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Simulation of energy consumption in a microgrid for demand side management by scheduling

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***Abstract*—Energy management systems (EMS) are necessary when smart grids and microgrids are considered. Simulation of energy consumption is very useful in planning and testing such systems. In this article we present the problems of simulating energy consumption and show concept of a very general load simulator. The simulator can generate time series of consumption from fixed profiles and also from the defined rules describing use of energy by the devices. The rules describe the probabilistic distribution of the device behaviour. The architecture of the implementation is also presented.**

I. INTRODUCTION

THE possibilities to test the energy management system in reality are very limited due to lack of existing microgrid infrastructures. But they may be tested using simulators. Data about wind speed, irradiance and temperature required for renewable energy sources simulation can be obtained from direct measurements or meteorological models.

Simulators of consumed energy described in the literature are usually simple as main effort is channelled towards creating management systems for the next generation of electric networks. They usually are based on general profiles collected from few devices. Each device has its own profile of energy requirement that varies in time. The amount of energy used by given equipment can be measured, but the general, statistical data of how frequently and how long people use devices are missing. Attempts have been done to measure the average amounts of power that different groups of consumers use during longer period. A report about the energy usage in Spain [1] is the most complete in that field (in [2] the short summary of the [1] in English is presented). Due to huge differences in culture, climate and wealth of the regions, the results of such research cannot be directly used in simulation of grids in different geographical locations, making the ability to simulate systems in defined localisations difficult.

The contents of the paper is as follows. The following section II will explain the idea of a microgrid and the context of the simulation. An idea of the character of the microgrid considered in this work will be also presented. In section III, the overview of the energy production consumption is described. The next section IV presents different methods of describing consumer behaviours, section V describes the concept of the simulator. The last section concludes the article.

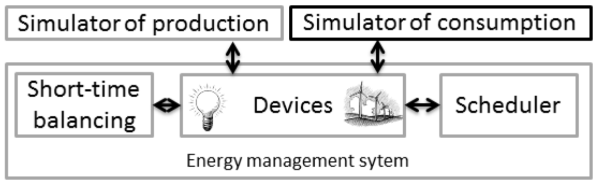

Fig. 1. A diagram of the elements of the considered system, where devices are represented by agents being parts of the Short-Time Balancing System, which uses production levels of controllable power sources from the Scheduler.

II. SMART GRIDS AND 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. A *microgrid* is a part of the grid, that might include producers, consumers, energy storage units and prosumers, which has the ability to connect or disconnect to/from the external power grid and balance the energy within itself.

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.

In this article a small microgrid consisting of few buildings and connected to an external distribution network is considered. The general overview of this grid is presented in Fig. 1. The microgrid is a research and education centre with a hotel and a restaurant. Its energy producers and consumers are controlled by the complex Energy Management System (EMS), which can be divided into two main parts: the Scheduler and the Short-Time Balancing System. Detailed description of this system can be found in [3].

The Scheduler (under development by Wroclaw University of Technology) is a program that arranges the planned events and tasks in order to minimise the cost of the microgrid operation (the cost of obtaining energy necessary to power all the tasks). The input data to the Scheduler are information on planned events, e.g. organization of a conference, a training, conduction of an experiment, hosting a person in the hotel, etc. All these events have defined time constraints, usage power profiles and locations where events can take place. The Scheduler is using a heuristic algorithm to place a task in a location at a certain interval of time.

The Short-Time Balancing System is dealing with deviations from the schedule. Its main goal is to balance the produced and consumed energy as fast as possible. It is implemented as a multi-agent system. Wooldridge in [4] defines an *agent* as a program that fulfils its goals by taking autonomous decisions based on the data received from the environment (sensors, input information). The concept of a multi-agent system as considered in [5] and [6] fits well to handle the problems of power grids. In the Short-Time Balancing System an agent is assigned to each source, energy storage unit and load node of the network. A node is an aggregation of consuming devices, e.g. one line of sockets on one floor of a building. The load nodes are divided into two groups: the ones that have to be powered (the reserved nodes) and the ones that can be switched off under power deficit (the unreserved nodes). An agent receives information about the state, the energy produced or required from its device. When the device is in an unbalanced state, the agent negotiates with other agents to contract energy for its device (both in case of its excess or deficit).

