Enhancing small hydro automation using distributed micro-controllers and simulation

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Abstract: The past ten years has seen significant advances in low-cost micro-controllers, data communications and personal computing. Applying these technologies to small hydro automation, affordable multifunctional distributed processing solutions is now a commercial reality. The ability to reduce costs is facilitated by innovative low-cost simulation tools. The successful application of these technologies to the control and protection of a 2MVA hydro generating unit is described.

Keywords: small hydro; automation; simulation; micro-controllers; distributed processing; governing; SCADA; data buses; personal computing tools.

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Biographical notes: Aidan Foss P.Eng. is the Principal Engineer of ANF Energy Solutions Inc. A graduate in mathematics from the Cambridge University, UK, with a Doctorate in turbine control from the Imperial College, London, Foss specialised in computer control and simulation and was Vice-Chairman of the UK Simulation Council. Through the National Grid Company, he focused on power applications, including auditing and modelling of generator control systems. Currently based in Ottawa, Foss provides technical consultancy services covering power systems, power measurement, power-plant automation and simulation.

Yves Grandmaitre, CSP, V.P. Sales and Marketing at Powerbase Automation Systems Inc., has been active in selling and interfacing with industrial controls for over fifteen years. His experiences have spanned the pulp and paper industry, petrochemical, waste water and many more. Grandmaitre practices a hands-on approach to selling and has been involved in many installations and commissioning of control systems. He has also travelled extensively and written papers promoting the benefits of an embedded application specific controller approach for small hydro sites.

William (Bill) Kemp, V.P. of Engineering at Powerbase Automation Systems Inc., has over 20 years of experience in the development of high performance embedded control systems, focusing on scalable hardware and software solutions to the on and off grid power generation industry. Also experienced in PV and wind technology, Kemp is the principal system architect of the Powerbase Platform. He has travelled extensively promoting to industry the effectiveness of the Powerbase platform as an ideal solution for the small hydro protection and control market.

1 Introduction

The first hydro station controllers were analogue. During the 1970s and 1980s, analogue controllers rapidly gave way to digital implementations based on Programmable Logic Controllers and Tailored Software Systems. The digital environment facilitated more complex control algorithms and brought SCADA (Supervisory Control and Data Acquisition) software within reach of most applications. Around the 1990s, low-cost data buses began to replace point-to-point communication links, facilitating distributed computing solutions. Processing components themselves were becoming vastly more powerful, through computer-on-chip technology.

In addition, the processing power available in standard desktop PCs continues to surpass the dreams of engineers a decade earlier. Today's development engineers use a very different toolbox compared to their predecessors. Tools that may have been expensive, unaffordable or inflexible, can now be realised for low-budget solutions:

- *Off-line simulation for control algorithm development*. Modern PCs with standard office software have been found to offer very powerful environments for dynamic system simulation. For instance, Excel with its inherent Visual Basic for Applications (VBA) capability is able to offer a combination of a graphical human–computer interface with a powerful high-level language-programming environment.
- *Embedded simulation*. The power of modern micro-controllers enables plant dynamic simulations to be coded in the target environment with the application software to enable rapid development and verification of software algorithms.
- *Hardware-in-the-loop simulation for system verification*. In addition to facilitating off-line simulation, the PC's internal clock can be used to effect real-time simulation. Combined with the use of commercially available PC I/O boards that offer direct communication with Excel/VBA, a complete real-time hardware-in-the-loop simulator can be realised at an extraordinary low cost. The Excel human–computer interface can be further enhanced through the use of commercially available virtual instrumentation software.

2 Processing structures

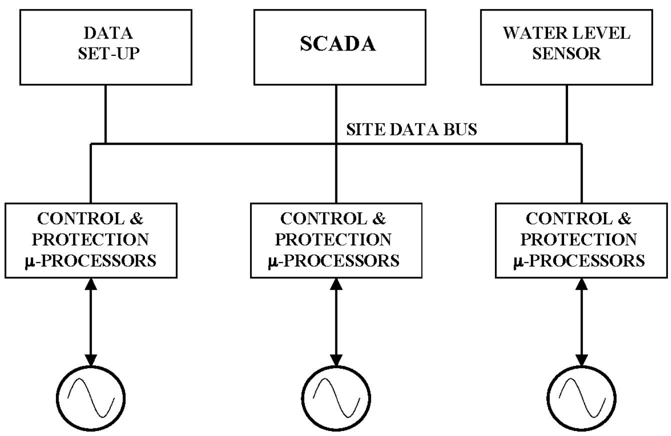
The first power stations were reasonably simple and small, with little or no automation. As the stations grew in size and complexity, more information on the plant status was required for the operator to make the necessary adjustments. Analogue governors were introduced to provide speed regulation, with protection relays and monitors to deal with fault conditions, and hard-wired trip and annunciation circuits. Generally, there was no communication between the units (Grandmaitre, 2000).

