

DESIGN AND IMPLEMENTATION OF REAL TIME MONITORING SYSTEM OF WATER FLOW IN HYDRO POWER PLANTS USING VIRTUAL INSTRUMENTATION SOFTWARE

Jakub Osmic
Faculty of Electrical Engineering
Franjevacka 2, Tuzla
Bosnia and Herzegovina

Emir Omerdic
Faculty of Electrical Engineering
Franjevacka 2, Tuzla
Bosnia and Herzegovina

ABSTRACT

In this paper it is presented the real time monitoring system of water flow in hydro power plants which is designed with virtual instrumentation software. Water flow through penstock has been measured by using flow sensor. Volumetric flow of excess water, in the case of emergency evacuation of water, has been calculated from position of control gates and water level. Relationship between the volumetric flow of excess water, position of control gates and water level has been a prior experimentally established and saved into look up table. Signals from position and level sensors have been used as inputs into the look up table. Entries into the look up table are interpolated using bilinear interpolation method and they are used for calculation of excess water flow. By using integration method with fixed step time, the volume of transmitted water through all outlets has been calculated. All necessary real time calculation, data presentation and data logging have been performed using virtual instrumentation software. With a proper application software organization and by means of digital communication real time measurement and presentation of results are ensured.

Keywords: hydro power plant, water flow, virtual instrumentation, real time, monitoring system

1. INTRODUCTION

The main reason for monitoring of water flow in hydro power plants is to ensure that water flow is below some critical level. The water flow that is greater than the critical can cause human casualties and property damage downstream of hydro power plant. Except this, for optimal use of water resources it is also necessary to monitor water flow. This is especially true if there is a number of neighboring hydro power plants on the same river. Water flow through penstock (see Figure 1) is turbulent and consequently flow velocity is almost constant across penstock cross-sectional area. So it is not difficult to calculate volume of transmitted water. It equals to product of penstock cross-sectional area, flow speed and elapsed time. Situation in the case of excess water flow measurement is much more complicated since we must cope with flow in open channels. Relationship between flow, fluid head and orifice cross sectional area is nonlinear and depends of the orifice shape and dimension. The best way to find such relationship is to make physical model of dam and reservoir and than perform real experiments. Then measurements can be saved into lookup table. Since measurements are made with a certain resolution it is necessary to perform on-line interpolation. As interpolation method a good choice is bilinear interpolation method. For calculation of volume of transmitted water it is also necessary to perform integration of water flow. Using trapezoidal integration method with sufficient

low integration step it is possible to achieve satisfactory accuracy. Since time constant of control gates is rather big, integration time of couple seconds is appropriate.

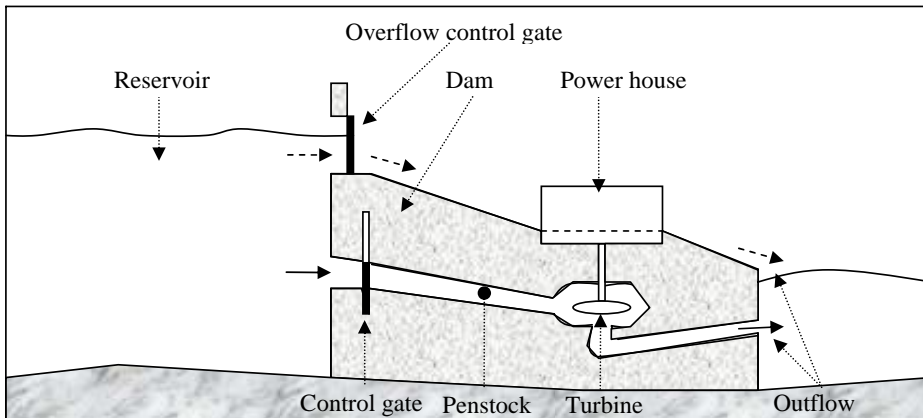


Figure 1. Hydro power plant – the main elements.

All calculation should be done in real time so it is necessary to use real time hardware and software platforms. As appropriate hardware and software platforms has been chosen National Instruments Compact Field Point cFP-2220 and LabVIEW with its Real Time Module respectively [1, 2].

For purpose of presentation it is necessary to spread all measured and calculated variables across the plant and command room by using Ethernet communication protocol. This can be achieved by using LabVIEW Shared Variable (SV) and LabVIEW Data Logging and Supervisory Control Module (DSC Module). Using DSC Module, Database Connectivity Module and Report Generator Module all variables are stored in Citadel event driven database and presented in the form of user friendly reports. Citadel database is implemented on Citadel database server (personal computer).

