OPTIMIZATION OF CONTROL ALGORITHM IN SMALL HYDROPOWER PLANT

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Abstract
Small hydropower plant is one of the widely used type of renewable energy sources in South Eastern Europe. Due to high investment cost the typically operate as single or two unit SHP. Due variable inflow conditions control algorithms for multi-unit SHP need to be site-specific oriented in order to maximally use available hydro potential. This paper represents methodology for improving general control algorithm by analyzing SCADA data collected for prolonged period of SHP operation in various inflow conditions. Based on the observation on real data, control algorithm is optimized for site-specific operation, which is expected to increase energy production for 2%.

Keywords: Small Hydro power plant, SCADA, Control algorithm, Energy efficiency, optimization.

INTRODUCTION

Small hydroelectric power (SHP) plants represent one of the key cornerstones of renewable energy sources. Unlike large hydro power plants, their impact on environment is considerably lower, as they don't employ large dams. They are design to run on river or as derivation type, so their production is tightly coupled with water inflow. Since they are typically build on small mountains streams and rivers which have high variations of inflow during year [1]. In order to use as much from available hydro potential they are typically build with single or two generating units. SHP with single generating unit has benefit of low investment, but their drawback is that they only use certain inflow range. They cannot work with both with small and high inflows, so in such cases available hydro potential will be lost. Two unit SHPs employs two generating units which power is arranged in ratio 2:1, so this type of SHP can use broader inflow range. For small inflows SHP operates smaller unit, for medium inflows larger unit is operated, while for large inflows both units are operational. This type of SHP has higher investment costs which pays off due better usage of hydro potential and since two unit SHP has higher availability in case of unit breakdown. Two unit SHPs, require control algorithm which will decide which unit will be operational. Challenge in control of SHP is that inflow is typically not measured directly using flow meter, since it usage will increase cost and reduce available head. Instead, inflow is typically measured indirectly using level measurement on inflow weir or in water chamber. Main objectives of control algorithm is to operate SHP at maximum efficiency by selecting appropriate unit for inflow conditions and also to keep the number of unit starts to less than five in order to reduce wear and tear on equipment [2,3]. The algorithm for switching units cannot be generalized and it's site-specific. In this paper we represent methodology of improving control algorithm of SHP by analyzing SCADA stored data.

EXPOSITION

Data on the operation of the small hydropower plant is collected and archived using the Citect SCADA (System Control and Data Acquisition), which represents software application for industrial process monitoring and control. It consists of a number of components that allow viewing and archiving current process values and alarms, generate reports and etc. The collected data can be visualized in a chart which enables staff to gain a better understanding of the operation of equipment and facilities [4,5].

The collected data is archived cyclically by the trend server and stored on the local hard drive, from where the data is accessed for analysis purposes. Citect uses a rotary storage system where logged data is archived into several files (default number is 2) that are changed every Sunday at midnight GMT. The data is stored in files with the file name and extension corresponding to the serial number of the historical file. When the last file is cycled, SCADA begins a new cycle in which previously stored values in file are lost. The data can be stored in a double precision format that takes up 8 bytes per single data, or in an abbreviated integer format that takes up 2 bytes per single data. In this particular case, the trends that are being collected in small hydropower plants can be classified into the following categories:

• Hydrostatic parameters (water level)

• Parameters of medium voltage distribution network (voltage, current, active and reactive power)

• Transformer parameters (transformer winding temperature)

• Turbine parameters (turbine speed, pipeline pressure, conduit position, hydraulic oil pressure and temperature)

• Generator parameters (voltage, current, active and reactive power, cosφ, winding temperature and bearing temperature)

• Other parameters (indoor and outdoor temperature)

In this paper data archived by SCADA system during the three months of operation (April to June) was used. From the available parameters, the following parameters, which are important for the purposes of data analysis in both hydropower plants, are monitored:

Table 1. *Parameters used in data analysis*

Parameter	Unit
Water intake level	cm
Water chamber level	cm
H1 MV cell active power	kW
H3 MV cell active power	kW
Unit funeral circuit position	%
Unit speed	%
Unit penstock pressure	bar
Unit active power	kW

The hydropower unit can operate in three control modes: manual, automatic and joint control. Manual operation requires all commands to be given by the operator in order for the unit to start operating. This control mode is only used when testing and commissioning of the unit. Automatic control allows the unit to run in a program-defined sequence whereby the unit operates independently in one of two operating modes: constant power mode and level control mode. If the unit operates in constant power mode, it will maintain the set power regardless of the water level in the water chamber, as long as the conditions for safe operation of the unit are fulfilled (water level in the water chamber is higher than the stop level). In level control mode, the unit will maintain the set level in the water chamber, adjusting the turbine power to the current water supply. SHP typically operates in the joint control mode, where unit operation is controlled by a separate PLC, which requires both units to operate at a certain constant power. The PID controller regulates the water level in the water chamber and, depending on the required power level, the PLC controller operates one or both units. The power distribution required by the PID controller is done in three stages. When the required power of the controller is less than the first level, a smaller unit with the required power will operate. When the first power level is exceeded, a smaller unit will be switched off and a larger unit will be started to operate at the required power level. When the second power level is exceeded, a smaller unit will be switched on and the required power level will be distributed as a percentage to both units. The maximum power that may be required from unit is limited by the hydropower permit of the power plant. To avoid frequent unit switching cycles, a power hysteresis is added. In case one of the units does not have all necessary conditions to start operation, the other unit will be started instead.

