# STUDY REGARDING THE INTEGRATION CONDITIONS OF THE WATER SUPPLY NETWORK HYDRAULIC MODEL WITH A SCADA SYSTEM

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Abstract: The paper presents an original study about the way a hydraulic simulation model for water supply networks can be integrated in a command and control SCADA system

Key words: SCADA system; Hydraulic simulation model; Strategic model; Detailed models; On-line module; Off-line module

## 1. INTRODUCTION

Among the analyzing instruments of a SCADA system a very important place is occupied by the service of simulation. This allows the network simulation, which offers among others the advantage that there can be installed fewer measurement elements, because the simulation will allow the value interpolation in some points where there aren't installed instruments like that as well as checking for errors the data received from the field. On the other hand, the entire simulation system allows the analysis of „what if?" scenarios, which can be referred to the impact of some developments, network extension, the effect of low pressure caused by a breakdown, etc. It is economic to use SCADA systems to monitor a small number of possible network variables. On-line instantaneous simulation can provide estimates of all network pressures and flows. Simulation can also be used in a planning context to help rationalize the measurements network. The optimization of water network monitoring can lead to savings in instrumentation and telemetry.

## 2. INTEGRATING PRINCIPLES FOR THE HYDRAULIC MODEL IN THE SCADA SYSTEM

By integrating a water network simulation model with a centralized control system problems related to the water distribution network, the calibration and validation of the model in real time with the data supplied by the SCADA system, the determination of the parameters in parallel with the optimization are solved.

The data that can be transferred between a hydraulic simulation model and a SCADA system are systematized as following (FINESSE, 2004):

***Historical demand data.*** Past demand data is required from the SCADA system to perform demand prediction. A specified time horizon with a specified time step is required (e.g. 7 days at 15 minute intervals). Some aggregations and data reconciliation may be required to convert measurements to demand flows for the required zones.

***Historical pressure and flow data.*** Time series of pressures and flow measurements are required for model calibration.

***State data from SCADA.*** The current state of the network is required at a specified time. These provide the initial conditions for simulation and optimization. The measured parameters are:

- Reservoir levels mapped to nodes;
- Treatment works and source flows mapped to nodes and elements;
- Valve control;
- Pump control;

***Control schedule data to SCADA.*** The control schedule, which is derived from optimization and verified by simulation, may be sent to SCADA or may be input manually. Each schedule will start at the same time, but they may have irregular time steps. Some or all of the following schedule data may be sent:

- Pump control schedules – Optimizes the pump on/off schedules;
- Pump speed schedules - Optimizes the pump speed schedules;

- Valves control schedules - Optimizes the source flow schedules;
- Demand forecast patterns and loads - redicted time-series of demand and load factors. These can be compared with measured demands.

***Restriction Data from SCADA.*** Not all restrictions will be present in the SCADA system, but will be kept in the local modeling database. Also, some of the restrictions in the local modeling database may be relaxed for purposes of experimentation. In the SCADA system many of the restrictions may be used as alarms.

Fixed and variable restrictions will be required to specify the time horizon. Most restrictions are fixed for a time horizon and therefore only single values are required. Of course a restriction (ex. The restriction about the reservoir level) may vary in time. For example, the restriction on a node pressure will specify a minimum pressure and a maximum pressure. Typically restrictions are applied to the following variable in optimization:

- Node pressures;
- Reservoir levels;
- Source flows;
- Source flow changes;
- Pipe flows;
- Fixed speed pump control;
- Fixed speed pump flow;
- Variable speed pump control;
- Variable speed pump speed;
- Variable speed pump flow;
- Valve aperture;
- Valve flow.

***Tariff Data.*** Tariffs are charges made on the use of network elements for a given time horizon. There are different types of charges. These include:

- Unit electricity tariff;
- Treatment work and source tariff;
- Other tariffs.

