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Flow Simulation to Link the Operation of Hydro Power Stations

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Owen Mooney, Hugh MacMurray, Alastair Barnett

A simulator is described, which is primarily used for training operators in the management of linked hydro power stations under normal and abnormal conditions. The simulator provides accurate modelling of hydraulic transients and includes a SCADA system emulation so that the simulator appears like the real control system. The simulator can be used to test alternative strategies for historical periods, thereby improving the overall operation efficiency.

Diese Publikation beschreibt eine Software zur Simulation von gekoppelten Wasserkraftwerken. Der Hauptzweck der Softwares besteht in der Ausbildung von Mitarbeitern unter normalen und nichtnormalen Bedingungen. Die Fortpflanzung von positiven und negativen Wellen kann genau simuliert werden. Die Software beinhaltet eine SCADA-System-Emulation, mit welcher das reale Kontrollsystem simuliert werden kann. Durch die Simulation von historischen Perioden ermöglicht die Software eine Beurteilung von alternativen Betriebsweisen und damit eine Verbesserung der Leistungsfähigkeit des ganzen Wasserkraftsystems.

1 Introduction

This paper presents experience with a hydro power system simulator that is in use at Meridian Energy Ltd and Mighty River Power Ltd, two of New Zealand's major generation companies. The main use of the simulator is for operator training, particularly under abnormal conditions of flood or low flow, but it can also be used to test modifications of the system, such as increasing the generation capacity, under a range of hydrological conditions.

The basis of the simulator is the AULOS software, which provides unsteady hydraulic modelling of improved accuracy using CELL Integral solutions (Barnett 1994, Barnett and MacMurray 1998). The hydro power system operated by Mighty River Power comprises eight dams on the Waikato River, with in some cases significant river reaches between the lakes. Therefore level pool routing methods would be seriously inaccurate, making accurate unsteady hydraulic modelling an important feature of the simulator. The Waitaki hydro power system operated by Meridian Energy is based on storage lakes connected by long man-made canals, so that accurate simulation of the propagation of positive and negative waves is essential.

Approximately 60 % of New Zealand's electrical energy is generated by hydro power systems. Therefore the precise management of such systems is very important in maintaining the stability of the national electricity supply. Also, New Zealand generation companies sell electrical energy at market-determined prices, so there is an economic incentive for accurate management of the generation systems.

The simulator includes a mimic of the SCADA system that the operators use for management of the actual river, so that running the simulator is almost exactly like controlling the river, except that all responses including the consequences of management decisions become manifest much more rapidly.

2 Benefits of the simulator

2.1 Management of generation and water balance between stations

Under normal flow conditions, the task of the hydro power system operator is to match generation to demand, while achieving the best possible hydraulic efficiency. In doing so the operator must consider: spreading the generation between stations in order to maintain water levels in the lakes or canals within satisfactory ranges; maintaining lake levels near the top of the operating range so as to maximise the generating head; running the generating units in or near their most efficient range; and avoiding the rough running ranges of the individual generating units.

In the Waikato River system, as is usual in chains of hydro power lakes, there is a range of lake sizes, depending on the locations of suitable dam sites. The maximum generation flows are similarly variable between stations. Thus to manage the generation and water balance between lakes is not a trivial task. In the past operators learned successful strategies on the job. Now the simulator allows a range of management strategies to be tested, normally by simulating a historical period, to find whether the operator on the day could have achieved a better result.

The simulator calculates an overall generation efficiency at the end of each simulation period, as the electrical energy produced divided by the total potential energy of water transformed.

The overall management system for the Waikato River includes a hydrological model that estimates the inflows to each lake as a function of antecedent and predicted rainfall. These inflows are used by the hydro system simulator, and are a significant source of uncertainty, particularly during high flow periods.

The hydro system simulator does not include any market variables. Thus it can help with achieving efficient operation of the system in physical terms, but not in financial terms.

Matching generation to demand requires that generation can be increased rapidly in response to an increase in electrical load. The simulator includes this spinning reserve, by automatically adjusting station output to meet actual demand. On the Waikato River system, Maraetai station has a flow capacity of approximately twice the other stations, to meet the spinning reserve requirement and cover demand peaks.

2.2 Management of abnormal conditions

Management of abnormal conditions is by definition difficult to learn on the job. The simulator makes it easy to add some abnormal conditions, for example an unplanned outage of a generating unit, to the historical record. Strategies to recover from the outage can then be tested. Similarly operators can be trained in the management of historical floods and low flow periods.

