A MultiAgent System for Microgrids

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Abstract-- **This paper presents the capabilities offered by MultiAgent System technology in the operation of a Microgrid. A Microgrid is a new type of power system, which is formed by the interconnection of small, modular generation to low voltage distribution systems. MicroGrids can be connected to the main power network or be operated autonomously, similar to power systems of physical islands.**

The local DG units besides selling energy to the network have also other tasks: producing heat for local installations, keeping the voltage locally at a certain level or providing a backup system for local critical loads in case of a failure of the main system. These tasks reveal the importance of the distributed control and autonomous operation.

***Index Terms*—Distributed Generation, Microgrids, Multi-Agent System, Energy Market.**

I. Introduction

Nowadays there is a rapid transition from a centralized power producing system to a distributed one which includes several small (1-20MW) units and even more, smaller (<0.5MW) units. It is obvious that this distributed power producing system needs a distributed and autonomous control system. In this paper, the implementation of a MultiAgent System (MAS) for the control of a set of small power producing units, which could be part of a MicroGrid, will be presented.

The use of MAS technology in controlling a MicroGrid solves a number of specific operational problems. First of all, small DG (Distributed Generation) units have different owners, and several decisions should be taken locally, so centralized control is difficult. Furthermore Microgrids operate in a liberalized market, therefore the decisions of the controller of each unit concerning the market should have a certain degree of intelligence. Finally the local DG units besides selling power to the network have also other tasks: producing heat for local installations, keeping the voltage locally at a certain level or providing a backup system for local critical loads in case of a failure of the main system. These tasks suggest the importance of the distributed control and autonomous operation.

This paper is organized as follows: the main market operations of the MAS are discussed in Section II. The software that was developed for the MAS system is described in Section III. Furthermore, in Section IV the implementation and operation of the MAS in the laboratory Microgrid, which is installed at NTUA, is presented. In the last section, a conclusion is drawn.

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II. Market operation of the microgrid

This section describes a possible market operation of a Microgrid. The first parameter of the market is the fact that the product is the energy (kWh) and not the power (kW). This is happening because it is very difficult to keep the production, especially of a small unit, steady for a long period due to technical reasons. However considering that energy is the interval of the power it is easier to produce an exact amount of energy in a certain period of time (in our case 15 minutes).

The market model that is used in the application is simple since the focus is mainly in the operation of the agents. The basic rule of the market is that if the MicroGrid is connected to the Grid then there is no limit to the power that can be sold or bought from it (as long there are no technical constraints). Furthermore the Grid Operator announces two prices: the price for selling kWh and the price for buying kWh. The production units that belong to the MicroGrid adjust their set point, after negotiation with the other units based on the Grids prices, their operational cost and the load demands.

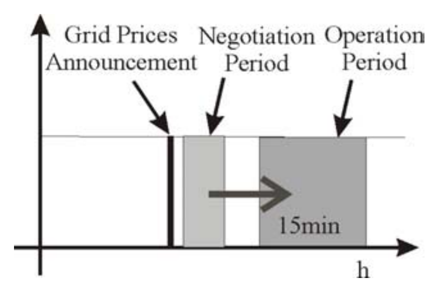

Fig 1. The actions sequence for the Market Operation in the time domain.

The overall procedure, which is based on the FIPA English Auction Protocol [2], is the following:

1. The Grid Operator announces the prices for selling (SP) or buying (BP) energy to the MicroGrid. Normally it is SP>BP.
2. The local loads announce their demands for the next 15 minutes and a initial price DP for the kWh which is DP>BP and DP<SP.
3. The production units accept or decline the offer depending on its comparison to the acceptable internal price (AP).

4. The local loads keep making bids according to the English Auction Protocol for a specific time (3 minutes). This means that the load increases its offer as long DP<SP or no production unit has accepted the offer.
5. After the end of the negotiation time all the units know their set points. If there is no production unit of the Microgrid to satisfy the load demand the power is bought from the Grid. Furthermore if the AP power is lower than the BP the production unit starts selling energy to the network.

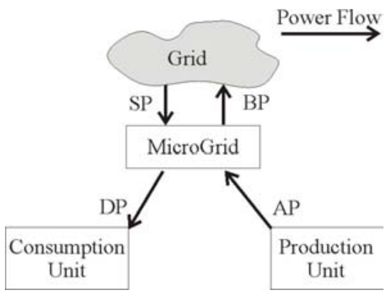

Fig 2. Power flows and bids in the Microgrid.

For the previous model of operation the following remarks should be mentioned.

- There is no need to send a Schedule to the Grid Operator since the only limits for taking or sending energy to the network is the technical constraints of the installation.
- In the Microgrid MAS there is an extra Agent who is called MGCC (MicroGrid Central Controller). Its primary job for our application is to record the bids and the power flow. A transaction is valid only if it is registered in the MGCC agent and this is vital in order to avoid double offers to separate loads. In Market Operation his job is to create the final bill for each load or unit.

