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CREATION OF INTELLIGENT DISTRIBUTED CONTROL SYSTEM BASED ON MULTI–AGENT TECHNOLOGY

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Recently, the multi-agent system approach is a very fast-growing technology. Because of its distributed nature it can be used in many applications to settle sophisticated problems, such as planning, scheduling, etc. A multi agent system consists of several autonomous agents with their own strategy and behaviour. Agents cooperate with each other to achieve common goals. Cooperating agents create agent coalitions. Coalitions can be considered as elements that create a network of agent coalitions. The paper introduces a method for creation of an intelligent control system based on multi-agent technology. Architecture of an intelligent distributed control system (IDCS) based on the network of agent coalitions is presented in the paper. The advantages of a multi-agent system approach are described. The proposed method is illustrated on an example of a virtual power system.

K e y w o r d s: control systems, agent coalition, planning and scheduling

1 INTRODUCTION

Multi-agent systems (MAS), being significant part of autonomous systems, are one of the most important trends for the next generation of control systems. Christian Rehtanz introduces in his book [8] the future control systems architecture for electrical power systems. A PEDA Multi-agent system is presented as a multi-agent approach to power system disturbance diagnostics. The book addresses many problems associated with the control system design and deals either with theoretical or with practical aspects of autonomous systems for power system control. Such systems are considered as large scale multi agent systems (LSMAS). Organization of a multi-agent system may be considered as dynamic agents form, team or coalition with respect to specific goals and their actual availability. Paper [3] describes a method for modelling, analyzing and control of interactions between the agents in MAS. Agents intelligence and relationship influence the cooperation process, mainly when the agents society is huge or composed of a variety of different agents. On the basis of this consideration a question may be given: how many agents and of which type are expected within a coalition, and how much information may be utilized for their fast and effective performance from the aspect of required tasks and goals. Agents cooperate with each other to reach a common goal. There are several methods and forms of agents cooperation, depending on which type of agents are used and which capabilities each agent can have. If the agents are radically different, then their cooperation may be very complicated. One of possible technical ways for agents cooperation is to form a coalition of agents. A coalition of agents essentially may be considered in the framework of multi-agent-system (MAS) as a group of such agents that are willing to cooperate with all other members in a group where common cooperative activities aiming at reaching the optimum of the given criteria [4], [5]. The optimum that the coalition members try to reach does not have to be always a global optimal solution [10], but in most cases it is only optimal from any point of view (criterion) or it is a Nash optimal solution (Nash optimal solution is defined e.g. in [2], [9]). The next step in cooperation within a MAS is a network of agent coalitions formation. A basic architecture of such a system is described later in this paper.

Creation of an intelligent distributed control system *eg* for production processes (including planning, scheduling, and decision making processes), requires suitable tools applying the artificial intelligence (AI) principle. The algorithms should satisfy the following three conditions [7]:

(1) There is a natural object (in technical practice, for example, different types of technological processes) with the properties of using perception, decision, reasoning, *etc.*

(2) There is an aim to create its duplicate as, for example, the model of a natural object.

(3) There is a possible way for realization of the supposed aim (the implementation of the concrete process by human or by some computer-realized algorithm).

From our aspect it seems that MAS have several advantages for creation of an intelligent control system for a production system. MAS can be used to settle complex problems, because [9]:

- communication architecture provides the negotiation mechanism,
- information architecture provides a framework for information modeling of negotiation.

The "mobile agent" based negotiation collects information and makes a decision for itself. It could be said that from logical/functional point of view an agent-based distributed control system (IDCS) is a systematic network (within or outside a hierarchy) of various local decision makers that have independent knowledge sources

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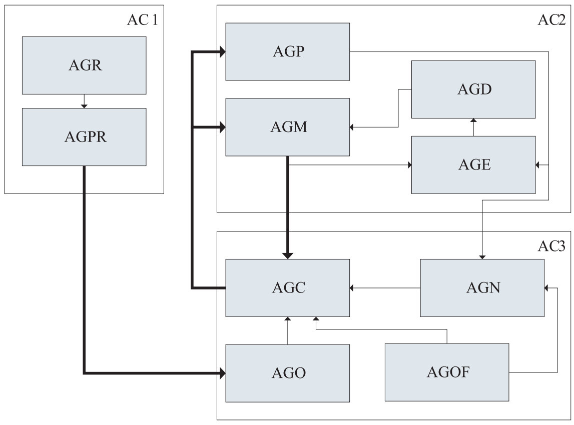

Fig. 1. The functional network of agent coalitions

such as ontology [1]. This advantage was the motivation to use MAS as an intelligent tool for decision process as a part of IDCS.

