Multi Agent Holonic Architecture: A Concept for Power Smart Grids

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Abstract- *In recent years, Smart Grid has become the collocation for highly efficient achievements in power generation, distribution and use. The vision presented in this paper is based on the connection of the Multi-Agent System (MAS) paradigm with Holonic Systems (HS) approach. Particularly, the holonic approach is proposed for structural modeling for such a large-scale complicated system. The issues related on knowledge management are pointed out in the context of electrical delivery to the residential areas, in terms of multi agent holonic systems. This approach opens the perspective towards the cognitive power networks including sensing, awareness of, learning about, and adapting to demands.*

I. INTRODUCTION

Initially appeared as a software paradigm MAS has become a very promising technology for problem solving in complex distributed systems. Over the last years, many industries requiring high level of automation embraced rapidly MAS technology developing some standards and a variety of agent-oriented platforms. Definitely, power grids is one of the most complex and large distributed network in the world which represent the vital system for our life and crucial for global economy. Some publications in the last few years address the issue of MAS in connection with power engineering stating the range of applications that include network control and automation, condition monitoring and diagnosis, power system recovery, and market simulation [11]. For particular applications the usage of agents becomes already traditional as manufacturing systems (i.e. Distributed Manufacturing Systems) [2], [10], supply chain management [18], and building automation, but certain limitations still remain in terms of real-time performance and resource usage in existing agent platforms [17].

Now, in the field of electric power grids the trends of the evolution add more challenges over the existent well known problems that are still partially solved or unsolved yet. The classic major problem on power grids is related on reliability and security in terms of keeping of demand and supply permanently balanced. This class of problems is mainly solved by SCADA (Supervisory Control and Data Acquisition) systems, but this is not able to remove all the vulnerabilities [3] and to provide a fast recovery of the capacity of the system after the manmade or natural disasters [11]. The extension of micro grids, the rapid trends in renewable power sources development, and the electro-mobility growing are seen as the major challenges to the control of the power grids [13].

The concept of distributed energy resource (DER) reflects the actual trends towards the small-scale generation connected to the local consumers [15], [22]. In this context, some interesting aspects related on the intelligent Demand Side Management (DSM) arise, which has to move from "utility driven" towards a "customer driven" via certain techniques as it is discussed in [13]. Intelligent Distributed Autonomous Power System (IDAPS) is also an interesting concept of building a resilient electric power system [15]. Resiliency in power grids is seen as a kind of "elasticity" of the power infrastructure in terms of the robust control. In our opinion, resiliency is the feature reflecting the attribute of "smart" or "intelligent" best when we refer to the electric power grid. So, the smart grid should be understood in the following terms: efficiency of power generation and power consumption, real-time robust control, and security and reliability. In a holistic approach we can affirm the sustainability is a key feature for next generation of power grid. The basic keyword in smart grid is "optimize" and this must be the target of any developed model-based control. The MAS paradigm has brought interest in power systems control, the few approaches and results being reported in [11], [14], [15], [22]. Part of these publications treat the subject from the micro grids perspective [15], [22] leaving aside the general context related to the traditional power grid infrastructure.

In this paper we embrace a system-of-system approach to describe the huge power grid infrastructure introducing the holonic model for our purposes. Holonic systems (HS) are paradigms for virtual organizations with application in economy and production [2], so they are a good candidate for system-of-system approach in smart grids. In this frame of work, an original scalable MA architecture for smart control and monitoring of the grids is defined. The role and the attributes of the proposed agents are largely described in order to define a shell for a granular agent-based system.

II. HOLONIC POWER GRID CONCEPT

Firstly, let's view the contemporary electric power grid as a huge, evolvable, scalable and heterogeneous organization where the human factor plays the driving role. This global organization has a physical layer-generically named infrastructure (i.e. equipments, parts), and a processes layer, which consists in the economic model. In these terms, the full dynamics of the organization results from market-driven relationships in the context of limits and capabilities of the certain infrastructure. In order to manage such kind of complexity refined intelligent techniques in smart grids are required. There are authorized voices claiming that centralized and hierarchical control philosophy in electrical power grids is inappropriate in the current [4], [6], [20]. This motivates us to explore the field of system-of-system from the perspective of holonic systems that combines the best hierarchical and heterarchical organizations. This paradigm is considered a suitable basis supporting multi-agent architectures in order to preserve the stability of a hierarchy, while provide the dynamic flexibility of a heterarchy. On the other hand, in order to imagine a certain multi-agent architecture it is strongly required to have a previous reference model of the electric power grids applicable to the large scale as well as to different levels of resolution. We propose the holonic model to describe the power grid in terms of granularity, dealing with the scalable hierachy and hetararchy appropriately.

The term of holon was originally introduced by Arthur Koestler [9] as a combination of the Greek *holos* meaning whole, with the suffix *–on* , in fact suggesting a particle (like prot*on* or neutr*on*).

The first example of virtual organization structured as a holonic system consisting of three basic building blocks (Product-Resource-Order System Architecture - PROSA) was reported in [2]. This was reference architecture with application in manufacturing systems. The holonic systems enhanced some particular features: the structural nesting, the self-similarity of relationships and essentially the systems distribution. This architecture has proved to be very appropriate for the design of large scale distributed manufacturing systems [19]. In terms of electric power grids a holonic perspective was introduced in our previous work [7]. Our proposal is a particular replica of the originally PROSA holonic structure with application in power systems as depicted in Fig. 1.

