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A LOW-COST, EASY-TO-USE, REAL-TIME POWER SYSTEM SIMULATOR

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ABSTRACT

We present the design rationale and basic workings of a low-cost, easy-to-use power system simulator developed to support investigations into human interface design for a hydropower plant. The power system simulator is based on three important components: models of power system components, a data repository, and human interface elements. Dynamic Data Exchange (DDE) allows simulator components to communicate with each other within the simulator. To construct the modules of the simulator we have combined the advantages of commercial software such as Matlab/Simulink®, ActiveX Control®, Visual Basic® and Excel® and integrated them in the simulator. An important advantage of our approach is that further components of the simulator now can be developed independently. An initial assessment of the simulator indicates it is fit for intended purpose.

KEY WORDS

Power system, MatLab/Simulink, power system simulator, dispatcher training simulator, cognitive engineering

1. Introduction

Recently, electric power systems have become very large and complicated. The introduction of electricity markets in many countries has led to complications for existing SCADA and other information and communications systems. The continuing rapid development of electricity markets does not provide much opportunity to systematically design information displays for control room personnel. Many problems are so new that substantial inventiveness is required to provide information that will support monitoring, decision-making and intervention most effectively. For example, it has become very important to analyze power system phenomena online.

Using a cognitive engineering framework, the authors have been exploring what the information needs are of the human controllers who are responsible for scheme monitoring and control. Cognitive engineering is concerned with the analysis, modeling, design, and evaluation of complex sociotechnical systems that are supervised in real time by human controllers [1-4] such as power plant control, emergency response, air traffic control, chemical process control, and so on. The goal is to develop principles and practices that allow us to design complex sociotechnical systems that provide a better fit between human controllers and the systems they control, not only under normal operating conditions but also when the unexpected happens.

An important cognitive engineering tool is the development of simulators in which to conduct controlled studies of the effectiveness of current vs advanced display concepts under normal vs unexpected operating conditions. Simulators already exist for investigating many aspects of electrical power generation, dispatch, transmission, and market behavior [5-15]. In general, however, they are very expensive, difficult for beginners to understand and use and often it is difficult to add new models and displays into it. In addition, real time power system simulators require major hardware support and software that typically requires major computing power to run. Power system simulators usually use human-machine interfaces and control functions that are identical to those of the on-line system, also requiring major computing support.

Real time interactive power system simulators, often known as the Dispatcher Training Simulator (DTS), have become an important tool. A DTS is used for dispatcher training and evaluation, engineering studies, power system model evaluation, and offline testing of energy management functions. With so many applications, the investment needed for a DTS can be justified. The more narrow use of a DTS for prototyping and evaluating of new displays normally does not justify such a large investment. Therefore, it is necessary to work out how to develop low-cost easy-to-use real time power simulators with open, flexible architectures.

The main objective of the research described in this paper was to develop algorithms for a low-cost simulator that would achieve the target cycle time. The detailed description of actual component models used is presented elsewhere. [16].

2. Power System Phenomena and Humans

The simulator we present here represents a hydropower company's view of its scheme and of its broader market and network context. The company's control centre deals with operating the power system and manage large water systems. Operating a hydropower company is increasingly complex as economic, security and environmental considerations grow in importance. Hydropower plant operation requires complex decision-making to find the right compromise between economy and security. With hydropower systems being operated closer to their physical limits, their operation is now more and more conditioned by fast phenomena.

Most dispatcher training simulators use simplified models of generating units, the protective relay system and the control system. A real time power system simulator also requires a real time simulation of how the system is seen from the control centre. The simulation cycling time of a few seconds, needed to match typical scan times of the control centre, usually imposes a compromise between modeling accuracy and solution speed. This cycling time is based on the observability of the power system through the SCADA system. This approach has not been questioned for a long time. Given our focus on information systems and display design and given the need to develop a flexible, portable, but comprehensive simulator, we were confronted with question of whether a simplified model would represent the system dynamics correctly [16].

Before we started developing the simulator, we considered various phenomena occurring in the power system and we also consider the spectrum of different types of events that are important for understanding the human controller's role. Figure 1 shows a spectrum of phenomena occurring in power systems, power system control, an in human interaction with the system. The horizontal log scale extends from time in microseconds (100 μs) to years. Phenomena occurring inside the power system can be very rapid, such as surge phenomenon, or very slow, such as load fluctuation within one day or economic effects over a year or years. As Figure 1 shows, mouse and keyboard events, eye movements, and gestures range form 10 ms to about 1 s. Coordination over shifts ranges from 11 hours to more than 11 days. These are all phenomena that can indicate the effectiveness of human coordination with power system events. It is almost impossible to observe all these phenomena in real time.

