Evaluating functional displays for hydropower system: Model-based guidance of scenario design

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Abstract

We discuss the human role in hydropower system control, noting how it is different from other supervisory control environments and the typical shortcomings in current displays provided to hydropower system controllers. We describe steps towards evaluating proposed functional displays with the industry hydropower controllers. This involves selecting test scenarios that may demonstrate the advantages, if any, of the functional displays. Starting from a basic human control loop: detect → analyse → act → evaluate, we identify scenarios in which the functional displays are expected to provide information in a more effective way than current displays.

Keywords: human supervisory control, hydropower system control, situation awareness, automation, functional displays, scenario design

1 Introduction

Designing displays for the hydropower system controller is a particularly challenging undertaking. This is because the hydropower system controller's role encompasses many different kinds of systems that have to work together, and many different timeframes in which activity takes place. In this paper we describe the role of the hydropower system controller and outline the shortcomings in the information system with which such controllers are typically provided. We briefly present some displays that have been developed in an attempt to overcome these shortcomings (Memisevic, Sanderson, Choudhury and Wong, 2005) and we outline our steps towards an evaluation of the new displays.

Figure 1(a) gives a very simple summary of the different elements of a hydropower system. The energy source for generation is water, a valuable resource that must be used strategically to keep options open. It can be an uncertain resource, depending upon weather, snow melts, runoff, and so on. Electricity generated is transmitted to the national electricity grid. However the generation of electricity is affected by operation

Relevant topics: human-machine interaction, situation awareness, evaluation methods and tools.

of a deregulated electricity market. Moreover, the generation of electricity is constrained by irrigation requirements—water coming from power stations is used for irrigation and there are agreements and contracts that must be respected for how much water is released, where, and when. Therefore there are multiple constraints, some physical and others intentional (e.g. financial), some in the short term and others in the longer term.

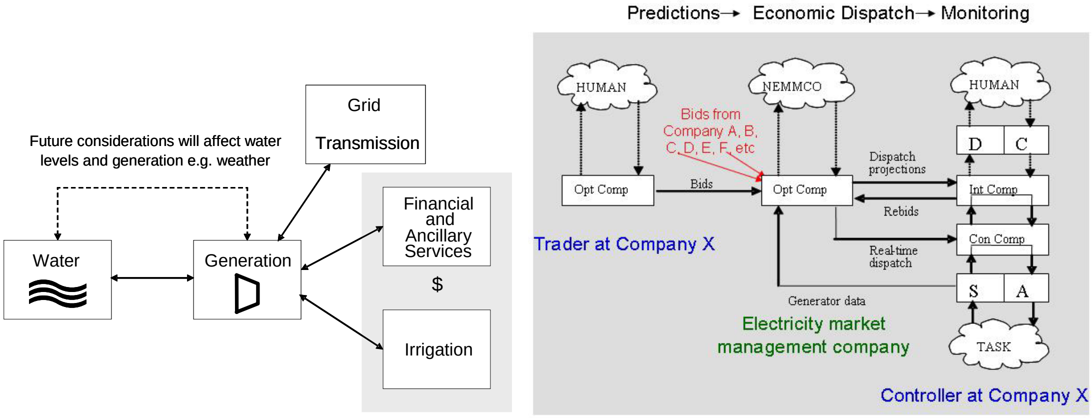

Figure 1. (a): Diagram of the relation between the different elements of a hydropower system. (b) Role of the human controller in the deregulated electricity market (adapted from Sheridan, 1987). D=display, C=controls, S=sensor, A=actuator.

2 Role of the human controller

The role of the hydropower system human controller in a deregulated electricity market is different from the role of his counterpart in regulated or centrally controlled power systems. The differences are explored below, and the role of automation outlined.

2.1 Human supervisory control in hydropower systems

Figure 1(b) is a variant of the familiar Sheridan (1987) model of human supervisory control. In the element at right labelled Controller at Company X, the human supervisor interacts with a task through displays and controls that couple him with a central Supervisory Control and Data Acquisition (SCADA) computer, which in turn drives a Remote Terminal Units (RTU) that interfaces with sensors and actuators at the physical level of control system. Models of human supervisory control have usually been confined to this element alone.