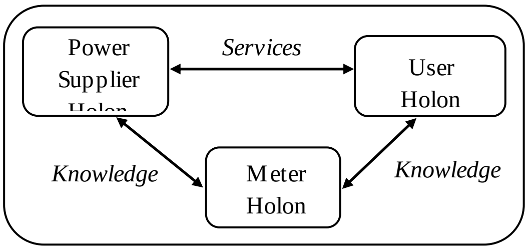

Fig 1. The basic holonic structure for power system

This triadic structural model reflects, in a natural way, the relationships between customer and supplier including the main entities as follows: *User holon* as a customer, *Power supplier holon* as a server, *Meter holon* as a kind of intermediary, and the adequate bilateral relationships between them. The three relationships are described in the following.

- The generic named *Services* reflects requests from user to supplier including power demand, technical assistance, and different queries, as well as the answers to meet requirements from the inverse direction.
- The *knowledge* exchange between the user holon and meter holon consists in data capture from user about power consumption and demand, and the information from the inverse direction about price, quality, load level, etc..
- The *knowledge* exchange between the meter holon and power supplier holon mainly consists in the level of load, and in the reverse direction information about supplier availability , the quality and the composition of the delivered power, the reference price, etc. is provided.

The basic holon depicted in Fig.1 is an original approach of the concept with application on power marketplace. It reflects both the engineering components and the economic model. This holon is a representative entity that can be replicated and clustered with the similar others based on the same kinds of relationships, across the large power grids. The essential feature of the basic holon is its structural self-similarity at different scales, reflecting the power to model the granular grid. It comes to that an individual user, a local community of users or a large-scale distributed clusters of users can be represented by this unique template. From functional and technical reasons imposed by power generation, transport, distribution and use, the electric power grids are organized in both, as a hierarchy as well as a heterachy. Generators, transport lines, substations, distribution lines, local circuits, and loads layer the basic hierarchic architecture, while the heterachical architectures are events-driven across the grid sometimes in ad-hoc manner.

The scalability in power grids can be modeled as a recursive holonic virtual organization, named holarchy, where the holons playing the same role at each nesting level are recognized: suppliers, users and meters, with the same kind of interaction between them. For instance, we can interpret the different level of resolution of the recursive holonic model applied to residential areas according to Table.1. The pertinent approach is to consider the scalability from user perspective as it is depicted in Fig.2. The users are hierarchically organized, so they can be represented at different levels by "nesting" while the relationships are self-similarly reproduced.

Table.1. Entities in a scalable holonic power grid

Level of resolution		Holons		
Nest (k)	Type	Supplier	User	Meter
1	Apartment	Power plant & different alternative co-generating sources (green power), including micro grids and the granular home located sources	Lodger	Home meter
2	Block of flats		Community of inhabitants	Joint meter
3	Street		Clusters of blocks of flats	Local circuit meter
4	Residential district		Group of streets	Local area meter
5	City		Clusters of residential areas	Dispatcher meter

The recursive model describing quantitatively the structure and dependencies of the system is given by equations (1), where k is the nesting level, z_k is the number of replicated holons at the k level, and l_k is the number of links inside the k level.

$$\begin{cases} z_k = 2k + 1 \\ l_k = z_k + k - 1 \end{cases} \quad (1)$$

The basic holon assimilated as "seed" is considered level $k = 0$, which correspond in Fig.2 to the deepest nested user holon, that could be a very elementary holon representing a load for instance.

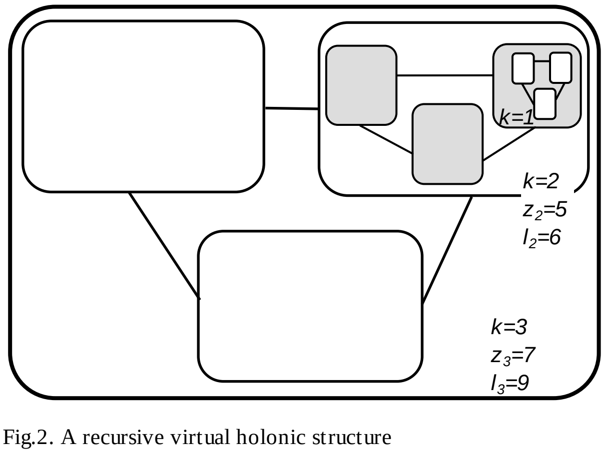

Fig.2. A recursive virtual holonic structure

At each level of resolution the nature of the relationships are kept essentially the same, while only the structure and the quantity of the exchanged data are progressively changing [8]. In Fig.3 an instance of granular structure in electric power grid that reflects the essence of the holarchy is depicted. Two aspects are remarkable for this approach. The first is referring to the aggregation of the holons, and the second-to the specialization of the holons. Both aspects are important for MAS designing in order to establish the certain roles and attributes to the agents.

A. *Aggregation*

Aggregated holons are defined as a set of related holons which can be seen as one bigger holon in terms of the functionality of the system. In case of power grid systems the power supplier is an aggregated holon including across the hierarchy related holons as power plants, distribution substations, transformers, lines and circuits. So, along the granular hierarchy the power supplier holon is seen as generator keeping the same kind of interaction with other type of holons.

