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Modeling consumption of energy by different devices in the center

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Chapter 1

Introduction

Power production has to cover demand and has to compensate for power loses – this balance is crucial for the operation of the networks. If we look from the point of view of high voltage networks the problem can be solved on the level of automatic sensors that would measure certain parameters of the current. On this level the aggregation of consumers and producers is such that only the major imbalances are considered.

When the only sources of power were huge electric power plants management of power in the network was relatively easy. The flow of energy was mainly unidirectional and the power production was centralized, which made it easier to manage the power production. But the constantly growing demand for power forced network to undergo constant modernization. When demand was rising, the prices went up; they increased even more when the world became aware of the ecological problems, in which energy producing sector has its part. Introducing more ecological solutions lead to fragmentation of power sources which requires more advanced power balancing systems.

The undergoing changes are not just in the area of energy production. Increasing prices and ecological awareness changed the way that people think about consuming energy. The energy usage is now an important factor that influences the purchase of new appliances, it is partly due to clear labeling of the average energy usage. The technology of production of most of daily use devices is evolving toward more energy saving solutions, like for example incandescent light bulbs are being replaced by the fluorescent lamps and by light-emitting diode lamps (LED).

With the development of smart grids the ideas for optimizing energy consumption went even further: to ensure the stable current parameters and rational prices for power the consumers have to actively take part in managing the energy usage. Demand Side Management (DSM) emerged as a new interdisciplinary research area. DSM considers some main issues as: convince people to take part in energy optimization, find the best way to communicate them the current status of the network, develop appliances that would be optimizing power without the human intervention.

First issue is about showing people the future problems and make them realize that they can make a difference. But such actions would require adjusting peoples lifestyle to the current situation. If there is a peak of demand, the more people agree to shift their energy consumption (by e.g. not switching home appliances or postponing their lunch) the cheaper and easier would be to cope with peak effects (usually additional power sources have to be switched on just to cover short term demand increase). Second problem is the communication of the network status: how the users know that there is a deficit of power? The most popular way of informing people is by presenting them prices. When there is peak of consumption the price of energy is high and it is lower when there is an excess of energy. That idea was behind introducing peak and off-peak tariffs.

To simplify the consumption management there is an idea to create intelligent appliances that would be proactively delaying or modifying their operation cycles to reduce the power peak. Such devices exist (e.g. washing machines of Miele), but they are still very unpopular due to: lack of trust of people (they do not like the feeling that something is happening outside of their knowledge), high prices and service unavailability in the network (power grid is not yet sending signal to the appliances).

The greatest obstacle of DSM technologies is the lack of preparation of legislation that would allow introducing: retail market, clear rules about exchange of information from smart grid, simpler rules of installation micro sources (both renewable and not-renewable), etc.

The problem of demand management is extremely important as the consumption control and forecast facilitates the power balancing. The context of this work is developing intelligent Energy Management System (EMS) tor the research and conference center. The center is the group of few buildings that have connected different power sources [8, 6, 10, 17]. The EMS includes different modules as short-time balancing, planner, model of the network, models of the devices, etc. To test the implemented system of power balancing it was necessary to create a simulation of the operation of the research and conference center which implies simulating power demand in frequent intervals for each node of the network. Simulation of energy consumption is more complex, because there is usually a large number of heterogeneous loads considered. Consumers can be considered at different aggregation levels: from models of single devices, to nodes of the network, whole buildings and bigger structures, as areas and cities.

In a household, small microgrids or single buildings it is most common to consider single devices, as oven or microwave [12]. Data about their power usage can be measured, which gives exact information about the dynamic of changes, but considering the large numbers of devices of the same type, broad testing is required to derive the generic usage of some appliances. The authors of this work were unable to find any studies about the characteristic power usage of basic devices. An exception here is a computer, its power usage can be measured on-line using simple software. In larger networks, at levels of groups of houses, general profiles are used (e.g. in [14]). In large networks profiles are grouped by sectors, such as commercial, residential, industrial.

For some purposes the general profiles are sufficient, e.g. in [16] they are used to verify the design of the network. The application had to be made to test the designed system of conference and science center to identify possible overloads or violation of constraints. For that purpose only eighteen exemplary load-flow calculations were designated, with 19 profiles for different categories of loads. Authors of [16] parametrized test by: season (summer/winter), hour (from 11 a.m. to 1 p.m.), type of the day (weekday/holiday), weather conditions (windless and sunless day/windy and sunny day), demand (maximum or minimum) and the state of energy storage units (OFF/charge/discharge). Such parameters combined with power profiles were sufficient to cover all extreme situations, like e.g. extremely high consumption with no production from renewable sources. The tests confirmed that the network was well designed and there is no threat of overload. But such load profiles are not good enough to test the dynamic behavior of the microgrid: values of a profile are 1-hour averages, so there are only 24 different load values for a day.

