DESIGN AND IMPLEMENTATION OF ADVANCED ALGHORITMS USING HOLONIC STRUCTURE CONCEPT

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Abstract: In hydro power plants from Romania, there is a major interest for the implementation of digital systems for monitoring and control replacing the conventional control systems for power, frequency and voltage. Therefore is necessary to develop new algorithms, in order to be able to implement digital control systems for monitoring and control of a group of hydro power plants in a cascade system along a river, in order optimize the use of the river resources. The paper proposes the development of advanced algorithms in distributed control systems for the hydro-energetic groups using holonic structure concept that must also ensure the robustness in exploitation, when the groups' target is modified according to the hydraulic and power requirements.

Keywords: Hydro power plant, advanced control, holonic structure.

1. INTRODUCTION

The planning of short and medium term operation of hydro power plant is an important method to provide power and water cost-efficiently. In hydro power plants from Romania, there is a major interest for the implementation of digital systems for monitoring and control replacing the conventional control systems for power, frequency and voltage. A series of hydro power plant systems in Romania are capturing the river water in a geographical area and store it in reservoirs connected through transport pipes. Every lake has its own hydro power plant and the water used through the turbines of one plant is sent to the next reservoir, thus using the hydraulic potential.

The automated control of an ensemble of hydro-electric plants must provide the following functions:

- The optimal conversion of hydraulic energy in electric energy in conditions of the variable flow of the water by maintaining the water level in the reservoir at a maximum.
- Maintaining the hydro-generators in the stability area considering the variable turbined debits and balancing the energy in the system.
- The correlation of the turbined debits for the plants installed in a cascade along the river course.
- The automatic starting and stopping of groups (with the solving of the synchronization and in-phase connection) considering the energy requests and the water available at an optimal use.

The paper proposes the development of advanced algorithms in distributed control systems for the hydro-energetic groups using holonic structure concept that must also ensure the robustness in exploitation, when the groups' target is modified according to the hydraulic and power requirements.

2. THE STRUCTURE OF HYDRO POWER PLANT SCADA SYSTEM

To ensure the coordination of the hydro-electric power plants built on water course (for example, the plants on the river Olt) the implementation of a distributed control and monitoring system is necessary. In this case, we recommend the following distributed structure:

a) A SCADA system at the plant level, that ensures:

- The control of the groups using PLC's, Data acquisition and processing (data storing and transmission, a dedicated communication server);
- The remote administration of applications (start/stop, the update of the software for applications, synchronization);

- The displaying of information for the processes (hydromechanic and hydroelectric) on the operator’s displays and the SCADA system engineering station.
- Editing, reports, alarms. [Vinatoru 2000].

b) A SCADA system at a dispatcher level of the hydro-electric plant ensemble, (figure 2), for monitoring and control of hydro power plants in cascade system along a river, in order to optimize the use of the river resources, with the following functions:

- Data communications with local or plant SCADA systems, ensured by communication servers through telephone lines and radio
- Running of local SCADA remote monitoring and control programs through application servers.
- Data storing and application history.
- The displaying of information regarding the system state on the operator’s and engineering console.
- The simulation of the plants operation for the validation of applications and training of operators.
- The alarm monitoring and the editing of reports.
- Hydro-graphic and electric schemes.

At the level of hydro power plant there is a local monitoring an control system, interconnected with the central dispatcher via modems and radio communication buses.

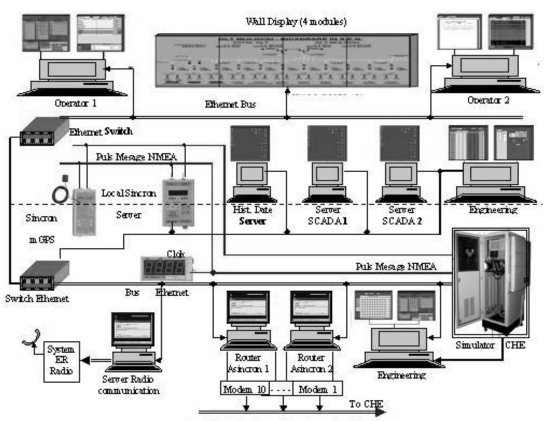

Fig. 2. SCADA system architecture - Dispatcher

3. HOLONIC STRUCTURES

The hydro power plant systems using together the potential energy of the same water stream require more and more the use of complex control systems, which have multiple functions such as:

1. Monitoring, control and data acquisition for operating processes- SCADA systems
2. Automatic control of technological parameters
3. Optimization and coordination of process flows taking place in series, parallel or mixed
4. Resources and production planning according with requirements, including forecasting algorithms.
5. Automatic reconfiguration of control systems, both hardware and software, to adapt to the actual operating requirements, both internal and external.
6. Fault detection and localization, increasing the fault robustness of the systems and automatic control in fault conditions.
7. Real time work trough parallel information processing.