2.3 Management of extreme floods

There are several cities and towns on the Waikato River downstream of the hydro power lakes. Management of system in extreme floods to prevent overtopping and possible failure of any dam is therefore very important, and there is a set of mandatory flood rules that must be followed at each dam after certain lake level thresholds are reached. These rules were originally developed without the benefit of a whole river simulation. While the rules have since been tested in a whole river simulation, there may be scope to improve them, or at least to delay the occurrence of the threshold for the mandatory management rules, by using the simulator to test strategies for dealing with extreme flood conditions.

2.4 Testing proposed system upgrades

The simulator can be used to test the effect of for example adding a further generating unit at one station, under a range of historical operating conditions.

3 Hydraulic simulation

For hydro power system modelling a hydraulic simulation must reproduce transients accurately. This requires that the initial conditions from which the simulation starts must also properly represent the transients that are in the system at the start of the simulation period. To achieve this, the simulator runs a pre simulation period, during which each lake is driven by a level boundary condition downstream, and flow boundary conditions upstream (both as historically recorded). At the start of the simulation period, the simulator automatically switches to flow boundary conditions at the dams, as set by the operator. The lake levels then respond to the operator's actions. The pre simulation period varies depending on the particular system, for example 24 hours is used in the Waikato River system, because that is somewhat longer than the time required for a positive or negative wave to traverse the longest river reach (between Aratiatia and Ohakuri dam).

As noted above, the hydrological inputs to the lakes on a river system introduce a significant uncertainty. In accuracy testing of the simulator this uncertainty was sufficient to make the simulated lake levels diverge significantly from those recorded after periods of 24 hours or less (the target for the accuracy testing was to be within 0.1 to 0.2 [m] of recorded lake level after 48 hours of simulation).

The system was therefore modified to calculate balance flows, which were applied as a correction to the historical estimates of tributary inflows. The method of calculating the balance flows for each lake was to apply discharge boundary conditions as recorded at the dam and at the head of the lake, and as estimated at any tributaries, and to apply the recorded water level at the dam as a boundary condition at an artificial branch of generous flow capacity. The flow drawn in or rejected at the artificial branch was then the balance flow.

Most of the lakes show significant seiching, and therefore the balance flows tended to oscillate. The raw balance flows when used in the simulation did not satisfactorily reproduce the recorded lake levels, and the balance flows were further processed with a low pass filter in order to achieve satisfactory results.

A useful feature of the simulator is that it accurately reproduces the delivery capacity of canals. For example on the Waikato system, water is delivered to Arapuni power station intake by a canal, whose discharge capacity is a function of lake level. If the operator requires more flow than the canal can deliver, the system produces a failure message and the simulation must be restarted.

4 Example output for one reach

Mighty River Power runs a system of eight hydro power stations operating on the Waikato River in the middle of the North Island of New Zealand (see Figure 1). All of these reaches are simulated as a single model. To illustrate the accuracy of the system we have chosen one river reach, which is the first between the control gates at Lake Taupo (marked in Figure 2 with a red line) and the first power station at Aratiatia.

The river reach from Lake Taupo to Aratiatia Station represents one of the more difficult to simulate. The flow into this reach is controlled by gates at the outlet of Lake Taupo. It flows through a flow measurement station, a series of falls, and then into Lake Aratiatia which has a minimal amount of storage, with a surface area of only 0.55 km^2).

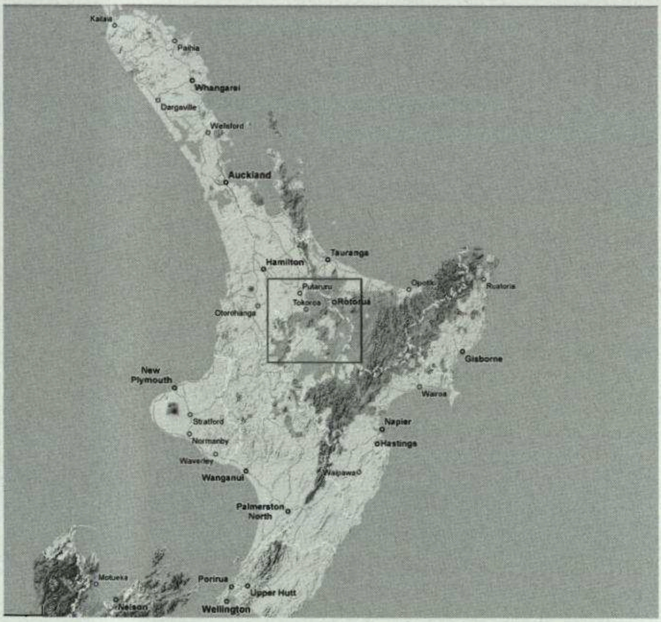

Figure 1 The North Island of New Zealand showing the location of the Waikato River hydro power system

Figure 3 shows the flow out of the control gates at Taupo (blue), and the flow measured at Reids Farm (green), about half way down the reach to Aratiatia Dam. The measured flow shows both the smoothing effect of the river routing and the transit delays.