2. COMPACT FIELDPOINT CONTROL SYSTEM

Compact FieldPoint (cFP) is a programmable automation controller (PAC) designed for (industrial) control applications performing advanced embedded control, data logging and Ethernet connectivity. It combines the packaging, specifications, and reliability of a Programmable Logic Controller (PLC) with the software flexibility, connectivity, and functionality of a personal computer. The modular I/O architecture with built-in signal conditioning and isolation provides direct connectivity to industrial sensors such as analog voltage, 4 to 20 mA current, thermocouple, RTD, pressure, strain, flow, pulse width modulation (PWM), and 24 V digital I/O [3]. CFP uses floating-point processors with speed that is much bigger then speed of microprocessors in classical PLC-s. This speed is usually of order of couple hundred MHz. Due to big DRAM and Internal nonvolatile memory (256 MB) it is possible to run rather complex embedded application software on the cFP real time target. In addition it allows storing very big look-up tables. The cFP also allows extending memory with removable CompactFlash memory cards with capacity of couple GB. This memory card can be used for data logging.

All above mentioned features makes the cFP as ideal choice for running application software for real time monitoring in hydro power plants. The external flash memory can be used in this particular application for data backup so that in the case of loosing connection with Citadel database server, most important data are stored in external flash memory. After the connection has been established data from external flash are transferred to the Citadel database.

Signals from flow, position and level sensors are transferred to the analog inputs of cFP in the form of 4 to 20 mA. To achieve high accuracy, analog inputs of cFP are equipped with analog to digital converters with 16 bit resolution.

The cFP connects directly to Ethernet network, auto negotiating on the network for 10 Mb/s or 100 Mb/s communication rates. It includes an RJ-45 connector for connection to network using protocol based on standard TCP/IP to maintain full compatibility with existing networks.