In order to make this data transfer the hydraulic water network simulation model must have two modules: on-line module and off-line module (Bistriceanu I., 2005).

**The on-line module** is made to link the modeling package with the SCADA monitorizing system in real time and it must work on top of the SCADA system performing the on-line analysis of the system. The model results are stored back into the SCADA database. This is a part of the hydraulic simulation model and it works on the central host, as a part of the control system. During each cycle, all measured SCADA data is imported into the network model and the model parameters updated. Then, a hydraulic and water quality model is automatically performed. After the analysis, output data from the model is stored in the SCADA historical database, as well as displayed on the screen. All the measurements are checked and validated with standard modules, which will flag potentially "bad" data and – if possible – fill in gaps in the time series. This means that only validated data will be transferred and used as boundary conditions in the strategic model. This is very important in order to avoid using wrong data and thus risking the use of results based on these incorrect measurements for decisions about the system.

The on-line module operates in an infinite cycle of predefined time steps—such as every 10 minutes. Each cycle consists of the following steps:

- Input data is read from the actual SCADA database. It is possible to read the following input data:
  - Analogue measured values of pressure, water level in storage tanks, and discharge;
  - Analogue measured water quality parameters, such as the chlorine concentration;
  - Analogue measured values of valve openings;
  - Binary input values indicating the status of pumping stations, control valves etc.
- Calculated demands, and calculated flow control valve settings are used to balance the input data and to overcome non-measured demands;
- Input data is checked for errors and the gaps are filled;
- Input file for the analysis is modified based on the measured values;
- Hydraulic (and optional water quality) analysis is performed;
- The output data is stored in the SCADA historical database and displayed on the screen. It is possible to store any computed parameters, such as:
  - Values of pressure, water level in the storage tanks, and discharge;
  - Travel time along predefined paths;
  - Water quality parameters, such as the chlorine concentration, turbidity, water age, source tracing, etc;
  - Reservoir volume changes and residual volume;
  - Pump power costs and variable water production costs.

**The off-line module** is used to model „what if?" scenarios, model system breakdowns, and predict system behaviour based on the demand and control rules prediction. The off-line module is actually a standard installation of the modeling package, where can be made any analysis on the hydraulic parameters and water quality. The off-line module enables the user to load a previously stored network model which can be automatically prepared and analyzed by the on-line module. This allows the user to inspect the stored computed model in greater detail in order to look for water distribution network problems, etc. The off-line module contains the preprocessed data from a data base allowing the user to control the process of modeling by selecting the modeling alternatives.

The off-line module provides the following services:

- Prediction of the hydraulic, water quality, and economic parameters based on the pre-defined or forecasted behavior of the system parameters;
- Demand forecasting;
- Implementation of the control rules, allowing to reproduce the real-time system behavior;
- HTML based reporting - for web based communication;
- System costs calculation including water sources, and pumping stations.

The steps that need to be followed for making a project of integrating the hydraulic simulation model in a SCADA system must be (Bistriceanu I., 2005):

- Making a water network hydraulic model;
- Define the boundary conditions (head and flows in tanks, pumps, valves, pipes, junctions) and define the link between measured data and the elements of the model using the data dictionary;
- Model calibration;
- Define the data results (e.g. computed pressures and flows), which will be transferred from the model back to the SCADA system;
- Begin the simulation in the on-line module to run the analysis in the defined time interval (e.g. 10 minutes);
- Use SCADA interface to compare the measured pressures and flows with the ones modeled;
- Use on-line module to model system costs (e.g. pump energy costs);
- Use on-line module to model water quality analysis;
- Use off-line module to model any past and projected system behavior including node demands (the demands are automatically predicted based on the historical data).

## 3. OPERATING SCENARIO MODEL BETWEEN THE HYDRAULIC MODEL AND THE SCADA SYSTEM

On-line scheduling applications rely on demand prediction, which is an important operational tool in its own right. Scheduling may also be used for operational planning on long time for evaluating operational policies and restraints. Modeling can support the development of new operating policies, such as the better use of reservoirs to reduce energy costs, and to reduce water turnover times for water quality improvement.

