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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 3

Description of consumer behaviour

The modeling of users behavior regarding the use of electric equipment is the most difficult part of simulation. It is due to a number of factors:

- there is a great variety in peoples' actions due to personal differences, habits, location, time, etc. – research made in one location will be not useful in others. This forces to make research on a larger scale and more detailed considering the social group, place and time;

- people do not like to be interrogated – questions about how they use electric equipment during the day would reveal their daily activities, in such case it is unlikely to obtain honest and exact replies;

- behavior of people might be extremely erratic – group of people might have a tight schedule, but their detailed actions will be different each day, that suggest a probabilistic or fuzzy models of such actions;

- constant evolution – the change of technology is extremely fast, even when the people behavior is predictable, the devices they use are constantly being modernized, which for devices as washing machines or fridges is a mater of decades, in the area as computers and cell phones might be a matter of years. Once described set of devices might change in few months and for sure it will change in few years. Only the trend of that change can be generally anticipated.

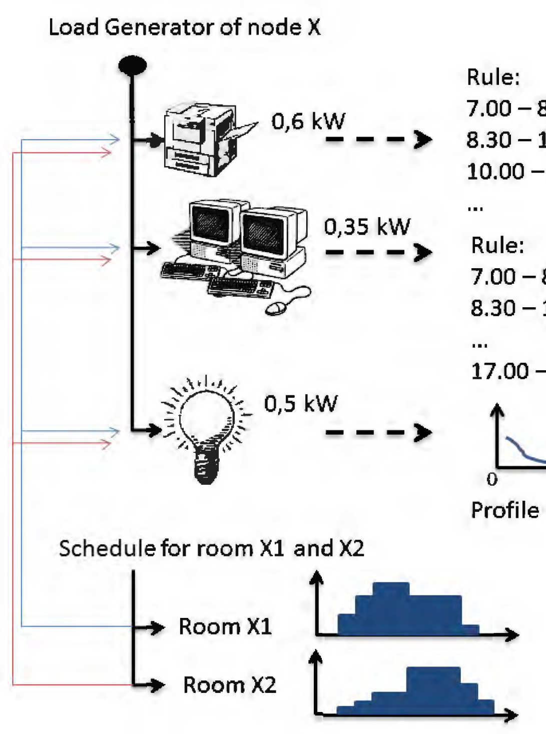

Figure 3.1: A diagram of different possible descriptions of energy consumption.

Devices consume power because people placed them there, switched them on and use them. The load simulator, in reality, tries to mimic the patterns of human behaviour. It cannot model the whole complexity of human reasoning, but can derive general patterns and statistical distribution of certain human actions.

The EMS considered in this work governs a relatively small microgrid. The maximum necessary load does not exceed 900 kW. In this situation, a room where a computer lesson takes place can use easily 4.5 kW, which can be visible in overall balance. Such lessons can be planned and entered to the Planner (see 2.2) that would inform energy management system about an increase in power. Power usage of computers in a room, projector, air conditioning and lights are gathered and their average power usage is placed in the schedule for a specific time with a duration of e.g. 1.5 hour. The important thing to remember is that Planner plans energy for the rooms, but one room can be connected to few different nodes: one node would be light, other computers and other general use sockets.

For the Short-Time Balancing System (see 2.3), the execution of the task "computer lesson" would mean the increase of power on two nodes of network, the one that would power the computers (which is reserved, i.e. the node has priority in receiving power) and the other for lights and additional equipment. That means that two agents would "sense" the increase of power usage and start the balancing procedure.

The goal was to create a load simulation device that would consider the information from Planner (scheduling in which locations the increase of power is expected), but also simulate the general operation of the devices in micro-grids (e.g. lights in the corridor, air-conditioning) and simulate randomized behavior of people (e.g. switching on and off computers, making coffee). Because Planner and Short-Time Balancing System are operating on different levels the simulator has to operate on the level of single device, and have information to which node device belongs and in which location it is.

Considered network has 164 nodes, out of which: 37 are bus nodes, 10 are generation nodes, 2 are for power storages (batteries and flywheels) and 1 is the balancing node, which is the connection point with external network. Remaining 115 nodes are consuming nodes connected to different parts of the Educational and Research Center. Detailed description and schema of the network is presented in [11, 3].

Load nodes are divided into two groups: conditionally and unconditionally reserved. Conditionally reserved nodes are the ones that are first to be deactivated in case of shortage of power, to such nodes is connected laboratory equipment, ventilation and cooling systems, electrical sockets for general use etc. To unconditionally reserved nodes devices like servers, computers, heating control equipment and elevators are connected.

Computer and telecommunication networks would be the most common equipment in the Research and Educational Center. In report [7] very similar Center was considered, where the loads of computer equipment was considered.

Estimated number of desktop computers in [7] is 100, with 350 W of used power per one computer. Additionally, 18 laser printers, which use 600 W of power each. The computer grid with servers consumes 16.7 kW. The power rate used in [12] desktop and laptop computers is 100 and 20 kW, respectively. This means that around 7 hours per day operating time is assumed.