Microprocessor technology evolution, combined with accessible costs and increased reliability allowed the development of new control systems, using distributed structures, multiple operational levels, and having dedicated hardware and software structures. [Popovici 1990, Vinatoru 2000]. Such production systems for hydro energetics, capable to rapidly adapt to market demands, require an evolved control system, which is flexible enough to adapt to new operational demands quick and without major perturbation of the process.

3.1. Control architectures utilized

Current literature regarding the design and use of advanced process control systems [Tunser Orun.2000, van Brussel, 1998, Borangiu 1995] is defining the following control structures for industrial processes:

a). Centralized control systems, employing one central control unit that takes all decisions regarding the production flow and directly control all system actuators. This system has the advantage of a simple architecture and allows a global optimization. The disadvantages are multiple: long response time, operational difficulties when software changes are required, reduced reliability if central unit fails or a communication path fails.

b). Distributed and hierarchical control structures, using multiple functional levels allowing a master-slave operation. In this type of structure, the process information is transmitted from lower levels to upper levels and the control commands are sent the opposite way. Every functional level has a specific hardware structure and software, based on the duties determined by the global system (see items 1 to 7 presented before. The system structure allows parallel processing at each level, in the same time ensuring a distributed structure of the database at each level. The structure allows local and global optimization of the process and control algorithms. In the same time, this structure provides an increased tolerance to defects of hardware and software components, and, if required by process, the equipment can be duplicated for redundancy (sensors, servers, communication paths, etc.).

c). Hybrid control structure, derived from the b-type structure, augmented with supplementary functions for cooperation and data sharing between controllers located at different levels, especially the ones located at lower levels. In this case, the central management system initiates all processes and the subordinate stations cooperate to achieve the objectives. If initial conditions sent by the local station operators change, then the central systems take over the control, the local stations continuing to operate based on normal conditions. The advantages of this control structure are: a high flexibility and a quick reconfiguration.

d). The heterarchical control architecture, consists of independent structures called "agents" which execute commands based on their current and future estimated loading. During operation, all agents, including the central station, are bidding for transmitted commands. When an agent is finishing a won task, automatically he becomes the manager of the future task. In this decentralized structure, the agents have local autonomy and the system can quickly adapt to any change. The main disadvantage of this structure is that global optimization is somehow difficult.

All these distributed control structures have a series of undesirable problems:

- significant delays in the information transmission on the data links between equipment at different functional levels, as well as traffic conflicts.
- synchronization problems between equipment, at the same level and at different levels.
- some difficulties in the implementation of special functions: automatic software and hardware reconfiguration in case of faults, local autonomy of control units for isolated production units.

3.2. The concept of holonic structure

The deficiencies that can occur in distributed control systems have led in the past years to the research, development and implementation of new concepts such as: Virtual enterprise, Knowledge-based systems, Agents oriented software, Holonic systems [Tharumarajat 1996, Ulieru 2006, Fletcher 2006]. The concept of holonic structure was developed by a series of researchers, with main applications in flexible manufacturing lines, military, and spatially distributed systems for disaster relief. The use of the holonic concept as an instrument for modeling and design of control systems for big distributed processes is based on two properties of holonic structures: autonomy-grants to holons the right to take decisions without consulting an entity from an upper level and cooperation that allows the holons to communicate with other holons to solve some objectives pertaining multiple entities in a holonic structure.

Recent publications introduce the concepts of Model of Holonic Coalitions [Fletcher 2006] and Emergence and Autonomy [Ulieru 2006]. Based on these concepts, the hierarchical character of distributed structures is extended to a hierarchy of holonic systems, which establishes, for the entire system of holons, a certain recursive hierarchy or a heterarchy of holons, without a central control, that allows the cooperation between holons to achieve the system objectives.

3.3. Analysis of hydro power plants control systems

a) *The run-of-the-river hydro power plants*, having a high installed capacity (Portile de Fier 1) are composed of multiple power groups (6 to 12) which are operating in parallel using the whole flow of the river. Therefore the energy production shall be coordinated with the potential hydraulic energy of the system (depending of the water flow and the water level in the reservoir). The energy production shall be also coordinated with the pluvial conditions (which are sometimes unpredictable), the energy demand in the power grid, and the availability of each group.

