TOWARDS AUTONOMOUS CONTROL OF ELECTRICAL POWER SYSTEMS

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Abstract: *The globalisation of the energy production and transportation, integration of different sources of energy, with the conventional power systems and the safety aspects of connecting the distributed generation to the interconnected large system will impose new concepts of control applied in Power Systems. The complexity of Power Systems is integrated into a new paradigm – Complex Adaptive Systems. Modelling of Power Systems Control is based on intelligent agents. The architectures and methodologies based on the agents' theory are discussed. Some concepts on hierarchical and distributed architectures which include different intelligent techniques are also presented in this paper.*

Keywords: *Electrical Power Systems (EPS), Multi-Agent Systems (MAS), Complex Adaptive Systems (CAS)*

1. INTRODUCTION

Knowledge society and a new type of economy, *Knowledge economy*, will be developed in the near future. In this framework the complexity of processes and the level of performances represent the real challenges for both producers and consumers. Production and transportation of energy in the globalisation era has a special impact on all other systems integrated into society and economy.

Power plants and power systems are generally considered to be mature technologies integrated into large and complex infrastructures. The globalisation of the energy production and transportation, as well as the recent major structural changes in this field have created significant challenges form the control point of view.

These structural changes are results of two developments: (a) restructuring due to de-regulation, and (b) development of distributed generation from renewable resources in response to environmental constrains. The power plants and power systems present new but different challenges, as they use different technologies, their operational philosophies are different and they invariably operate at different voltage levels.

In this context, the integration of different sources of energy, with the conventional power systems and the safety aspects of connecting the distributed generation to the interconnected large system will require considerable attention.

In the perspective of the new Economy, the power system, as the aggregation of all subsystems of energy providers and producers, should be treated from a technical and economical perspective. At regional and global level, alternative scenarios must be developed at this stage for the evolution of the planetary power system status until 2020.

The interconnection of individual power systems, even integration of power systems of Eastern Europe with that of the Western Europe give rise to inter-area oscillations and stability problems of the complex power systems that are more difficult to control.

The optimization of the power system consists in following several steps: reviewing the power resources, forecasting the power requirements, optimizing the participation ratio of each power supplier in providing the energy requirements forecasted, analyzing the aspect of environmental pollution for each scenario of power system development, and finally, optimizing the power subsystems.

2. THE INFRASTRUCTURE OF AN ELECTRICAL POWER SYSTEM (EPS)

From the systems' theory and analysis perspective, an electrical power system (EPS) is an ensemble of generation, transformation, transport, and distribution elements for electrical and/or thermic energy (Fig. 1) [2, 4, 8, 6]

An EPS is characterized by: simultaneous production and consumption of energy; geographical area distribution; auto regulatory properties for the majority of power processes from an EPS, but with a relatively high degree of natural statism; combination of rapid and slow processes; strict quality criteria which must be met by the generated power; and uninterrupted power supply, especially for industrial consumers.

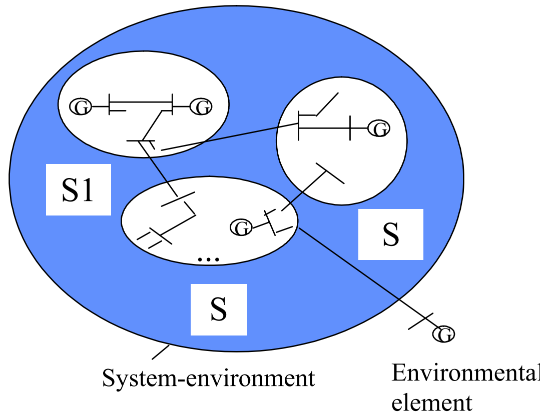

Fig. 1. Electrical Power System

A large system can be recognized considering the following set of features: interconnected structure; the existence of multiple objectives, sometimes vague and/or in conflict; restrictions in the information structure; high dimensionality; presence of uncertainties; and structures with dynamic changes.

EPS coud be considered a large system but the most important attribute it is the complexity.

Investigating the characteristics of large systems, comparative to those of an EPS, we can conclude that: *An EPS is a large and very complex system* with variable structure depending on the consumption and production balance.

As stated above, with their various equipments and relational complexity among them, modern EPSs are highly coupled systems, of large size and high complexity, which imply rapid on-line decision making, while meeting increased safety functioning criteria. Inappropriate functioning of any elements in this ensemble leads to serious economical, social and political consequences.