In [7] it was assumed that there will be 34 TV sets (32 in the hotel rooms and 2 in the receptions). The maximal use of power was assumed 2 kW for all TV sets (around 62 W per a TV set) plus 200 W for installation. The power rate for a TV set used in [12] is 10 W. Thus, it is assumed that a TV set is turned on around 4 h in average. In the considered center the following assumptions can be made:

- The two TV sets in the receptions are turned on 24 h per day.
- The probability that a TV set in a hotel room is turned on when the room is occupied is 0.2 between 7:00 and 9:00, 0.1 between 9:00 and 18:00, 0.8 between 18:00 and 23:00, 0.1 between 23:00 and 0:00; between 0:00 and 7:00 the set is turned off.
- The number of occupied rooms is normally given by the reception. For the purpose of simulation, each day this number can be drawn with equal probability of $1/33$ for each number, including 0. The check off and check on time can be taken as 12:00 o'clock.

Telecommunication system - 2.1 kW. Projection and sounding equipment - 8 kW. Monitoring by cameras - 860 W. Moving detection alarm system - 500 W (from 0:00 to 6:00 hours).

Additionaly we consider that in future Center will have to power electric vehicles, which, considering their large batteries, will consume significant amount of power. Five plug-in sockets for electric vehicles are assumed with the power 1.92 kW. They start to be used randomly (uniform distribution) from 8:00 to 9:00 hours. It is assumed that the cars have the battery sizes of 45 kWh. Their state of charge (SOC_m) is drawn randomly from the uniform distribution between [0.3, 0.8]. The charging can be stopped and begin again any time. It is stopped when the bettery is fully charged. Between 17:00 and 18:00 the charging is stopped randomly, even if the battery is not fully charged until this time. Another three battery cars are charged starting around 18:00 o'clock. Two of them are of the size 80 kWh and one 45 kWh. Their SOC_e is drawn randomly betwen [0.2, 0.5]. The time needed for full charging of a battery is

$$t_c = \frac{s(1 - SOC)}{1.92}$$

where s is the size of the battery and SOC is either SOC_m or SOC_e, respectively.

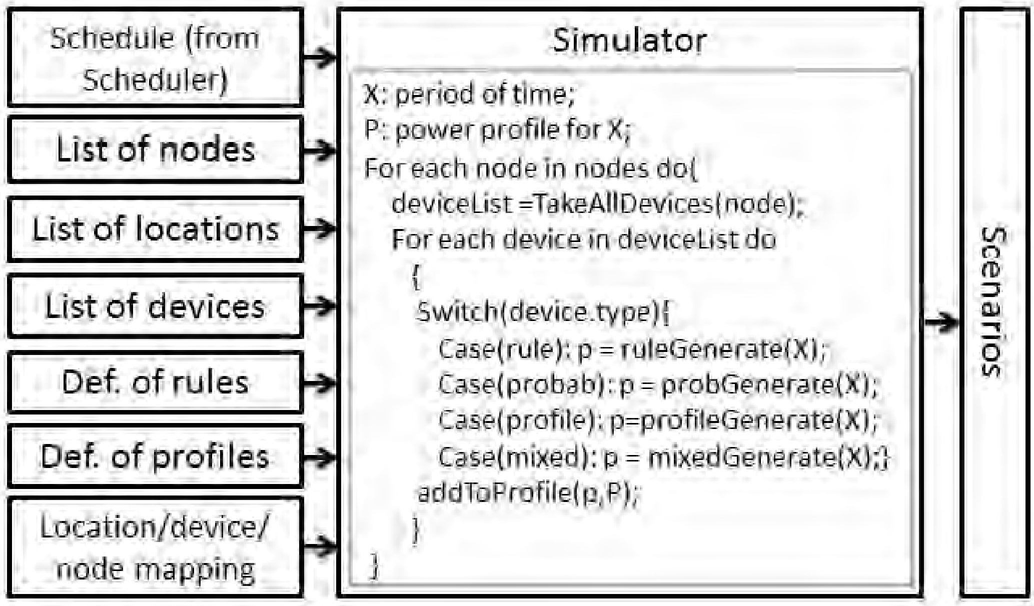

Figure 3.2: Concept of the Simulator of consumption with data sources, outcome and general description of the algorithm.

Although the power consumption kitchen equipment can be very well described, for example using the study described in [1], but to simplify the simulations food preparation will be described by a profile.

3.1 Concept of the simulator

The simulator is designed to generate load data for each node for a certain period of time, with a given start date and a time. Generated data are stored as test scenarios which allows to repeat the test with different configuration of sources. The schema of the system is presented in Fig. 3.2.

Data that have to be available for the simulator consist of the schedule made by the Planner, the list of nodes with information how many and what type of devices are connected to them, the mapping between devices, nodes localizations (e.g. rooms), the profiles of nodes and individual devices that are connected to a node, and the rules for devices without profiles. The outcome of the simulator are power values aggregated for each consumption node of the network, with the sampling frequency defined by a parameter.