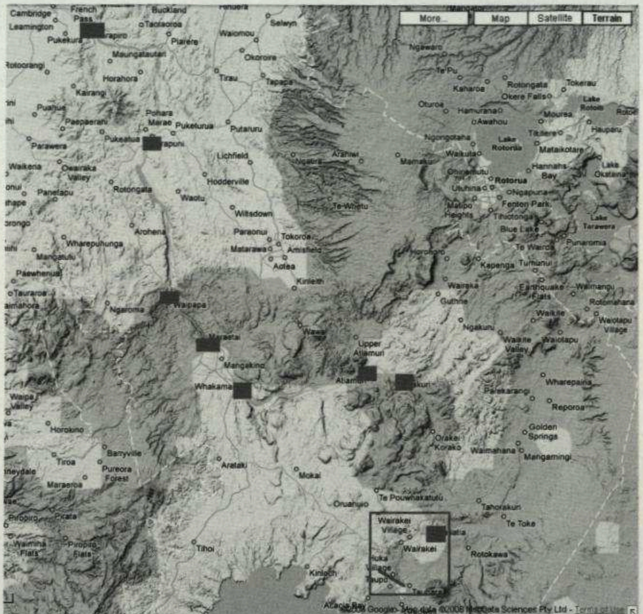

Figure 2 The locations of the dams and Lake Taupo control gates of the Waikato River hydro power system

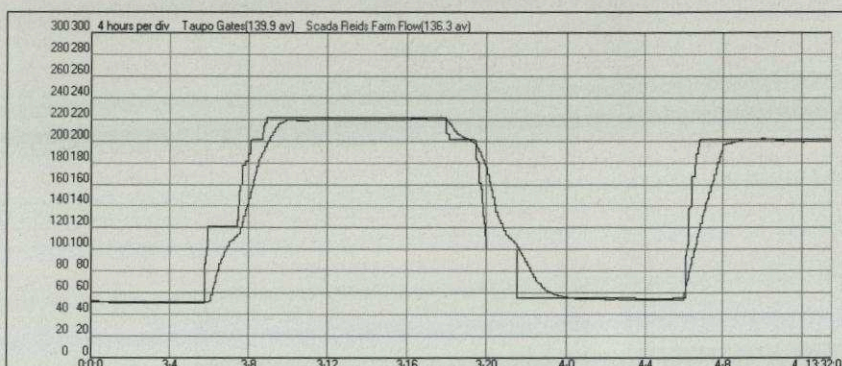

Figure 3 Measured flows at Taupo control gates and Reids Farm gauging station, Waikato River hydro power scheme

Figure 4 shows the flows downstream of Aratiatia Dam (green) and the Taupo gates (blue). Notice that the operator has to allow the flow through the Taupo gates approximately one hour before he uses the water for generation. The simulator has to accurately reproduce this routing delay. The Aratiatia flow includes the flows over the Aratiatia Rapids, which are released three times a day for tourism purposes. These are visible in the green time series as spikes at mid morning, mid day, and mid afternoon.

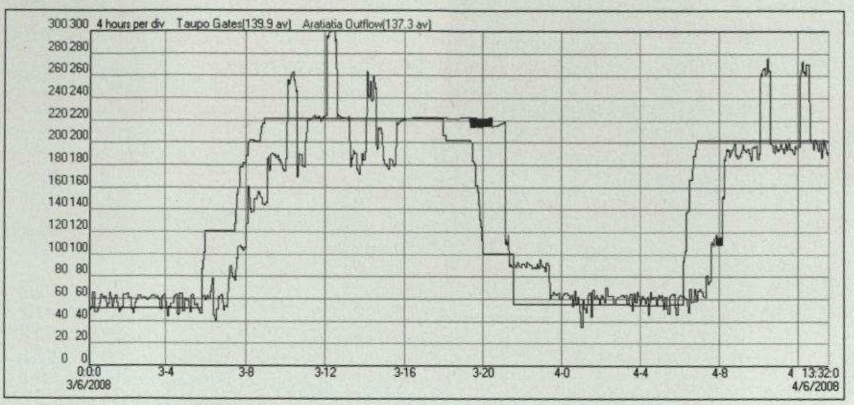

Figure 4 Measured flows through Taupo control gates and Aratiatia power station, Waikato River hydro power scheme