From the structure and control perspective, these EPSs can be viewed as hierarchical systems, muti-level and/or multi-layered (Fig. 2). This architecture is consistent with both functional design aspects, as well as geographical aspects and chronological implementation solutions [5,8].

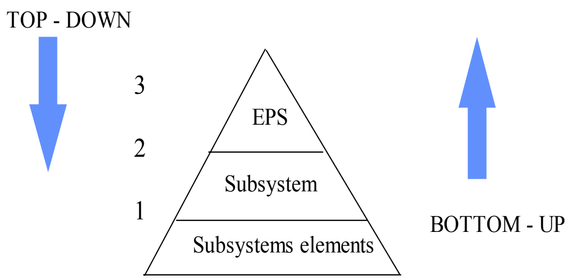

Fig. 2 Hierahical EPS

The management of productive-economic activities of the whole system and for each subsystem is done by the systems coordinator, or subsystem coordinator respectively. The coordinator performs several functions such as: forecast, planning, organization, and the command of underlying processes, including quality insurance functions (for the power supplied).

Taking into account that an EPS requires a continuous correlation of the power supply with power consumption within strict constraints, all the control system's functions should be performed daily and should have the ability to readapt each moment to the unpredictable disturbances that take place.

In conclusion, the control of an EPS is a problem of real-time control, with an emphasis on an auto-adaptive and auto-protective behaviour. The complexity of EPS implies a new perspective on modelling and control [2].

3. COMPLEX ADAPTIVE SYSTEMS (CAS)

From this point of view the infrastructures are more than just an aggregation of their components, the behaviour that isn't convergent represents an attribute of CAS [3].

Power systems are typical multivariable systems with non-linear complex coupling, operate over a range of operating conditions and are subject to random disturbances. There are a lot of uncertain factors and it is difficult to describe the process dynamics. Using the conventional linear controllers with fixed parameters to control such complex process will not obtain the quality and good performances of the power systems.

New strategies applied to power systems control based on adaptive intelligent technology give more satisfaction (Fig.3) [9]. By using a neural network technology for identification and an adaptive controller to control the excitation of generation as a power system stabilizer could improved the robustness of stability of the power system.

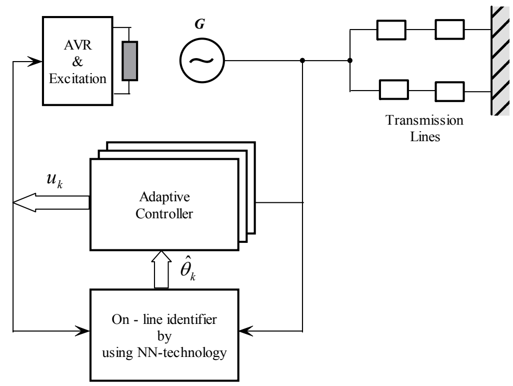

Fig.3. Adaptive control structure for EPS

Power systems have the unique characteristics as large-scale, multi-input / multi-output, nonlinear systems distributed over large geographical areas.
New strategies of control and management of these very complex adaptive systems will increasingly rely on data communication network and equipment that will enable improved energy delivery and consumer services and improving the electric power security, quality, reliability and availability. Agent-based technology for modelling control of power systems represents a real challenge for this type of adaptive complex systems (CAS). The communication and cooperation between intelligent agents is also a challenge.
With more reliable and higher quality power expected by the consumers, the leading challenge is to balance the consumer needs with the cost of upgrading the system.

One effective way to investigate CASs is to consider it as populations of collaborative agents with different level of intelligence. In this way the intelligent agents offer a high-level information knowledge sharing, cooperative problem solving and mobile agent / object solutions.

The high-level of complexity for systems architectures defines four main connections between agents: Physical, Cyber (information, knowledge), geographic and logical control.

This paper will manage the complexity trough different approaches for modelling, design and operating taking in consideration the concept and integration of elementary functional unit and management unit. In this framework we have to integrate in different levels the World Modelling, Value Judgement and Behaviour Generation as main functions of the intelligent systems [2, 3].

4. THE THEORY OF TECHNICAL AGENTS AND AUTONOMOUS SYSTEMS APPLIED TO EPS

The latest evolution of control problems imposed new approaches, among which multi-agent systems' theory [7,9].

In this paper, the term **agent** refers to a system that exhibits well-determined properties. In this context, a complex system constituted of several subsystems with well-determined functionalities can be viewed as an ensemble of actively interacting technical agents. We shall further refer to this ensemble as a system of multiple technical agents.