The simulator processes each node separately in order of their numbering. It queries all the devices connected to the node and then generates for each device the load for the requested time period. Then it sums up all power consumptions of the loads connected to the node for each moment. Each device is processed depending on the type of the device, and the load is generated from the profile, probability profile, rule or from rule and short profile.

The devices have defined their type, which defines a way of generating the consumption. The types are:

- profiles
- probability profiles
- rules
- combined rules with short profiles

Generating methods are described in following sections.

3.2 Profiles

Usage of energy by some devices can be described as a profile, which is an approximation of a function of energy usage of the device. Profiles are made to represent energy usage by a device during a certain time period. They come from real measurements and are applicable for the devices (or group of devices) that have stable and defined work cycles. Examples may be a dishwasher, a fridge, heat pumps, meteorological station or a freezer. Profiles are also reliable when a sum of power feed of devices that require relatively small power is considered, for example a set of light bulbs in the corridor. In this case a single device has little influence on the overall power consumption and in general case multiple small deviations tend to level the usage.

Profiles define the average, typical behavior and are not suitable to describe events that happen with low frequency or that require extreme power usage. For example, the profile of a coffee machine is repeatable and can be measured, but the information of how often and when users make coffees has to be derived from statistical behavior. The main limitation of the profiles is that they have defined one value per hour, which is not frequently enough if the quasi real time processing is considered. Also lack of information about the variance within the hour period makes it difficult to add some randomization in the profile. Simulators based on profiles encounter troubles to represent small variability in the generated data, even when random disturbances are introduced.

Simulator might increase the diversity of generated data by using multiple profiles for a single device, e.g. there might be 10 profiles for a computer. It can be switched on for 1 hour or for 24 hours, might be used for energy demanding calculations or might be in a sleep mode for most of the time. This approach would require a large number of different profiles that would represent certain cases and still would not show all possible combinations.

Each device in the microgrid is connected to the node of the network. Nodes group devices according to their function and location in the building. These profiles were used for calculations of power flow in the network and to calculate possible violation of power constraints in the initial stage of designing the grid. More about the network can be found in [10, 17, 16]. The power consuming nodes were initially divided to general 17 categories:

- air condition in the rooms (1)
- ventilation in the rooms (2)
- preparation of the meals (3)
- powering of the elevators (4)
- external lighting of the buildings (5)
- interior lighting of the buildings (6)
- teleinformatic equipment of the buildings (7)
- other consumers (8)
- power feed of boilers (9)
- power feed of circulation pumps (10)
- power feed of cafe equipment (11)
- power feed of hydrophore (12)

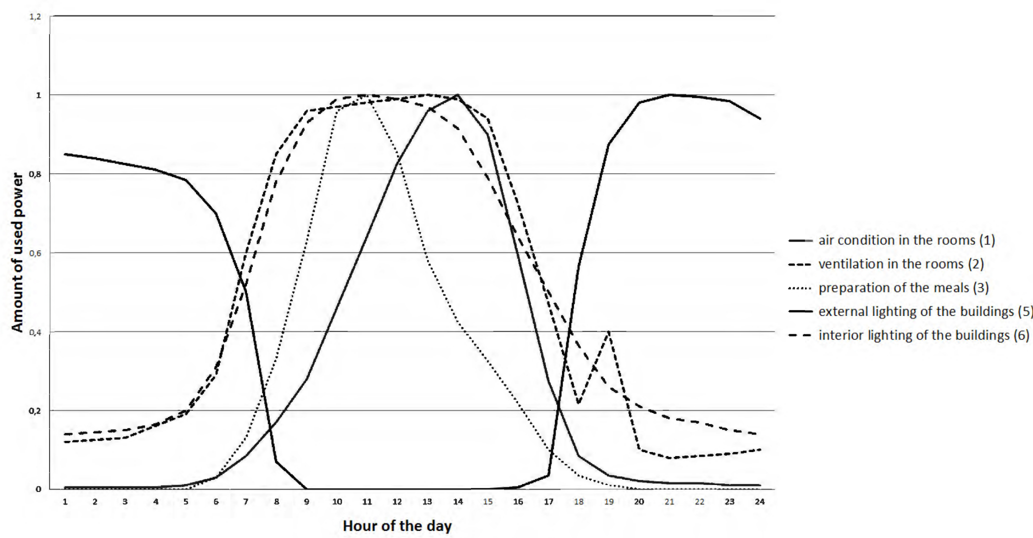

Figure 3.3: Examples of profiles for chosen categories of devices.

- power feed of waste water pumps (13)
- power feed of meteorological station (14)
- power feed of heat pumps(15)
- power feed of the buildings (16)
- power feed of science experiments (17)

During development of the system new categories were added:

- power feed by single hotel room (20)
- power feed by double hotel room (21)
- power feed by empty hotel room (22)

The categories had defined daily profiles, which assigned the percentage of power use by the node with hour of the day, example of the profiles are presented in Fig. 3.3. Deitailed description about these profiles can be found in [9].

The list of categories was made for the defined system, but can be easily expanded if needed. Using of the profile is very simple, the algorithm just chooses the proper value from the profile based on hour of the day, adds some small value to randomize the power usage and returns the usage.