Next, digital computers, offering increased functionality and versatility, began to replace many of the analogue functions. These enabled more complex control algorithms to be implemented. For instance, multiple control modes covering start-up, shutdown, commissioning, power control and head-level regulation. Two digital-programming techniques evolved based either on Programmable Logic Controllers, with software specific to that application, or Tailored Software Systems, in which algorithms are pre-coded with a facility for parameter customisation. Digital technology also facilitated the use of SCADA (Supervisory Control and Data Acquisition) software to provide overall site control and monitoring. Initial SCADAs were hierarchical in nature, with point-to-point communication links with each of the unit controllers.

As communications technology advanced, these point-to-point communication links began to be superseded by data bus structures as these offered significantly less wiring infrastructure. Data bus structures also facilitated distributed processing using modern low-cost micro-controllers. Single-chip micro-controllers are now commercially available equipped with on-board analogue-to-digital converters (ADCs), digital-to-analogue converters (DACs), and serial and parallel communication ports.

With distributed processing structures (Figure 1), the site-based functions such as SCADA and water-level measurement can be considered as peripheral functions attached to the site data bus. This structure also facilitates more efficient use of data set-up tools, and thus supports computational solutions based on tailored software systems. Data set-up itself becomes another peripheral function on the site data bus. These structures are further complemented by more powerful desktop PCs, which are able to readily communicate on the data buses as well as hosting multiple peripheral functions such as data set-up and SCADA. Multiple communication buses are also widespread.

Figure 1 Distributed processing structure

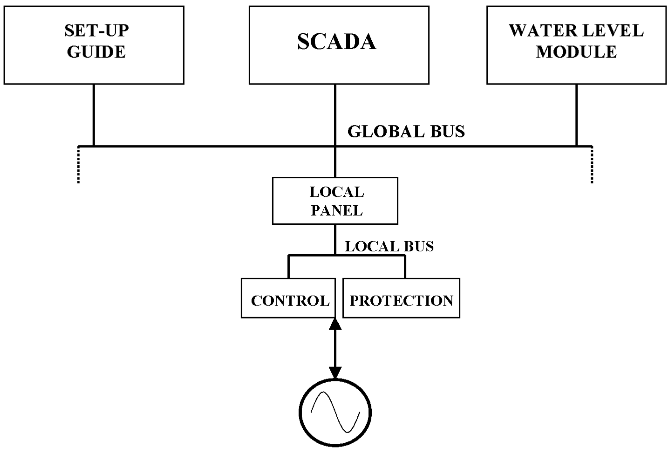


3 Application to a 2MVA hydro-plant

The successful application of these structures and tools to the automation of a 2MVA Francis turbine hydro generating unit is described. The project involved the replacement of older protection and control equipments with a modern multi-functional micro-controller-based solution. The main components of the new system were (see Figure 2):

- *controller module*: covering start/stop sequencing, wicket gate closed-loop PID control, synchronisation, fault detection and fault response
- *protection module*: covering all required generator protections
- *local panel*: with inter-bus communication capability
- water-level sensor module
- *SCADA*: software installed on a standard PC
- *set-up guide*: software installed on a standard PC
- global (site) and local (unit) data buses.

Figure 2 Equipment structure for 2MVA hydro-plant application



The project required functional enhancements to existing equipments (e.g., SCADA, set-up guide, local panel), as well as the design and implementation of three new equipments:

- multifunctional protection module containing all required generator protections
- multimode controller module covering speed, power and wicket gate regulation in addition to various sequencing operations
- high-pressure hydraulic power unit (HPU) equipped with high-precision servo-valve.

Rapid development and commissioning in a cost-effective manner was achieved through the creation and use of new simulation tools, which are described below.

4 Simulation tools

4.1 Off-line simulation tools

The first tools employed were the Excel/VBA off-line simulators, which were used for algorithm development for both the protection and control modules.