We expand the Sheridan (1987) model to illustrate some of the challenges of human supervisory control in a deregulated electricity market. Figure 1(b) shows that requests to make electricity (bids or rebids) must be sent to an independent market operator—The National Electricity Market Management Company (NEMMCO). Bids may come from the controller at Company X, but sometimes they have been made previously by Traders at the same company. NEMMCO receives bids not only from Company X but also from many other companies participating in the market.

All the bids are submitted to an optimisation routine that is designed to match electricity supply with electricity demand at the minimum cost across the market for each dispatched interval (5 minute). NEMMCO sends back to each company projections of how much electricity that company will be required to make, or ”dispatch”, in each dispatched interval for the rest of the day. Throughout the day, the controller at Company X prepares his generators in time to make the electricity requested. Then, for each moment that Company X is dispatching electricity in real time to the grid. The Automaic Generation Control (AGC) driven centraly by NEMMCO control all generator units inside market in automatic mode at the time keeping frequency of the power system around the nominal value.

The human controller's role is to monitor this process to ensure it is done successfully. The controller intervenes where necessary to ensure an unbroken supply of the electricity the company has been dispatched to make for the market and to avoid penalties. The dynamic nature of the electricity market has led to profoundly different patterns of generation than before, and a need to respond to contingencies and opportunities much faster than before the market existed.

Given this environment, the human controller's work is a mixture of *reactive* and *proactive* control. The process of monitoring for failures and intervening is reactive. However monitoring also involves a proactive search for situations that might become problematic if not handled early. When detected, such problems lead to discussion, decisionmaking and planning of future action, which often takes the form of changing when and from where electricity will be made.

2.2 Relationship between human supervisor and automation

The above description focuses mainly on generation and trading. As indicated in Figure 1(a), hydropower system operations also cover the management of water storage and water diversions. In the longer term, there are also irrigation requirements to be met.

The levels of automation that support the above functions are vastly different. Because electricity travels at the speed of light, a high level of automation is needed to maintain power system stability as the human controller simply cannot respond quickly enough. The optimization of water usage driving the division of the generation among the generation units within hydropower plants aggregated into one aggregate unit is also automated.

In contrast, water storage management takes place over hours and days in the short term and up to months and years in the longer term. Here the human controller makes short-term decisions, supported by software tools that help him predict future water levels. Particularly, water surge is controlled by automation.

Finally, decisions on participation in the electricity market are determined strategically by company traders in consultation with controllers for matters relating to plant safety and availability of resources. Particularly, controllers have to follow transmission constraints provided by NEMMCO recalculation on the basis of the overall system stability and security concern.

The current displays in hydropower control room, extracting data from SCADA and AGC system, present the current scheme status in separate physical systems-hydraulic network, generation, electricity market and transmission network. For example, for monitoring water, controller often have a hydraulic overview display, which allows navigation on the water network and from there to drill down to specific components such as gates, valves, and so on. Indeed these displays are not able to provide information that integrates past, present, and future views, or integrates the different subsystems shown in Figure 1(a) so that higher-level properties are seen. To support decisionmaking, companies either buy further off-the-shelf applications or develop their own tools in house. Even so, it is seldom that the kind of integration is provided that allows controllers to assess consequences across the different subsystems shown in Figure 1(a).

3 Functional displays

Figure 2 shows two of the displays conceived by Memisevic in an attempt to overcome the above problems. The displays are the result of an analysis of the work domain and its temporal characteristics that is discussed in Memisevic et al (2005).