3.3 Probability profiles

Profiles are very suitable, and adequate to represent devices which are dependent on time of the day (e.g. light, ventilation). When device shows big variance in the operating time profiles become imprecise and not useful. The main example for device that should not be described by the profile is a computer, it is a device that if once switched on usually stays on for a long time, even when it is not used. This is due to: long starting and stopping time; the long time needed of switching on and off the programs that are needed during work; and the false assumption that the components of the computer get used more quickly during the switch on and off phase [2]. When computer is not occupied by the tasks it can enter an idle mode, in which it uses around one third of the average power consumption. Users tend to switch on the computer when they come to work and switch it off in the afternoon when they go home, but some group of people would schedule time consuming operations for night time and then do not switch computer off at all. During short brakes at work people often do not bother to switch off the monitor or printer, not mentioning the computer. So the operation of computer can vary a lot among different people and different duties.

For such devices some other way of describing power consumption had to be defined. We propose here describing devices operation with probability profiles: in this case the profile is not showing the total power consumption at certain time of the day, but the probability of switching the device on and off. During its operation there are introduced some random fluctuation of power. For each case at least two profiles are needed: one describing probability for switching on the device and one for switching it off. Example of the profiles for a device is presented in Fig. 3.4, as can be seen at 4 pm considered device can be switched on with 5% probability (if at the time it is inactive) and can be switched off with 20% probability (if it is active).

There might be multiple profiles for a single type of device representing different possible behaviors, but each device have to have one pair for probability profiles. In the beginning program reads the profiles from database, then calculates which part of the profile apply to the current time (in general situation profile can be defined for shorter periods of time than 1 hour).

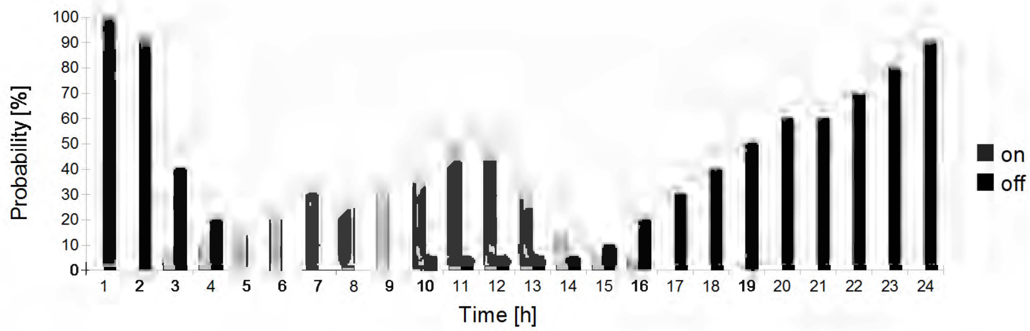

Figure 3.4: Examples of probability profiles for switching on and off of the device.

Then, a random value is generated and, depending of the state of the device, this value is compared to the value of probability of switching on or off of the device. If the device is on and stays on, the value of it energy consumption is changed by adding or subtracting some value from the last state (or average state if the device was just switched on), this value takes values from Gaussian distribution.

The set of five pairs used in the simulation is presented in Fig. 3.6 - 3.10.

The example of working generator for one chosen node is presented in Fig. 3.5. It is the node that has 12 computers and one projector connected to it. Computers are defined by 5 pairs of probability profiles. Consumption of projector is defined by the rule.

3.4 Rules

The power consumption of devices that do not have typical profiles and do not usually operate for long time have to be described differently. An example of such device is microwave, it is switched on for short moments, maximum few times a day, usually in the afternoon or evening. The time period when the device is active is called activation period. The method of describing that behavior may be a probability distribution of devices operation. That means describing loads by a set of rules. This type of description is introduced in [1] according to the Spanish behavioral data. The work of appliances like dishwashers, ovens, etc. is described by the probability of their operating in a certain time. For example, an electric kitchen (a stove) is mainly used

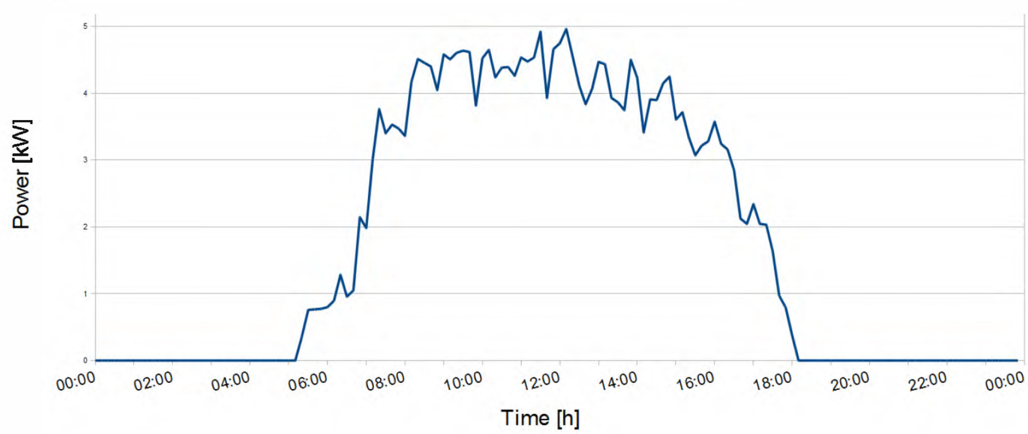

Figure 3.5: Examples of probability profiles for node 189.