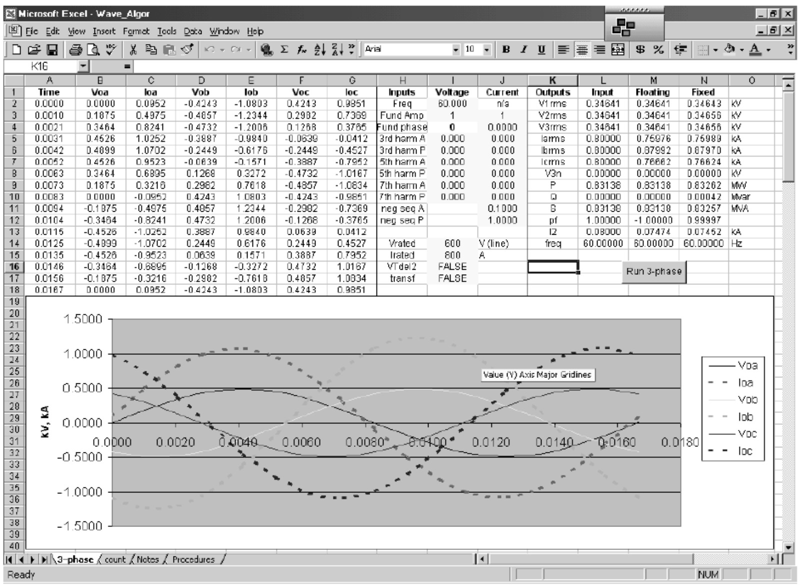
For the protection module, it was desired to develop algorithms for the calculation every half-cycle (8.33 ms) of Foss et al. (2003):

- RMS voltage and currents
- power and energy (active and reactive)
- negative sequence current
- voltage third harmonic.

Figure 3(a) shows the human–computer interface for the 'power measurement' tool that was implemented using Excel/VBA. Three-phase waveforms for the current and voltage were simulated, with options for:

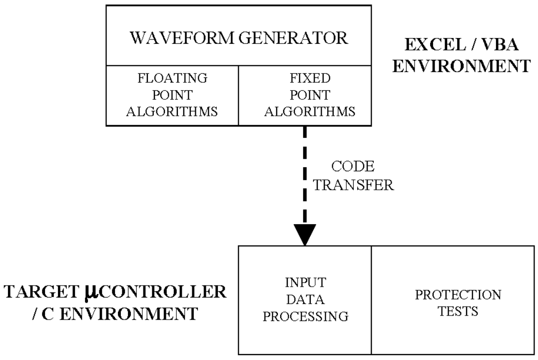
- voltage and current amplitudes
- fundamental frequency
- current phasing relative to voltage
- 3rd/5th/7th harmonics phase and amplitude for voltage and current
- negative sequence current (magnitude and phase)
- phase or line VT measurements
- three-phase transformer between the voltage and current measurement points.

Figure 3 Power measurement tool (a) interface and (b) development environment



(a)

Figure 3 Power measurement tool (a) interface and (b) development environment (continued)

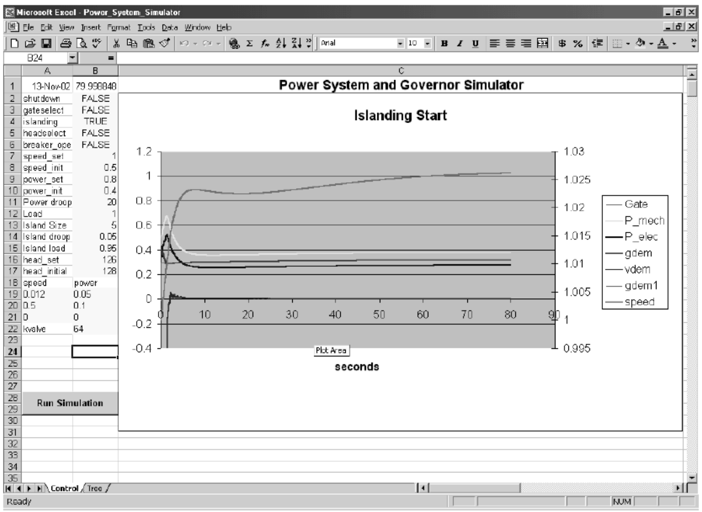


(b)

Using the simulation, measurement algorithms were prepared and verified taking into account appropriate sampling and analogue-to-digital conversion requirements. Algorithms were first prepared and verified using floating-point arithmetic, and then implemented fixed-point arithmetic in order to achieve the required computational speed whilst maintaining accuracy. Following verification, algorithms were converted to 'C' and copied across to the target micro-controller environment (Figure 3(b)).

