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Energy management in a microgrid using a multiagent system

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Contents

Chapter 1

Introduction

The renewable energy sources developed rapidly over recent years. Production of the energy by many of them is, however, very volatile. This is one reason why the idea of dispersing the sources, within the power grid, is believed to be economically profitable. It is essentially connected with the prosumer concept [34], that is an entity that not only purchases energy, but can also produce and export it to the power grid. With such configuration there appears need for new, efficient, and reliable management systems.

Traditional energy management systems with centralized structure fail to provide well-suited solution to recent distribution generation concepts. This is caused mainly by the traditional system assumption of unidirectional flow of energy, from the distribution companies to the loads, located in the leaves of the distribution grid. Generation of energy inside the distributed grid ruins this assumption, as the energy flows bidirectionally. Thus, need for a new management systems appears [27]. A microgrid can be treated as an aggregated prosumer, which consumes or produces energy. Prosumer-like networks are mainly energy self-sufficient and may work in a so-called island operation mode, but periodically they may buy or sell energy from or to the higher level grid (distribution network).

Efficiency of these subnetworks depends mainly on the power balancing systems. As generators are dispersed in the grid, the idea of a decentralized management system arises as a natural solution. Recently, decentralization of decisions in computer networks is realized more and more often by multi-agent systems [28]. This paradigm is also applied in the energy management system considered in this paper. Agents are associated with devices, like power sources, loads, and energy storages. They have their own knowledge and individual goals defined. Agents communicate with others in order to ensure security of the energy supply, and to reduce (minimize) unplanned shortages or surpluses. Thus, both sides, the supply and the load devices, take part in resolving imbalances of the energy. This forms a distributed energy management system.

The developed multi-agent system aims to balance the differences in short time intervals. Agent-based Power Balancing System for the Microgrids follows the idea given in [20, 21]. The deviations are caused by unpredictable level of dispersed, renewable sources of energy, and by variations of the actual demand.

An auction is a well-suited solution to solve the problem with decentralized, autonomous parties that tend to realize only its own goals. As in the actual trading, particular entities can reach sub-optimal allocation of the goods in the competitive environment, even without the assumption of the shared knowledge. Thus, in the Agent-based Power Balancing System for the Microgrids, the bargaining of the unbalanced energy is performed to minimize differences between actual energy production and consumption. As short reaction time as possible is looked for to suppress imbalance, and to lower the costs borne by devices owner. Thus, a quick auction type has been chosen, viz. the reverse one-side auction. The goal of the paper is to discuss application of this auction algorithm and to present results of its implementation in a simulated microgrid.

Chapter 5

Implementation and experiments

5.1 Implementation

5.1.1 JADE

In this work the JADE framework was used JADE (Java Agent DEvelopment Framework) is an multiagent framework that is written in JAVA language: it includes a library to develop agents and their behaviors, an agent environment to launch agents, and tools realizing services as white and yellow pages. JADE is implemented according to FIPA specifications.

Foundation for Intelligent Physical Agents (FIPA) is organization that makes attempt to introduce standard to improve the interoperability between different agent technologies. It is an IEEE Computer Society standards organization that also promote agent approach in development of different systems, especially in market and negotiation modeling. FIPA was officially accepted by the IEEE on 8th of June 2005.

The strong point of FIPA was introducing formal models where it was necessary, but leaving the protocol definition in simple and accessible form. These standards are not limiting they define the necessary minimum of functionality and description. It combined precision of formal languages with exhaustive explanation and examples. Most popular frameworks for agent-based systems are compatible with FIPA standards.

JADE organizes agents into platforms the logical structure that defines the boundaries of multiagent environment. On platforms are deployed containers, which are grouping certain amount of agents. Platform can be spread over network of physical computers, whereas contained is tied to a defined machine. JADE allows for migrating the containers and agents between different physical machines in a transparent way, from the point of view of an agent.

JADE is implemented in JAVA, and requires Java version of 1.4 or older. It is a distributed as an open source software under the terms of the LGPL (Lesser General Public License Version 2). The JADE Board consist of: Telecom Italia, Motorola, Whitestein Technologies AG, Profactor GmbH, and France Telecom R&D.

5.1.2 System architecture

The whole system consist of different modules: Planner, Power Flow Calculator, Weather simulator, Consumption simulators and Short-time Power Balancing system. The Planner, Power Flow Calculator and eather and Consumption simulators are external systems that communicates with the Short-time Power Balancing system via database and filesystem.

