A Multi-Agent 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.

1. Introduction

Nowadays there is a progressive transition from a centralized power producing system to a distributed one. This includes several small (1-20MW) and even 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, are 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 operating in a market require that the actions of the controller of each unit participating in the market should have a certain degree of intelligence. Finally, the local DG units next to 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 main system failure. These tasks suggest the importance of 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. In Section IV the implementation and operation of the MAS in the laboratory Microgrid installed at NTUA is presented. The last section concludes.

2. Market operation of the MicroGrid

This section describes a possible market operation of a Microgrid. The market model that is used in this application is simple since our focus is on 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). It should be noted that the product traded 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, constant 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). It is assumed that 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 points, after negotiation with the other units, based on the Grids prices, their operational cost and the local demands.

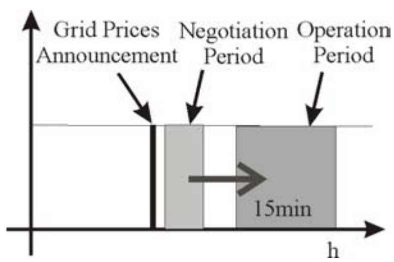

Figure 1. The actions sequence for the Market Operation in the time domain.

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 an initial price DP for the kWh. DP>BP and DP<SP.
3. The production units accept or decline the offer after comparing it with 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.

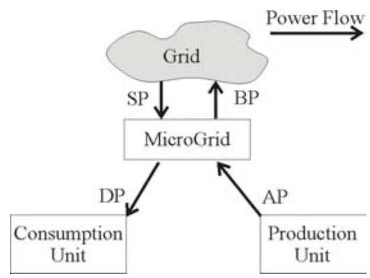

Figure 2. Power flows and bids in the Microgrid.

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

- 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 its 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 basic 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. 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.

3. Software implementation of the MAS

3.1 The MAS technology in MicroGrids

The MAS theory appears to be a very useful tool for the operation and control of a MicroGrid. Before continuing with the presentation of our implementation, it is useful to provide a short description of the main theoretical principles of the agent theory, as linked to our application [3,4].

The main element of a MAS is the agent, which is a physical entity that acts in the environment or a virtual one without physical existence. In our case the physical entity is a microsource, e.g. a Microturbine and a virtual one a piece of software that makes bids to the energy market.

An agent is capable of acting in the environment, which means that the agent changes its environment with its actions. A diesel generator by altering its production changes the setpoints of other units, changes the voltage level in the adjacent buses and in a more global point of view changes the security level of the system [affects the stability of the system in case of a short circuit for example].

Agents communicate with each other and this is part of their capability for acting in the environment. Consider a system that includes a wind generator and a battery system: the battery system receives some power from the wind turbine to charge and to provide it back to the system in time with no wind. In order to achieve this operation, the two agents have to exchange several messages and, of course, this is a type of action because the environment is altered in a different way than if the two agents were acting without any kind of coordination.

Agents have a certain level of autonomy, which means that they can take decisions without a central controller or commander and to achieve that, they are driven by a set of tendencies. For a battery system a tendency could be: "charge the batteries when the price for the kWh is low and the state of charge is low too". The system decides when to start charging based on its own rules and goals and not by an external command. In addition, the autonomy of every agent is related to the resources that it possesses and uses. These resources could be the available fuel for a diesel generator, the bandwidth in the communication channel or the processor time.

Another significant characteristic of agents is that they have partial or none at all representation of the environment. For example in a power system the agent of a generator knows only the voltage level at its own bus and maybe it can estimate what is happening in some certain buses, but it does not know what is happening in the whole system. This is the core of the MAS theory, since the goal is to control a very complicated system with minimum data exchange and minimum computational demands.

Finally, another significant characteristic of an agent is that it has a certain behavior and tends to satisfy certain objectives using its resources, skills and services. One skill could be the ability to produce or store power and a service could be selling power in a market. The way that the agent uses the resources, skills and services presents its behavior. As a consequence it is obvious that the behavior of every agents is formed by its goals. An agent that controls a battery system and its goal is to supply uninterruptible power to a load will have different behavior than a similar battery system whose primary goal is to increase its profit by participating in the energy market.

3.2 Description of the MAS

In this section the specific MAS implementation is 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.