The evaluation of new display concepts is the predominant purpose of the new developed simulator, which imposes some criteria and constraints. Tests of the new displays should verify the quality of the new display concepts on broader phenomena, as much as possible. The experimental session during which the new display concepts are evaluated cannot be to long. Three-hour long experimental sessions are a reasonable compromise. During the experiment the participant will work through almost all phenomena in the power system an electricity market. The interaction between different phenomena such as bidding/rebidding, target predispatch/ dispatch, power generation, water network control, and vigilance about lake levels will become obvious. We are better able to estimate the degree of workload and the level of situation awareness of the control during longer rather than shorter sessions.

There are several phenomena that have a large impact on the hydropower company's view of the power system that are not represented in Figure 1. These phenomena do not occur in the power system itself and include fluctuation in temperature, precipitation and humidity over a few minutes or hours up to across seasons or years. Weather phenomena have a large impact on load forecasting, inflow and lake level forecasting. These data are highly correlated and any mismatch between the forecast and real time data from one field will propagate quickly into another domain.

As already noted, the cycling time of a real time power simulator is usually approximate to the SCADA system cycling. Fast processes such as surge, harmonics, subsynchronous resonance, power swing phenomena, HVDC, SVC control, and the operation of the protective relay system cannot be simulated by a simulation cycle of a few seconds. However, in reality there is no interaction between the controller and such extremely fast processes. Humans do not have the capability to observe and interact with such phenomena in power systems. The controller is simply an observer of the effects of a disturbance and the resulting control system or relay action. The analysis of very fast processes is important in engineering studies, but for a study of interface display concepts we do not need such a fine level of accuracy. For this reason we decided to use a cycling time of 1s for our simulator.

Any simulation of a power system requires equations to be solved that describe the various power system components. The underlying models can be divided into two kinds: static models and dynamic models. Static models can be represented in an algebraic equation. Components that can be modeled this way include transformers, relays, circuit breakers, transmission lines, pipe network calculation and valves/gates, and the electricity market. Dynamic models can be represented with differential equations. Components that can be modeled this way include the surge tank model, frequency calculation model, and so on.