The control of hydro power groups is also performed using a distributed system organized on multiple levels (three levels at Portile de Fier 1), every level having specific duties [Vinatoru 2005, 2007]:

-the control of the water feed parameters, the turbine and the generator are performed at level 1;

-the control of generated power, flow or frequency for each group is performed at level 2;

-the optimization of the hydro system, the calculation of the power use or flow for each group, based on the available hydraulic power and the grid power requirements, the estimation of the total required water flow, operational forecasting are performed at level 3 (plant management level).

b) In the case of the power plants systems operating in parallel in the same river basin, such as the ones operating on Olt River, the distributed control system shall ensure the coordination of power generated by all plants, in order to coordinate the water flow through the plant with the upstream and downstream plants. This coordination shall consider the water flow times between plants, otherwise the water will be lost through the dam overspill or the plant will operate at reduced parameters (power, efficiency). In this case, the control system consists also of multiple control levels (4 levels in Ramnicu Valcea region), presented in the parte 2 of this paper.The analyses of these systems have been presented by in a series of papers [Vinatoru 2005].

All these systems have some common characteristics such as:

-require distributed control systems to satisfy the grid requirements (global scope) and the local group requirements (safety, conversion efficiency, efficient and total use of resources);

-the technological equipment in a group and the plant's groups shall work as one to provide the required power;

-the control systems for each group shall work together to satisfy the real-time requirement but must obey the commands from the central management level of the plant;

-the control system shall provide alarming and interlocking in fault conditions, since a fault in the equipment may have catastrophic consequences.

These distributed and hierarchical control systems have also a series of disadvantages:

-require the doubling of equipment in order to provide structural reliability;

-does not allow the collaboration between the equipment, especially at the base level;

-the diagnosis, monitoring and correlation systems shall be installed separately, since the rigid hierarchical structure do not allow these functions;

-software changes are difficult requiring changes in the whole system.

4. THE GLOBAL ARCHITECTURE OF HOLONIC SYSTEM

4.1. The proposed system architecture

The proposed system architecture, as illustrated in the figure 3, will have the following key components:
- A web-based graphical human-machine interface for industrial expert to configure and simulate a process application, this interface would provide an access to the remaining components of the system;
- A local database of alternative scenarios and configurations that the expert examines and evaluates;
- A simulation system residing at the expert's site capable of simulating the process node, as configured by the expert, using the database. The simulation would be performed in operation space so that the expert can consider the space requirements (e.g., flow of processes) in addition to traditional issues related to capacities, costs, and utilization.
- A comprehensive database consisting of: energy resources and demand profiles for specific situations, energy demands to fulfill the requirements from energetics system, performance of the plants including the capacities, repair and maintenance frequencies, and costs;
- Holonic coordination and control would provide a capability to use distributed communications to enable decision making between various elements of the system, and provide coordination and control of their activities. This holonic system would have a multi-layered architecture with the lowest level representing the process devices, the middle level representing Process Nodes, and the highest level representing the Management Nod.

Process Device Simulators are another key element of the system, that ensure simulation of the actual behavior of the main process devices in specific operating conditions, which the simulation of the whole system represents.

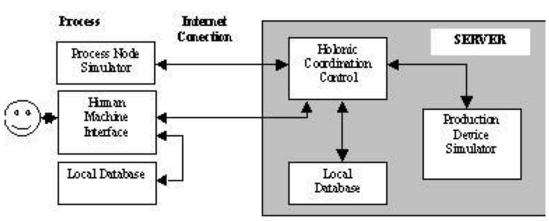

Fig. 3. Holonic System Architecture

The main goal of these research activities is to use the frame of reference to the modeling and control of autonomous and cooperative systems, and to develop intelligent systems for the special integration requirement.

The component of future research results are:
- Comprehensive database, supply and demand profiles of hydroelectric plants organized on the river, validated simulation models of energetics devices, nodes and management systems, Holonic Plug-and-Produce intelligent process devices and nodes, Holonic coordination and control of process.

4.2. The model elaboration

a). Hierarchical architecture. Hierarchical architectures are widely used and accepted in enterprise control systems and control systems modeling. (figure 4). Our research focuses on an abstract model that connects the process level with the upper level at the enterprise pyramid and thus it creates a more integrated modeling approach. In order to develop advanced modeling methodologies based on soft computing approaches, ideas and existing approaches from information theory are investigated and utilized to represent and process information in a hybrid and hierarchical industrial system [Medsker 1995].