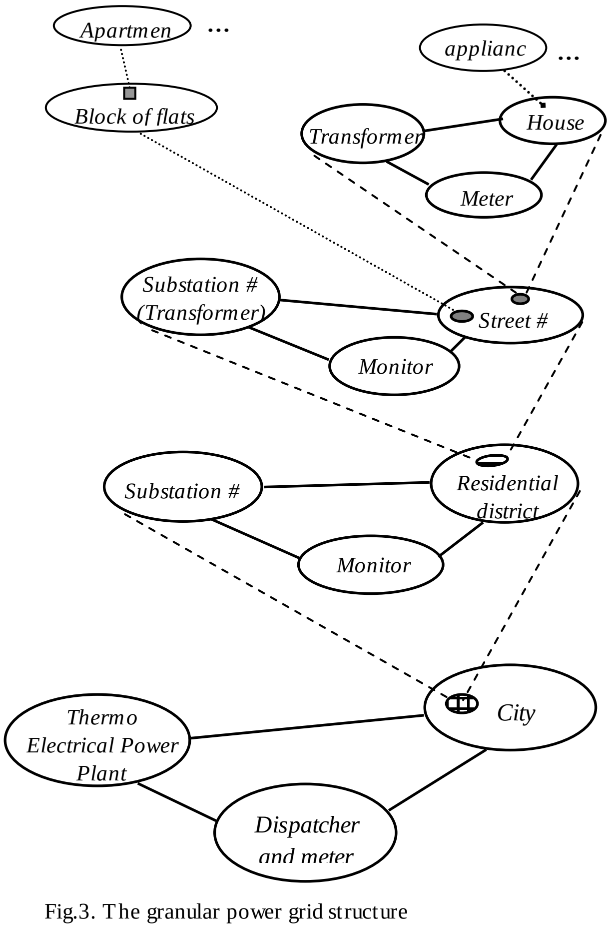

Fig.3. The granular power grid structure

A similar approach is for meter holon which is also an aggregated holon containing the entities of dispatching, power monitoring and effective power metering from different levels of the hierarchy. The user is an aggregated holon containing related holons that are clustered together forming distinct holons with their own identity at different scales.

Depending on the purpose of the observer, aggregated holons are split up into their sub-holons or treated as a whole. In addition, the aggregated holons allow dynamically changing their contents according to the needs of the system. The aggregation of the holons completes the vision on the architectures of a multi-agent power supplier and of a multi-agent meter system.

B. Specialization

The basic tree-holons structure proposed for power systems could be a bit abstract, so the discussion about specialization is useful to clarify the aspects on task decomposition and role definition to the holons in the granular structure. Specialization of user holons separates them into certain classes like appliance or individual load, house or apartment, block of flats, street, residential district, urban area, industrial area, etc. Other attributes complete the picture in terms of user holon specialization like: critical, occasional, domestic, industrial, etc. The power supplier holon is separated in various classes according to the nature of the power source and to the functionality of the system. These correspond to the following specializations: generating stations including step-up transformers or invertors, high voltage transport lines, distribution substations including step-down transformers, switching substations, lines and circuits.

The meter holon specialization highlights the following classes: high level dispatcher, local area power monitoring points, smart meters distributed to the end users.

These aspects are crucial to define the model of information processing including data structuring, storing and archiving, formats for storing and archiving, communication protocols. On the other hand the specialization of the holons reflects the aspect of technology in terms of capabilities of the existent equipments, but also the needs for new kind of devices as well as for new standards.

C. Scalability

The scalability is an important feature in power grid systems. On one hand, it is essential to develop the system easily, but, on the other hand, it is critical from the complexity point of view. The scalability in smart grids should be approached from two points of view: the first is a dimensional evaluation of the system, and the second is to manage the scalable architecture as easily.

The holonic power grid concept shows horizontal and vertical scalability. Vertical scalability is driven by technical and organizational reasons in agreement with operative standards, while horizontal scalability is driven by extensive development in agreement with certain economic policies.

According to the model described by equations (1), which reflects the vertical scalability, the complexity of the system increases versus the nesting level as depicted in Fig.4. It is notable that the number of links grows faster than the number of entities - an aspect that should be taken into consideration for communication resources allocation.

Horizontal scalability comes to increase more and more the power grid complexity. This process depends on the number of same type of holons replicated N_k on each certain level k of the structure. The structure grows in an additive manner according to the following:

$$\begin{cases} Z = \sum_k N_k z_k \\ L = \sum_k N_k l_k \end{cases} \qquad (2)$$

where Z and L give the total number of entities and links of the grid.

III. THE AGENT BASED FRAMEWORK

The aspects on how adequate the multi-agent systems are for certain power engineering application were largely debated in [11]. In recent literature [14], [15], [21], [22], some proposals of MAS application in power grid control are reported. However, it seems that the concept of smart grid itself still needs more elucidations to be fully embraced by stakeholders and the large class of customers.

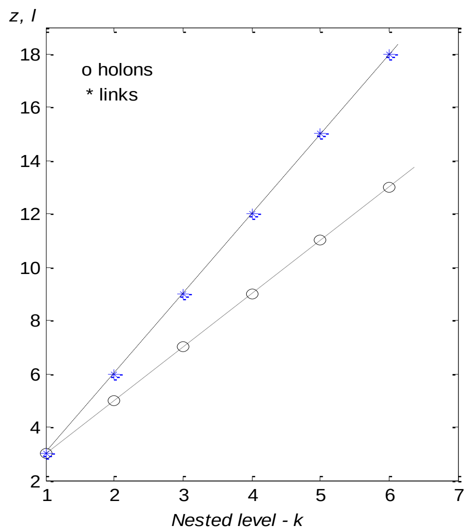

Fig.4. Trend of complexity in holonic power grid

In our opinion the main goal of the smart grid is sustainability. The general frame defining the main attributes of a sustainable system is given in [1], [12]. From this perspective, we see the smart grid as a knowledge driven power infrastructure in order to provide qualitative energy, any times and everywhere at an affordable price for the people, with a minimal impact on the environment. Definitely, this is a complex problem involving many difficult tasks, which can be solved by involving both: distributed computing resources, and suitable communication technologies.

There are many options to define an adequate framework of MAS for smart grid. Our approach starts from the requirement of compliance between the multi agent architecture and the existent non agent based power grid architectures. In fact, the major purpose is to upgrade the present power grid towards a smart grid.