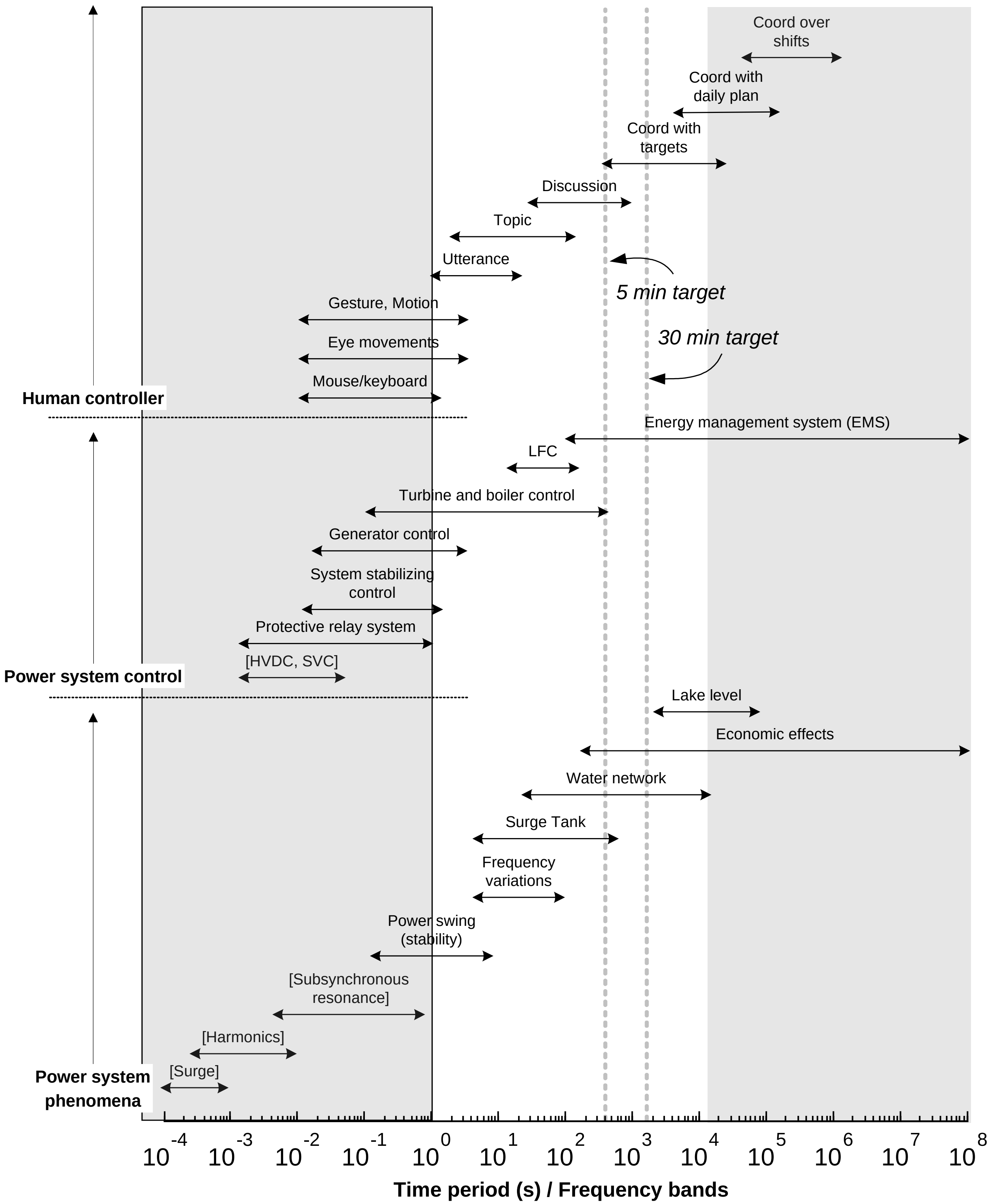

Figure 1: Power System Phenomena and Human Control Activity. Simulation covers timeframe in center band.

