Smart-Grid Control

Adaptive Multi-Agents Architecture

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***Abstract*—This article is about the control and management of smart-grid and new generation of electrical systems. In fact, most of the advanced technologies and systems depend on energy, especially electrical energy; even the daily activities of simple consumers, their tools and equipments are based on electric power. The developed solutions remain within the boundaries of existing and limited systems and do not meet the requirements of the future generation of the electrical networks, such as including intermittent energy resources, and electric vehicles. In this research, we present a solution based on the use of an adaptive multi-agents architecture to control and manage smart-grid. The main output of this paper is an explanation of our solution, the most important points, and the main parts of the proposed architecture.**

Keywords-smart grid; multi-agent system; multi-agent adaptive model; auto-organization mechanism.

I. INTRODUCTION

The management and control of electrical systems presents an issue with many facets. In fact, such important topic involves several stakeholders, including states and governments, consumers, environmental interest groups and local officials etc., to discuss and interchange points of view [1].

The discussions focus on two main issues and challenges. The former is on how to design the best system that meets all requirements in quality and quantity [2], while the latter is on how to migrate the existing networks to a smarter system, especially with the current aged infrastructure.

The importance of the smart-grid concept lies in the fact that it is the best choice to meet the requirements of the near future electrical system [3].

To satisfy the smart grid requirements, there is a need for a lot of investments, new energy markets, policies and pricing, and appropriate legislation. In addition to these issues, there are many scientific challenges, such as the introduction of new Information and Communication Technologies (ICT) and the development of models and standards [4][5].

Our approach focuses on the information and data management with consideration of other aspects, such as physical and electrical components, business objectives and market policies. The idea is based on the use of multi-agent architecture for the management and control of smart-grid with adaptive functionality.

The main questions discussed in this paper concern the choice of an agent-based architecture [6], the interest of its adaptive nature [7][8][9], and the skeleton outline of the solution developed.

This article is intended to answer these questions and try to makes a pathway that helps smart-grid designers to design and model adaptive multi-agents architectures by defining a minimum basic architecture that can be extended later, according to the smart-grid specifies to design and manage. In future work, the solution will be implemented on a micro grid to test, evaluate and optimize it. Additionally, the solution will focus on some aspects that are considered the most important, e.g., real-time processing of information, self-healing, and system security.

The rest of this paper is structured as follows. Section II presents studies and works on smart-grid elaborated by committees and different stakeholders. Section III briefly explains the utility of the proposed approach. Section IV presents in more detail the principles of adaptive multi-agent architectures. The proposed approach is explained in Section V. Section VI presents advantages of the developed architecture. Finally, a conclusion summarizes the main aspects illustrated.

II. STATE OF THE ART

The electrical smart systems attract more and more the interest of nations, laboratories, academics, economists and all types of electricity customer (commercial buildings, industrial factories and residential consumer). Several studies and approaches are proposed to find effective solutions to smart-grid challenges, namely, the model developed by the National Institute of Standards and Technology (NIST) [10], the European Union, which proposes a Smart Grid Architecture Model (SGAM) [11], the Institute of Electrical and Electronic Engineers (IEEE) proposition [12] and the International Electrotechnical Commission (IEC) one [13]. All these models give just standards and models to design architectures for smart-grid and do not propose detailed and practical solutions. However, these models play an important role and invite designers and researchers to complete the work based on their results.

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Other solutions exist and benefit from advanced technologies, such as cloud computing [14] or market-driven approaches [15]. Although they are agent-based solutions, they do not explain and fully address the concept of adaptability and the basic agent structure, which represents the basic building block of the multi-agents architecture.

We pointed out in our approach the importance of the system adaptability with unexpected scenarios and its capacity to pass critical situations. We also present the structure and behavior of the architecture core component (the agent).