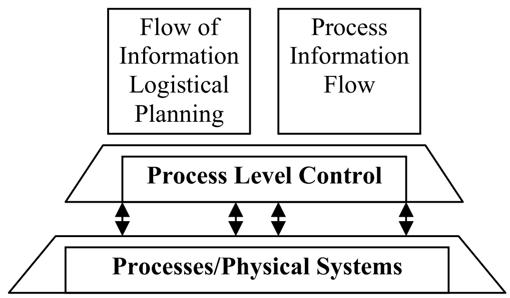

Figure 4. Hierarchical architecture

The proposed methodology is a Fuzzy Cognitive Maps (FCMs), which can model dynamical complex systems that change in time following non-linear laws. Fuzzy Cognitive Maps use a symbolic representation for the description and modeling of the system [Koscko 1997]. A Fuzzy Cognitive Map consists of concepts that illustrate different aspects in the behavior of the system and these concepts interact with each other showing the dynamics of the system. At the process level of the plant there is a common technical information system for the process control, the computerized and technical management systems that is shared between the production and the management teams. This information could be unified and used to construct a Fuzzy Cognitive Map, which will represent a conceptual, organizational and operational model of the system [Craiger 1996]. The knowledge on manufacturing plants includes the layout of the plant, the expected behavior of some parts of the plant, an aggregation of attributes or quality variables that are important. Cognitive Map design as it indicates whether a change in one concept causes change in another, and it must include the possible hidden causality that could exist between several concepts.

b). A Fuzzy Cognitive Map Model for Process Industry. The characteristics, development methodology and features of Fuzzy Cognitive Maps have already been presented in some papers. In this Section a Fuzzy Cognitive Map model for a simple part of a hydropower plant will be developed in order to illustrate the procedure of developing an FCM model for a system and how FCM would look like.

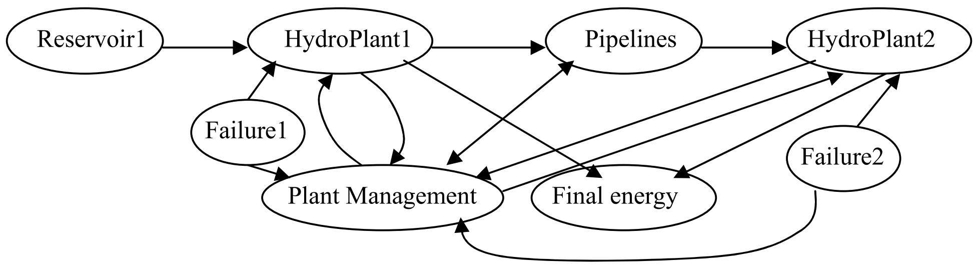

Figure 5. A Fuzzy Cognitive Map Representing the Behaviour of a Hydropower plants

The examined example consists of two hydro turbines - generators, which produce the electrical energy using the water from the same river. The pipelines (penstocks and transport canal) connect the two turbines with the reservoir and their status influence both processes as it takes the output of the first group and provides the input to the other but with a time delay. Conventional controllers are used to control these two processes and human operators will supervise and control the whole system.

For this hydropower plant a Fuzzy Cognitive Map can be developed that will model human supervision. This FCM is illustrated in figure 5.

c). A Hierarchical Two-level Supervisory Structure.

The general characteristics of power plants process Systems are their complexity and their large scale construction that make researchers use structural models such as hierarchical, heterarchical and other models in order to model such systems. In Power Plants Systems framework the human operator offers and supports Supervisory Intelligent Control through the use of a vague control methodology, within which he takes into consideration different factors and their relationship. On the other hand, there is a high requirement for more sophisticated systems with advanced characteristics such as the possession of human-like expertise within a specific domain, their adaptation and learning to do better in changing environments. It is assumed a hierarchical structure where the lower level consists of conventional control methodologies and the supervisor is modeled with this symbolic abstract methodology and the whole structure follows the principle of "decreasing precision and increasing intelligence" [Stylios 1999]. It is suggested a hierarchical two -level structure, where the lower level system is sufficiently controlled by local conventional or non conventional controllers and the supervisor at the second level. The proposed structure is depicted in Figure 4, where the supervisor is modeled as a Fuzzy Cognitive Map and consists of five sub-FCMs. Each one of these sub-FCMs accomplishes a special action for the plant at the lower level; one FCM is monitoring the plant, another one is used for failure diagnosis, the next one is used for decision-making, the other for planning actions on the plant and the last FCM describes the execution commands and sends them to the plant. These five FCMs are interconnected and they may have common concepts. The plant at the lower level has its own local controllers that perform usual control actions and the supervisor is used for more general purposes: to organize the overall plant in order to accomplish various tasks, to help the operator make decisions, to plan strategically the control actions and to detect and analyze failures. This supervisor with an augmented Fuzzy Cognitive Map attempts to emulate the human control and supervision capacity for the plant.

e). The Architecture of a holon and holon interaction.

