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Energy management in a microgrid using a multiagent system

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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 2

Microgrids

Smart grids and microgrids seem to be the future trend in the energetic revolution that is ahead. A *smart grid* is a concept of introducing exchange of information between different elements of electrical grid (consumers, producers, storage units and prosumers). Thanks to that, controlling and coordinating of supply and demand of energy can be introduced to ensure quality of electric power in the grid, reduce the cost and promote renewable energy sources.

These new technologies require an advanced control system that can use the potential of bidirectional communication. Implementing such systems requires working in real time operation mode. It is a challenge, as consumption and production is changing very dynamically, due to users activities and weather conditions.

Prosumer is a concept that was originally defined in economy as a junction between words professional and consumer. A prosumer is a unit that internally produces and consumes energy. Usually prosumers are small energy units and individually they do not impact a lot on an overall balance of the grid. In a big mass their influence is different, but due to the internal management of energy they may create fewer problems to control systems of the big power plants than completely uncontrolled small individual users, like e.g. residential homes. As the production and consumption of the power within the prosumer grid do not always balance, a prosumer can be seen by the external grid as a source that delivers energy to the grid or as a load that consumes it, depending on a current power flow.

A *microgrid* is a separated part of a grid which produces and consumes energy, and only occasionally exchanges it with the rest of the grid. A microgrid is a group of consumers, producers, prosumers or energy storage devices located on small area that can operate autonomously. The range of a microgrid is usually within low (400/230V) or medium (1 kV - 60 kV) voltage network. Prosumers have usually small power production units, up to a dozen or so kW, like for example photovoltaic panels, hydroturbines, wind turbines and gas turbines. A characteristic feature of a microgrid is that it can be treated as one entity from the point of view of the larger network.

It is more and more noticeable that the power systems actually evolve in the direction of microgrids, see [17] for discussion of advantages and details of solutions. However, there are still a lot of issues that have to be solved before reliable, safe and trustful microgrids appear.

To manage the energy, it is important to understand specifity of the microgrids. There are many features that discern microgrids from big power systems. The issue has been discussed in detail in [16]. The physical effects in low-voltage grids are different than in the big ones that have enough inertia. Moreover, a possible autonomous (island) operation of a microgrid requires solving of additional problems. For example, subsistence of the frequency that is normally controlled by the external grid has to be solved. In the island operation mode a microgrid has often not enough power to support a usual load all the time. In such case there should be a mechanism of switching off the loads with lower priorities. In any operation mode, changing consumer behaviors have far bigger impact on the volatility of the total microgrid load than in the macrogrids. This makes predictions of the load much more difficult. The essential features for functioning microgrids as semiautonomous power systems include use of power electronic converters, specific control systems, and ability to communicate within the microgrid. Another fundamental feature of microgrids is installation of many renewable energy sources, which is of great importance from the point of view of environment protection. Most of the microsources are being connected to microgrids via power electronic converters, which also provide them with required control abilities. These abilities are also necessary from the point of view of ensuring security and proper level of reliability of supply.

The key issue is also control of the microgrid operation and requirements for protection of the microgrid functioning. Particularly it concerns such tasks as voltage regulation, frequency regulation, power flow control, and voltage stability. These issues are especially significant during island operation. It is also important for a microgrid to have an ability to change smoothly the state from the synchronous operation mode to the island operation mode or vice versa.

Protection systems installed in microgrids have to work properly in the case of faults appearing both in the microgrid and in the external distribution network. Taking above mentioned factors into consideration it is also essential to design proper measures for protection against electric shocks [13].

In the microgrid island operation mode, control systems have to take into account the inertia of the different types of the microsources. Some microsources have long respond times and low inertia. In contrast to this, a big power system is highly inertial, which is ensured by big generators installed in the system. It is especially significant during frequency regulation in the island operation mode of a microgrid. One of the most important feature is also the DSM (Demand Side Management) function when controllable loads exist in the microgrid. Loads supply reliability is a strict requirement for a microgrid to work in the island operation mode. For methods developed to control the load see e.g. [8, 12, 23].

The concept of a microgrid is based on the fact that there is a cooperation or at least non-hostility among the participants in the microgrid. This problem is simpler when all sources and loads in the microgrid belong to the same owner. Then there are no conflicting views, no problems with distributing the profits from producing the energy or sharing the costs of buying additional energy. This is actually the case considered in this paper, where it is assumed that the whole infrastructure belongs to a single owner. However, the described approach of treating devices as independent agents can be also applied in a many-owner microgrid, providing that economic result of the whole grid operation is the common goal.

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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