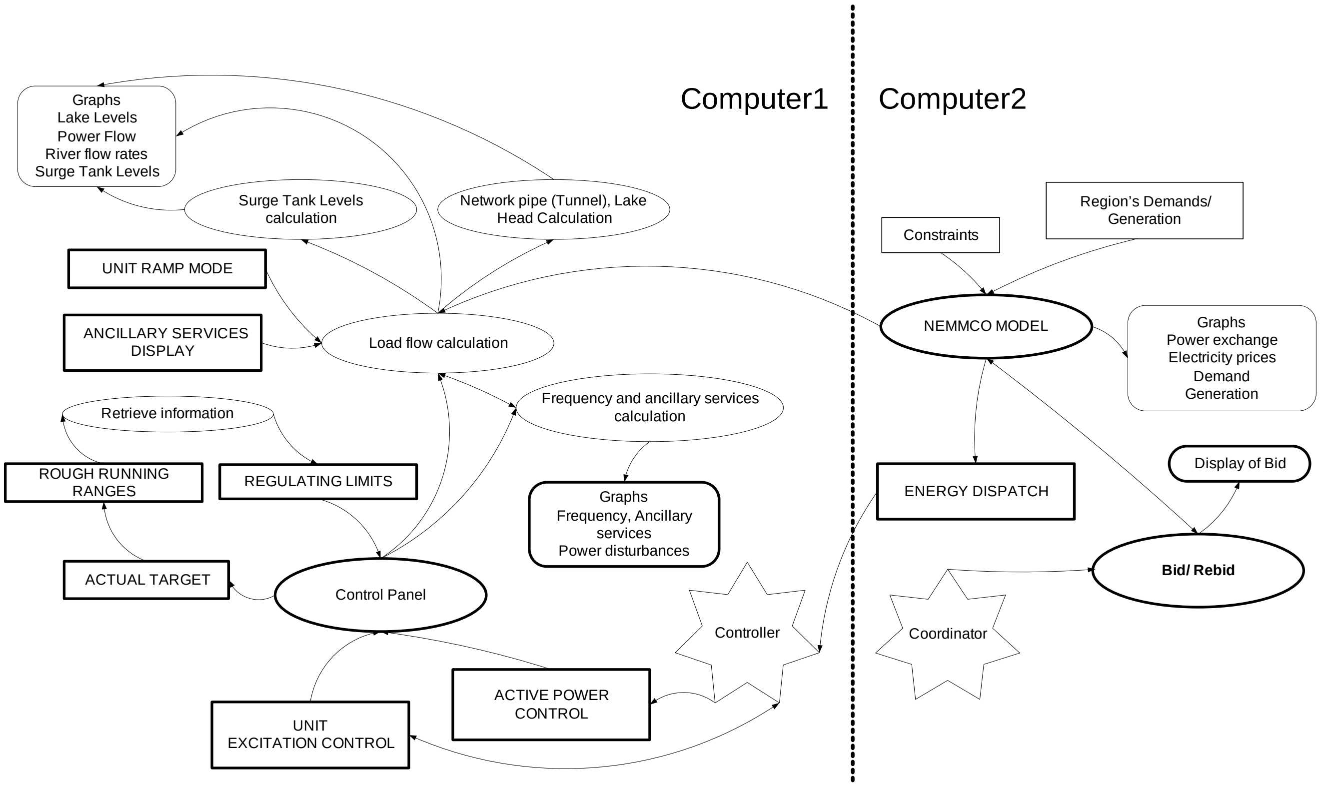

Figure 2: Simulator architecture

3. Calculation Cycle

Figure 2 shows the architecture of the simulator, which runs on two networked computers. The allocation of functions to Computer 1 and Computer 2 roughly parallels the principal preoccupations of the control room controller and coordinator, respectively. Computer 1 runs a simulation of scheme operations; Computer 2 runs a simulation of the market operator (NEMMCO: National Electricity Market Management Company).

A block diagram of the software is shown in Figure 3. Matlab/Simulink has been used as a shell for the power system simulator. DDE (Dynamic data exchange) has been used to let simulator components communicate within the simulator. Network DDE has been used let Data Repositories communicate within simulator. The communication between the Matlab models on different computers is achieved through the Data Repository. From Figure 3 it is clear that the structure of the Matlab/Simulink shells is the same on each computer. The Matlab/Simulink shell coordinates the cycling time of the power simulator, solving the dynamic model equations, cycling the solution of static equations, and refreshing the displays developed with Matlab Tools.

To ensure that the power system simulator was sufficiently accurate and fast, we had to find an appropriate cycling time for (1) solving the static models of power system components, (2) refreshing the displays on the screen, and (3) using an appropriate method for solving the dynamic models. The cycling time we have chosen for Load flow calculation is 4s, and we have used the same time for the Water Network calculation. The Water Network overview display includes the entire water network: lakes, surge tank, local inflows, spills, tunnels and rivers. Some of the processes of this domain are slow, such as changes in the lake level, whereas other processes are fast, such as surge tank oscillations. To ensure an adequate time resolution for the faster processes we chose the shorter cycling time for the refreshing the display, which is 15 s.

Dynamic models can be solved by numerical integration methods and usually the time step for fixed step methods is 1s. In our case we choose a variable-step continuous integration method. Variable-step integration methods decrease the simulation step size to increase accuracy when a system's continuous states are changing rapidly but increase the simulation step size to save simulation time when a system's states are changing slowly. This approach ensures accuracy and speed at the same time. We achieved satisfactory results with the “ode15s” method (also known as Gear's method) available in MatLab. During the simulation we set constraints on the size of any integration step. The maximal step size is 2 s and a minimal step size is 0.25 s. The Matlab/Simulink shell updates the data from the Data Repository every 1 s.

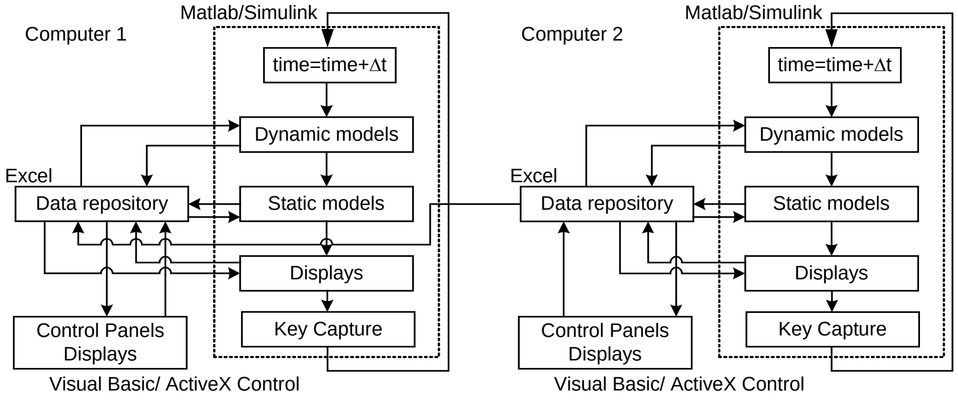

Figure 3: Block diagram

The same cycling is used for writing the output data from the dynamic models into the Data Repository.

