Control agents for enabling customer-driven Microgrids

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***Abstract*—This paper will present some basic aspects regarding the concept of Multi-Agent System (MAS). MAS is a new concept used in power systems and can provide solution in various applications like market participation or power system restoration. Furthermore some practical implementations will be presented and more specific the installation of Multi Agent based Control System in real test sites.**

***Index Terms*—Multi Agent System, Microgrids, Cognitive Agent, Reactive Agent, Ontology, Energy Market.**

I. INTRODUCTION

THIS paper will provide some basic aspect of the MAS system as well how these systems work. The basic description of the entity agent has been presented in various papers[1-3], therefore the authors would like to present some more advanced characteristics.

Taking into account that a Microgrid comprises mostly small-size production units, a centralized control approach would prove to be a quite expensive choice compared to the cost of the production units. Although in large production plants, the control units reflect only a small percentange of the overall cost, this is not the case with small-size production units. Thus, low-cost innovative solutions must be investigated. The implementation of an intelligent agent requires only a processing unit with a microprocessor, similar to those found in every PC. Furthermore, depending on the intelligence of the agents, they are able to act without being constantly supervised, and, therefore, there is no need for an operator of the system.

Section II provides an introduction on MAS as well the general approach on our system. Furthermore section III describes the Test sites were the systems were installed. Section IV presents the hardware implementation of the MAS system and Section V presents some theoretical aspects regarding agent communication. Finally Section VI present some results from the test sites.

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II. MAS THEORY

There are several definitions in the literature for what an agent is [4-13]. The definitions described in the references are not the some, however there are some common concepts: agent, environment, autonomy. According to [6], an agent is merely “a software (or hardware) entity that is situated in same environment and is able to autonomously react to changes in that environment.” The agent can be a physical entity that acts in the environment or a virtual one, i.e. with no physical existence. In our case the physical entity is the agent that acts directly in the system and a virtual one is a piece of software that announces price schedules.

Main goal of this paper is to present that the various power system applications utilize part of the agent’s characteristics. In order to further analyze this we should categorize the agents in two main categories [4,5]:

1. Reactive Agents
2. Cognitive Agents

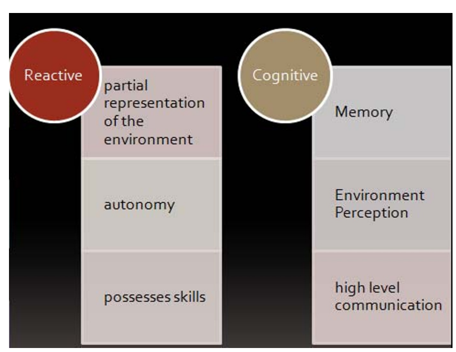

Fig. 1 Types of Agents.

The reactive agents are less intelligent and can be used for applications that need fast response like power system restoration or protection. On the contrary, the cognitive ones are used for applications that require increased intelligence as well high level communication and ontologies.

Several issues regarding the agent technology are confusing and the main cause for this situation is the lack of a strict description of what an agent is. Any entity or device that has

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one or more of the characteristics mentioned in the beginning of the section can be considered an agent.

For example, an under-frequency relay may be an agent:

- it has partial representation of the environment
- reacts autonomously according to its goals
- possesses skills

According to the literature [4] this type of entity can be considered as a reactive agent who is just responding to stimuli from the environment. Another category indentified in the literature is the cognitive agent. This type of agents have the ability to perceive the environment, in other words they have intelligence. However, still the definition of an intelligent agent is quite fuzzy since there is no formal definition about what intelligence is.
Therefore, the authors adopt in this text some main attributes that describe an intelligent agent for Microgrid control. These are:

1. Memory in order to acquire knowledge of the environment. The memory is one fundamental element of the intelligence and the ability to **learn**.
2. Ability to perceive the environment. The internal modeling and representation of the environment should be detailed enough in order to support the decision making process.
3. Ability to take decisions according to his memory and the status of the environment and not just to react.
4. Ability for high level communication. The agents should have the ability to exchange knowledge and use the communication as a tool to proceed with complex coordinated actions.

The applications presented next were based on the Jade [14] platform for developing Intelligent Agents.

III. Practical implementations

In this section two main MAS-based applications installed in Greece will be described. The first concerns an isolated settlement that consists of 11 houses in the island of Kythnos and the second one is a Virtual Power Plant that comprises a CHP, batteries and PV production in Athens. The Kythnos installation was done within the More-Microgrids[16] project and the installation in Athens within the EU-Deep[17] research project. Both project are financed by EU.