The Short-time Power Balancing System is a multiagent system composed of few main components. The diagram of the components is presented in Fig. 5.1. The center of the whole system is a database where the required configuration of devices and their features is defined. Whole communication with the database as well as basic data structures and definition of the production/consumption units are placed in the MicroGrid Structures component. Agents that are simulating operation of the devices are placed in the MicroGrid Environment Simulator component. An example of such agent is a set of photovoltaic panels that produce energy when the weather simulator reports that there is sufficient sunlight. Agents that are dealing with the change of energy and are responsible for balancing of the power, are placed in the MicroGrid Balancer component. The Launcher is the component responsible only for initialization of the system: it reads from the database what kind and how many of the devices shall be simulated and launches appropriate agents from the Balancer and Environment Simulator components.

5.2 An example of the algorithm performance

The algorithm for balancing the power was tested on simulated data. There were 19 devices considered in the grid. Simulation of each device and its

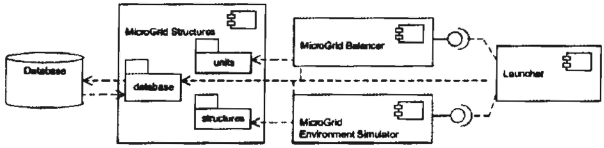

Figure 5.1: Diagram of main components of the system.

agent were run on a separate machine. The database and the Morris Column agent were placed on an additional twentieth machine. Each computer was an Intel(R) Core(TM) i5-3450 CPU@3.10 GHz 8 GB RAM machine, with 64-bit Windows 7. The computers were connected by the 1 Gb Ethernet network. The test revealed that the balancing takes less than 60 ms, except for the initial slightly longer time (up to 800 ms). This longer initial time is due to the necessary registration of the agents to the Morris Column during the first few seconds and their interrogation of the devices about their operating points. Agents in the system are not centrally synchronized and the delays between agent initial actions caused initial delays in balancing the power.

To show how the system balances the power, a simple example has been planned. Only 3 devices are considered, a gas microturbine, a wind turbine, and a single consumer that has a total power demand of up to 100 kW in the peak time. Additionally, to make the power balancing possible, the external power grid is introduced that has unlimited power consumption and production abilities. The negotiating device agents try to avoid buying/selling the energy from/to the external grid agent, but instead strive to balance the power by negotiations between producers and consumers within the grid, and keep the exchange on the zero level.

The power produced or consumed by devices during the test are presented in Fig. 5.2. The gas microturbine operating point is bounded by 12,5 kW from below and 50 kW from above. When the total demand power from the microturbine is out of these ranges, the trade with the external grid has to be used to balance the energy. In Fig. 5.2 the negative value of the power for the external power grid means that the microgrid sells power. It happens when the power consumed in the microgrid is lower than produced by the wind turbines and the microturbine operating on the minimal level. On the other hand, when the power demand is greater than production by the wind

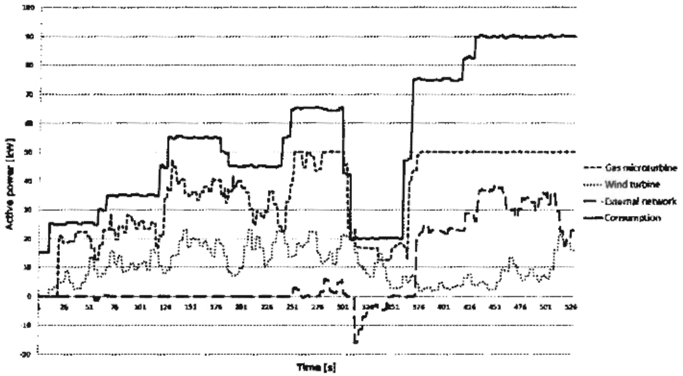

Figure 5.2: The amount of power produced by the controllable source, the uncontrollable source, the amount of power consumed by consumer and the amount exchanged with external power grid.

turbine and the microturbine operating on the maximum level, the external grid compensates the lacking power, which is depicted by the positive values for the external grid.

To show more clearly the power balancing process, the sum of production and consumption are presented in Fig. 5.3. It can be seen that there are small imbalances in short periods that are due to lack of synchronization in the system, but also to the time aggregation on the graph (the data in Fig. 5.3 are averaged within one second period).

Balancing can be done faster than the time assigned for the devices to report their state. This shows that the power balancing system can be an efficient method for matching the produced power and the consumption. There may be some small imbalances, but the time of their existence is so short that they do not influence the operation of the system as a whole.