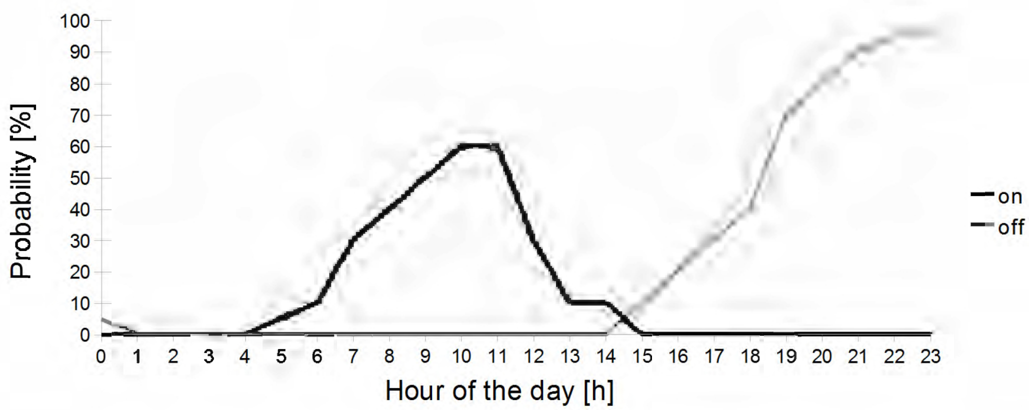

Figure 3.6: Set of the probability profiles representing average working day, it reflects the flexibility of switching the device on and off.

around 9:00, 13:00, and 21:00 hours with the respective probability around 20% at the 21 o'clock, 10% at the 13 o'clock, and 2% at the 9 o'clock [1](page 100). To simulate the consumption data some random generators has to be used to ensure that each generation will be different, but that the average operation time is within some defined limits. In more general approach a person has to be able to define that the microwave operates by average twice a day from 10:00 to 16:00 and on average it is heating up food for 2 minutes.

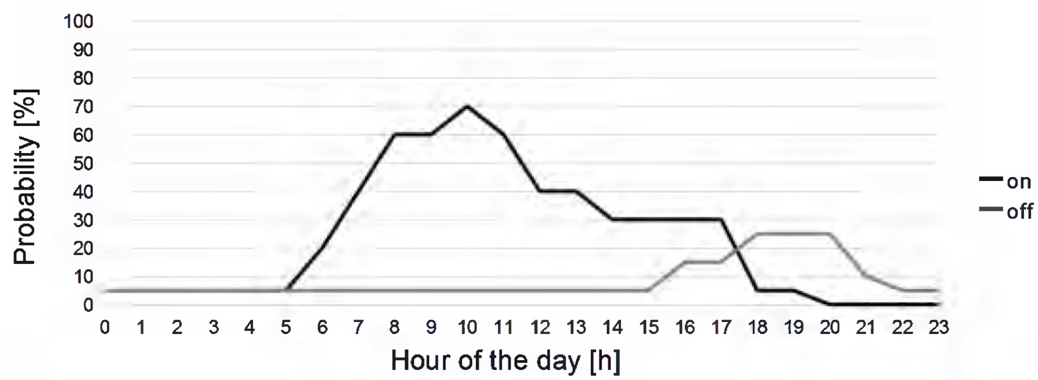

Figure 3.7: Set of the probability profiles representing average working day, similar to one in Fig. 3.6.

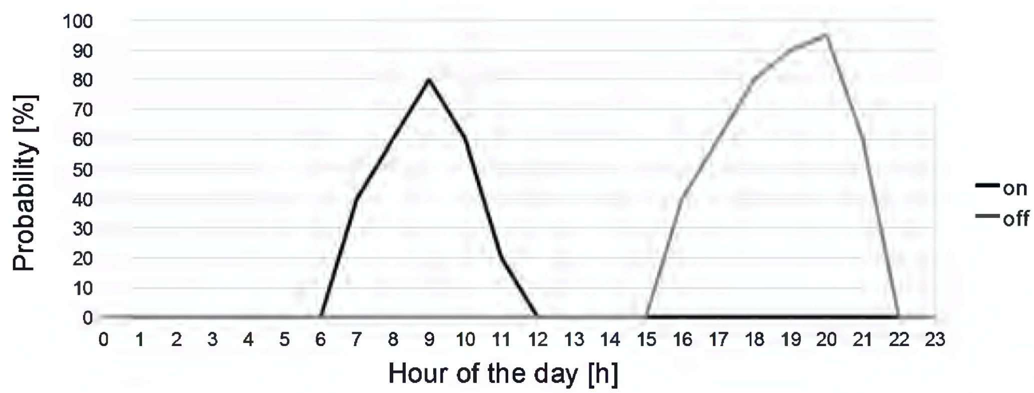

Figure 3.8: Set of the probability profiles representing average working day, it reflects the situation when time of switching on or off of the device is usually fixed.