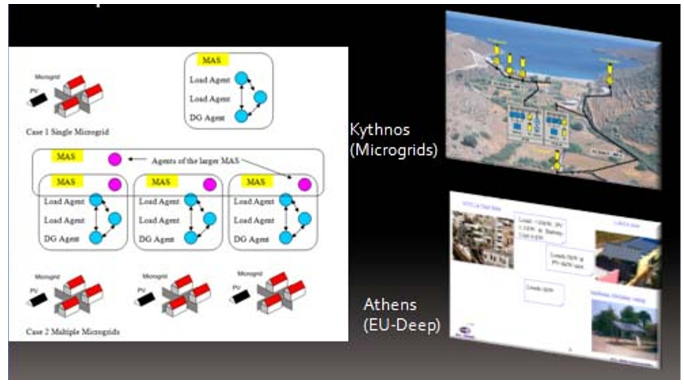

Fig. 2 MAS installation in Greece

In these applications several aspects of the MAS and Microgrids operation were tested including the market participation as well the communication and coordination.

Kythnos site

The pilot Microgrid in the island of Kythnos, shown in Figure 2, electrifies 12 houses in a small valley of Kythnos, an island in the Aegean Sea, Greece [4], [10]. The generation system comprises 10 kW of PV, a nominal 53-kWh battery bank, and a 5-kW diesel genset. A second PV array of about 2 kW, mounted on the roof of the control system building (System House), is connected to an SMA inverter and along with a 32-kWh battery bank provide power for monitoring and communication. Residential service is powered by three SMA battery inverters, connected in a parallel master-slave configuration, forming one strong single-phase circuit. More than one of the 3.6-kW battery inverters is used only when more power is demanded by consumers. The battery inverters can operate in frequency droop mode, allowing information flow to switching load controllers if the battery state of charge is low, and limiting the power output of the PV inverters when the battery bank is full.

Athens Test Site

The test site of Athens comprises of several remote sites. The sites that participate in the field test experiment are the following:

- National Technical University of Athens (NTUA)
- Centre for Renewable Energy Sources (CRES)
- "Meltemi" holiday camp

These sites are located in the prefecture of Attiki, Greece as shown in the map (Fig.3).

Fig.3: Geographical location of the four tested sites

A) NTUA

One of the EU-DEEP Test Sites, NTUA participates in the experiment. NTUA comprises a complex of buildings located inside the campus of National Technical University of Athens which is one of the major high educational organizations in Greece located in “Zografou” area in Athens.

Due to the nature of the site (University), NTUA has a higher occupation in normal periods (Monday-Friday) and lower during weekends, holidays and from July to September.

The loads on site are lighting, computers, photocopy machines, refrigerators, HVAC units, elevators and laboratory equipment. The average maximum total electric power consumption of the site is approximately 300 kW. The electric needs are covered by the Public Power Corporation via a system of two Low Voltage transformers of 400 KVA each. Furthermore, a CHP unit of 80 kW electric power installed in the frame of EU DEEP Test Site Experiments, participates in the local energy system covering a part of the electricity needs of the site when needed.

Two boilers (natural gas fired) of 1.45 MW thermal power each are used to provide heating to the site. The installed CHP unit is also used to preheat a part of the water of the two boilers. The rated thermal power of the CHP unit is 135 kW.

Furthermore, 2 identical batteries of 60 KW electric power, two inverters rated 35 kW each and a static switch have been installed on site.. In case of problems with the grid, the static switch opens very quickly and the system of the CHP and the batteries support the critical load of the site.

B) CRES Site

CRES is a public research organization responsible for developing and promoting technology on the field of Renewable Energy Sources. It is located in a superb named “Pikermi” approximately 20 km far from Athens. CRES site consists of the building which houses the department of photovoltaics.

The building is occupied by personnel and students working on their diploma thesis. It usually appears high occupation from Monday to Friday during the week and from 8:00am to 5:00pm. This occupation decreases during holidays (Christmas, Easter and August) or in some other occasions. CRES site can be clearly seen in Figure 4.