For the calculation of operational control schedules for the next time horizon, the table below can be used. The time horizon is typically a 24 hour period or more. The scenario can be repeated at any time but the frequency is likely to be less than the control time horizon.

The scenario is presented as a sequence of tasks. In general, the operator initiates each task and can view its outputs, but it is possible to automate the sequence to some extent. The scenario contains 9 tasks. Some of these would not need to be repeated every day. It is assumed that the network model is already available and has been simplified if required (FINESSE, 2004; Bistriceanu I., 2005).

| | Task | Model input | Model output |
|---|---|---|---|
| 1. | Obtain data for on-line scheduling from the SCADA system. | SCADA data including time series of demand flows, pressures and pipe flows. System states such as reservoir levels and control schedules. | Reconciled SCADA data mapped onto hydraulic model. |
| 2. | Predict Demands. | Reconciled time series measurements for each zone (part of the output of task 1). | Predicted demand time series for each zone. |
| 3. | Calibrate model (optional). | Network model with unknown parameters. Reconciled pressure & flow measurements. Network demand. Actual schedules and reservoir states. | Adjusted model parameters including hydraulic resistances and nodal demand factors. |
| 4. | Create a “starting point” for scheduling | Calibrated network model with predicted demand flows, reservoir states and user-defined schedules. Simulation constraints (soft limits) and tariffs (optional). | Set of hydraulic simulation results (nodal pressures and element flows). |
| 5. | Revise scheduling constraints and targets. | Existing or default constraints on reservoirs control variables and hydraulic results. Control variables fixed by the user. Existing tariffs if necessary. | Revised constraints. Revised control variables fixed by the operator. Revised tariffs. |
| 6. | Calculate optimal schedules. | Calibrated network model with predicted demand flows, reservoir | Optimal continuous control schedules, plus |

| | Task | Model input | Model output |
|---|---|---|---|
| | | states, user defined schedules, simulation results and constraints and tariffs. | hydraulic results (reservoir levels, pressures, flows etc) and costs. |
| 7. | Calculate discrete optimal schedules (optional). | Output of task 6. | Control schedules with discretised variables where required (e.g. pump on/off). |
| 8. | Check and compare schedules using simulation (optional) | Outputs of tasks 6 and 7 and results from any of the simulations. | Full set of hydraulic and cost simulation results under the optimal schedules. Evaluation of the results through comparison, e.g. discretised versus continuous etc. |
| 9. | Send results to SCADA | Outputs of tasks 6 and 7. | |

## 4. THE BENEFITS OF INTEGRATING A HYDRAULIC MODEL IN A SCADA SYSTEM.

*Parameters estimating for the locations that do not have measurement elements.* SCADA systems monitor the water distribution system performance at discrete stations scattered throughout the service area. Howerver there may be situations in the water distribtuion system when it is necessary to know the parameters in a location where do not exist measurement instruments. For these situations, the flows and pressures can be estimated from SCADA information at nearby stations. When these calculations are not complicated, they can be performed within the SCADA software (for example, by offsetting pressure readings from other stations based on differences in elevation). However, when the situation is more complex, a hydraulic model interfaced with the SCADA software is required to obtain parameter estimates.

The steps that need to be taken to obtain the information in the zones that are not monitorised include the following (Walski T. M., et al., 2002):

- Export data on boundary conditions from SCADA;
- Configure the hydraulic model to match those specific conditions;
- Model running;
- View the results or import results from the model back into SCADA.

This type of procedure is typically automated and accomplished with some form of dynamic data linkage between the SCADA system and modeling software.