Under these circumstances, we propose an agent based architecture as a smart driver into the grid dealing with the holonic structure in terms of control and monitoring. The hierarchic dimension of the grid assures the stability, while the heterarhical structure guarantees the real time control.

The general framework for MAS is defined in the following. According to the holonic grid structure already defined, three major communities of agents are proposed.

- The *power supplier* agent community that includes few distinct classes of agents as are: generators, power plants, step-up transformers, different types of substations (transport, distributions, collector, switching), the distinct step-down transformers, invertors, storage capacities. This agent community is essentially scalable and includes low level classes of agents consisting in certain interface units, communication units, control and monitoring units (switches, interrupters, sensors, shunts, compensatory loads, etc.). In conclusion, the power suppliers are seen as a collection of physical agents describing a part of the holarchy of grid, which we name supply-multi-agent system (*sMAS*).
- The *user* agent community denotes customers including a large class of clients for power, which represents the other part of the holarchy. This is also scalable according to the level of granularity of the system going from macro-level such as the largest urban areas, to the micro-level such as a distinct load in a home appliance. Users can include some special agents as interface units, their own storage capacities, UPSs, etc. All these entities are physical agents that are included in the user-multi-agent system (*uMAS*).
- *Meter* is a distinct class of agents reflecting the essence of the transactional process in the power grid. This is the community of agents including mainly the advanced metering infrastructure (AMI) but not limitative. It also includes all the distinct parts of the ICT: servers, data storages, communication channels, and specific monitoring interfaces. These kinds of agents form a generic meter-multi-agent system (*mMAS*).

Agents: prototype and specializations

An agent is a software program that can be assigned to a distinct physical entity. The paradigm of multi agent systems derives from the agent oriented programming technique and has rapidly become a concept as well a very promising technology for control and management of distributed systems. The relevant statements in this field were made by Foundation for Intelligent Physical Agents FIPA-OS (http://www.fipa.org/). The agents for smart grid are just smart objects with certain roles and abilities such as thinking, communicating, migrating, cloning, acting according to its own initiative and desire [5], [16].

The prototype of the agents is based on the philosophy named *beliefs–desire–intentions* which represents the foundation of so called BDI agent model introduced by Rao and Georgeff [16]. This model allows us to design a large class of agents charged with various responsibilities and proved with different level of intelligence. It represents the agent prototype for building very flexible agent communities dedicated to solve the tasks into the grid. In Fig.5 the BDI- agent prototype is described in terms of its components, and internal processes.

A BDI-agent is an informational engine that exhibits *intentions* to put a certain plan into practice according to the goals (assimilated with *desire*), with the support of its knowledge named in a large sense *beliefs*. The basic intelligent task of the agent is to decide which goal must be achieved and accordingly, to select the suitable plan of action. The certain tasks of the agents in a smart grid as well as the level of their intelligence depend on the particular design of the multi-agent architectures. The intelligence of the agent is described in terms of so called *flexible autonomy* - a feature which characterizes how the agent puts its actions into practice as the response to the environmental changes.

Three attributes of an intelligent agent are recognized [11]:

- *Reactivity*, consisting in taking the action that includes the appropriate reaction to the changing in agent's environment, in agreement with the goal-oriented function of the agent.

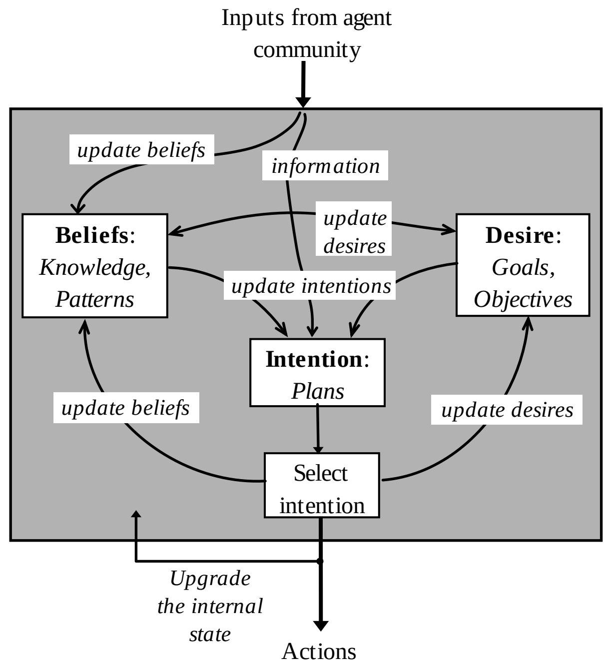

Fig.5. The structure of a BDI agent prototype

Pro activeness, consisting in goal-driven behavior, and the intrinsic initiative of the agent.

- *Social ability* meaning more than communication in terms of data exchanging, but also capability to negotiate and interact in a cooperative manner.

The specialization of the agents is imposed by the needs of the organization. As there is a hierarchy but also a heterarhy in the smart grid, the agent communities will include three kinds of agents: intelligent, oriented, and simple. On the other hand a set of specialized agents are identified as bricks to build a scalable smart grid. We define few templates of agents designated for the smart grid purposes; starting from the role that each agent has to play into the system. In Table.2 are presented these templates in terms of abilities from BDI agent model.

IV. THE ORGANIZED MAS IN THE SMART GRID

The above defined agent communities Power supplier, User, and Meter are organized in their corresponding *sMAS*, *uMAS*, and *mMAS* according to the following principles:

- The agents share and cope with the existent power grid infrastructure;
- The agents as well as MAS are capable to cope with human operator at any level of the system;
- The MAS are able to self-organize autonomously as a response to the scalable upgrades of the grid, or to any other change of the operating parameters.