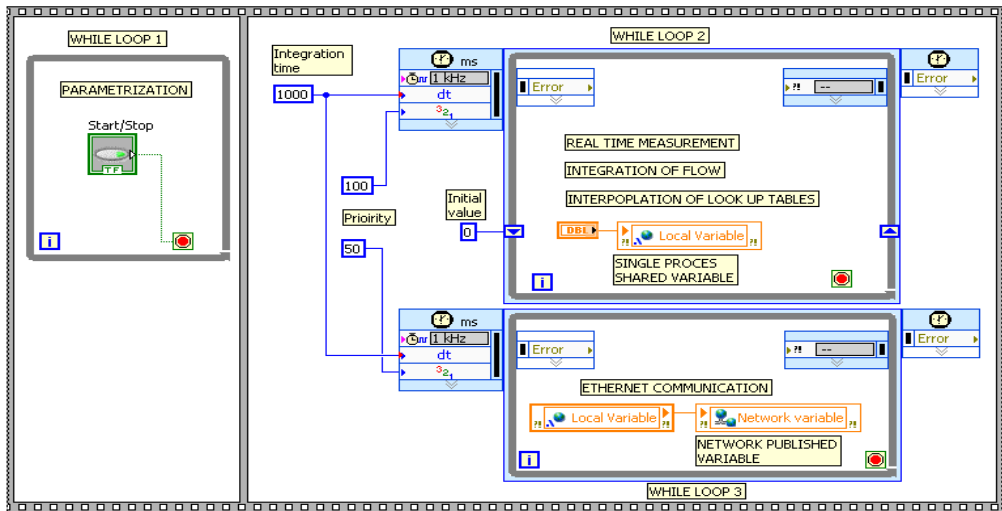


Figure 2. Principally scheme of embedded application software

3. EMBEDDED APPLICATION SOFTWARE

The embedded application software has been developed using LabVIEW and necessary modules. The embedded application roughly speaking consists of three *while (timed) loops* (see Figure 2). The first *while loop* is used for parameterization. When the cFP is turned on, the *while loop* number 1 is running and waits for user action. In this stage it is possible, by using Service application software that is running on Engineering workstation, change number of parameters such as scaling factors of analog inputs, dead zone of input sensors, integration time etc. By using appropriate jumpers on digital inputs of the cFP it is possible to skip this part of program after turning on the cFP. In this case *while loop* number 2 starts first since it has higher priority (100) than *while loop* number 3 (50). After completing *while loop* number 2 starts *while loop* number 3 which is used for Ethernet communication. The above process repeats until cFP has been turned off. Both *while loop* number 2 and *while loop* number 3 executes every 1000 ms (integration time). Such organization of software is desirable since all time critical parts of program, such as real time measurement and integration of flow, are executed in *while loop (timed loop)* with the highest priority. In this way it is ensured that all input signal are sampled at defined time intervals (1000 ms) which is very important for accurate integration of flow. Communication between loops is performed using Single process (local) shared variables while exchange of date across Ethernet networks is performed by using network-published shared variables. The network-published shared variables are visible to every user that is connected on the Ethernet network. All single process shared variables are deployed on cFP while network published variables are deployed on machine running Citadel data base. Variables related to volume flow are stored every three minutes into Citadel database or at every change of state of control gates. Water levels are recorded in the Citadel database when there is a big enough relative change in their values. In this way it is ensured that small variations of water level due to existing of waves on the surface of reservoir or due to measurement noise are not recorded. As a result has achieved savings in memory required to store data.

For calculation of water flow through control gates it is necessary to make interpolation of look-up table. The look-up table is two dimensional with x axis being position of control gates and y axis being water head. Entries into the look-up table are water flow. As method of interpolation good choice is to use bilinear interpolation method. Bilinear interpolation is an extension of linear interpolation for interpolating functions of two variables on an equally spaced grid. The interpolated function should not use the term of x^2 or y^2 , but xy , which is the bilinear form of x and y . Interpolation is performed first in one direction, and then in the other direction.

Suppose that one wants to find the value of unknown function f at the point W_0 (see Figure 3) where values of f are known at the points Z_{11} , Z_{12} , Z_{21} , and Z_{22} .

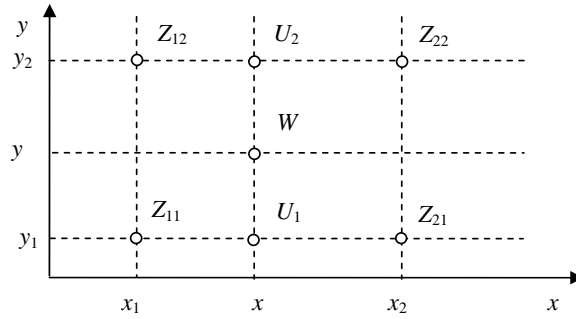


Figure 3. Bilinear interpolation

In the first step interpolation is performed in the x direction. Interpolation along line $y = y_1$ gives

$$\frac{f(U_1) - f(Z_{11})}{x - x_1} \approx \frac{f(Z_{21}) - f(Z_{11})}{x_2 - x_1} \quad (1)$$

From (1) follows

$$f(U_1) \approx \frac{x_2 - x}{x_2 - x_1} f(Z_{11}) + \frac{x - x_1}{x_2 - x_1} f(Z_{21}) \quad (2)$$

In similar way linear interpolation along line $y = y_2$ gives

$$f(U_2) \approx \frac{x_2 - x}{x_2 - x_1} f(Z_{12}) + \frac{x - x_1}{x_2 - x_1} f(Z_{22}) \quad (3)$$

Then linear interpolation in y is performed along line $x = x$ which yields

$$f(W) \approx \frac{y_2 - y}{y_2 - y_1} f(U_1) + \frac{y - y_1}{y_2 - y_1} f(U_2) \quad (4)$$

By using (2), (3), and (4) estimation of function f in arbitrary point (x, y) can be calculated as

$$\begin{aligned} f(x, y) \approx & \frac{(x_2 - x)(y_2 - y)}{(x_2 - x_1)(y_2 - y_1)} f(Z_{11}) + \frac{(x - x_1)(y_2 - y)}{(x_2 - x_1)(y_2 - y_1)} f(Z_{21}) \\ & + \frac{(x_2 - x)(y - y_1)}{(x_2 - x_1)(y_2 - y_1)} f(Z_{12}) + \frac{(x - x_1)(y - y_1)}{(x_2 - x_1)(y_2 - y_1)} f(Z_{22}) \end{aligned} \quad (5)$$

4. CONCLUSIONS

Virtual Instrumentation software is a powerful tool for design and implementation of monitoring and data acquisition systems in hydro power plants. In the future we plan to use same software tool for design and implementation of supervisory control system for hydro power plants.

5. REFERENCES

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