By definition a Holon is an autonomous and co-operative element of an abstract system. It is autonomous since it can derive its own plans and execute them. It is co-operative since it can interact with other holons in the system to define mutual plans and contingencies. In fact it is very similar to a software agent, yet it has its differences. First, there is a strict structural definition regarding the different types of Holons and their functionality, secondly it consists of a physical part such as a manufacturing resource or product and has a special mechanism to interface with that physical part. In practice its autonomy can be achieved by simple logical tests, while its co-cooperativeness can be achieved by programmable interactions between objects. A Holon has an VPD (Virtual Process Device) and a Kernel. The VMD defines the interface to the physical process devices based on the MAP/MMS and ISO OSI layer model. The Kernel is an implementation of an agent that drives the Holon, thus making the Holon Process Control Systems (HPCS) a specialized Multi-agent System (MAS). The Kernel defines the interface to an agent and thus all the logic of the Holon is contained in the Kernel.

The external interaction is the interaction between holons within the HPCS and external information systems, between holons, implemented through the method invocation and exchange of holons (objects), and between kernels using the implemented MAS. The intra-holon interaction is performed using the event mechanism implemented in the HPCS architecture (Figure 6). The Kernel contains the Holons decision logic, which is used to interact using both long and short-term interaction. Long-term interaction for a Holon can be a message about the future arrival of an Order Holon, enabling the Kernel logic to make advance decisions. Short-term interaction concerns real-time decisions about dispatching of orders or events. The HPCS architecture supports this internal structure of a Holon by providing a set of classes and an event mechanism to support interaction between the kernels of the Holon and the Holon.

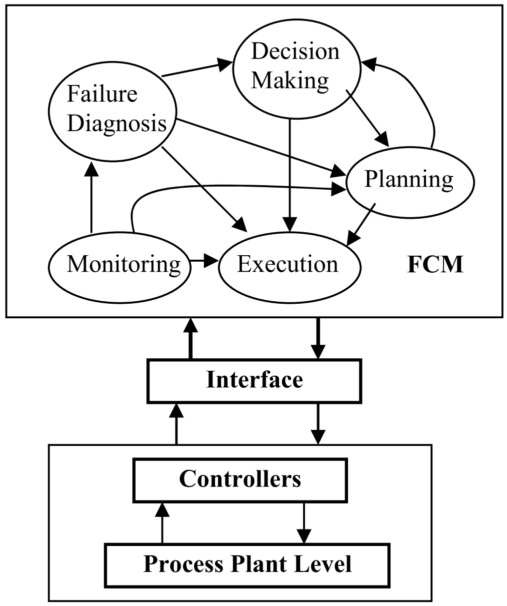

Fig. 6. Hierarchical Proposed Structure

5. CONCLUSIONS

The holonic architecture may be implemented in distributed control system as a solution for the communication between the control levels of the pyramidal structure and the rules of the hierarchy. In this context, some authors [Ulieru 2006] consider the holarhy as having holons whose context are described by their goals and the priorities associated with these goals. All goals are classified as either intended or imposed. We distinguish between holons at the high level of the holarhy and holons at a lower level, and they define the ratios: need ratio, priority ratio, leaving ratio and adaptive risk number.

In the future, we will develop the methodology for tuning the self-organizing capability of a holarchy around a user's need for hydro power plants.

The methodology establishes the intended goal for a low level holon (process control holons):

- The holon decides on a need ratio;
- The holon joins a holarchy an receives an imposed goal from a higher-level holon:
- It decides on a priority ratio comparing its intended goal to the imposed goal;
- While in the holarchy, the holon observes holons on its level and according to its priority ratio will group with the number of holons needed to follow the imposed goal, as such to create a cluster around imposed goal fulfillment need;
- According to its need ratio the top-level holon will decide which holons will be eliminated from holarhy;
- The holon monitors the leaving ratios and priority ratios of holons in the surrounding area, adjust its adaptive risk number, and hence may or may not eventually adjust its priority ratio.

The strategy of communication in the distributed control systems using holon concept is resolved by stigmergence. The stigmergy, according to Parunak, 2003, is a method of communication in a system in wich the individual part of the system communicates with another part by modifying their local environment. This modification of the environment may unknowingly lead to the emergence of grouping amongst parts and a likely driving force of this grouping is the perceived benefit of parts associating with other parts which have similar intended goals and priorities associated with these goals. This association has as end result an optimal configuration around fulfilling a certain task.

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