In this work we make a simplification by considering 24-hour period on which the rules are defined.

This type of description might be giving large variability in consumption generation, but this is the expected behavior. Obtaining such rules require detailed studies on a large enough sample, which is difficult and costly to conduct. The advantage of using such approach is that, by increasing the certainty of the behavior, the rule can be easily adjusted.

Rule is defined by a set of parameters:

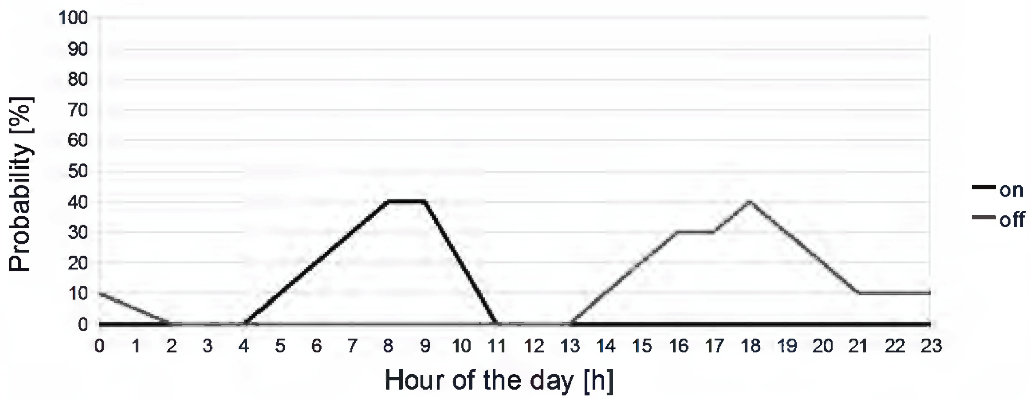

Figure 3.9: Set of the probability profiles representing average working day, changing the state of the device is rare in this case.

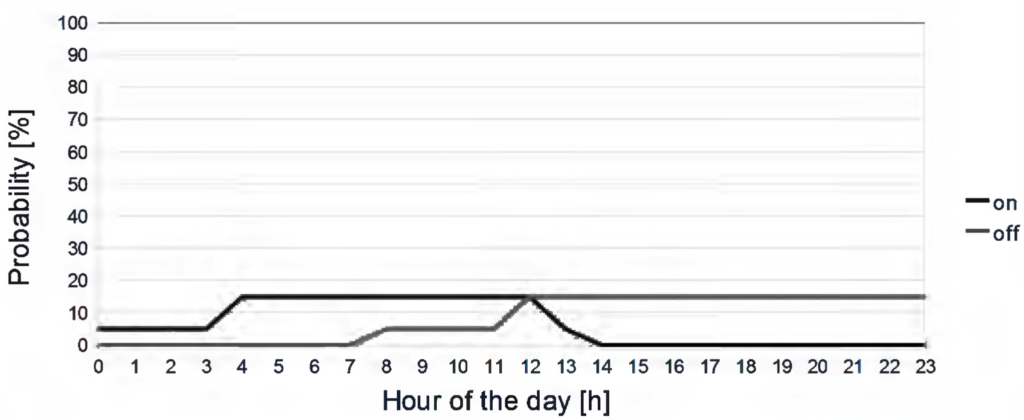

Figure 3.10: Set of the probability profiles representing average working day, it reflects the rarity of changing state of the device, e.g. when computer is on it stays on for a long time.

- duration – a value describing the average duration of the active period of given device,
- time from – earliest time of the day that the device can start working,
- time to – latest time of the day that the device should stop working,
- amount – amount of power that device uses during the activity period,

- number of times – a value describe how many times the device is active in a given time frame,
- deviation of time – deviation of the switch on time of the device,
- deviation of amount – deviation of the amount of power the device use,
- deviation of duration – deviation of the length of the active time of the device,
- deviation of number of times – deviation of the number of times the device is activated during given time frame.

The example of the simulation using rules is presented in Fig. 3.11. To this node are connected four projectors that are defined by the same rule:

- duration: 120 [min];
- time from: 09:00:00,
- time to: 17:00:00,
- amount: 0.1,
- number of times: 5,
- deviation of time: 20 [min],
- deviation of amount: 0.1,
- deviation of duration: 20 [min],
- deviation of number of times: 2.

The values for the presented example are chosen using the common sense, as unfortunately no research has jet been made about the frequency of using the projectors, neither a test installation has been available for this study.