Table.2. The templates of the agents

Name: *Consumer Agent (CA)* Role: Load or smart load with more or less intelligent capacitie Description: It is usually a simple reactive agent corresponding to a physical appliance.		
Beliefs	Desire	Intention
Internal power management program	Optimizing the power consumption	Simply switching on-off or adopting stand-by mode.
Name: *Power Generator Agent (PGA)* Role: Unitary power supply Description: It is usually a simple reactive agent corresponding to a physical power source.		
Beliefs	Desire	Intention
Working regime, assisting program	Optimizing the delivered power	Adapting its own regime, reserve, and local storage capacity
Name: *Electricity Meter Agent (EMA)* Role: Measures, records and transmits power consumption and demand. Description: It is a cognitive, communicative and reactive agent corresponding to an advanced metering infrastructure.		
Beliefs	Desire	Intention
Knowledge about the system it measures and monitors	Facilitating real time data acquisition and transmission	Initiating communication and transmitting the data
Name: *Duty Agent (DA)* Role: Accomplishes various tasks in the field of ICT and control, as well as ancillary services. Description: It is a cognitive, communicative and proactive agent that can be cloned for different purposes such as supervising, monitoring and learning, biding, negotiating and mediating, etc. It could correspond to a large class of physical entities like: data basis, interfaces, controllers, etc.		
Beliefs	Desire	Intention
Knowledge about the system it serves	Facilitating data acquisition and transmission	Initiating communication, Receiving and transmitting the data, control and command

The general frame of physical power grid is depicted in Fig. 6. It reflects the main composition of the power grid built around the generic distribution system operator (DSO) and the regional power operator (RPO). Thanks to the holonic approach now we benefit of bench to configure the MASs at each level of the power grid, vertically, and horizontally, too. For example, we present two instances of MASs which correspond to the extremes vertically: first to the bottom level considering the holon power plant-city-dispatcher, and second to the top level, i.e. the final user holon transformer-house-meter. Both related MASs are defined only using the agents templates presented in Table.2 and the basic holonic proposed shell. For instance, a detailed city user level is depicted in Fig.7, and a detail for home user level is presented in Fig.8.

Agent identity, roles, and relationships

A systematic description of agent communities clustered in three MASs is necessary for both described cases. In detail of the Fig.7 there are certain agents and links denoting an operational structure as follows.

PGAs denote few generators belonging to a thermoelectric power station, which are clustered in the supplier holon. We note the PGA is present also in the user holon as a local micro power generator. It is connected to a certain critical consumer (CA), for instance, via a duty agent (DA) playing the role of local power storage (LSA). In this case the *uMAS* includes many CAs that models at this level the residential districts, big commercial areas, big critical utilities (a hospital, for instance).

All the agents marked with circles in the figures represent different sorts of the same template named Duty Agent, which model some physical equipments distributed across the operational structure as described below:

- The agent *suTr* that monitors the step-up transformer.
- The agent *TSS* that controls the transmission substation.
- The interface agent *IA* that collects data from *TSS* and also communicates with its correspondent from the dispatcher holon in order to receive the signals and orders.
- The *DSS* agent controls a certain distribution substation.
- The *AIA* agent is responsible for ancillary services between the generation site and the consumers.
- The *SIA* denotes a subscriber information agent, whose role is to store the identity of the consumers into the *uMAS* and to communicate with the *mMAS*.

Finally, the *mMAS* includes at the largest physical level- the dispatcher certain duty agents in terms of driving the man machine interfacing as human interface agent (HIA) and also other IAs for communications. They respond of virtual instrumentation displaying information and capturing commands. The distinct electricity meter agents (*EMA*) are also met in the dispatcher's *mMAS*.

Going to the structure of home user level, which is detailed in Fig.8, the same templates of agents are met, but they are different from physical point of view. Hence, the *uMAS* becomes a collection of home appliance agents (*HAA*) in the conceptual shell of *CA*, together with other kind of agents, while the *sMAS* is a reduced collection of *DA*s in the conceptual shell of power supplier. The *mMAS* becomes a limited metering and communication chain including an *EMA* and related interfaces *IA*. A nuance is given to the *uMAS* that additionally includes a *PGA* for a local micro generator and a local storage unit (UPS) with an associated *LSA*.

In terms of relationships between the agent communities we note the presence of knowledge exchanging for both levels under the control *IA* agents, and the ancillary services under the control of *AIA* agents.

Now, when exploring the scalability of the grid on the horizontally we are fully exploiting the self-similarity of the holonic structure.

The extension of the smart grid by replication of certain MASs is accompanied by introducing of new kind of agents which we name simple *mediators* but act as a veritable supervisor and decision maker. The presence of mediator agent (*MED*) is strongly required in heterarchies because it is able to provide the links with appropriate hierarchical levels. This role can be played by a DA agent if it is suitable customized and located in a right place. As the example, let the case of a street with more dwelling houses. The corresponding MASs are depicted in Fig. 9. We note the *MED* agents must have certain abilities to cooperate horizontally and also vertically into the holarchic smart grid. They are able to support the ancillary services as well as data communications, but also they are intelligent enough that perform knowledge management. Definitely, this kind of agent will make the difference between the traditional electric power grids and the smart grid. In fact, this is the missing link in present electric power grids. Hence, we still don't have supervisory and control services granular enough, that is really a weakness of the contemporary power grid in front of failures and deregulations of electricity supply.

As we mentioned above, the *MED* agents have a key role in cooperation between the agent communities from different levels of the holarchy.