Fig.4: CRES test site

Some physical characteristics of the site are the following:

- One single floor building of 440m^2.
- PV generators of maximum capacity 22 kW$_p$. The whole PV system is connected to the mains through a 3-phase switch. The latter is located in the main distribution panel of the building.
- 1 Heat pump (61 kW cooling/67.5 kW heating capacity, 22.6 kW/20.6 kW consumption when Cooling/Heating, 50 A Maximum Current). The system operates from -5 to 15°C when heating and produces 44 to 90kW$_{th}$. These data correspond to 45°C leaving water temperature. When cooling the corresponding temperature is 7 degrees and operation limits are: temperature 28-42 degrees and produced power 67-46 kWc. This system is considered to be the flexible load during TF3 experiment campaign.

Other loads on site are laboratory equipment, computers and lights. Usually, the power consumption of all these loads does not exceed the 30kW. All the electric loads are supplied through the main distribution panel of the building which is of 90 kW total installed power. As it is obvious from the above, the main load of the site is the heat pump.

C) “Meltemi” Holiday Camp

“Meltemi” is a holiday camp located in “Rafina”, around 10 km far from CRES premises. “Meltemi” comprises 220 cottages which are fully inhabited in the summer (from May to September) and mostly empty in winter. A typical cottage in the camp is a single floor building of 70 m^2 surface as it can be seen in the Figure below. Most of the cottages are more than 30 years old.

Fig. 5: A typical cottage in “Meltemi”

The main loads of the site are:

- Super market refrigerators (maximum consumption 15 kW). One of these refrigerators is considered to be the flexible load during the TF3 experiment campaign. The power consumption of the flexible load is 1200 W.
- Typical household appliances such as refrigerators, electric cookers, lighting, split air condition units for cooling, tv´s, radios and the external lighting of the camp.

The whole camp is supplied by a 3-phase Medium-to-Low Voltage substation. The maximum load consumption of the site is approximately 220 kW.

IV. CONTROL INFRASTRUCTURE

Within the More Microgrids project an Intelligent Load Controller (ILC), has designed and developed which was installed in the Kythnos Microgrid as well in the test site in Athens. Software has been developed, which allows the implementation of Multi-Agent Systems. Namely, every ILC is controlled and represented in the system by an intelligent agent.
The ILC is a system that can be used to monitor the status of a power line and take Voltage, Current and Frequency measurements. In addition it can remotely control up to 256 PLC A10 devices (PLC load switches) connected to the power line. As far as the houses of the settlement are concerned each ILC will control two PLC switches. Main objective of the application is to control the operation of non-critical loads.
Regarding the Kythnos Microgrid each house is equipped with a water pump, which is responsible for replenishing a water tank andin this way supplying water to the residents of the house. The water pump is considered as a non-important load and therefore, in case of power shortage, it should be disconnected if needed. Therefore, the first PLC Switch controls the water pump, while the second PLC Switch controls a power socket and any load connected to it (e.g. air-conditioning unit). In this test site in Athens the loads also were categorized in critical and non critical.
Additionally, the ILC features a Wi-Fi interface that enables it to wirelessly connect to a Local Area Network. This eliminates the need of a data-cabling infrastructure and simplifies the installation of the units. This feature was used only in Kythnos test site. In the test site in Athen DSL,LAN and PSTN communication channels were utilized.
The core of the unit is an integrated computer module that runs the Windows CE 5.0 operating system. The integrated computer module is driven by the powerful Intel XscaleTM PXA255 processor at 400MHz and features 64MB of RAM and 32MB FLASH Memory (instead of a hard disk drive). Thus, it is suitable for demanding applications.
The operating system supports the installation of a Java Virtual Machine. Therefore, an agent environment based on the JADE platform [14] can be easily embedded in the controller
The ILC hosts an integrated Web Server, as shown in Figure 5, through which we are able to control the operation of each controller.

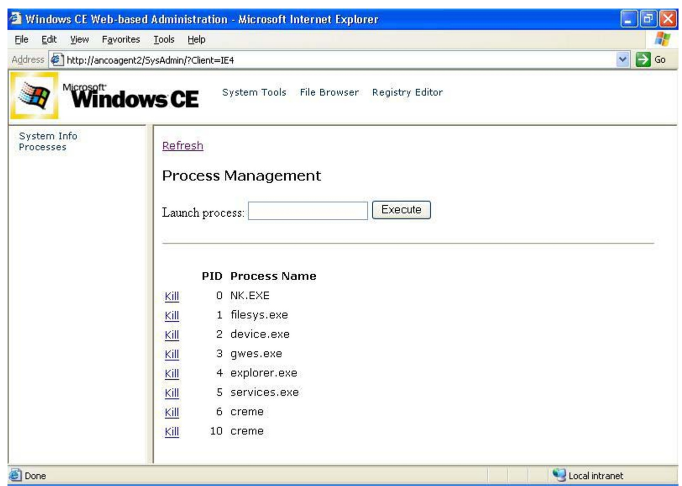

Fig. 5. The ILC hosts an integrated Web Server.