Algorithm of generating such data has one major complication: the device might be switched on multiple times, but the periods of switching on should not overlap. In this example it is preferred that projector is switched on for two hours, but we the situation when it has to be on for 240 min, or 250 min is also possible, but it would be unwanted to see it on for 30 minutes. To realize that requirement the algorithm uses heuristic algorithm of choosing

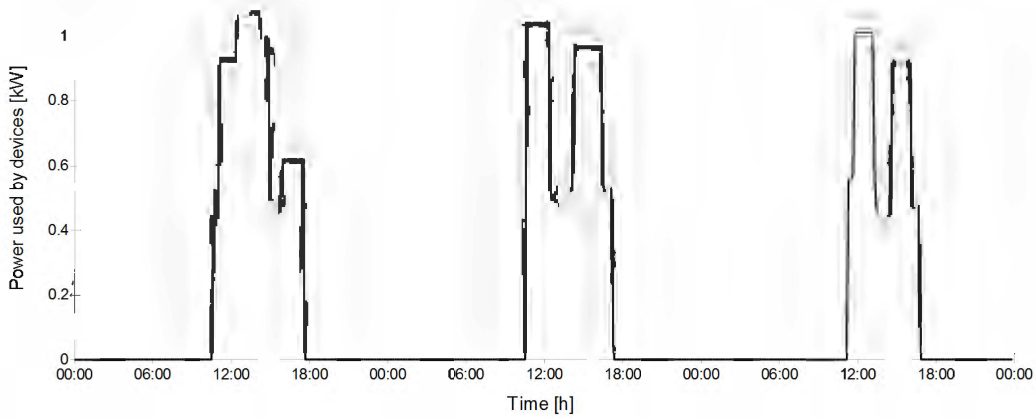

Figure 3.11: Examples of simulated power consumption for node 124.

the time period. The outline of the algorithm of simulating the devices power consumption from the rule is presented in Alg. 1. The most interesting part of it is the function correctOverlap, which is in more detail shown in Alg. 2. Method iterates through all the set activation periods and checks for overlaps, if the overlap is found it randomly choses if the chosen time should be shifted backward in time or forward. Shifting means moving the start time of the device in such a way that it starts immediately after the overlapping activation period (in case of forward shift) or that it ends immediately before the activation period starts (in case of backward shift). The trick is that each time the shift is made the activation period counter is reseted to initial value, which forces the program to check from the beginning for overlaps. This algorithm uses random shifting and is not guaranteed to simulate requested number of activation periods, but it prevents overlap and does not equally distribute the activation periods which would look artificial.

Rules used for simulation are as presented in table 3.4.

3.5 Combined rules with short profiles

The requirement was that the simulator developed should be as general as possible, to be able to simulate the operation of most existing devices. That can be obtained by combining the ideas of rules and profiles. For devices described by a profile, such as a fridge or a freezer, the profile is used. De-

Algorithm 1 ruleGenerate()

```
Create empty profile
Find rule for this device
Draw number that indicates how many operation cycles has the device
for i = 0 ; i < numberOfTimes ; i++ do
    duration =chooseDuration()
    chosentime = chooseTime()
    chosentime = correctOverlap()
    addToProfile(duration, chosentime)
end for
```

Algorithm 2 correctOverlap()

```
counter =0
for  j = 0 ; j < i ; j++ do
    if counter>n then
        return  null; {It is not possible to find time period when device will
        be switched on.}
    end if

    if chosentime overlaps with previously chosen operation times then
        if randomBoolean == true then
            chosentime = ShiftForward()
            if chosentime outside of the time limits then
                chosentime = ShiftBackward()
            end if
        else
            chosentime = ShiftBackward()
            if chosentime outside of the time limits then
                chosentime = ShiftForward()
            end if
        end if
        counter++; j=-1;
    end if
end for
return  chosentime
```

Name of the rule	duration	time from	time to	number of times	deviation of time	deviation of amount	deviation of duration	amount	deviation of number of times
light	50	18:00	01:00	5	120	0.4	40	0.9	2
emergency light	60	16:00	05:00	1	120	0.4	60	1	2
printer	10	10:00	18:00	4	120	0.4	5	1	3
projector	120	09:00	17:00	5	20	0.1	20	1	2

Table 3.1: Rules used in the simulation

vices that are activated by a person and controlled by person's actions, are described by rules. Devices that would benefit from both are appliances that are operated by human, but if they are switched on they have a fixed operation cycle. Example of such situation is a coffee machine: user choses the time to switch it on, but the cycle of coffee making is almost the same for all types of coffees. Rules define a probability of starting an action at certain time. When a device is active, the simulator generates consumption data according to its profile. A rule has the same set of parameters as described in section 3.4.

Profiles are by default short and unlike in rules from section 3.2 they are described as a list of pairs: minute of change and value. The minutes are representing a moment of change: first minute is always 0 and the next entry is showing how many minutes later the change in power occurs. Value represents the percentage of the maximum power usage of the device. Example of the generated profile for node number 152 is presented in Fig. 3.12, to this node 4 printers are connected, which have defined rules and profiles. Short profiles used for testing of the system are presented in Fig. 3.13–3.14.