Profiles for a big group of consumers can be easily derived, as any outstanding or uncommon behaviors tend to be compensated by each other, so they do not vary very rapidly. On country scale, they can be easily obtained from large power producers. Profiles show cycles of daily and weekly changes that reflect the human activities. Night is usually the time of lower energy usage, and peak usage is around late afternoon. Weekends and holidays are introducing disturbances to the working day cycles. Moreover, seasonal differences are visible, caused by different demands: changes in the outer temperatures (e.g. large amount of power is used for air-conditioning), long holiday seasons and changes in labor structure [1].

By contrast, in microgrids, each consumer has a relatively larger influence on the profile than in large grids: a 4kW induction cooking plate will not be visible in profile on the regional level, but can dominate the energy usage in a single household. When a single domestic device can make a change its switch on and off time is visible in the power usage. Averaging power consumption is such situation introduce imbalances, because the usage is changing very dynamically and the most effective would be controlling changes in real time. Thus, profiles are not sufficient for microgrid simulation purposes, because their resolution is usually too small (every hour or half an hour).

The most comprehensive research about the structure of energy usage has been done in Spain [1]. Users presented in the report are divided in 5 groups: residential, commercial, touristic, large consumers and others, with the total contribution of power usage 20%, 6%, 0.5%, 25%, and 48.5%, respectively. These values might differ among regions and countries and depend on the method of categorization. The authors emphasize the big differences in the energy usage between user groups, as for example households, tourist facilities or companies. Other factors that influence the amount and structure of power usage are e.g. seasons of the year (in case of Spain there are 2: summer and winter, but it may differ in other climatic zones), days of week, times of day, months, holiday distributions, structure of labor and economic situation. It demonstrates the difficulty to obtain one reliable description of consumer structure even within small area.

Simulating the power usage of each device gives much higher accuracy, makes the simulation less abstract and gives possibility to base the model on existing devices, whose parameters might be measured or found in the literature. In [13] a detailed analysis of representative office environment was conducted to test the model designed. 500 electrical devices were identified, mostly user dependent.

Chapter 2

Energy management system

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. 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. For discussion of advantages of using microgrids see [4].

The considered EMS consist of certain modules that cooperate and exchange information to optimize the production and trading of the power in the considered research and conference center. This modules are:

- Models of the devices,
- Planner,
- Short-time balancing system,
- Simulator of production and consumption.

Components are presented in Fig. 2.1.

2.1 Models of the devices

The models of the devices in the simulated center are divided into three groups: energy sources, energy storage units, energy consumption units (loads). The energy sources comprise [10, 17]:

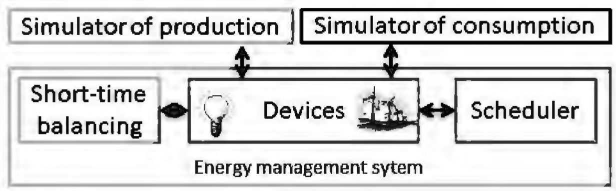

Figure 2.1: A diagram of the elements of the considered system, where devices are represented by agents being parts of the Short-Time Balancing System, which uses production levels of controllable power sources from the Scheduler.

- wind turbines,
- photovoltaic panels,
- reciprocating engine,
- gas microturbine,
- hydropower plant.

The total inner production of energy cannot be known exactly because of, to some extend random production by renewable energy sources, as wind turbines and photovoltaic panels. To balance the power in the center, the energy bought from the external network is used. It is assumed that the external network can send unlimited power[1]. Trading with external network is realized by the user, supported by the External Trading module, that knows the load profiles and the schedule. The module prepares required amounts and times of delivery of electric energy and suggests deals. Better energy prices are possible to be negotiated on the electric energy market, if the amount and time of buying the deficit energy is known in advance. Advanced planning of the lacking energy helps in diminishing the cost of its buying. If the connection to the external system is deactivated, the center system switches to the island mode, and all plans are invalidated.

Energy storage units considered in this system are: batteries and flywheels. Flywheel is a fast reacting unit, that can quickly balance energy, but is unsuitable to provide long, stable flow of power. Battery can be treated as a source when it is discharging and consumer when it is charging. Use of

[1] The power is actually limited by the transmission ability of the transformer. It is, however, assumed that this limit is never achieved.

power storage units can significantly improve the operation of the microgrid, detailed research about the role of batteries are presented in [15].