Figure 6 shows how the ILCs are connected in the electricity grid. Each ILC unit is connected to the Power Line outside the house, before the kWh-meter and the house’s electrical panel. After the electrical panel and near the loads, the PLC switches are installed. Each PLC switch has a unique address, so that it can receive commands from the Intelligent Load Controller.

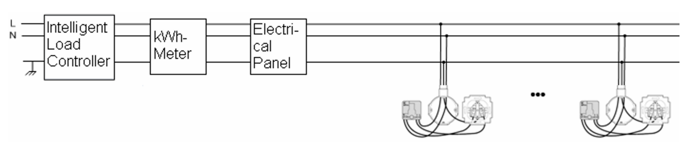

Fig. 6. Typical Installation of an ILC Unit.

The Intelligent Load Controller built-in software provides the following functionalities regarding the power line measurements:

- Frequency measurement.

- Voltage RMS measurement.
- Current RMS measurement.
- Sag events detection and announcement.
- Overvoltage events detection and announcement.
- Overcurrent events detection and announcement.

The RMS values are calculated by sampling the power line at a rate of 3,500 SPS (samples/second). As far as the events detection functionalities are concerned, the controller announces the event start and termination, records the duration of the event and, depending on the event, records the maximum or minimum value measured. It is important that, with the software we have developed, the controller is capable of processing these measurements. As a result, the agent who is implemented in the controller is able to identify certain events and take the relevant actions. For example, the agent can recognize an overcurrent event resulting from an engine start and can distinguish it from an overcurrent event due to a failure.

V. Agent Communication

Communication is one of the main elements that allows the intelligent agents to form a society. The communication problem focuses on the context of every message and the knowledge the agents exchange. Figure 7 presents the agent version of the story of the Tower of Babel where the workers could not finish the tower since they could not communicate.

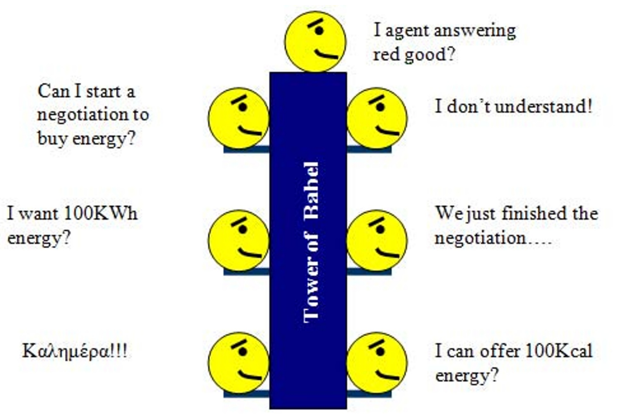

Fig. 7. The problem of coordination.

In Figure 7 the three main problems of the agent communication can be identified:

1. The first problem is the ontology or the vocabulary. All the agents speak English except one that says “good morning” in Greek. It is vital that the agents should have a common vocabulary. But this requires more than just using the same words. Same words should have the same meaning for all agents. In the example, one agent asks for energy in kWh and the other answers in Kcal. It is obvious that both agents should understand the word energy in the same.
2. One of the agents says “I agent answering red good?” which is a phrase without an understandable meaning. The agent messages should have a common structure that is provided by FIPA in ACL. This will be analyzed next.
3. The final problem is revealed, if we focus on the discussion of two agents of the example. The first asks to start the negotiation and the second replies that it just finished. This is a critical problem in an environment with multiple dialogues and a protocol that defines how each dialogue should be structured and identified must be introduced.

One main feature of FIPA compliant MAS platforms is using the ACL (Agent Communication Language) [15] with high-level ontologies. It is a general conclusion that high level communication is one significant element [4,5] to develop intelligence inside a society, no matter if this society is a human one or a Multi Agent System. For the system presented here, an ontology was developed according to the needs of the system. This ontology supports two main tasks.