Figure 5 shows the measured water level at Lake Aratiatia (green) and the simulated water level (blue). This simulation used the raw flow data, before the balance flows (calculated as described above) were applied as a correction. The simulation agrees well with the measured lake level until the flow releases over the Aratiatia rapids for tourism purposes. During those releases the simulation diverged sharply from the measured lake level, which indicates that the tourism

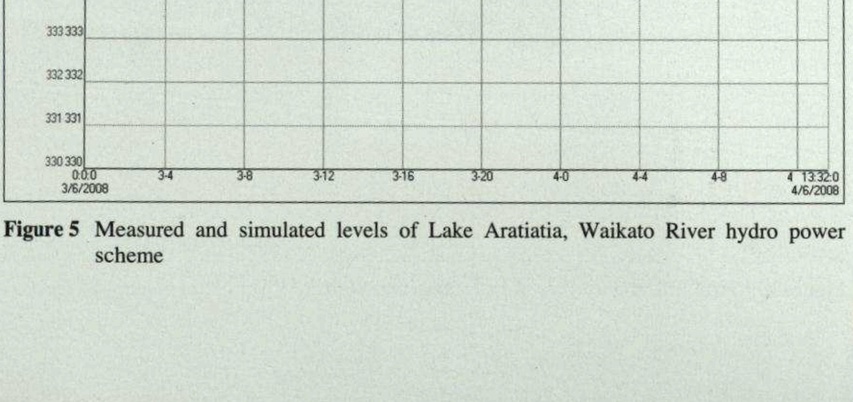

Figure 5 Measured and simulated levels of Lake Aratiatia, Waikato River hydro power scheme

flows are not accurately gauged. After the tourism flow releases, the simulation tracks more or less parallel with the recorded lake level, until the start of the next day's tourism flows when there is another sharp divergence. The lake level error in the simulation is quite sensitive to any errors in flows, because the lake surface area is so small. Figure 6 shows the measured Aratiatia power station flow, and the flow releases over Aratiatia rapids for tourism.

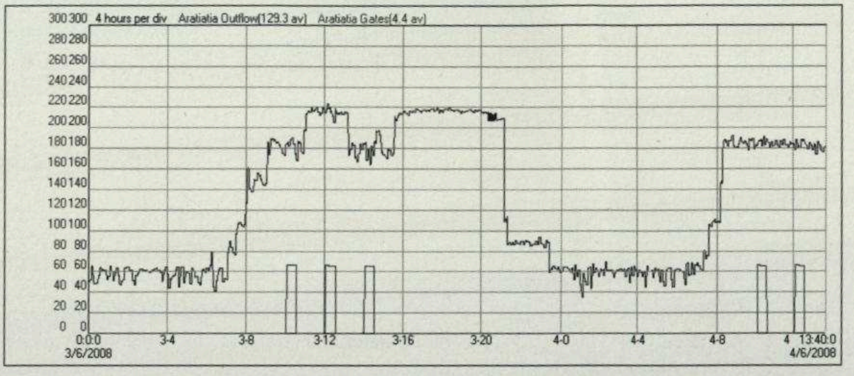

Figure 6 Measured flows through Aratiatia power station, and over Aratiatia Rapids, Waikato River hydro power scheme

Figure 7 shows the balance flow, calculated as described above, but before filtering to remove the higher frequency oscillations associated with seiching in the lake. This shows that the flow adjustment required to make the simulation agree closely with the measured lake level is actually reasonably small, averaging 1.1m^3/s over the period. Lake Aratiatia is unlike the other lakes in that

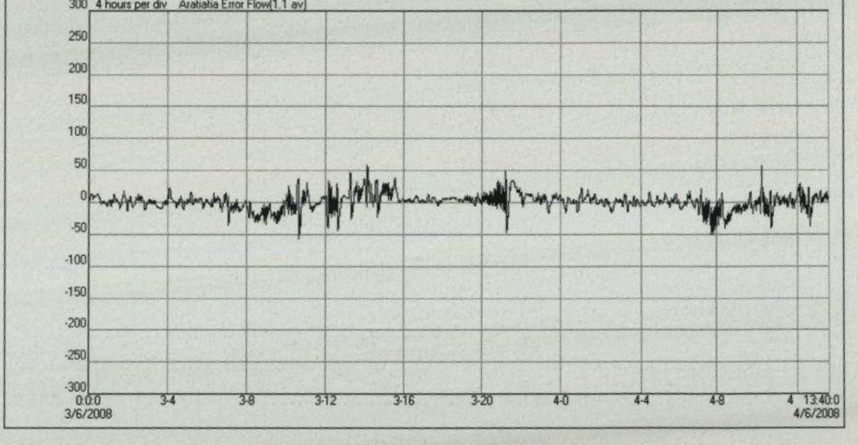

Figure 7 Calculated balance flow at Lake Aratiatia, Waikato River hydro power scheme