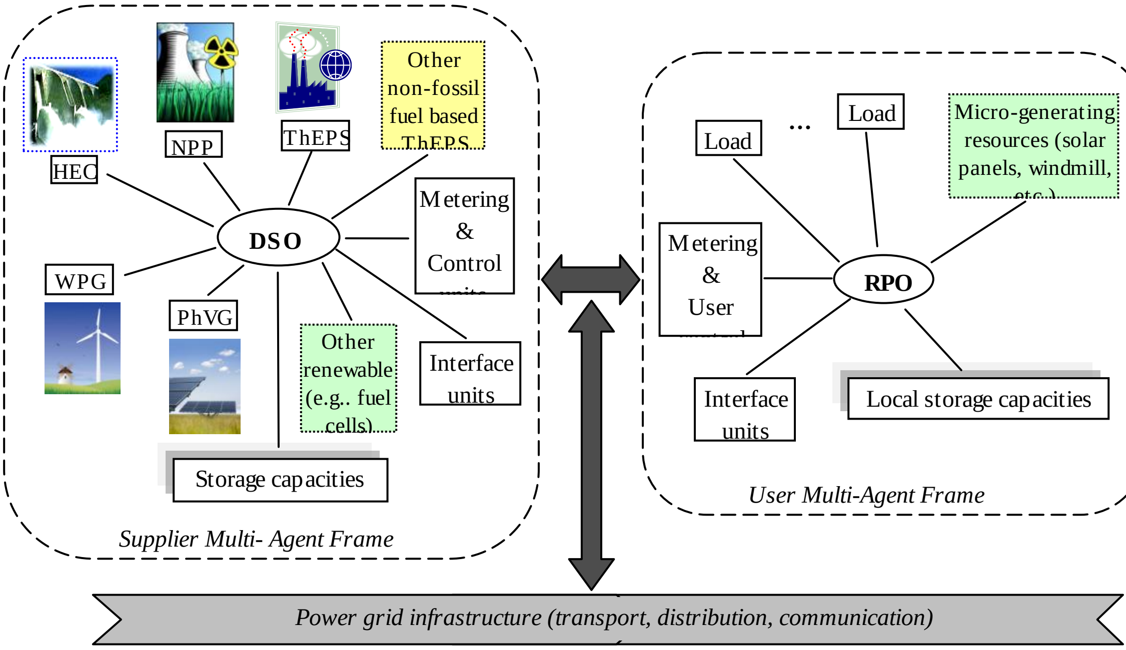

Fig.6 The global framework on the agent oriented approach of power grid

Here are some important aspects about this kind of agent:

- By default, a *MED* agent is resident on a machine which can be located into or complementary with any physical agent that belongs to a certain MAS. For instance, the *MED* agent that mediates the relationship between *uMAS* and *sMAS* (see Fig.9) should be located right into the closest DSS resource. Actually, from technical reasons *MED*s should belong necessarily to a standalone part of the power grid such as are *DSS*, *TSS*, or a dispatcher.
- The *MED* agents perform some key tasks as bidirectional communications, aggregation in terms of data fusion, decision and learning, and effective command.
- It is mandatory for *MED* agents to have knowledge about the entire grid in order to react adequately to the far changes. Hence, they communicate not only with agents into their area, but also with homologous *MED* agents from other layers of holarchy.

V. WORKING SCENARIOS

Various collaborative scenarios are possible between the agents into the holonic framework of the power grid. The sorts of scenarios derive from the different situations that can arise in normal mode of grid operating, and for critical situations. In the first kind of situations the smart grid should meet the limited imperfections and failures, while in the second case the smart grid must cope with large scale failures. Moreover, according to the basic purpose of the smart grid it must operate optimally, which opens discussions on the certain criteria for optimization. As we mentioned before, the sustainability must be the generic criterion of the effective smart grid. Sustainability in terms of viability, equitability and bear ability generates a generic working scenario as follows.

In the smart grid the generated power should be quantitative and qualitative exactly as demanded. The scenario includes the following steps:

- when the power demand is low in the certain area, a *MED* agent requires the current *sMAS* to stop firstly related generators with fossil fuel and possibly hydro-generators in order to preserve the water level;