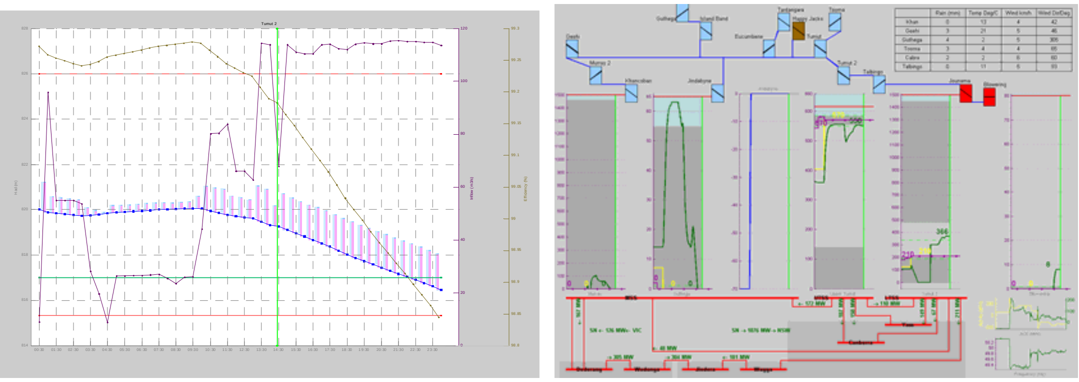

Figure 2. Two functional displays. (a) Water levels, constraints, and efficiency, with past and future states from left to right. (b) Energy source, energy production and energy production from top to bottom (Memisevic et al, 2005).

The Water Short-Term Planning display (WSTP) in Figure 2(a) supports short-term planning, integrating past, present and future in a 24 hours basis. It shows levels in a storage, with the vertical dimension representing water head, inflow, efficiency. Time, in the horizontal axis, runs from left to right, with a vertical bar near the centre indicating the present moment. The future state of the water storage, given present and planned use of water, is evident. Hollnagel’s characterisation of a control room as a ”room with a view” of past, present, and future states is supported with this kind of display (Hollnagel & Woods, 2005).

The Energy Flow diaplay (EF) in Figure 2(b) supports real-time evaluation of generation and transmission, integrating the energy source (on short term), energy production against targets (generation), and energy distribution (transmission) in a flow from top to bottom of the display. Across the centre are representations of each collection of power stations, showing their electricity targets from NEMMCO and their output. Constraints on generation are shown, including the ”reserve” they must maintain in case generation needs to change quickly, and any limitations coming from the grid on the electricity they can transmit. At top is shown the current state of the water storages, which is the energy source, and at bottom is the transmission network, where the energy will be distributed.

A further display (not illustrated here) shows the short-term flow of revenue (Revenue flow or RF display) using the same framework as the WSTP display. Past, present, and anticipated inflow and outflow of revenue are depicted from left to right, with a vertical line separating past from present.

4 Evaluation

The goal of our research is to evaluate the functional displays described above. The evaluation will be done at a participating hydropower system with industry controllers whose time with us is limited to a few hours only. A medium-fidelity simulator representing the hydropower company's operations is prepared. (Memisevic, Choudhury, Sanderson, and Wong, 2004). For the evaluation, the controllers are required to operate the scheme with a subset of the current displays (Current interface) or on the current displays supplemented with the new functional displays (Functional interface) under several scenarios each around 30 minutes in length. Of key concern are the scenarios we present and the measures we take of human controller performance.

4.1 Scenarios and proof of principle study

The scenarios focus on contingencies that are expected to highlight the anticipated advantages of the functional displays. For each contingency, we have completed a proof-of-principle walkthrough with a subject-matter expert of how Current vs. Functional displays might support cycles of (1) detection, (2) analysis (understanding and projection), (3) determination of possible actions, and (4) evaluation of impact of action (see Table 1 for general format) (Hollnagel and Woods, 2005; Sheridan, 1987).

Table 1. Framework for evaluating how effectively the Current vs. Functional displays support human controllers during contingencies of different kinds.

	Current displays				Functional displays			
	Detection	Analysis	Action	Evaluation	Detection	Analysis	Action	Evaluation
Conting'y 1								
Conting'y 2								
Conting'y *n*								

The eight contingencies selected for the walkthrough are listed in the left column of Table 2, which is intended to cover most represantive operational risks and financial risks that a generating company might have. There is not enough space here to outline the findings under each of the eight headings in Table 1. Instead, in the right column of Table 2 we summarise some of the ways the Functional displays may provide unique assistance to the controller when he handles each contingency. The assistance involves either providing an integrated view of past, present, and future, allowing the controller to see the impact of current conditions, or providing an integrated view of the interplay between different subsystems at present, allowing the controller to see immediate possibilities for action.