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 it makes bids to the available Production Units in order to cover the estimated needs.
- Power System: This agent represents the Main Grid to which the Microgrid is connected. According to the Market Model presented in Section II 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.

3.3 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 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 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.

3.4 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

3.4.1 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).

3.4.2 Predicates

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

3.4.3 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

3.4.4 Behavior and Actions

In this section the behavior and the actions of the agents are described. The behavior of every agent has two main parts:

- Initialization in which every agent announces its services to the DF agent.
- Normal Operation which includes all the tasks and actions that every agent performs. In the following paragraph the behavior of each agent is presented separately. All the agents use cyclic behavior.

MGCC: The first task of this agent is to record every message of type "**Record**" and the second is to announce the period of the negotiation. According to the market model adopted, and in order to avoid double assignments, no energy exchange inside the Microgrid happens unless it is recorded in the MGCC.

Power System: This agent announces the Grid sell/buy price to all agents that participate (according to their service declarations) in the Market. The announcement is made just after the end of the negotiation period or whenever we have a change in the prices. In order to simplify the start up of the other agents, it is not allowed for a market agent to bid in the market if it has not received at least one announcement for the grid prices. This means that the new agent launched will bid in the next period.

Consumption Unit: This agent has currently two tasks. The first task is to estimate its energy needs for the next period and the second is to bid in the market.

- Energy estimation: In our application the "persistence" method is used, i.e. estimation is based on the current power demand assuming that this demand will be the same in the next 15-20 minutes.
- Market operation: The agent sends an offer to all available sellers for price higher than the price BP that the Grid would buy. If the agent does not receive any "accept" message then increases the bid a bit more. This cycle continues, as long the bid is lower than the sell price SP of the grid. After this it is obvious that it is in the interest of the agent to buy energy directly from the Grid.

Production Unit: This agent just receives offers from the consumption units. The agent decides based on its operational cost and the available capacity, if this is acceptable or not.

4 The NTUA Microgrid

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

4.1 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.

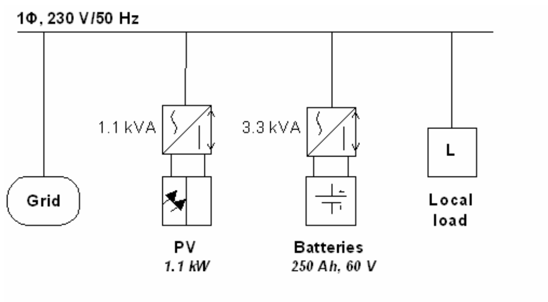

Fig 3. The laboratory Microgrid system.

The active power control is primarily performed by their power frequency control characteristics, known as droop curves.

4.2 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. This method was selected since the manufacturer of the inverter has available an OPC server suitable for his device.

4.3 Software Operation

In the Fig. 4 a display of the GUI of the agents is presented. From this screen the operational cost can be adjusted. Similar forms have been developed for the Loads and the Main Grid.

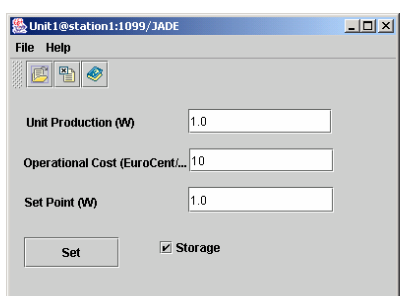

Fig 4. Screenshot of the GUI for the Production Unit.

In the implementation developed, 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 the resulting set point can be sent to the inverter only every 4-5 seconds. This long 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 limitation if the aim is 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.

5 Conclusions

This paper presents an agent based operation of a MicroGrid. The main focus so far has been on the communication of an agent that controls a production unit with its market environment. Preliminary results have shown the feasibility of this approach. Work is in progress in order to build controllable loads linked to the Consumption Unit agents. The most efficient and cheap method to achieve this 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. In addition, more sophisticated market operations are tested in order to reveal potential technical problems, like the one presented before (keeping the power at a certain level).

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Acknowledgements: The authors wish to thank the European Commission, DG Research for funding the project "MICROGRIDS: Large Scale Integration of Microgeneration to Low Voltage Grids", Contract No: ENK-CT-2002-00610