The main scope of this paper is as follows: significant characteristics of MAS are described in section two and an illustrative example is presented in section three.

2 AGENT BASED INTELLIGENT DISTRIBUTED CONTROL SYSTEM

Planning, scheduling and control performs the key function in manufacturing and production system control. It usually requires a considerable important knowledge or information characterizing the behaviour of the system. On the basis of that information an appropriate method can be chosen to design the available approach for the above-mentioned processes of the given system. Our goal is to describe a possible method for the solution of the above elements.

The planning process is a periodical activity and aims at obtaining the best scheduling of the required technological task. In manufacturing, planning can be just difficult because one must deal with detailed data, summary data, internal-external data, subjective information, and sometimes there is no information at all [5].

Scheduling (which runs together with the planning process) may be defined as the process of allocation of restricted resources to production tasks on the basis of information such as machine characteristics (of production process the resources), production requirements, time of performance, production constraints, economical factors, *etc.*

The control system determines the sequences of control actions for the resources used either in production or non-production systems.

The role of execution is to follow the performance of the system and to give feedback information for the control system that, on the basis of this information, creates a new available sequences of control actions.

Generally, the system which may be controlled consist of two parts:

- A process (production, economical, social etc.) which may be expressed by its mathematical, logical etc. model. This model is then applied in the control system algorithms.
- Control algorithms and other tools as significant parts of control system.

Multi-agent system may be considered as an intelligent tool for the solution of such problems as planning, scheduling, decision making and control issues. There are several advantages of the MAS technology [5], [11]:

- *Modularity*: Each agent can have different capabilities or functionalities and through cooperation the agents are able to achieve various goals.
- *Parallelism*: The MAS approach allows to work in parallel. A complicated problem could be resolved within an acceptable time by using a number of agents, *eg*, gathering information from various resources allocated in different places.
- *Flexibility*: The MAS approach is able to react flexibly to each change appeared in the environment. Through cooperation the agents can assist each other to compensate the lack of capability or knowledge. They can share information or own capacity to resolve a newly appeared situation, if one agent is not able to do so.

Basic elements of IDCS in relation to MAS approach can be defined as follows: Let us consider the following types of agents:

- AGR agent representing the user requirements
- $AGPL$ agent representing the planning process
- AGP agent representing the process
- AGM agent representing the model of the process
- AGE agent representing the local evaluation of output differences
- AGD agent representing the decision making for the determination of model parameters
- AGO agent representing the process constraints
- $AGOF$ agent representing the objective function
- AGN agent representing the negotiation proces
- AGC agent representing the control algorithm or decision process

The simple framework of agent-oriented intelligent distributed control system may be expressed as a set of agent coalitions (AC). AGR and AGPL represent the agent coalition 1 (AC1); AGP, AGM, AGE, AGD represent the agent coalition 2 (AC2), and AGO, AGOF, AGN, AGC represent the agent coalition 3 (AC3).

The procedure of the agents cooperation in AC 1 then creates the production or process plan from the user requirements. The procedure of cooperation of agents in AC 2 follows the realization of optimal control actions and the realization of task, the adaptation of model parameters to the process changes. The procedure of the agents cooperation in AC 3 follows the generation of optimal control, decision actions.

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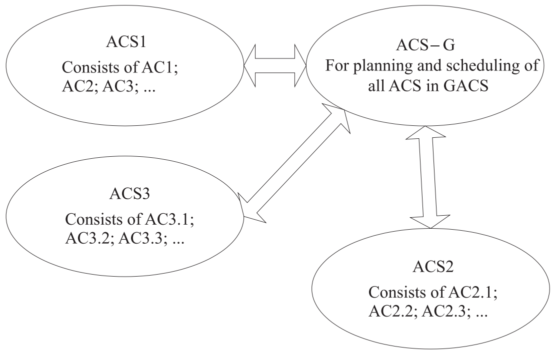

Fig. 2. Example of a typical agent coalition system

From the functional point of view, an agent-based intelligent distributed control system (IDCS) is a network (within or outside a hierarchy) of various local ACs, which have independent knowledge, local tasks and database system. The functional network of agent-based IDCS with cooperation of agents within an agent coalition and among agent coalitions is shown in Fig. 1.