*Compensating SCADA data error.* By comparing in real time the data supplied from the water network hydraulic simulation with the data received from the measurement elements of the SCADA system it can be seen if the data sent from the elements of automation are contains errors. The model supplies detailed results and can compensate the sensors breakdowns, accomplishing this way the role of virtual sensors, which will instantaneous evaluate the observed data which are good for fast decisions. Also in case of missing data from the RTUs these can be replaced with the simulated data by the hydraulic model, on the base of the historic data recorded by the SCADA system.

*Estimating water losses due to pipe breakdowns.* Tracking the water discharged from the system during main breaks can help quantify losses. Generally, a significant main break will show up in SCADA records as low pressures readings, an unexplained decline in tank levels, excessive pump flow, or other unexplained data inconsistencies. SCADA information for the time period surrounding the break can be downloaded to a hydraulic model and the model can then be executed to simulate system conditions at the time of the break. By adjusting the demands (or emitter coefficients) at the break location and trying different start and finish times for the break, the modeler should be able to match modeling results to the SCADA records during the break and thus determine the quantity of water lost. These results can then be used in estimates of unaccounted-for water.

*Prediction analysis.* In the functioning of some networks it is very important to follow the variation tendencies of the state variables, with the mentioning of the fact that data recording on certain time periods can be used for predictions, as well as for finding administration problems after subsequent analysis. Because this it will be recorded in a data base an event history, which besides the state values, will contain the possible alarms and commands from other operators. Tracking and analyzing the tendencies is essential in taking good decisions. This service expects the registration of data on one hand, and on the other hand predictive analysis. Consume analysis (which can be deduced from the state values) are useful for tracking peak daily, weekly, monthly or yearly demands; on this data basis the parameters can be set for predictive analysis, the results of these making the work of the operators easier.

The SCADA system can view the current state of the network and its history. While the on-line long-term simulations can predict the future functioning of the network (this facility supplies important complementary information for using in management, engineering and operational). On the recorded data basis of the SCADA system, the hydraulic model can predict the time evolution of the state variables by interfacing it with the graphic mode displaying the predictive graphics of the variables.

*Modeling the parameters that can not be measured.* Some proportions that appreciate water quality in pipes, like water age and water source tracking (the water percent that comes from one source in a water volume from the pipe network), can not be directly measured, they are calculated by modeling the water flow through pipes with the help of the water network hydraulic simulation model on the basis of the data received from the SCADA system.

*Complete model calibration for the water networks***.** The continuous evaluation of the measured values and calculated pressures and flow shows the precision of the calibrated model. The link between the monitorizating and analysis system of the model is the only way for a complete calibration of this for water networks. The measured pressure and flow time series are necessary for the model calibration. The usual validation of the model is made once a year. Still, the observed data must be archived. Once with the accumulated data, the authorisated staff will activate more often the genetic algorithms for calibrating the water network.

*Calculating system costs.*There are different types of costs necessary for using the network elements on a certain time period. These costs include energy costs for pumps, water treatment costs, etc. The model can be used for calculating system costs like the actual water costs in any point of the system. The optimization of the total network energy costs, including pumping costs (at different energy tariffs), water production costs (energy and treatment costs) can be made by reducing them which can be achieved by model based on the flow and energy costs balance to sustain the planning decision and by applying the management procedures on different time periods.

## 5 WAYS TO USE THE HYDRAULIC SIMULATION MODEL IN PROJECTING A SCADA SYSTEM

To offer decisional support, the SCADA systems must offer a large range of services. It is hard to install monitorization systems in the urban zones without the base knowledge about the behavior of water distribution systems. The water network hydraulic simulation model can make the work of the SCADA developers easier by projecting these services. Some usage examples of the hydraulic model in projecting a SCADA system are shown below.

