budgeted on the basis of quantified long term data of efficiency losses. Especially in North America awareness for efficiency monitoring and implementation of such systems started early with the availability of the developing computer technology [1]. Such systematic analysis of efficiencies of hydro power plants are reported for example in [2] and [3].

Major challenges of systems to monitor efficiency are the long term stability of all instruments, a repeatability of at least 0.2 percent and repeated plausibility tests. Where applicable redundant data should be gathered to increase the reliability of the system.

Experience shows that the acoustic transit time method (ultrasonic method) is especially well suited for monitoring purposes [8]. However, for a real-time efficiency monitoring system not only quantities such as pressure, power and flow rate [4] have to be measured continuously. Further key parameters like blade angles, gate settings, head- and tail-water levels have to be acquired in order to associate the operating point with a point in the hill chart. For detailed analysis of losses, cooling water flow rates and temperatures and additionally all available local pressure measurements are needed.

The IEC standards, e.g. [4], require steady state operating condition for efficiency measurements. However, such steady state conditions prevail rather infrequently in hydro power plants, especially with today’s grid stability requirements. Also surge tank oscillations lead to data fluctuations. This subject of steady state operation requirements is addressed in [5] and [6], where a method for elimination of slowly varying quantities is proposed. A further method to extract quasi-steady operation sequences from acquired real time data in time is discussed in [7] with focus on the hydro power plant of Filisur.

Since the hydraulic system and its response on load point variation is different in each power plant, the monitoring procedures have to adapted individually for each plant. Time constants depend on system characteristics but also on the installed instruments, e.g. acoustic transit time flow rate measurement usually show a slow response on discharge variation.

The output of a monitoring system should not only provide efficiency data but should also allow to identify the causes for an eventual efficiency decrease. Thus a loss analysis has to be included in the system.

Implementing a monitoring system not only requires sophisticated data analysis, but also the efficient handling of a huge amount of data for off-line data analysis in order to enable the evaluation of long-time efficiency histories.

2 Implementation in the Hydro Power Plant of Filisur

The hydro power plant of Filisur, Switzerland, is operated by the Albula-Landwasser Kraftwerke AG. Two vertical axis Francis type turbines of each 32.5 MW are installed. The head varies in the range of 385 to 425 m.

The monitoring system was installed in collaboration with the Albula-Landwasser Kraftwerke AG and the control system manufacturer Rittmeyer AG. With the target of a comprehensive monitoring system additional pressure transducers and flow meters were installed and implemented in the control system of the power plant. A total of almost 50 signals are measured and stored.

Core element of the monitoring system is an Ubuntu Linux Server. This server reads the raw data from the IEC 6087-5-104 bus and stores all data with a data rate of 1 Hz
to a high performance NoSQL database (Non SQL, non relational data base) as well as on a backup data base. Via the SSDP network protocol (Simple Service Discovery Protocol) and Ethernet connection the data are send to a Windows PC for further data processing and representation.

In order to retrieve efficiency from the data complex algorithms were developed for detection of time series with steady-state or quasi-steady condition of the machines. Different filtering was applied for the long term history of efficiency and the real time display of efficiency. In addition, a large number of site specific characteristics are calculated and further processed.

The representation of data encompasses the following main features for the hydro power plant operator:

- efficiency history (see example in Figure 3)
- real time efficiency (online monitoring)
  - overview (see example in Figure 1)
  - efficiency curve
  - hill chart
- plant operation
- trend analysis

All selected diagrams can be chosen for only one of the machine groups or for both in overlay modus.

2.1 Efficiency History

The display of the efficiency history allows to select the duration over which turbine efficiency is shown in the range from two days up to two years. Per day one weighted efficiency value is evaluated and displayed. The graph includes the temporal development of the efficiency difference to a reference measurement. With both machine groups on display a temporal overview on eventually differences in the efficiency history of the two groups becomes available.

2.2 Real Time Efficiency

Real time efficiency can be displayed in case of steady state operation of the machine groups (a green display button on the screen indicates steady state or quasi steady operation). Figure 1 provides an overview on real time efficiencies. The information on this display includes plant, machine group, turbine efficiency as well as quantification of all measured or evaluated power losses.

Other selectable sub-GUIs (Graphical User Interface) allow comparison with annually performed sliding gate measurements [9], either as efficiency curves or as point in the hill chart, which also indicates the operational range of the turbines.
2.3 Plant Operation

In the display of the plant operation the real time plant operation is compared to a theoretically optimized plant operation. Due to wear and different repair and operation cycles both machine groups have slightly different efficiencies. Accordingly, the turbine with the better efficiency should preferably be used whenever only one machine operation is required. The monitoring program sums cumulatively the energy difference up that results from non-optimized plant operation.

2.4 Trend Analysis

In this display two user defined quantities – measured raw or evaluated data, such as hydraulic efficiency – can be compared to each other in order to analyze the temporal development of the data. The displayed data rate is one per second. Due to the high number of points the maximum range is limited to two days in this mode. However, this range can be chosen for the actual data of for data lying up to three years in the past.

3 Efficiency Loss Detection

The monitoring system of Filisur is now operational since 2016. Valuable information could be gained from these data. The decision to store data with high temporal resolution proved to be correct in spite of the challenges in connection with the data base.
In summer 2016 a screw nut got entrapped in the vaneless space in between guide vanes and runner blades. This nut bounced back and forth and damaged the guide vanes and the runner blades (see Figure 2).

The damages shown in Figure 2 led to an efficiency drop of about 1.6 % within only a few minutes of operation, as shown in the graph of Figure 3. After this incidence the turbine was shortly dismantled and repair works were carried out. With these actions an efficiency increase of 0.7 % was achieved, but an overall decay of about 1 % still remained.
4. Conclusion

The condition monitoring system of Filisur provides data of the plant operation with high temporal resolution. The system allows to survey the real time efficiency as well as its history. In addition, a large number of site specific characteristics are acquired and stored to a database with a sampling rate of 1 Hz. All these data can be analysed on demand. Based on these data optimized plant operation becomes possible, losses can be quantified, repair works can be better planned and the benefit of repair works substantiated.

The turbines of Filisur are exposed occasionally to high suspended sediment loads leading to hydro abrasive erosion and in turn to gradual efficiency losses. These efficiency losses are now quantifiable. Also the loss of income due to decreased efficiency can be assessed.

With the experience gained from this site-specific installation the monitoring system will be expanded with additional expert knowledge to improve the reliability of the data. Furthermore, it is planed to add instrumentation for online sediment monitoring to the system. Together with the efficiency data it will then be possible to develop a strategy for machine shut down in case of too high suspended sediment concentration.

In addition, the monitoring system will also be commissioned for the second hydro power plant Tiefencastel of the operator Albula-Landwasser Kraftwerke AG (second stage of the corresponding cascade).
References


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