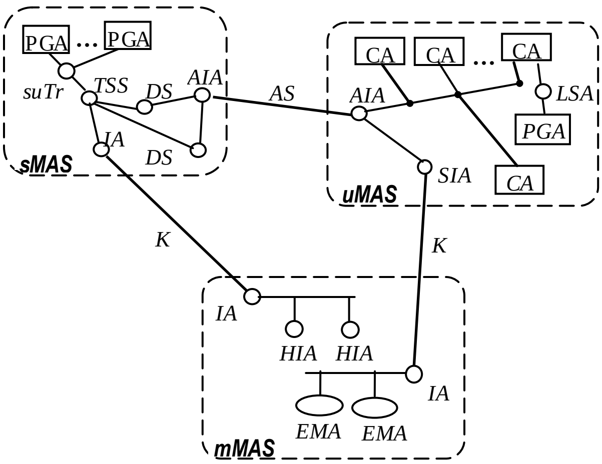

Fig.7. MAS for smart grid at city level

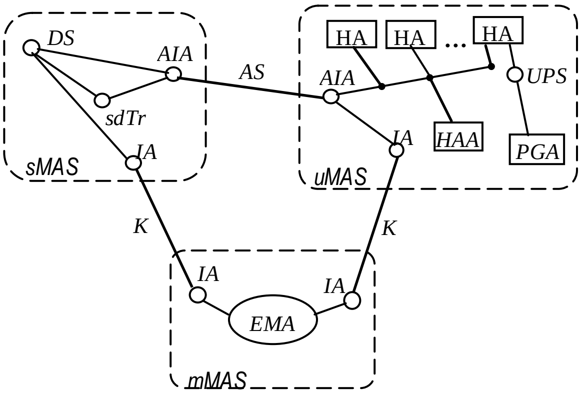

Fig.8. MAS for grid at home user level

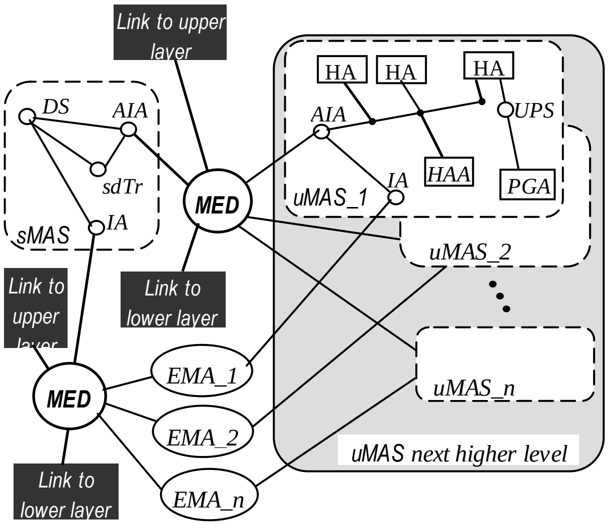

Fig.9. A horizontally extended MAS

- If the power demand is high it provides necessary power prevalently from generators using renewable energy sources. If more power is still needed a *MED* agent initiates a query towards more *sMAS*s and negotiates to obtain the energy at lowest cost.
- Other additional or complementary criteria can be included, if necessary, as the reliability, for example - starting certain generators which have prescribed availability.

The scenario can be deeply extended considering in detail what happened with the *uMAS* when the consumer agents *CA* provide their own behavior. Therefore, certain pattern of power demands adds more information and decisions can be refined accordingly. This kind of information comes originally from the basic level of the grid that is the top of the holarchy- the individual loads. Actually, the home appliance agents *HAA* are responsible for specific information including their type and category, running profile, and certain electric features as exemplified in Table.3 for common domestic power consumers.

Table.3. Specific power indoor consumers

Appliance	Running time profile	Nominal power	Category
Refrigerator	Periodically	Low	Critical
Air conditioner	Periodically	Medium	No critical
Ambient Heater	Periodically	High	Critical
Lights	Occasionally	Low	No critical
Multimedia equipments	Occasionally	Low	No critical
Washing machines	Occasionally	Medium	No critical
Security equipment	Permanent	Low	Critical

A. Communication and messages

In the complex power grid the number of links between the entities increases significantly, according to the model described by eq. (2). The data conveyed on the channels are enveloped by appropriate protocols in order to be recognized in the whole multi agent system. Generally speaking, the information that circulates into the smart grids as messages should contain certain data structures as follows.

a) Fixed sequence:
- the topographical data in terms of local coordinates;
- the name and the address of the holder;
- the type of user (the nature of the load);
- the technical data label of the appliance (e.g. nominal power);
- the nature (origin) of the electrical energy source of the power supplier;

b) Variable sequence:
- current date and time;
- current level of power demand at different scales;
- the status of the appliances and the instant time when they switch-on and switch-off;
- Current working regime and parameters: temperature, spinning reserve, storage reserve, status and availability.

c) Additional sequence: may contain the current environmental state information in the certain location of the agent (temperature, sun shininess, wind strength, etc.).

An example of data sequence enveloped into the message including the above described groups of information is depicted in Fig. 10.

Location information: *GPS coordinates*
User: Street__, No__, District__; *John Smith*
Home Appliance: *Water Boiler*
Label: *2000 Watts* (no reactive power)
Energy origin: *co-generative supply*

Date & Time: *Sat_12_Dec_ 2009; 10:24:15 PM*
Total instant power demand: *3000 W*
Status: *On*; Time_On=*10:20:20 PM*;

Outdoor temperature: *4 ℃*
Dark
Wind intensity: *moderate*

Fig.10. An instance of message content

We present in the following, a typical communication in the frame of smart grid in terms of a proposed dialogue for MAS in a holonic shell. We mention that these messages are mediated by the responsible agents *MED*.

uMAS
Request/Query:
{Power demand
Current level
Anticipated level}

sMAS
Response:
{Provided power
Available level
Predicted level
Power composition (% type of sources)
}

A particularly query on green power current demand addressed to agent *MED* by *uMAS* from the certain RPO can be described in two steps as the following:

{Consumer ID, requisite power, current date and time, current loads (optional)}

On its turn, the agent *MED* passes the request to the appropriate DSO, including an aggregate data structure from many consumers. The response of *sMAS* from certain DSO has the generic template:

{Available current power level: …, [%fossil, %hydro, %renewable], Predicted power level: …, [%fossil, %hydro, %renewable]}

The content of message exchanges makes possible a real improvement of DSM from the perspective of energy efficiency as well as for demand response.

B. Data capture and learning

Other essential information in a smart grid should come from the pattern of consumptions that reflects the power demand. Power demand pattern is important for the suppliers as well as for the users. As the matter of fact, certain abilities to capture the data and to learn are provided to the agents. At physical level this is primarily based on data capture by advanced metering infrastructure (AMI). Then the knowledge extraction and learning becomes possible with the support of specialized duty agents.

Basically, AMI makes possible to pass over a present weakness of the public power grid: the consumption in the house is measured continuously, but the individual users report it monthly, resulting a low data resolution in time. The first improvement is the agents *EMA* based on AMI are able to measure, record and reports usage data from minute to minute at least. The second improvement consists in bringing to the power supplier not only the global power demand usually monitored by dispatcher, but also the aggregated data provided by certain agents *EMA* via the appropriate agent *MED*.

From the perspective of smart grid it is relevant to cope with domestic power demand. The residential areas are interested in terms of demand side management (DSM) because they add more complexity due to the consumers' diversity and variability of load. The residential areas include a lot of users and home appliances that determine a complex pattern of power demand. Enhanced system architecture for power delivery should deal in real time with such kind of dynamic and complex pattern of power demand. The goal of the system consists in power delivery optimization based on cost-price and ecological criterion.