*Making a graphic mode.* The operators must be able to see on a synoptic board the way the network looks, showing the most important states. This board must show the whole view of the network, with the essential state information, without being overcharged. The values of some points or portions will be shown on smaller screens, which can be of normal computer screens. On the same detail displays the operator must have some commands that can initiate operations for the far away execution elements. The data display and of the possible command elements , with the programs used for these functions, make up the graphic mode. All the network elements that need to be displayed on the SCADA application board as well as the links between them are symbolized in the hydraulic model. The SCADA designer can follow the model and take out from the library the graphic elements of the SCADA program, the elements that are in model without a supplementary documentation.

*Report projecting.* A report is a presentation or a description of the system conditions, which can run periodically, at request or when an event takes place (for example, a variable state change). The hydraulic model of the water distribution network supplies reports under a table or graphic form for the elements of the network, these reports can be considered as model for the reports which will be supplied by the SCADA program because they have all the situations for the network elements (pipes, junctions, tanks, reservoirs, valves, time models, element controls). Besides, for the integration of the model in the SCADA system, as it was shown, the reports generated by the model must be compatible with the reports of the SCADA system. The realized reports can be shown in the graphic mode, printed, saved in HTML format (to be viewed on the Internet) pr sent to SQL data bases.

*Settling alarms.* A SCADA system must have an efficient system for identifying and isolating the breakdowns, reducing this way the time when it is not working. The alarms must be processed, organized, shown, and deactivated by taking the specific measurements for oust the errors. Running the hydraulic model shows the places where there are high risks of breakdowns as well as how important they are in the network functioning so that when the SCADA system is projected it must be paid a special attention to these sensitive locations.

*Events set up.* The events are set up so that when they start, some commands are done. For example when a process is ended, the operator is told and a series of specific instructions is executed.

For example the events can run:

- Automatic in the chosen moment;

- Automatic when a condition becomes TRUE;
- Automatic in the chosen moment, if the condition is TRUE.

Similar to the SCADA events, in the hydraulic model the controls which correspond are declarations which determine how the network is operated in time. They specify the statute of the selected links as a time function, water level in the tank and the pressure at the selected points in the network, etc. For a SCADA system developer it is easier to settle the events which are about to happen in the network functioning by following the hydraulic model controls which have the same role (closing or opening some valves depending on some pressure or debt conditions, turning on or off the pumps depending on the level or pressure in reservoirs, etc.)

*Architecture development.* Except for the current purposes of a water network hydraulic simulation model there are: daily operational uses including staff training, emergency responses, fire studies, there are also long-term purposes 10-20 years which include: long-term planning, including developing, rehabilitating and water quality investigations.

When developing hardware and software architecture for a SCADA system future network developments must be kept in mind, so that the flexibility and scalability of it is assured, without major changes regarding the hardware or software part existing in the system, on the base of the developing plan resulted by running the hydraulic simulation model in various network extension possibilities.

*Choosing the measurement, action and automation elements* By running the water network hydraulic model the maximum and minimum values of the parameters can be determined (pressures, flows, levels, etc) and based on this values the best measurement elements can be chosen according with the measurement domain. Because the hydraulic model contains all the networks elements symbolically represented, the necessary action and automation elements can be determined (ordered valves, command pumps, etc.).

## 6. CONCLUSIONS

By integrating the hydraulic simulation model with a SCADA system and studying the way the system behaves on-line and off-line for several possible situations, without being influenced by the possible errors received from the field measurement tools, the simulation model can be used by making a link between the existing system and the model for data exchange between the two, so there is a double control, once for the calibration in real time of the hydraulic data model and once for verifying the errors received by the SCADA system from the field.

Also, by implementing a SCADA system on an existing water network, the hydraulic simulation model of the network cuts down the time necessary for this implementation because he already contains , in a schematic way all the physic elements of the network, eliminating the necessary time for identifying them. By running the model for extreme situations they can determine the minimum and maximum values for the system variables and to pick this way the measurement domains for the interpretation elements (pressure, level, flow, etc.).

The simulation model of the water network can bring major time and money benefits not only for the already working SCADA systems but also for those in a project state.

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