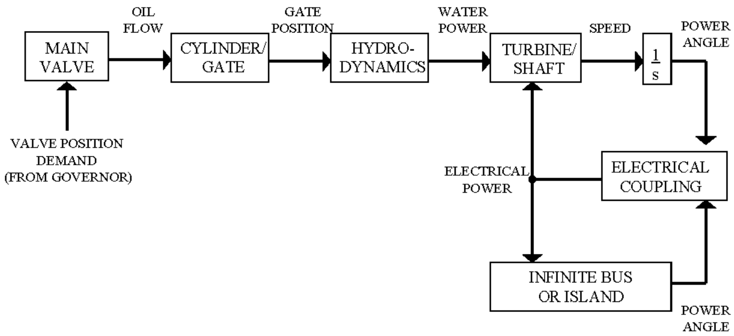
A similar approach was followed for the off-line hydro-plant dynamic simulator. The requirement was to design the control laws for a multi-rate multi-mode controller covering start-up, gate control, head regulation, power control, islanding control, shutdown and black start. In accordance with the appropriate IEEE standard (ANSI/IEEE Std 125, 1988), the starting point was to establish a dynamic simulation. Figure 4(a) shows the human–computer interface and Figure 4(b) contains an overview of the plant dynamic model. The model contained a 'single-machine-to-system' equivalent with provision for the system to range from an infinite bus to a small island.

Figure 4 Off-line hydro simulator tool (a) interface and (b) dynamic model



(a)

Figure 4 Off-line hydro simulator tool (a) interface and (b) dynamic model (continued)

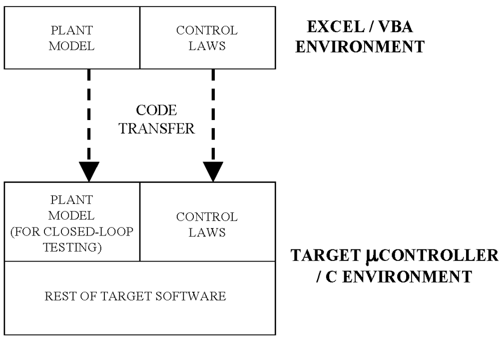


(b)

4.2 Embedded simulation tool

Following development of the controls laws using the off-line simulator, both the control laws and the dynamic model were converted to ‘C’ and copied across to the target micro-controller environment (see Figure 5). With the plant simulation embedded within the controller software, this provided a facility for early closed-loop verification of the software algorithms within the target micro-controller.

