Output improvement of Sg. Piah run-off river hydro-electric station with a new computed river flow-based control system

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Abstract. The lower Sg. Piah hydro-electric station is a river run-off hydro scheme with generators capable of generating 55MW of electricity. It is located 30km away from Sg. Siput, a small town in the state of Perak, Malaysia. The station has two turbines (Pelton) to harness energy from water that flow through a 7km tunnel from a small intake dam. The trait of a run-off river hydro station is small-reservoir that cannot store water for a long duration; therefore potential energy carried by the spillage will be wasted if the dam level is not appropriately regulated. To improve the station annual energy output, a new controller based on the computed river flow has been installed. The controller regulates the dam level with an algorithm based on the river flow derived indirectly from the intake-dam water level and other plant parameters. The controller has been able to maintain the dam at optimum water level and regulate the turbines to maximize the total generation output.

1. Introduction

Tenaga Nasional Berhad (TNB) being the biggest power utility company in Malaysia owns all the electrical transmission and distributions networks, and a number of power stations in Peninsular Malaysia. TNB delivers a total peak demand of about 15,000MW electricity at the end of year 2012 for Peninsular Malaysia that has a population of about 25 million. Almost all of the hydro-electric stations in Peninsular Malaysia are owned by TNB and they are located in the northern part of the country. One of the small ones that located in the state of Perak is the cascaded Sg. Piah run-off river hydro-electric station that has maximum generating capacity of 70MW. The lower Sg. Piah hydro-electric station has two Pelton turbines (almost same runner as shown in Figure 1) to harness energy from water flowing through a 7km tunnel after an intake dam. Each turbine is capable of producing maximum 27.5MW when sufficient river flow is available. Its output is connected to Sg. Siput’s 132KV double circuits to feed to the national grid. As the station has a small reservoir such as shown in Figure 2, the feature of run-off river hydro scheme, the operation strategy is to maximize its output according to the available river flow by minimizing the dam spill to the allowable limits.

As the price of fossil fuel increases over the years and often spikes when events such tensions between countries or shortages of gas occur, hydro-electric generating stations can assist to lower overall fuel costs by maximizing their outputs. Therefore to maximize its output, both units of the
Lower Sg. Piah station were equipped with an Online Load Controller or simply known as Online Controller (OC) to harness the energy according to the dam water level. The practice is to regulate the turbines according to water level at the dam \([1 - 5]\). However, the OC had developed a “control hunting” problem at early age of the power station. Since then the OCs for both units were never put in service that the practices were to turn off the OC. Consequently, the station was not able to produce energy optimally most of the time during its operation. Most of the time, much water were being spill over the dam instead being used to generate additional energy.

![Figure 1: Turbine Runner at Upper Station almost similar to the Lower Sg. Piah’s](image1)

![Figure 2: Lower Sg. Piah’s Intake Dam](image2)

Based on the annual rainfall data, computed river flow, tests performed on the station and observations of operation practices at the stations during 2010, it can be concluded that about USD 3 million additional revenues annually can be attained if the station is operated according to the available river flow. To improve the station annual energy output, a new controller called automatic online controller (AOC) has been installed. The controller regulates the dam level with an algorithm based on the river flow instead of the depending on solely on the dam water level. The river flow is derived indirectly from the intake-dam water level and other plant parameters.

2. AOC System Architecture

2.1. AOC System Design

The new AOC has been implemented according to the following specifications:

a. The AOC major components are Siemens S7-315 Programmable Logic Controller (PLC) and Touch Screen Human-Machine Interface (HMI). The PLC and HMI are given Figure 3 and 4 respectively. All control algorithms including flow computation and the logic sequences are implemented within the PLC. AOC acquires plant parameters both from the Supervisory Control and Data Acquisition (SCADA) remote terminal units (RTU) and control cabinets.

b. Interface between operators and control system either to initiate commands or enter the coefficients is realized on the HMI. The commands such as AOC ON and AOC OFF buttons (to turn on or off the AOC) will be realized on the HMI instead of using the OC ON & OC OFF buttons on the control desk. The touch screen buttons on the HMI will alter the appropriate memory bits within the PLC. Also the generation load demand can be optionally raised or lowered from HMI.

c. Also, the HMI touch screen allows operators to enter coefficients needed for targeted load reference calculations. The floating point coefficients or constants such as K0, K1 and K2 can be
entered by personnel via HMI page similar to the one given in Figure 5. The constants are then forwarded to PLC for turbine discharge flow computations.

2.2. Remote Operation and Drive Level

In addition to the control buttons on HMI, operator can control the station remotely from Bersia group regional control center (BGCC) via the SCADA system. The interface cabinets for SCADA at Lower Sg. Piah station are RTU 1 and RTU 2 which contained terminals points for interfacing to the AOC. At the drive level, the electro-hydraulic governor will regulate the turbine nozzles and deflectors in response to speed setters and load reference setters. At this station, each turbine unit is equipped with two pair of nozzles (Pair 1 & 3 and Pair 2 & 4). The second pair of nozzle is opened when the load is about half of maximum load.

3. AOC Dam Level Control Algorithm

3.1. Computed River Flow-based Dam Level Control Algorithm

The main function of the AOC is to regulate turbine automatically, mainly based on the computed river flow. It can regulate either both or one units only. As for the feedback, the controller’s load setter is compared to the turbine load reference rather than MW, to overcome the effect of turbine nozzle hunting zones.

The main computations within the AOC include river flow calculation \( Q_{rf} \) as given by equation Equation (1), optimal/target flow \( Q_{opt} \) (equation Equation2), regulation periods, and protection schemes to ensures safe operation of the Upper Sg. Piah station.

Average river flow (\( Q_{rf} \)) for a given time interval (\( t_i \)) can be calculated using Equation (1) as follows:

\[
\int_0^{t_i} Q_{rf} \, dt = \int_0^{t_i} Q_{tur} + Q_s \, dt + (WL_c - WL_p)A_p
\]

Equation (1)

Where

\( Q_s \) = Spillage (m\(^3\)/s)

\( Q_{tur} \) = Turbine discharge (m\(^3\)/s) for both turbines
\[ WL_{1p} = \text{Previous dam water level (mSLE meter sea level elev.)} \]
\[ WL_{1c} = \text{Current dam water level (mSLE)} \]
\[ A_p = \text{Average water surface area for intake pond (m}^2\text{)} \]
\[ t_f = \text{Final time for the designed regulation interval (s)} \]

Optimal total turbine discharge \((Q_{opt})\) is calculated as follows
\[
Q_{opt} = \frac{1}{t_f} \int_{t_0}^{t_f} Q_f \, dt + (WL_{1c} - WL_{1p}) A_p \quad \text{Equation (2)}
\]

Where
\[ WL_{1p} = \text{Targeted dam water level (mSLE)} \]

3.2. PLC Ladder Logic Program
All the flow computations including \(Q_{turb}, Q_s, Q_{rf}\) and \(Q_{opt}\), logic sequences, and protection logics are realized in the form of a ladder logic program which is about two hundred pages long. Six pages of HMI graphics including a trending, AOC commands, monitor and data entry pages have been created.

4. Conclusion
During the two weeks performance tests, the controller has been able to regulate both the dam level and the turbine output successfully. Each turbine was tested to operate up to 25MW when the river flow permits such operating conditions. In near the future we need to conduct further optimization to search for optimum variable target dam water levels versus turbine outputs to optimally generate energy from the varying river flow.

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