the main source of error appears to be the gauging of the tourism flows, whereas in the other lakes the main source of error is the tributary inflow estimation.

5 User interface

5.1 Requirements

While the AULOS software provides accurate hydraulic simulation, the normal simulation tools do not provide a suitable interface for training operators. The requirements include: a reasonably close mimic of the operator SCADA screens; the ability to control the timing of the simulation; and accurate simulation of other generation features such as spinning reserve, generator capacity, and rough running ranges.

There are two possible approaches, and both have been implemented.

5.2 SCADA emulation at Mighty River Power

The simulator for the Waikato River hydro power scheme includes a full emulation of some of the SCADA screens. The two screen captures below show the original SCADA screen (Figure 8) and the simulated SCADA screen (Figure 9).

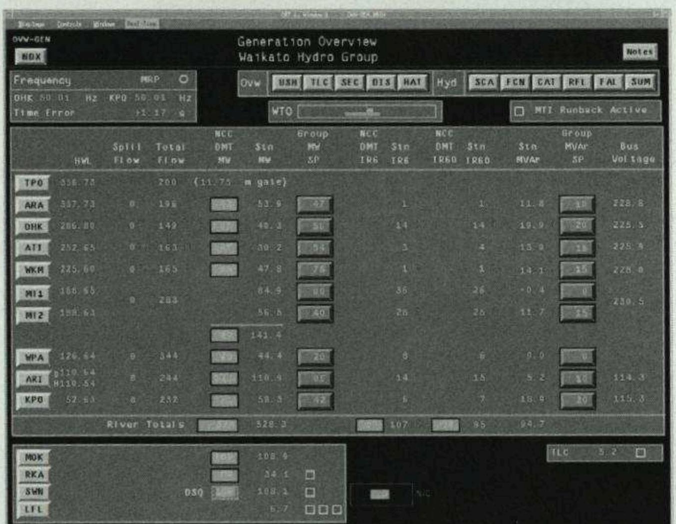

Figure 8 SCADA screen from Mighty River Power control system

All of the information relevant to hydraulic management is shown including water levels, generation output, flows, generation reserve, and the historical required generation values provided by the customer, Transpower. In addition, a small time management panel in yellow is provided in the simulated screen, allowing the operator to step through the simulation.

Figure 9 Simulated SCADA screen

5.3 Implementation at Meridian Energy

The installation at Meridian Energy takes a different approach. In this case a full SCADA system is provided for the operator interface. This approach allows the emulation of many other features besides hydraulics to be integrated into the simulation. The hydraulic simulation runs as a separate executable, receiving data from the main SCADA emulation in terms of flows, and providing level and flow information back.

6 Conclusions

1. Accurate hydraulic simulation is necessary for simulation of hydro power schemes that include rivers and canals
2. The simulator described includes transients in the initial condition of the simulation period

3. The simulator can be used to calculate balance flows, thus making the historical flow data consistent with observed lake levels.
4. The balances flows need to be processed by low pass filtering to remove the effect of Lake Seiching.
5. The adjusted historical data is valuable for training operators under normal and abnormal conditions, and for assessing the effects of proposed changes at power stations.
6. Strategies for managing extreme floods can be tested using the simulator.

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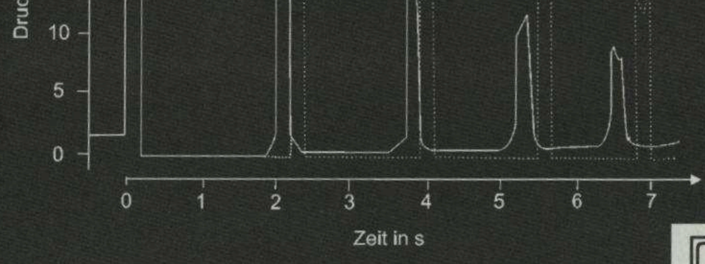

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