The first task is to provide an adequate description of the system, so that it includes all the necessary information for its control. Thus, all software modules of the control system perceive the system in the same way and this is important in order to develop a high level communication system, where the agents exchange knowledge. In order to understand the importance of having a common perception of the environment, consider the concept “energy” which has different meaning in quantum physics, food, or electric systems. Furthermore, the object oriented nature of the ontology and the data abstraction, support the development of a distributed control system, since each agent handles only the necessary (or allowable) part of information and knowledge.

VI. Results

The adaptation of the Multi Agent based software for the needs of the Kythnos installation was finished. The basic software was the system developed within the work package B and is based in the Jade platform. The adaptation focused on the algorithm that runs in Kythnos. The developed algorithm focused on the creation of a negotiation procedure that fits to the goals of the system.

The goal of the algorithm is to optimize the operation of the houses taking into account the available energy in the batteries. The load shedding does not burden only one house, but is equally divided among the whole settlement. The energy management algorithm focuses in the regulation of the water pump operation.

Next figure present some of the collected measurement in one of the controllers in Kythnos island:

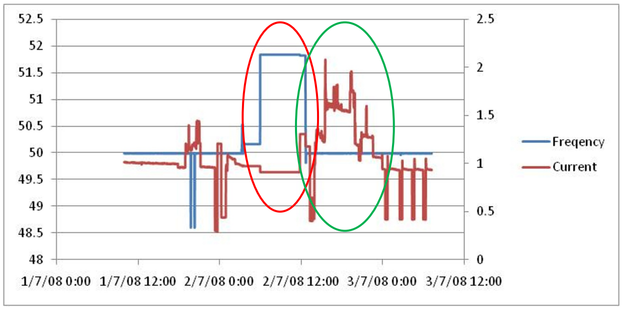

Fig. 8. Energy consumption and frequency variations in Kythnos island.

The chart includes a three day operation horizon of the system. During the first two days the house consumption was not affected by the controller especially since the batteries had high SOC (red circle – high system frequency). In the second day (green circle) the controller started load shedding operations.

In the Test site in Athens during the winter period four scenarios were implemented as these are synoptically hereby presented.

Scenario 1: The whole system – including all three installation sites which are presented again in the following paragraphs – participates in the market as a single entity. In this scenario the total consumption is considered as non-flexible and what is actually tested is how the CHP and the battery would participate in the market in a co-ordinated way, so that they could satisfy the power demand.

Scenario 2: The whole system participates in the market as a single entity considering the production as constant (non-controllable). By this scenario what is actually tested is how the loads would participate in the market in a co-ordinated way, in order to adjust their power consumption which should meet the power being produced.

Scenario 3: The whole system participates in the market as a single entity trying to maximise its overall gain considering that both production and partly the consumption are controllable. Reinforcement learning techniques are being used.

Scenario 4: The three sites participate in the market as three entities (MASs) that may cooperate (or not). This experiment will help to extend the results considering the collaboration of a large number of agents (probably thousands) and the ways they could be organized and communicate with each other harmoniously.

In the next figure results are shown regarding the operation of the system using the reinforcement learning algorithm.

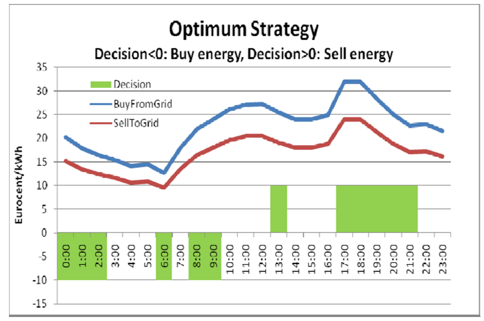

Fig. 9. Results of the experiment.

The previous sections presented some of the results of the experiments within the Test Site in Athens. The next question is to identify what we have learned from these experiments.
The experiments have two main sub goals, technical and operational goal:

Regarding the technical Goals we have learned that:

- It is feasible to control large amount of units by using the proposed advanced architecture.
- The system can be build using cheap commercial products. The load control used within the test was expensive since it was a laboratory prototype, however the commercial version can be very cheap.
- The system can use any available communication method that supports TCP/IP (internet based communication).

Regarding the Operation Goals we have learned that:

1. The agents can take good decisions according to price signals. However the full investigation of the accuracy as well the correctness of the result is further analysed within the offline simulations.
2. The agents have the ability to coordinate and decide for a future schedule: e.g. Figure 9 presents that the agents learned how much to sell during high prices or to buy during low prices.

The next step for future project is to further test, develop and standardise these procedures.

VII. Acknowledgment

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IX. BIOGRAPHIES

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