III. NEED FOR NEW APPROACHES

The information systems of large and complicated projects, such as electrical networks, are characterized by a very advanced level of complexity. They have become increasingly difficult to manage because reference systems and emerging applications become progressively more distributed, open, handling large amounts of information and having new capabilities to work in cooperation and adapt their behavior with changes. On the other hand, administrators and electrical networks managers have an increased need for effective management and control systems with dynamic architecture. Added to the structure flexibility, the electrical network must be able to be managed as independent parts (case of several micro grids) with local processing of information and autonomous management units and components or in cooperation (case of entirely system) [14] with the ability to interchange data and messages. We chose agent-based architectures because it recognizes criteria and capacities to meet the complex and dynamic systems that need powerful and flexible approach and present an adequate field and environment for test and validation of Multi Agents Systems (MAS). This situation is almost the same for all systems, especially more complex systems, such as smart-grids. This heterogeneity, large scale and distributive architecture exclude all opportunities to express all necessary knowledge to manage and control the system, hence the necessity to develop an adaptive multi-agent model with the ability to change its behavior according to changes and environmental disturbances.

Such a model, which can adapt its behavior and its internal structure with the situation of the system, requires self-observation mechanism to detect emerging events.

IV. ADAPTIVE AGENTS -BASED ARCHITECTURES

A. Adaptive Multi-Agens Systems

Multi-agent systems come as a result of research evolving a set of theories, such as Artificial Intelligence (AI), Expert Systems (ES) and object-oriented systems to exceed their limits. Multi-agent systems are used to model complex, heterogeneous, nonlinear and especially dynamic and evolving systems. This requires adaptive agents capable of dynamically acquiring knowledge not introduced earlier by the designer or the system operator, enabling them to adapt their behavior at the individual level (agents) and collective level (organization of agents) [7][8][9].

B. Differents Models and Architectures

Multi-agent systems have started with two basic models: a first reactive agent [7] (used for cases of immediate response and not much individual intelligence; however, a collective intelligence is required) and a second cognitive agent that is smarter and has advanced processing and reasoning capabilities. This type of architecture is favored in cases of complex decisions.

The two models presented are subsequently emerged to find a new architecture that benefit from the speed of the reactive agent and the intelligence of the cognitive one. This new hybrid architecture traces a path between the two approaches by combining reactive and cognitive properties, typically implemented in different modules.

TABLE I. COMPARATIVE TABLE OF MULTI-AGENTS ARCHITECURES

Architectures	Advantages	Disadvantages
reactive	- fast response - simplicity of implementation	- limited to simple systems - not much intelligence
cognitive	- agents are intelligent can model complex systems	- expensive implementation for littre systems
hybrid	- undeniable qualities in software engineering respond to diverse spots	- does not resolve the issue of variable granularity [7]

Modular architectures [7] have passed the hybrid model. They make the agent as an open system benefit from the modularity introduced and the ability to exchange modules between agents.

Hybrid architectures (traditional) do not resolve the problem of granularity; in fact, they are not able to support a design system whose agents have varying granularities. This gave birth to a new generation of operational and generic architectures [7]. They are based on platforms with reduced core and basic features such as communication with other agents and environment entities. This idea is to have a basic building block for the development of a model of adaptive architecture that can be integrated into various systems.

This model allows the integration of all architectures, starting from a minimal agent, and then adding the desired functionality by successive refinements.

V. ADAPTIVE MULTI-AGENT SYSTEM APPROACH TO MANAGE AND CONTROL SMART-GRID

A. Developed Approach

As explained earlier in this paper, complex problems and computer systems require the modeling and design of computer systems, which become too complex.

Therefore, the trend is moving more and more towards the development of new approaches integrating adaptability and self-organization capacities [17].

To respond to the different objectives of smart-grid, the mechanism of self-organization is an interesting way to design an adequate management and control system. This enables the smart-grid to adapt its behavior to environmental changes in an unsupervised manner.