We developed all our static models and Matlab based displays as Matlab/Simulink Triggered Subsystems. These subsystems called Matlab S-functions. The S-function's structure is displayed in Figure 4.

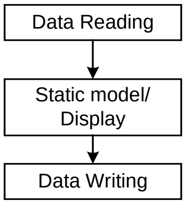

Figure 4 Structure of the S-function

The S-Function reads data from the Data Repository at the start and also writes the output of the static model into the Data Repository at the end of a function. The power system simulator is usually installed separately from the software that supports the interfaces. Refreshing the displays and handling the human controller's input also have time demands, which is why the latter are on a separate processor. To minimise time consumption by these functions we used Excel Spreadsheets as a data repository as well as displays wherever possible. For displays relying mainly on alphanumeric output this solution was adequate. For displays that required graphics, however, we used MatLab graphics tools. The time consumption of the Excel displays is minor and the time consumption for refreshing the Matlab based displays is between 0.1 - 0.20 (s) depending on the complexity of the display.

In Figure 5 we show one of the displays developed for the water network, reflecting the hydropower plant company's existing display. Displays developed in the Excel/Visual basic/ActiveX environment are shown on Figure 6.

4. Conclusion

Our ultimate goal has been to use our simulator to perform empirical studies that will test whether advanced displays support more effective human-system integration. A preliminary version of the simulator was taken on two laptops to the industry site, where the displays were connected with larger monitors. Three pairs of scheme controllers/coordinators evaluated the simulator for its physical realism and for how well our version of the current displays serve as a baseline for comparing performance with advanced displays. Controllers and coordinators experienced an incident scripted into our simulator. They worked together to resolve the situation.

Apart from some inaccuracies that were straightforward to fix, the feedback was that the simulator had sufficient realism and complexity to serve as a testbed not only for display design but possibly also for some forms of training.

We are therefore satisfied that an integrated view of hydropower scheme operation and its real-time coupling with the electricity market and the electricity network can be simulated to a medium level of fidelity in a highly portable configuration. We are now designing advanced displays that will link water management, generation, transmission, and market information in ways that better support controller problem-solving.

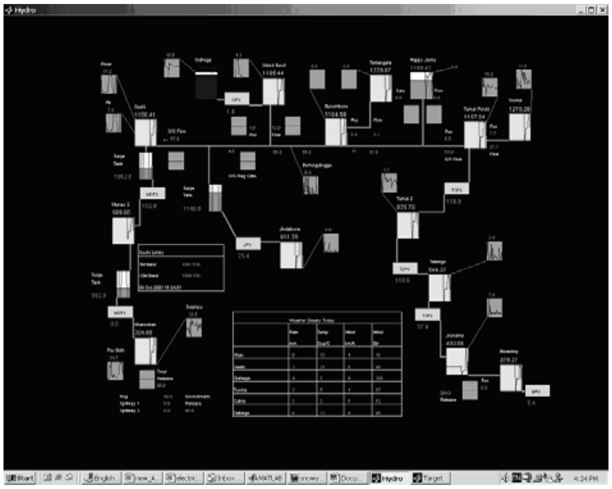

Figure 5: Water network overview

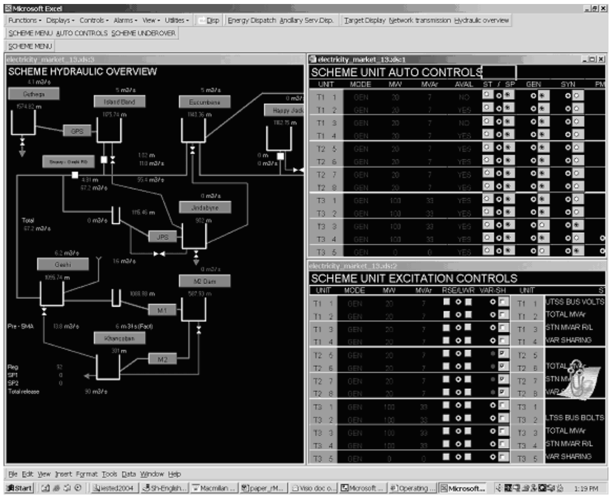

Figure 6: Excel-based displays in the simulator

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