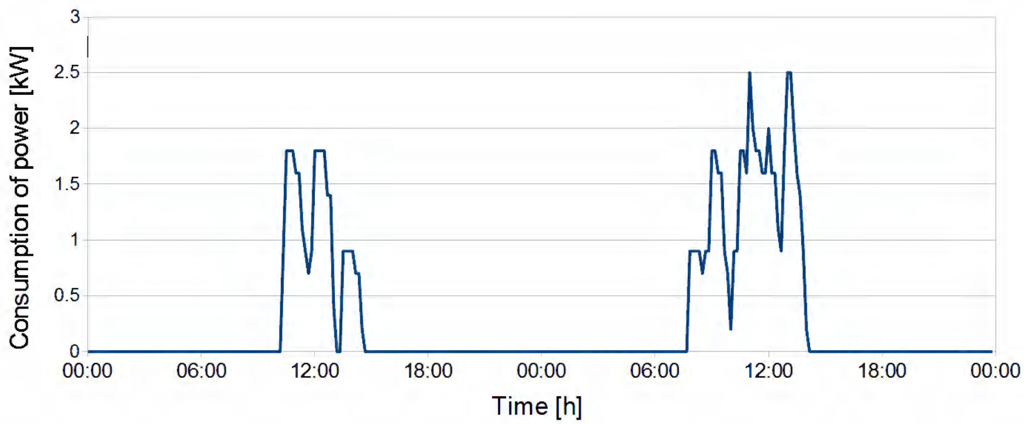

Figure 3.12: Examples of simulated power consumption for node 152.

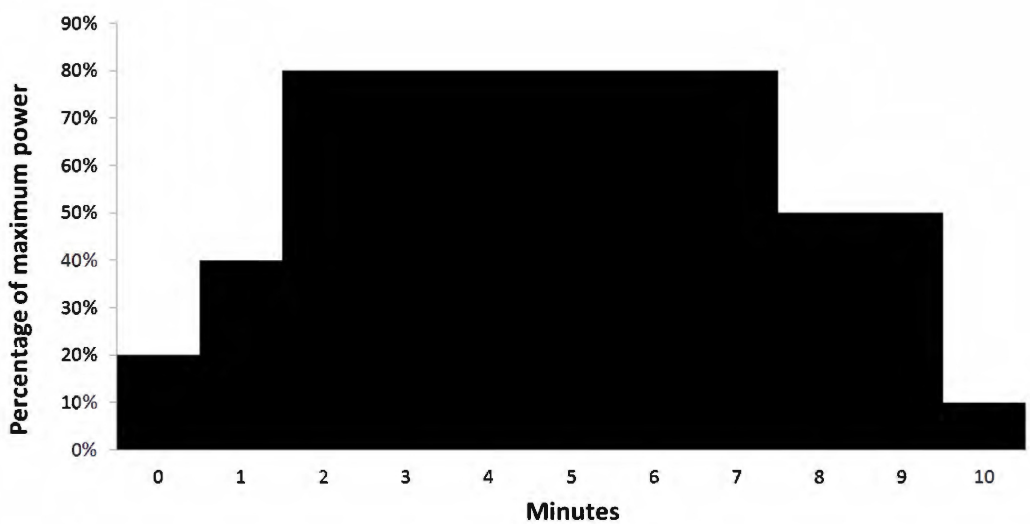

Figure 3.13: Short profile used to describe operation of some lights.

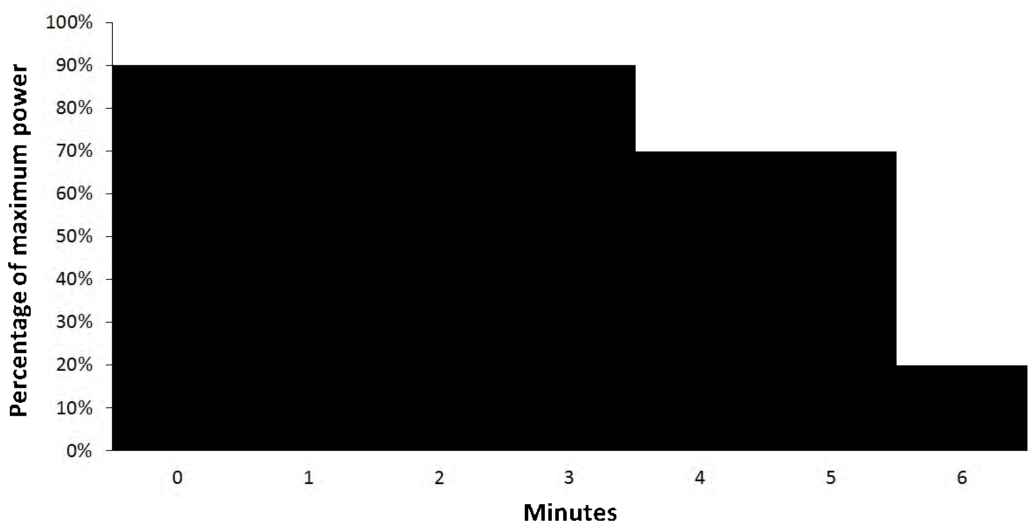

Figure 3.14: Short profile used to describe operation of a printer.

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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