Energy consumption units are all devices that consume power. In the considered microgrid network has over a hundred of consumption nodes, each node represents part of the network, like e.g. computer sockets in one floor of the building, ventilation in the building, elevator, corridor lights, etc. To each node a certain amount of devices is connected, assumption is made that the connected devices reflect the character of the node, e.g. it is assumed that no kettle is connected to the computer socket.

2.2 Planner

The Planner module analyzes the list of submitted tasks (e.g. lesson, conference, science experiment) and suggests better time for realizing them taking into account limitations defined by the user. Some tasks require negotiations before the execution time has been fixed. For example, when a conference is planned, the system checks if the suggested dates do not collide with other events, in terms of resources used, or with some energy-consuming experiment, and may suggest postponing it for few days. The Planner takes into account the expected load, based of historical data, the profiles of usual power production and consumption, the prices and availability of electric energy, and evaluates the cost to realize the task at the proposed time. The Planner constructs a schedule using heuristic algorithms, which allow for a compromise to be made. The schedule is only suboptimal but it guarantees to provide a result within a specified time. The schedule includes not only the list of tasks that are executed at certain time point, but also the operating level of all controllable devices in the system. Having such information, it is possible to compute the total surplus or deficit of power in every time period by comparing the planned consumption of power to the expected amount of production.

The Planner operates in a long time scale, usually few days ahead of the planned events, although it updates the plans every half an our, if necessary. It considers historical data from a number of previous years and daily consumed and produced energy, gathers information about the events that may last from a part of an hour to days (such as conferences or experiments).

2.3 Short-time Power Balancing System

Because of uncertainties of energy consumption and production, the schedule can differ from the actual values. Short-time power imbalances may be caused by unpredictable activity of some sources, non-exact realization of planned events and by unregistered energy consumption. The Short-time Power Balancing system takes care of this. This is a multi-agent system, in which each device and node is represented by autonomic agents. Agents monitor the physical devices (in this simulated case the models of physical devices) and when the change in the state is sensed, the agents look for balancing it by other devices. A negotiation process allows the agent for choosing a possibly best complementary producer or consumer of the energy. The best in this case considers: minimizing the cost of devices operation and preference of more ecological technologies. Agents set changes of the operating point of the devices (the amount of power the device can produce or consume), if the units allow for that.

The Agent-based Power Balancing system is directly connected to the devices interfaces and can change the operating points of the controllable devices. A model of a device includes a simulator of its work, in which the operation profile and information about the date and time are used. The inputs to the model that depends on meteorological conditions are simulated. More detailed information about Short-time Power Balancing system can be found in [8].

2.4 Simulator of production and consumption

In the considered scenario there are renewable sources The amount of produced energy from renewable sources depend on weather conditions. To calculate the power produced by photovoltaic panel the data about irradiance and temperature have to be known, for wind turbine the wind speed is required and for micro water turbine the amount of flowing water has to be given. Weather data were gathered from 9 years and 50 years for the water. To generate the sufficiently long time series of data the method of matched-block bootstrap was used, described in details in [5].

Chapter 5

Conclusion

Testing is an important step in developing EMS, especially when systems work in a microgrid environment, where small changes in load have a big impact on overall balance. To have statistically significant data about microgrid operation, a large number of long-term tests has to be made. Ideal situation would be testing base on real measurements of power usage. A real infrastructure for testing purposes was not available, which forced looking for more theoretical solutions. Maximum power usage of the device or profiles of energy usage of devices could be measured, but they do not reflect the way people use devices. User behavior is very varied and influenced by many factors. There are very scarce study about habits of using devices or description of duties that requires specific electronic equipment. All of this makes simulating of consumption imprecise and simplified. Simulator of energy consumption has to mimic this behavior with all its impreciseness and unpredictabilities, which requires using probabilistic distribution combined with fixed profiles. Presented energy consumption simulator requires rules and profiles that define device's behavior. Based on that it creates time series of energy consumption aggregated per node, which is a tool for EMS testing. Rules are limited in number and profiles are limited to typical days to represent weekends, holidays or special events the set of new rules and profiles has to be created,

For purpose of testing EMS systems such description of consumers behavior is sufficient, but it is clear that more efforts should be made to examine the nature of different energy consumers to obtain the statistical distribution of loads considering different social and environmental factors. That would also help to find where energy is wasted and how to avoid it. The next stage of the research is exhaustive testing of the EMS and then connecting it to real devices.

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