The next critical point is the behavior of the Units inside the MicroGrid. There are two major ways of operation: Collaborative and Competitive.

In the collaborative market all agents cooperate for a common operation. It is obvious that this case exists if the agents have the same owner or a very strong operational or legal connection. Furthermore in this kind of operation coordination among the production units could take place in order to achieve a better operation and maximize the gain of selling energy to the Main Grid.

In the competitive market each microsource has its own interests. This does not necessarily mean that the other agents are opponents. If the microsource is a battery system and its primary goal is to feed a number of computers with uninterruptible power then the behavior of this particular unit in the market would be very passive. On the other hand if the microsource is a CHP and its primary objective is the heating of the local installation then it might become a very aggressive player because the operational cost for this unit is reduced since it incorporates savings from heating. Furthermore we should consider that some rules of the traditional Power Market are very hard to apply. For example the bid in the traditional market is not allowed to be lower than the actual cost something that is very hard to apply in a Microgrid: in a CHP occasionally the cost might be lower than the fuel cost in comparison to a simple gas turbine.

In the application presented in this paper the market is assumed competitive and the players focus mainly in the market.

III. Software implementation of the MAS

In this section the specific MAS implementation will be presented. For the implementation the JADE Agent Management Platform was used. JADE (Java Agent Development Framework) is a software development framework for developing MAS and applications conforming to FIPA (Foundation for Intelligent Physical Agents) standards for intelligent agents.

A. Description of the Agents

Four kinds of agents are developed:

- Production Unit: This agent controls the Battery Inverter of the Microgrid. The main tasks of this agent are: To control the overall status of the Batteries and to adjust the power flow depending on the Market Condition (prices).
- Consumption Unit: This agent represents the controllable loads in the system. This agent knows the current demand and makes estimations of energy demand for the next 15 minutes. Every 15 minutes he makes bids to the available Production Units in order to cover the estimated needs. Currently this estimation is virtual.
- Power System: This agent represents the Main Grid to which the Microgrid is connected. According to the Market Model presented the Power System Agent announces to all participants the Selling and the Buying price. It does not participate in the market operation since it is obliged to buy or sell any amount of energy it is asked for (as long as there is no security problem for the network)
- MGCC: This agent has only coordinating tasks and more specifically it announces the beginning and the end of a negotiation for a specific period and records final power exchanges between the agents in every period.

B. Services

According to the Agent Directory Service Specifications every agent announces to the DF agent the services that it can offer to the MAS. The available services currently are:

- Power_Production: This agent is a power producer.
- Power_Consumption: This agent is a load.
- Power_Selling: This agent can operate in the Energy Market and can sell electric power.
- Power_Buying: This agent can operate in the Energy Market and can make bids for buying power.
- MGCC. This agent is the MGCC.

It should be mentioned that Power Production is a different service than the Power Selling since the Power System agent produce power but it does not participate in the Market. The same applies for the loads.

C. Ontology

According to the FIPA specification agents that wish to make a conversation need to share the same ontology. The ontology used in the application has four main parts

1) Concepts:

- **Agent** that operates in the MAS. This ontology includes information like Name, Description, Available Services etc.
- **Bid** that the agents exchange during the Market negotiation and includes information about the amount of energy that is requested or offered, the price for this amount and the period of time for which this bid is valid.
- **EnergyPackage** which is the amount of energy that is going to be exchanged between **Seller** and **Buyer** after a transaction in the energy market.
- **GridPrices** which are the prices for selling or buying electric energy from the main power network (grid).

2) Predicates:

- **Buyer** is an **Agent** that **Buys** energy from another **Agent**
- **Seller** is an **Agent** that **Sells** energy to another **Agent**

3) Agent Actions

- **Buy EnergyPackage** from an **Agent**
- **Sell EnergyPackage** to an **Agent**
- **Record Bid** and **EnergyPackage** which is an order to MGCC indicating that a deal came to an agreement.
- **Accept** a **Bid**
- **Deny** a **Bid**
- **Request** an **EnergyPackage.**
- **Make** a **Bid**
- **BidStart** is an announcement that the agents can start making bids
- **BidEnd** is an announcement that the agents should stop making bids

IV. The NTUA Microgrid

The MAS system that was developed for controlling the operation of Microgrid was tested in the Laboratory Microgrid of the NTUA.

A. Equipment Description

The composition of the microgrid system is shown in Fig 3. It is a modular system, comprising a PV generator as the primary source of power. Both microsources are interfaced to the 1-phase AC bus via DC/AC PWM inverters. A battery bank is also included, interfaced to the AC system via a bi-directional PWM voltage source converter. The Microgrid is connected to the local LV grid, as shown in Fig 3[1].

When the system is connected to the grid, the local load receives power both from the grid and the local micro-sources. In case of grid power interruptions, the Microgrid can transfer smoothly to island operation and subsequently reconnect to the public grid.