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The idea developed in this paper presents an approach in this context designed for smart-grids. It is based on the concept of distributed and self-agents learning that are guided by a set of local decision rules that are refined continuously under the influence of the environment. This approach is based on several theories, mainly Adaptive Multi-Agent Systems (AMAS) [16][17]. Such a system is composed of several types of agents (load agent, generation agent, transmission agent, distribution agent, etc.) that are equipped with local knowledge and a representation of their environment. They make their decisions using this knowledge, their cooperative social behavior and adaptability skills and capacities (see Figure 1).

For example, the following agents are part of the proposed architecture:

- Load agent: responsible for the management and control of electrical appliances in homes, companies and factories. It has a dual role (two directions), it routes requests energy consuming from appliances to network controller and monitors the implementation of the political system.
- Generation agent: it manages one or more resources of energy and decides the amount of electricity to produce with reference to customer demand and the capacity of the resources. This agent is implemented in several forms, depending on the resources it manages. In fact, management of intermittent resources and current fossil-based resources is different, risk and danger of nuclear power plants is not the same in friendly- nature resources.

Therefore, each agent adapts its behavior according to its position in the network by choosing the features and the necessary means to fulfill (perform) the tasks entrusted to it.

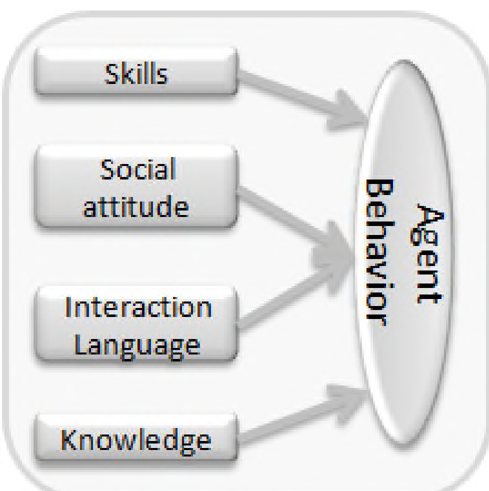

Figure 1. Agent Architecture [16].

The first step in the proposed bottom-up design approach is to identify the agents; then, to ensure that the local agent is or trying to be in cooperative interactions with other agents. Neural networks can be used to identify agents, which provide well-defined agents on a set of parameters and criteria defining each agent and specifying its architecture.

The second step is to define the agent's components, because each agent in this architecture is divided into several proactive components. This allows reusing of these components by different agents by instantiating them if necessary. It should be noted that each component can be reactive or cognitive, which allows building hybrid agents not only hybrid architectures, and this is one of the most important criteria of this approach inspired from the architecture Development and Implementation of Multi-Agent Systems (DIMA).

The components of an agent are always chosen around a core (main component that contains the component identifier (ID)). This main component is the only one that cannot be changed, all others can be modified or changed and these interactions (see Figure 2).

To present these components, the notation used is that of Unified Modeling Language (UML) [7]. It defines any component as a set of classes with their methods.