Some aspects on the more or less periodicity and related on the particular duty-cycle (on-off ratio) of different home appliances can be discussed in terms of uncertainty. The particular pattern of power consumption for an individual user results as an overlapping of the on period for different appliances during the considered period. Two factors are responsible of the variability of the on-cycles: the indoor/outdoor environment and the users' customs. For similar kinds of appliances (like the refrigerators, for instance) the on-cycle can slightly differ from user to user, but for the many others the on-cycles are quite different.

Typically, for an inhabitant into a residential area the 24 hours pattern of power demand could be represented as in Fig.11.

Specific power consumers can be recognized here as they were described in Table.3. The user's custom profile is typical for a common family where the adults go to work and the children go to school in the morning and come back to home at 5 PM roughly. At the large scale of users the patterns of power demand can differ each from other more or less. For instance, a significant difference appears between the cold and the hot seasons and also it could appear between the weekend and the other days of the week.

All these patterns are subject of learning in charge of agents *MED* which coordinate certain duty agents and the agents *EMA* from different levels of the smart grid. *EMAs* have the key role in continuously monitoring and reporting of the absorbed energy in their area of responsibility.

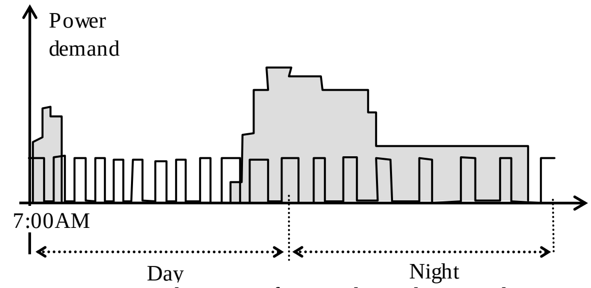

Fig.11. Typical pattern of power demand in a residence

As we mentioned before, *EMAs* are cognitive, communicative and reactive staying alive to learn about power demand in their area of interest defined by the *uMAS*. In terms of BDI model *EMAs know* the current situation and manifest *desire* to transmit the knowledge to the power supplier. A *desire* (i.e. the goal) is put into practice as an *intention* in terms of a plan to address the next *MED* agent that corroborates the messages from other *EMAs*. The aggregated message is further sent via a distinct set of *MEDs* to the DSOs in the region. Certain *sMASs* will receive a negotiated request about an optimal power delivery solution involving different type of PGA agents and storing agents. For example, if a peak of power demand is instantly reported in the middle of the day, the system should decide to increase the quota of delivered energy from the photo-voltaic power plant in a certain DSO. This scenario is applicable to the all levels of resolution of power grid from the indoor to the large urban residence areas.

C. Towards an evolvable grid

The MAS power for smart grids consists in real-time dynamic reconfigurability (capacity of reorganization) on the optimal states in terms of sustainability. The “evolvable” term is understood as the evolutionary dynamics initiated and self-controlled by internal structure exclusively. The multi-agent systems and holonic shell makes possible implementation the cognitive power grid, which we consider as a superior stage of smart grid including full autonomy based on the collective intelligence. Certain collaborative mechanisms between the agents are very important in evolvable grid as follows.

- *Virtual emergency* of the agents is an ad-hoc, temporary association of certain agents, forming virtual clusters, in order to solve different categories of demand side management.
- *Mediation* is a specific mechanism that acts in two modes: intermediate and aggregate the requests in normal regime, and negotiate and decide in case of critical situation. The role of mediation is provided to the agents *MED* which are cognitive.
- *Cloning* of agents is the capacity of the multi-agent system to generate different agents as the copies of those existent. This approach is essential for reconfiguration of the power grid.

The evolvable grid is the expression of the real time adaptability and learning capability when the power grid becomes metamorphic. This is the typical behavior in islanding of the power grid in case of partial fall down.

VI. Conclusions

This paper introduces an original approach for adoption and application of the holonic model as a frame for the multi agent system dedicated to power grid. The proposed framework is based on the three related virtual entities named holons: supplier, user and meter. This triadic structure is an appropriate model to describe the complex energy power grid using self-similarity at different scales of the system. The holonic approach provides the guidelines for designing of the multi agent systems in terms of the standard templates and shell for specialized agents.

The paper presents a bench for prototyping the physical agents that fit to the smart grid. The BDI MAS architecture proposed provides a suitable foundation to implement certain artificial intelligence in terms of learning and approximate reasoning abilities which are strongly required in a smart grid. This approach improves the capability of the system to learn, to predict and to self adapt in order to satisfy the electric power needs of the ever growing and sophisticated human ambient.

We highlight few technologies which still need improvements in order to fully implement the agent based smart grid.

- Communication infrastructure and suitable standards for data transfer at each level of the grid.
- Agent platforms for small embedded devices like smart meters, intelligent electronic devices (IED) which have to play a key role in the smart grid.
- Security solutions, as the most sensitive issue keeping in mind the web-based technologies could

be inappropriate for critical infrastructures such as the electric power grid.

Possible advances promoting new generation of power grid will emerge in agreement with the state of the art of technology and the related standards. Hence, in order to implement the proposed multi agent architecture into physical layers the specific hardware and special improved appliances should be developed and smoothly integrated. First, the ordinary electric-meter should be replaced with an agent oriented meter improved by a two-way communication module able to transmit continuously the instant consume and to receive data about power availability, price and quality. Second, the actual system of power metering should be developed by including supplementary point of measuring at different levels of the power grid.

Finally, this paper reveals some ideas for future researches in area of electric-power management equipment, in smart home appliances and in cognitive systems for power engineering.

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