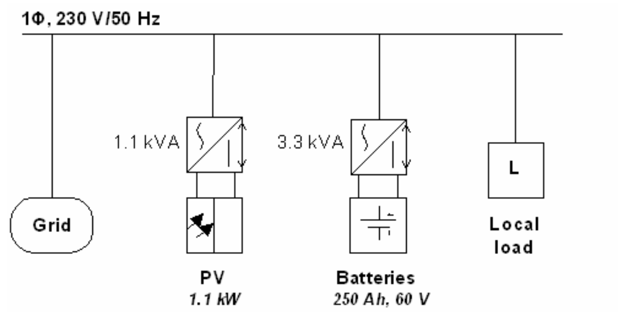

Fig 3. The laboratory Microgrid system.

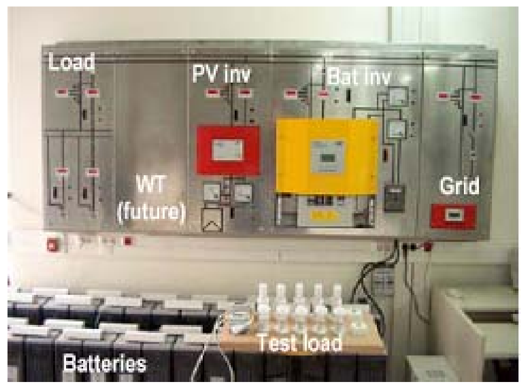

Fig 4. Photo of the laboratory Microgrid system.

The active power control is primarily performed by their power frequency control characteristics, known as droop curves and are schematically presented in the Fig 5.

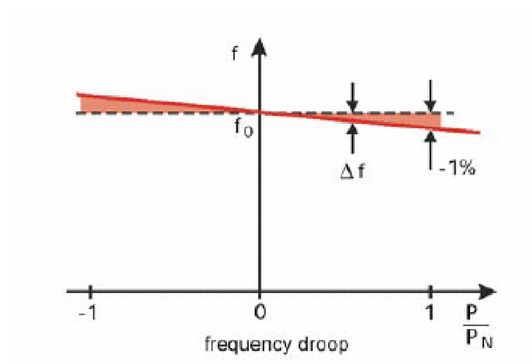

Fig 5. Grid compatible frequency droop

The idle frequency corresponds to the value of the frequency when the active output is zero. The drop value is the slope $\Delta f/\Delta P$ denoting the difference in output frequency between no load and full load operation.

B. Communication between Agents and Local Sources/Loads

One of the main difficulties for the development of our system is to establish the communication between the agents and the inverters. The main method for communication is through OPC [OLE for Process Control and OLE stands for Object Linking and Embedding] servers/clients as shown in Fig. 6. This method was selected since the manufacturer of the inverter has available an OPC server suitable for his device.

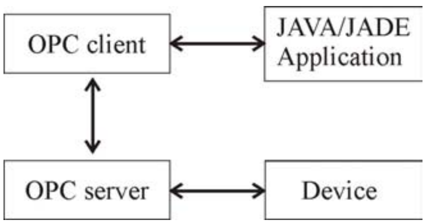

Fig 6. Communication method between the electrical devices and the MAS application.

C. *Software Operation*

In the Fig. 7 a screenshot of the GUI of the agents is presented. From this frame the operational cost can be adjusted. Similar forms have been developed for the Loads and the Main Grid.

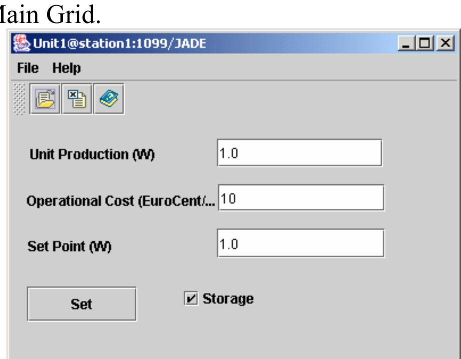

Fig 7. Screenshot of the GUI for the Production Unit.

In the implementation that was developed in the lab, the main target is to produce or store a certain amount of energy in a specific time period and this is done with a procedure that calculates the droop frequency set point. This calculation is very fast, however due to communication limitations this set point can be sent to the inverter only every 4-5 seconds. This large period of time does not allow us to have a steady power production since the grid frequency changes very fast. On the other hand the 4-5 seconds delay is not a problem if we want to produce a certain amount of energy in 10 or 15 minutes. This routine is implemented inside the agent that is controlling the production units.

V. CONCLUSIONS

This paper presented an agent based operation of a MicroGrid. In this initial form the main focus was on the communication of an agent that controls a production unit with his environment. The next two critical steps are:
The first step is to create a controllable load, which will be linked to the Consumption Unit agent. The most efficient and cheap method to achieve that is by using a PLC (Programmable Logical Controller). The Consumption Unit agent will have measurements in order to estimate the consumption and to make more realistic bids. Furthermore this agent will have the ability to control the load and to limit it according to the market status or the MicroGrid security.
The final step is to test more sophisticated market operations and to reveal potential technical problems like the one presented before (keeping the power in a certain level).

VI. REFERENCES

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VII. BIOGRAPHIES

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