Procedure in AC 1:

Step 1: creation of process plan on the basis of user's requirements

Step 2: allocation of the tasks following from the plan to AC 3

Procedure in AC 2

Step 1: realization of control actions in AGP and AGM

Step 2: comparing of the AGP and AGM outputs

Step 3: determination of the difference ε by AGE

Step 4: on the basis of ε, determination of the new parameters of AGM by AGD

Procedure in AC 3:

Step 1: creation of the objective function considering the output from AC 1

Step 2: checking the constraints of the technological process

Step 3: computing the set of decision (control) actions

Step 4: choice or selection by AGN of the suitable control actions

Step 5: sending the suitable control actions to AGP and AGM.

The functional network (Fig. 1) can be considered as a system of agent coalitions (ACS) with the above procedures, where each ACS has given tasks and goals.

This idea can be extended for the control of large scale systems (LCS). In this case we could speak about the global agent coalition system (GACS). A LCS consists of several different (technological, energetic, economic, social *etc*) processes, each being expressed by its own ACS. We suppose that for the solution of control problems in GACS the MAS approach can be applied as for single ACS. In this case we consider the global plan P as the sum of particular plans distributed to the ACS:

$$P = \sum p(ACS1) + p(ACS2) + ... + p(ACSn) \qquad (1)$$

and the global objective function Q

$$Q = \sum q(ACS1) + q(ACS2) + ... + q(ACSn) \,. \qquad (2)$$

In the case formulated above, a very important role belongs to the planning and negotiation processes.

3 AGENT BASED INTELLIGENT DISTRIBUTED CONTROL SYSTEM

Typical case of agent coalition system (ACS) may be, for example, the different types of power stations. A thermal power station (TPS) consists of a boiler, a steam turbine, an electric generator and a switch board. Similarly, other power stations have similar equipment. Energy supply to customers in the network consisting of the above components must be planned and scheduled. For this purpose, according to the consideration introduced above, a GACS as the global power system can be created which consists of different types of ACS such as power stations (Fig. 2).

In Fig. 2:

- ACS 1 denotes a nuclear power station (NPS)
- ACS 2 denotes a thermal power station (TPS)
- ACS 3 denotes a hydroelectric power station (HPS)

Agent coalition systems denote the subsystems in the framework of global power systems. In the next section we discuss the tasks (planning and scheduling) and performance of ACS-G. Mathematical formulation of this problem may be as follows: Let $\Im_i$ denote the set of different power subsystems (ACSk) with different capacities. Let each subsystem $\Im_j \in I_i$ contain $j = 1, 2, \dots, m$ elements. The condition

$$\Im_h \subset \prod_{i=1}^{n} I_i \,, \qquad (3)$$

$$\Im = \prod_{h=1}^{l} \Im_h \qquad (4)$$

holds for each subsystem $h = 1, 2, \dots, l$ for different I_i and for the required production in time t_0.

Relations (3) express the unification of different subsystems for the performance of given requirements. Sequence of the subsystems $c = 1, 2, \dots$ depends on their characteristics and on the time of their working ability. From the synchronization aspect of the subsystems the possible order is an important factor. The constraints of the initial conditions of j subsystem of i type in order c are:

$$t_{i,j,c} \geq 0 \,, \ \forall i, j, c \qquad (5)$$

which express the initial time of the loading of the corresponding subsystem and order as well. If the followed subsystems $c+1$ are from different I, the disjunctive time constraints may be expressed as follows:

$$t_{i,j,c} - t_{i+1,j+1,c-1} \leq \lambda_{i,j,c+1} \,, \ \forall i, j, c \qquad (6)$$

where λ is the factor of the time synchronization. Let:

- $T_{i,h}$ express the production time of energy requirement in subsystem h, type i
- $\tau_{i,h}$ express the time needed to load the subsystem h, type i.