A multi-agent system (MAS) can be regarded as a new design method to construct a complex system with, de-centralised fashion in contrast to conventional centralized architecture. Each agent can be defined as an autonomous entity to preserve its own goals, which has the ability to perceive the environment, communicate with other agents, and take actions to affect the environment based on its knowledge and the results of communications. Interactions and cooperation between agents are important features of MAS to achieve a global goal that is beyond the capability of each individual agent.

A MAS is characterized by the following properties:

- process optimization: a [technical] agent is a system aimed at optimizing the functioning of one or more technical processes;
- autonomous behaviour, which implies that such an agent is quasi-continuously active in order to achieve the optimizing function's stability;
- control by interaction, which implies that a technical agent in an MAS will interact with other agents in order to achieve its optimizing purpose. This interaction may be physical or technical-informational, wanted or unwanted.

The lack of precision in the mathematical modelling of the constituting elements and subsystems in an ESP give rise in the last 20 years to a series of unconventional concepts applied to process control. Thus, concepts of artificial intelligence were employed for the development of knowledge-based systems and expert systems. An intelligent control system is developed and implemented by an intelligent methodology, as a sum up of techniques that emulate the functions of biological systems.

The development of an operating framework to allow the successful interaction of the subsystems within a complex system has been researched and became a final purpose for a long period of time.
This aspect is of extreme importance in engineering where a stable control is necessary to implement the decisions (commands) taken by the system.

Technological advances imposed with the development of multi-agent systems' theory determined the necessity of autonomous functioning so as to enable each constitutive element of a system to make independent decision in an unknown, dynamic environment.

To ensure its proper functioning, such a system should be designed as an (artificial) intelligent system, as depicted in Fig. 4 [2]. This model emphasizes the four essential functions of such a system: *perception*, *learning*, *reasoning*, and *behaviour generation*.

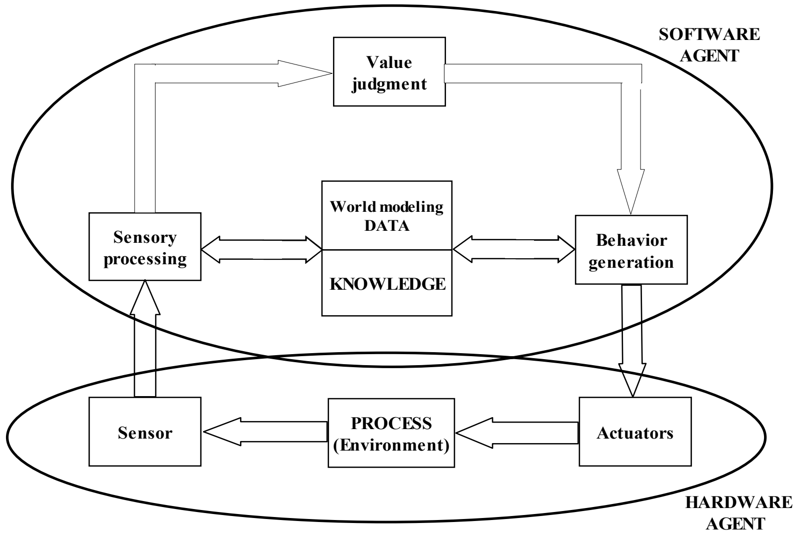

Fig. 4 A Multi Agent System

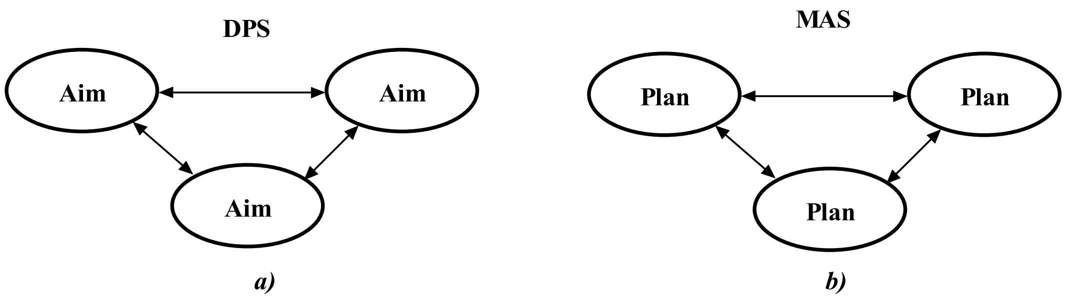

Fig. 5. Concepts on distriduted artificial intelligence

Another perspective to which the concept of agent can be connected is that of **distributed artificial intelligence**. Within this paradigm, there are two usage classes:

- *distributed problem solving* (DPS), where several systems work together to solve a global problem, each system being able to solve that particular problem independently (Fig. 5a).