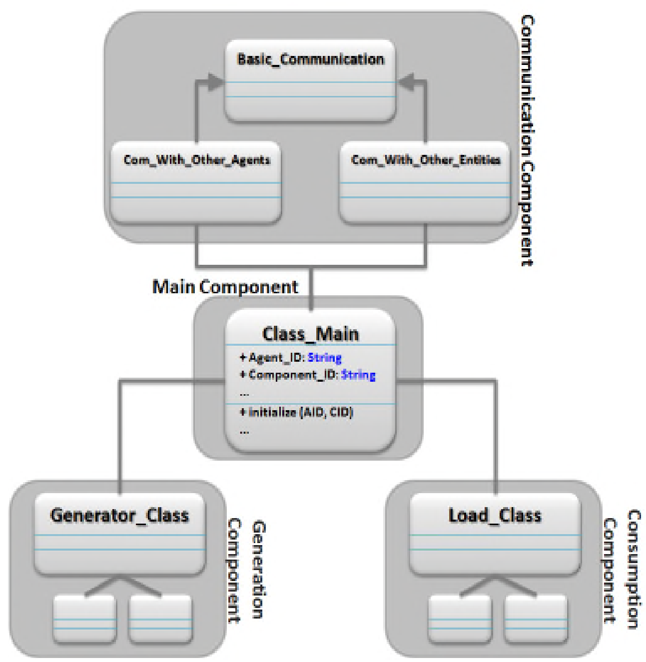

Figure 2. Agent Components

B. *Basic Agent Components*

1) Main Component: It contains the basic informations of the agent and the component such as their IDs, their statements, etc.

2) Communication Component: This component is essential in the architecture. This module will guarantee

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reliable communication with other agents. It is responsible for the delivery of messages between agents according to the appropriate protocol conversation.

With this approach, the design of agents is operated in a relatively simple manner, starting with a minimal agent and adding the desired modules according to its mission.

Several modules (components) can be attributed to agents such as components controlling energy generators, consumers, network transmission or distribution, etc.

C. *Agent Communication Language*

Designing MAS requires coordination and cooperation between its agents to perform their tasks. So, designers should formalize how the agents coordinate themselves. In fact, like any community assembling several individuals, a common and conventional language must be specified to facilitate communication within this shared environment. This is the case in all communities (social, IT, scientific, etc.). To this end, the Foundation for Intelligent Physical Agents (FIPA) [19] has defined some specifications and standards for the use of multi agents systems.

Many languages have been created such as Agent Communication Language (ACL) [19] and Knowledge Query and Manipulation Language (KQML) [19] for use in MAS development.

ACL is a FIPA specification-based language. It is the most preferred in the development of multi-agent systems [18]. It defines a specific structure for the messages circulating between the agents. This structure includes attributes containing information about the agents involved in the conversation, i.e., the sender, receiver(s), the message content, etc. (see Figure 3).

An ACL message should contain the following parameters [18]:

- Communication type (performative): this parameter indicates whether the message is a request, a reply, a piece of information, etc.;
- List of the participants in the conversation: it contains information on the sender and the receiver(s), and reply-to fields, including the names of the corresponding agents;
- Message content;
- Description of the content: the used language, encoding and vocabulary (ontology);
- Conversation control parameters: such as a conversation identifier and protocol.

```
(REQUEST
:sender ( agent-identifier :name agent1@platform:1099/JADE )
:receiver (set ( agent-identifier :name agent2@platform:1099/JADE ) )
:content "Hello! How are you?"
:language FIPA-SL0
)
```

Figure 3. Sample ACL message, using the default ontology [18].

The example in Figure 3 presents a sample ACL message, but in complex conversations, using a common language may not be sufficient, so ontology (i.e., formal representations of knowledge) should be specified to define the vocabulary that agents use in their conversations.

D. *Inheritance Notion*

A set of generic classes (Framework) defined different types of agents and the services they provide. These generic classes are inherited by subclasses to detail the specifics depending on the role of this container agent. For example, classes of agents that control the electricity generators inherit a generic management generator class and redefine methods and may add new attributes and / or methods according to the characteristics of their resources (intermittent, un-intermittent, permanent, seasonal, etc.) hence the obligation to assign any agent an adequate adaptive design starting with the same generic model (class).

Figure 4 presents an example of inheritance relationship, in fact, classes Intermittent_RES and Permanent_RES inherit the standard methods of all generators of energy from class Class_Generator. Classes Intermittent_RES and Permanent_RES are in turn inherited by the classes Solar_Panel, Turbine_Wind, Fossile_RES, and NuclearPowerPlants which redefine the methods to their suit characteristics.

This property greatly simplifies the task to the designer who benefits from a framework containing almost all basic classes; otherwise, its task is reduced to mapping classes and redefining their methods.