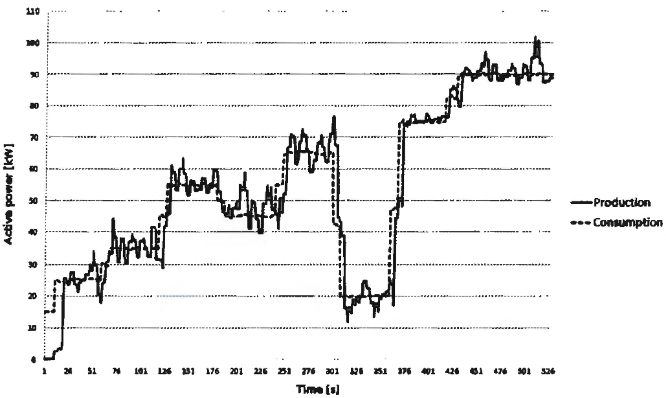

Figure 5.3: Aggregated powers of production by the microgrid devices and consumption.

5.3 Problems recognized during simulation

To perform the simulations faster the system time had to be sped up by factor 120, it made agents balance faster and the number of sent messages, entries and queries to the database increased a lot. That caused computers to use their processors to maximum during the time of the simulation. The difference between running simulation on single machine and in distributed environment is noticeable. The system is heavily multi-threaded and race conditions occur. Even though agent are not performing heavy computation their speed of performing constant check on devices and communication is an effort for the system. It is not possible to perform reliable performance test on single machine.

Testing should be performed on an adequate number of computers, where database has separate machine, then morris column, external grid agent and JADE specific tool agents (like DF) should be grouped on another machine. The device agents should be spread as uniformly as possible on the remaining available computers with strong suggestion of not placing more than 10 devices on siugle machine if the test is done with the time speed increase.

Chapter 6

Conclusion

Impressive changes in electricity grid structures have been initiated by the emergence of new technologies, the new regulations to fight against the global warming, increasing demand for the secure supply of energy and rising prices of electricity. These changes gravitate toward development of renewable energy sources, prosumers and microgrids. Recent research results indicate that it is possible to create an energy self-sufficient community, that can be even selling surpluses of energy. The energy produced by renewable sources is, however, volatile, as it depends on changing meteorological conditions. Also the consumption of the energy in microgrids is proportionally much more volatile than in bigger grids. The problems caused by uncertain production and consumption can be overcome by using the computer based Energy Management Systems.

In this work, a modular distributed EMS is presented. The novelty of the solution presented is first of all in the complex treatment of the problem. It includes two modules dealing with balancing the power produced and consumed in the microgrid. One module solves in advance the task scheduling problem, in order to find a suboptimal way of shifting the loads to be possibly covered by the energy produced within the microgrid. The second module balances the power in the real time by activating both the generation and the load side of the microgrid. For this, it uses the multi-agent technology. Thus, both production and consumption of the energy in the grid self-adapt to the changing energy needs and supply. The reaction of the real-time system is accelerated by using short time forecasts of generation and demand of energy.

The main aim of the system is to optimize (generalized) costs of exploiting the electric energy in a Research and Education Center, which is simulated with a considerable high accuracy to allow for testing the EMS operation. As compared to the simple reduction of the energy bought, caused by straight exploitation of the renewable energy sources, application of the EMS provides savings due to making long-term deals with external power grid, which is cheaper in comparison to trading on the balancing (spot) market, and then possibly precisely following the contracted power trajectory, in spite of disturbances resulted from randomness in generation and demand of energy. In all decision making stages soft suboptimal algorithms are applied, as metaheuristic or multi-agent ones.

Although a Research and Educational Center is considered in the paper, the elaborated system and methodology is of a general character. Many solutions are opened and can be easily redefined. So, it can be applied as well for other grids.

To test the system the insolation, wind speed, water level and consumption simulators had to be designed and implemented. For weather data some specific requirements had to be met: data had to be adequate to the location of the microgrid and had to be calculated fast for long time (more than a year). For this purpose the Matched-Block Bootstrap was used. It is a fairly simple and fast method that generates data that have satisfying statistical properties.

Simulating power consumption proved to be more complex and much less researched problem than weather simulation. The most common method of describing the consumption are 24-hour or longer profiles, which is not enough for system that should balance continuous changes in power levels. Consumption simulator offers different, adjusted to the type of a device, ways of describing the behavior: profiles, probability profiles, rules and combination of rules with short profiles.

There are many aspects that were not yet studied in this work, like short term predictions, trading with external network, demand side management, island mode operation and many others. These are very interesting aspects of smart grids and very important ones. Up to now the research were blocked by lack of testing equipment and inaccessibility to existing smart grid installations.

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