- *multi-agent system* (MAS): several systems solve a local problem, where the problem solving of one system is positively or negatively influenced by the solving of another system's problem (Fig. 5b).

Both types of systems in Fig. 5 are applicable to EPSs. Translated to the autonomous systems technology, a control structure applied to the national power system can be designed as depicted in Fig. 6, emphasizing three functioning levels / layers:

- executive level – implements classic control functions (e.g. PID control), imposed by adaptive control parameters;

- coordination level – integrates the functions on the executive level with planning, learning, supervising and coordination functions, fault identification and on-line control strategy or dynamic reconfiguration;

- management level (strategic) - supervises the other levels by monitoring performance and symbolic decision making.

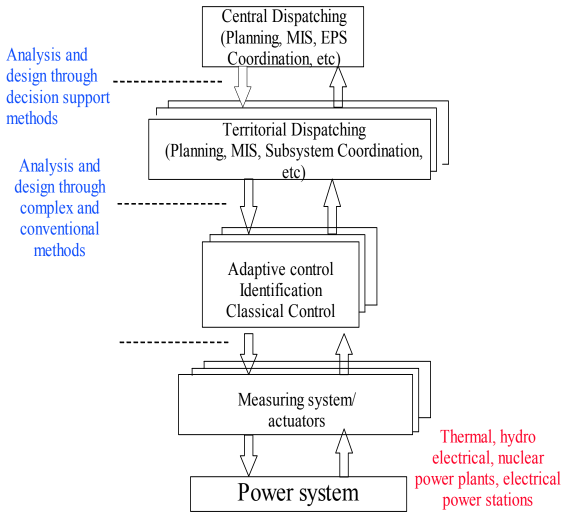

Fig. 6. A 3-level control system for EPS

5. TOWARDS AUTONOMOUS CONTROL OF EPS

The entire philosophy of the control implemented on the CAS is based on the dynamic reconfiguration of control strategies. This dynamic reconfiguration assumes an on-line accurate security system with real-time monitoring, control and protection of the power system. We are going to create real autonomous control systems for power systems.

A general structure of autonomous control systems organized as a hierarchical architecture that includes the *execution*, *coordination* and *strategic* (management) levels for bay-control, substation and network control is presented in fig. 7.

The general functional architecture of hierarchical system is transposed into the operational architecture related to the control system of electrical power systems which integrate also the protection system.
For each level are included several autonomous component with these functional layer: EXECUTION (E), COORDINATION (C) or MANAGEMENT and ORGANIZATION (M,O).

The main functions of execution layer are: Error and self-diagnosis, Action execution, Adaptation and State Assessment and Action Review. From the communication with the coordination layer is based on the action and the reaction determinated by the events which a corresponding to major changes in process.

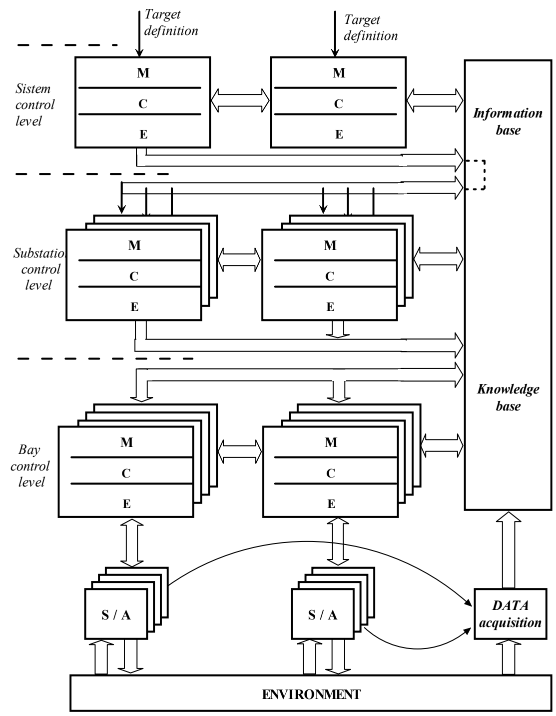

Fig. 7. General structure of autonomous control systems

The coordination layer has the task to activate action execution on the base of the general progress definition and defined action steps from management and organization layer. The main functions of this layer are defined as: Function Assessment; Definition of Actions; Parameter Predefinition; Determination of Action Transitions; Event detection and Process Identifications.