Figure 5 Off-line and embedded simulator tool environments

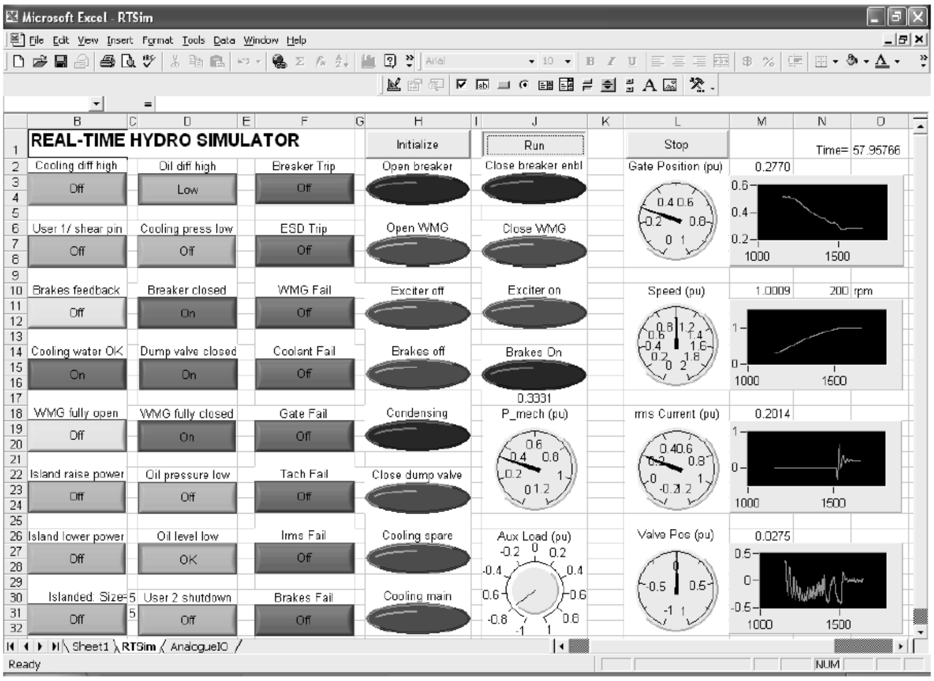


4.3 Real-time simulation tool

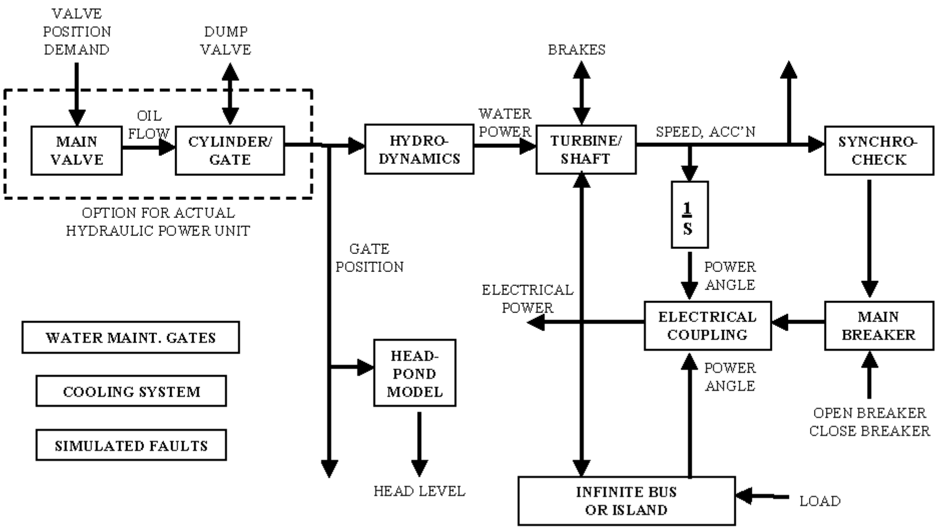
Although hardware-in-the-loop simulators have been well established for controller development, these are frequently expensive and often require specialist computational environments. A very low-cost solution adopted in this instance was to (see Figure 6):

- augment the off-line Excel/VBA simulation to include the full set of controller I/O channels (analogue and Boolean)
- purchase off-the-shelf I/O boards, which when plugged into a standard PC allowed access directly into the Excel/VBA software environment
- use the PC’s internal clock to trigger repetitive operation of the model equations to enable real-time computation.

Figure 6 Real-time hydro simulation tool (a) interface and (b) dynamic model



(a)



(b)

Three further features contributed to the versatility of the real-time simulation:

- virtual instrumentation software was purchased and used to enhance the human–computer interface
- thus simulated pushbuttons, knobs, dials, LEDs and trace recorders augmented the usual Excel interface
- a number of plant faults were programmed into the simulator to aid testing of the fault detection and response software
- the simulator could be run in two modes
- either the HPU could be included in the simulation, or the actual HPU could be part of the hardware-in-the-loop test environment.

This enabled cost-effective factory-based hardware-in-the-loop testing of a complete system comprising controller module, protection module, local panel, SCADA, set-up guide, Water-level module, hydraulic power unit with global and local data bus connections.

5 Conclusions

New control system structures and development tools are being facilitated by technological advancements such as:

- low-cost versatile embedded micro-controllers
- low-cost communication data highways
- low-cost personal computing software and hardware.

The new structures are based on distributed computing, with processing elements linked via data communication buses. Development tools that may have been expensive or unaffordable in the past can now be realised for low-budget solutions.

This technology was successfully applied to the control and protection of a 2MVA hydro generating plant. The design involved a set of micro-controllers covering control and sequencing, protection, human–computer interface, synchronisation and water-level measurement, linked via site and unit data buses. Equipment development, factory-based system testing and onsite commissioning were optimised through the creation of cost-effective simulation tools covering:

- off-line simulation in a standard PC with office tools
- embedded simulation in the controller processor
- real-time simulation in a standard office PC augmented with low-cost input-output boards.

The tools and structures facilitated a modular solution with comprehensive functionality at an overall low cost.

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