Since the primary task of the PID controller is to regulate the water level in the water chamber, it will require the maximum possible power according to the current control algorithm to achieve the level control. During the analysis of the data, it was observed that this phenomenon occurs frequently, leading to situations where the units are unnecessarily switched on, which increases the wear of the equipment and reduces the efficiency of the hydroelectric power plant. For example, a slight increase in the level in the water chamber will result in a demand for more power, which in the short run will trigger the process of switching on the additional unit and if it is not currently needed. This phenomenon is also common when starting a hydroelectric power plant when the water level in the water chamber is high, as shown in Fig 1.

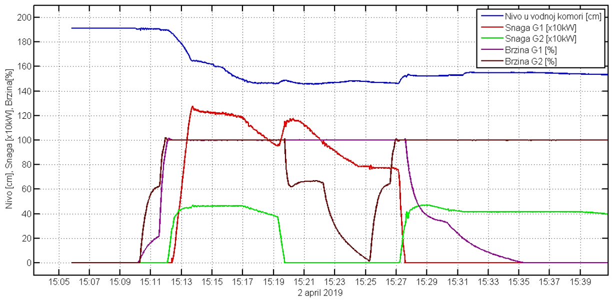

Fig. 1. *Improper start sequence of two units*

The hydropower plant was started with a high water level in the 190 cm water chamber. Since the control level in the water chamber is 160 cm, the PID controller requires operation with maximum power to reach the control level, which results in the start of both G1 and G2 units. The start-up of both units quickly lowers the water level in the water chamber because the flow of water is insufficient for the continuous operation of both units, and soon the smaller unit will shut off when the water level drops below the control level. The hydroelectric power plant continues to operate with the larger unit and the water level continues to decline, so the larger unit will be shut off so that the hydroelectric power station will continue to operate continuously with the smaller unit. This results in unnecessary switching on of both units for a short period of time, which results in unnecessary wear and tear on the equipment and reduces the accumulation of water during the switching on of the unit until the unit reaches synchronous speed and is synchronized to the distribution network.

Changes in levels can also cause a transition from a smaller to a larger unit where the larger unit can remain operating for a longer period at the low power level required. The analysis found that for the same inlet at the boundary of the transition from the smaller to the larger unit, the smaller unit produces about 60 to 70 kW more power than the larger one, as shown in Fig 2.

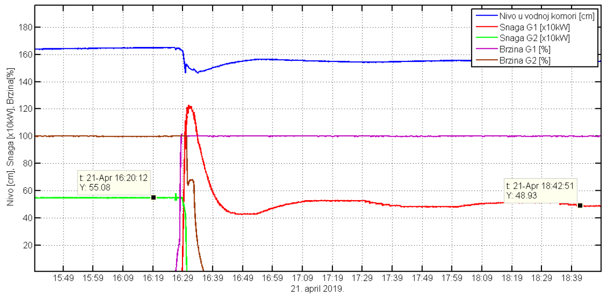

Fig. 2. *Transition from smaller to larger unit due inflow variation*

Based on the performed data analysis and the observed shortcomings of the currently implemented integrated control algorithm, the following changes in the mode of regulation by level in the water chamber are proposed:

Operation in this mode is controlled by a PID controller, which can operate in three modes (Mode G2, Mode G1 and Mode G1 + G2) between which it switches when the water level in the water chamber goes above the upper level setpoint (*Level Plus*) or drops below the lower level setpoint (*Level Minus*). These levels differ from the Setpoint Level PID control level by a few tens of centimeters, thus preventing changes to the operating mode of the controller due to small variations around the Setpoint Level control level. The formation of water reserve in intake channel prevents changes in the mode of operation due to small variations in inflow. The maximum value at which the upper switch level (*Level Plus*) can be set may correspond to the overflow level on the water chamber. The minimum value at which the lower switch level (*Level Minus*) can be set is unit shutdown level due to the low level u on the water chamber.

The hydropower plant in the joint control mode starts its operation depending on the water level in the water chamber. If the water inflow is low, an overflow in the water chamber will occur at a certain level which is less than the setpoint (*Level G2 overflow*) and the controller will start to regulate the level in Mode G2 mode, whereby the required power will be assigned to a smaller unit. In this mode of operation, the output of the PID controller will be limited by the operating range of the permitted power of the smaller unit G2. If the overflow level is higher than *Level G2 overflow*, the PID controller will start to regulate the level in Mode G1 mode whereby the required power will be allocated to a larger unit G1. If the overflow level is higher than the *Level G1 overflow*, the controller will start to regulate the level in G1+G2 Mode whereby the required power will be divided between the smaller and larger units. The analysis of the data revealed that both units proportionally regulate the required power level, which is constantly changing in the joint control, which can cause frequent demands for positioning of the funeral circuits of both units. To overcome this situation, it is suggested that in the operating mode when both units operate, the smaller unit operates at a constant power level, while the larger unit performs power regulation. This approach will avoid the situation that a smaller unit is operating in an area where it is less efficient and a larger unit will operate in an area close to maximum efficiency, which will improve the efficiency of the hydropower plant.

CONCLUSION

The paper presents optimization of control algorithm of the SHP in order to improve energy efficiency in multi-unit SHP. Implemented algorithm is expected to improve energy production for about 2%, which will be verified by observing production data for the following year.

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