The highest layer of the Autonomous Control System is called management and organization layer and includes as main functions: Action Planning and Decomposition; Function Evaluation; State Forecast and Optimization and Learning. This layer is getting the target definition or inquiry from the process operator or other autonomous components together with the related boundary conditions.

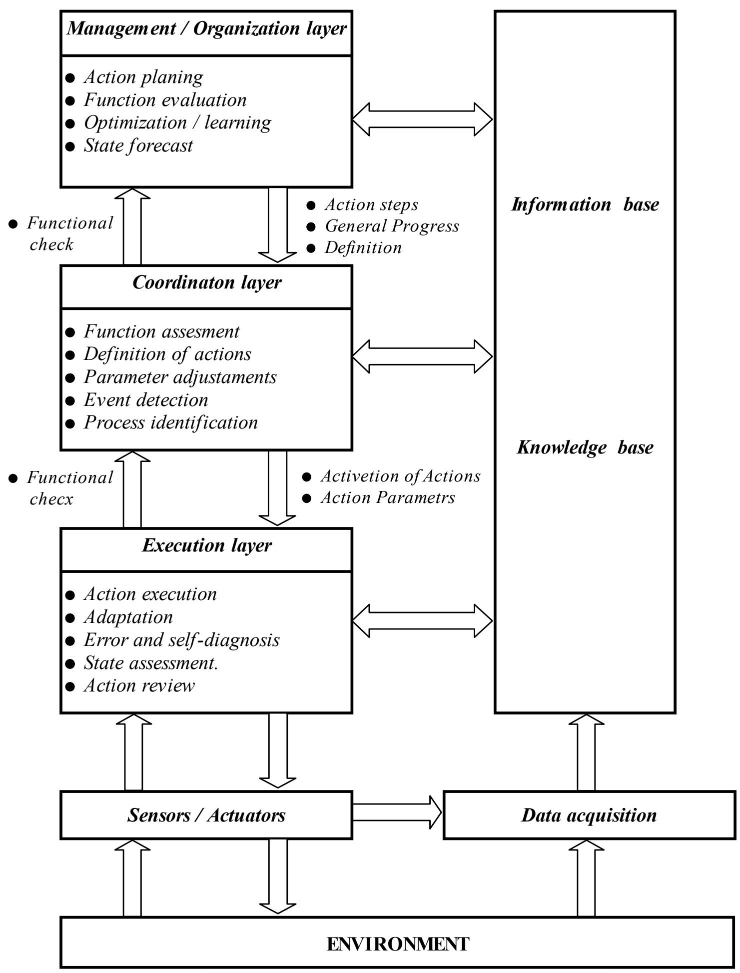

Fig.8. The general functional architecture of autonomous system applied to EPS

State forecast help to extend the time horizon for the action organization and mean also that all possible existing states have to be determinate and proper actions organized.

The learning function of this layer gives the possibility to adapt and optimize the actions in function of evolution and assessment situations. On this layer is defined the self-organizing and self-learning control with higher degree of abstraction than the functions in the lower level. In self-supervision and diagnosis of the autonomous component is used par the determination of action modifications.

The management and coordination layers are serving to take decisions and could be implemented as an abstract and mainly discrete process and the execution layer implements the functions mostly a continuous or quasi-continuous process.

Therefore the autonomous component as a whole contains a hybrid continuous – discrete architecture. All layers of autonomous system that are connected to information have been as a hybrid setup of direct data access to other components and a distributed data.

An autonomous component as a self responsible acting unit can also be called agent, which is acting within its environment.

The general functional architecture of autonomous system applied to electrical power systems is presented in fig. 8

The actions and information of the components on the higher levels are transmitted via the information base to the underlying levels.

6. CONCLUSIONS

This paper aimed to introduce new approaches to ESP, as systems with a major impact in the continental organization of the New Economy, at the European level and international.

In summary, a three axes approach for EPS has been described:

- with respect to systems' theory, which is already adopted by the scientific community in this field;
- with respect to systems' analysis, which is primarily used when approaching the informational systems aspect in an EPS;
- with respect to technical agents theory, which is a currently emerging trend [5,10,11].

This approach on the object system – EPS – on the three axes described above, will prove feasible in the analysis and design of ESPs on various levels, since the key success elements – both theoretical and practical – characterizing these paradigms will automatically transfer to the field of EPSs, enabling the development of new kinds of architectures and control algorithms.

In the next future based on the concepts related to the three axes described above will be adapted and designed into new approaches to EPSs. Some of them have been already proved promising results to increase the quality and reability of power systems.

From the CAS perspective, applications and further developments of the preliminary results described in [6] are to be pursued in the future.

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