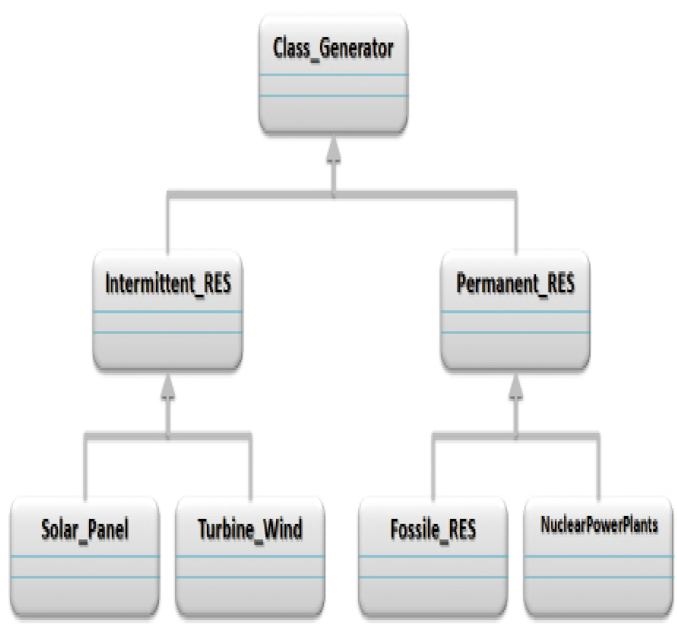

Figure 4. Example of inheritance between classes within a generation agent

E. *Decision-Making Structure*

In a smart-grid, like any complex and dynamic system, an agent may often be faced with dilemmas in the decision-making process. In fact, an agent must have a decision-making structure enabling it to evaluate the situation and decide what to do.

The proposed approach excluded the idea of predicting all possible cases for the simple reason: it is not feasible except for small systems and / or simple scenarios and of course this is not the case for smart-grid where different variations cannot be known a priori. The architecture of the agent, in this case, must provide the ability to easily adapt the decision-making process to the changing environment.

With its decision-making mechanism, an agent needs two sets: a first set of conditions to be used to test the context of the agent and a second set of actions (methods) that modify the state of agent and / or its environment.

The decision-making process can be described by a Petri network or Programmable Logic Controller (PCL) whose states are the situations that can take the agent (see Figure 5).

VI. PROPOSED APPROACH ADVANTAGES

The approach presented in this paper is based on the decomposition of smart-grid into subsystems managed by agents that have dynamic modularity. It benefits from the properties of adaptive multi agent systems such as:

- Multi-granularity: agents have different granularities;
- Dynamism and openness: the agents are dynamically created and destroyed. They often change their behavior and change their internal structures regularly by adding or removing modules (components) and services;
- Heterogeneity: the architecture includes different models of agents (reactive, cognitive, hybrid, modular);
- Real-time reflection: the system reacts to changes and events in a timely manner;
- Reusability: the same components can be used in several agents.

The solution differs from others [14][15][18] by a set of criteria which proves its high performances when we compared it with other solutions (see Table 2).

TABLE II. COMPARATIVE TABLE OF SOLUTIONS PERFORMANES

Performances	Proposed solution	Other solutions
Adaptability	Able to adapt to unexpected situations.	Don't fully address the adaptive nature of the system.
Flexibility	Flexibility is witnessed at all levels namely the design, implementation, etc.	Some solutions [14][15] may be qualified by this adjective, others are static and rigid as current systems that are invariant.
Structure & modularity	Variable and modular structure, otherwise has a variable and dynamic granularity.	Static structure [14] [15] [18] defined from the beginning.
R eusability	Based on generic components that are used by different agents.	There is no re-use because of the lack of units and generic components equipped just with common services.
Clarty & simplicity	Clear and easy to understand even for non-specialists and simple in terms of implementation.	Clarity and simplicity are relative and vary from one solution to another.