Then

$$Q = \sum_{i=1}^{n} \sum_{h=1}^{l} T_{i,h} + \tau_{i,h} \tag{7}$$

expresses the time criterion of the required energy production. The cost criterion may be formulated as follows:

$$E = \sum_{i=1}^{n} \sum_{h=1}^{i} \gamma_{i,h} + \beta_{i,h} T_{i,h} \tag{8}$$

where

- $\gamma_{i,h}$ — cost/time unit of loading subsystem h, type i,
- $\beta_{i,h}$ — production cost/ time unit in subsystem h, type i.

The goal is to minimize the loading time and production cost of energy. The task of ACS-G in GACS for the problem formulated above is optimal planning and scheduling of energy production for the given requirements. Let us assume that the power system formulated as GACS consists of 2 nuclear power stations (NPS); ACS1,1; ACS1,2; 3 thermal power stations (TPS); ACS2,1; ACS2,2; ACS2,3; 4 hydroelectric power stations (HPS); ACS3,1 ;ACS3,2; ACS3,3; ACS3,4 . The first indices denote the power station type – agent coalition system, and the second indices denote the concrete ACS from the corresponding types. Let us suppose that the production is divided according to the requirement into 4 time intervals: IV1 (22–04); IV2 (04–10); IV3 (10-16); IV4 (16-22). IV2 and IV4 are very important from the aspect of energy consumption; thus, in the first step in the negotiation process the priority will be applied. In the second step the ACSG determines the planning and scheduling strategy, considering the objective functions (6) (7) and customer requirements, in the following way:

(1) the customer requirements (CR) are given

(2) on the basis of CR the first variant of ACSi,j order will be determined

(3) on the basis of (6), (7) the effectiveness of the first variant will be evaluated

(4) the negotiation process continues in the procedure given under points 2) and 3) until obtaining the min. of (6), (7) and satisfying CR and all constraints (4), (5).

Let us consider the following assumptions in the negotiation process:

- in IV4 the energy consumption is 100%
- in NPS $\rightarrow ACS_{1,1}; ACS_{1,2}$ energy production is constant.

The basic parameters for the negotiation process are given in tables 1 and 2.

Table 1. Consumption demand.

Time intervals	IV 1	IV 2	IV 3	IV 4
Consumption demand in %	50	80	75	100

For the considered parameters (see tables 1 and 2), objective function (6) (7), assumptions and constraints the following suboptimal order of ACS_{ij} was determined by negotiation in 4 time intervals:

- IV 1: ACS11 + ACS12 + ACS34
- IV 2: ACS11 + ACS12 + ACS22 + ACS31 + ACS32
- IV 3: ACS11 + ACS12 + ACS22 + ACS31
- IV 4: ACS11 + ACS12 + ACS21 + ACS22 + ACS31 + ACS32 + ACS33

This procedure could be applied for other cases, where the random error, change of energy consumption in time, *etc*, should be considered as well.

4 CONCLUSION

In this paper, an agent based framework for the creation of IDCS is investigated. The proposed IDCS architecture consists of agent coalition and agent coalition systems. Each ACS has its own task in the GACS and communicates with others to obtain the common goal of GACS. The initial inputs in each ACS issue from the planning and scheduling process. According to the requirement changes the inputs are determined for each ACS by the negotiation ACS. This paper deals in detail with optimal planning and scheduling using the MAS negotiation rule. It will be very interesting to deal with the optimal performance of all ACS according to the GACS architecture. Intelligent distributed control system performance was verified on a general power system consisting of different power stations. By the MAS negotiation rule the optimal order of their loading was determined that depends on the required energy consumption.

Table 2. Installed capacity in %.

Subsystem ACS	ACS_{11}	ACS_{12}	ACS_{21}	ACS_{22}	ACS_{23}	ACS_{31}	ACS_{32}	ACS_{33}	ACS_{34}
Installed capacity in %	25	20	15	15	10	15	5	5	5
τ	5	6	35	3	3	2	1	1	1
γ	3	4	1.5	1.5	2.5	0.5	0.7	0.8	0.9
β	4	6	5	2.5	3	2	0.5	0.5	0.5

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