For example, there may be a change in forecast inflow and water runoff (see Table 2). Current displays simply show forecast figures in a table. Software tools allow controllers to predict storage levels at a fixed moment in the future, but do not provide an integrated view over time of the impact of the new forecast figures. In contrast, the Functional WSTP display in Figure 2(a) immediately lets the controller see whether the new forecast values within or outside the desired operational boundary, and when viewed in the context of all WSTP displays for all storages, allows alternative plans to be drawn up.

As another example, there may be a change in the constraint that transmission capacity places on the amount of generation possible. Current displays show constraints in a separate software application unconnected with scheme SCADA. In contrast, the EF display in Figure 2(b) shows a red bar across the displays representing the affected aggregate units, indicating a maximum possible generation level. The controller can then determine visually whether generation can be moved elsewhere in the scheme.

Table 2. Contingency events proposed for scenarios with some of advantages of the Functional displays for handling each contingency that emerged from the walkthrough.

Contingency	Advantage of Functional display(s)
Failure of a transmission line within the HPS region	EF display shows immediate impact and participation of different aggregate units in the consequences.
Failure of a generator belonging to HPS	EF display immediately shows whether dispatch target can still be met and supports immediate responding.
Change in forecast inflow of rain and water runoff	WSTP display indicates whether a spill or low storage level will result and whether daily water target is met.
Change in energy demand for some hours ahead	WSTP shows impact on water use and storage; RF display shows impact on earnings.
Change of bid from a participant in another region	WSTP shows impact on water use and storage; RF display shows impact on earnings.
Change in transmission constraint	EF display shows change immediately and indicates whether generation can be moved elsewhere.
Change in market target for pumping	EF display will show change for next dispatch interval and how reserve is affected.
Change in demand (sudden) that changes frequency	EF display will show deviation in frequency and the scheme's recovery process.

The scenarios we will use for the evaluation have been constructed by combining one or more of the above contingencies into a coherent stream of events. Five complex scenarios have been created, four of which will be used in the evaluation itself.

4.2 Measures of performance

Controllers will work at a series of scenarios, some with the Current displays and others with the Functional displays. The order of Current and Functional displays and the mapping to scenarios will be counterbalanced across participants. Four general classes of measures will be used: (1) situational awareness, (2) control quality, (3) activity measures and (4) measures of control adaptation.

Situational awareness measures will include probe questions and viewing patterns. Probe questions will be posed immediately after the scenario, and will focus on awareness of current state, the awareness of significance of current state, and ability to predict future state. To indicate how situation awareness develops dynamically (Sandom, 2001) viewing patterns will be gathered via a small head-mounted camera that tracks the controller's general direction of gaze and will indicate current focus.

Control quality will include proactive measures of how well the controller configures plant to meet incoming demands, indicated by revenue, water efficiency, and meeting daily water goals. It will also include more reactive measures of how the target is followed in real time, as reflected in deviation of actual output from dispatch target and the application of any market penalties.

Activity measures will include simple observables such as the time to detect a problem, time after detection to act, and time for action to take effect.

Finally, with control adaptation measures we will explore patterns of variability in controllers' responses. As discussed elsewhere (Li, Sanderson, Memisevic, Wong, & Choudhury, 2005; Hajdukiewicz and Vicente, 2004) small variability within or between participants in achieving high level system goals combined with full use of the discretion available in actual control actions may indicate good human-system coupling; the opposite can be interpreted as poor human-system coupling.

5 Summary

Hydropower system controllers work across physical and intentional domains, and they monitor and control processes whose time constants range from instantaneous to minutes, hours, and days. If controllers are to maintain effective situation awareness and exercise effective proactive and reactive control, their displays must integrate their work across the above two dimensions. The displays we have developed and are evaluating are a first step towards with goal. However, evaluation with industry controllers familiar with conventional displays must be carefully designed as so to give novel display concepts the best possible opportunity to reveal their advantages.

6 Acknowledgments

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