VII. CONCLUSION AND FUTURE WORK

The paper presents an agent-based architecture given as a solution for the problem of smart-grid management and tries to pass the boundaries of current solutions to a new dimension of autonomous steering (management, control) system. To achieve such a system, we must overcome many difficulties and challenges mainly modeling smart-grid and designing its information system that presents a delicate and crucial task. In fact, the theoretical model will define policies of the real networks.

In order to achieve a consistent system, it is strongly recommended to divide the system into subsystems easy to identify and model. This division must be justified and follows a systemic methodology. It represents our next object of work and it should provide the desired benefits to the proposed architecture.

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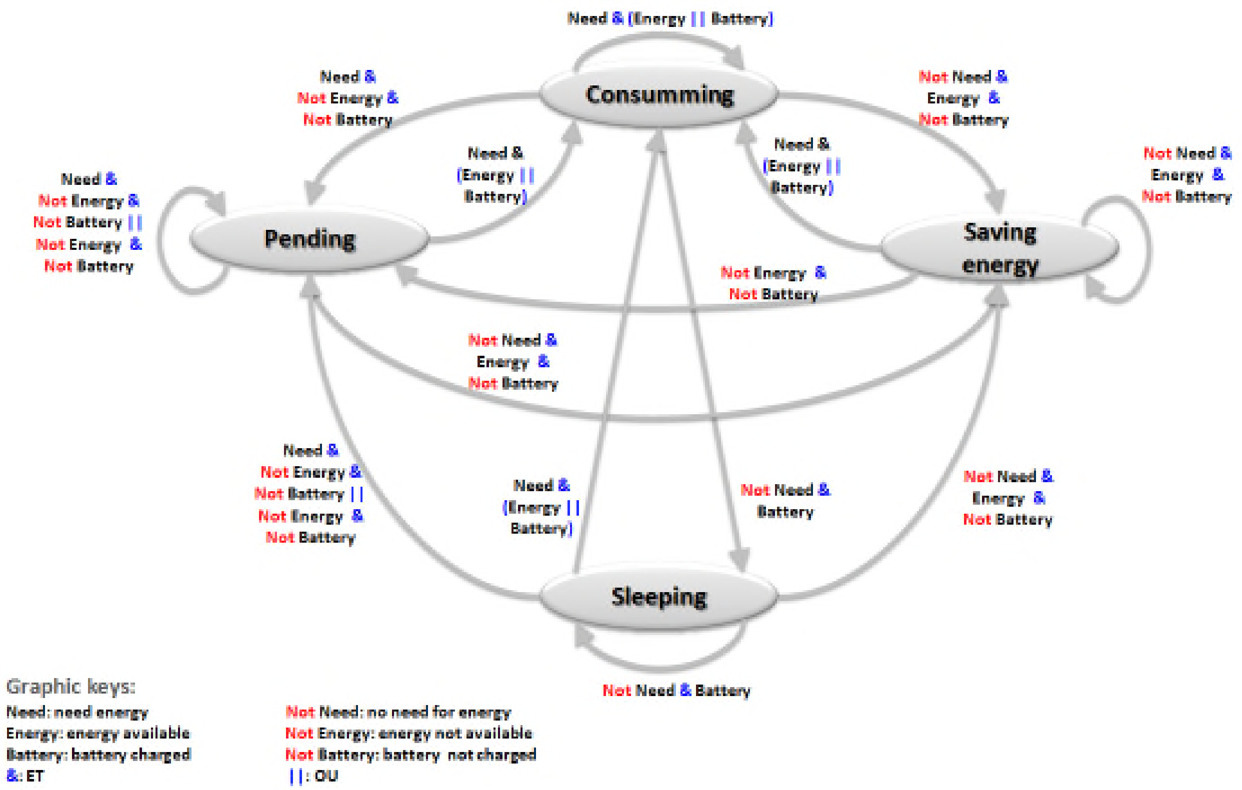

Figure 5. Example of PLC decision-making mechanism for a load agent