EMS is ready and working, but testing it requires running it for a certain amount of time, e.g. one year, and multiple times, to get the average time of balancing and the number of imbalances. In [7] authors assume that a test of multiagent system is statistically significant with the simulation size of at least 200.

III. Simulation of energy consumption

Simulating the amount of energy produced by renewable sources requires simulating the weather conditions. The data such as temperature, wind speed and water flow are available for us for a large number of years, but insolation was measured for much shorter time and might not be sufficiently long for an exhaustive testing.

In any case, the gathered information is not sufficient if long time simulations have to be done (e.g. to test how system copes with seasonal differences). It is necessary to generate long time series of data. We used for this a block-matched bootstrap method which samples available data and assembles them to create a time series that has statistical properties close to the original data, and is of the required length [8], [9].

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. In a household, usually single devices, as oven or microwave, are considered [2]. In larger networks, at levels of groups of houses, general profiles are used (like in [10]). In large networks profiles are grouped by sectors, like commercial, residential, industrial.

For some purposes the general profiles are sufficient, e.g. in [11] they are used to verify the design of the network (to identify possible overloads or violation of constraints). Only eighteen exemplary load-flow calculations are presented there, with 19 profiles for different categories of loads, but they 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 (values of a profile are 1-hour averages, so there are only 24 different load values for a day) to test the dynamic behaviour of the microgrid.

Profiles for a big group of consumers can be easily derived, as any outstanding or not common behaviours tend to be compensated by each other, so they do not vary very rapidly. On the 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 its peak usage is around late afternoon. Weekends and holidays are introducing disturbances to the working day cycles. Moreover, seasonal differences are visible, caused by changes in the outer temperatures (e.g. large amount of power is used for air-conditioning), long holiday seasons and changes in labour structure [1].

On the contrary, in microgrids each consumer has a relatively bigger influence on the profile than in large grids, e.g. 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. Thus, profiles are not sufficient for microgrid simulation purposes.

The most comprehensive research about 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, whith 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 categorisation. The authors of the report emphasise 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, days of week, times of day, months, holiday distributions, structure of labour and economic situation. It demonstrates the difficulty to obtain one reliable description of consumer structure even within small area.

The EMS considered in the present paper 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 is a considerable amount. Such lessons can be planned and entered to the Scheduler 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

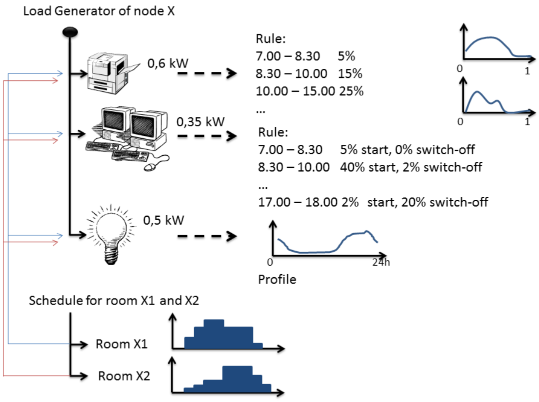

Fig. 2. A diagram of different possible descriptions of energy consumption.

average power usage is placed in the schedule for a specific time with a duration of e.g. 1.5 hour.

For the Short-Time Balancing System, 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 load simulator generates the power that is consumed in certain nodes. It also knows which nodes in what level contribute to the supplying energy for the location that Scheduler chose for the executed task. Considering both Scheduler locations and node division, it is required to perform the load simulation in smaller parts of the microgrid than belonging to one node. Simulating the power usage of each device gives much more 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 [12] a detailed analysis of representative office environment was conducted to test the model designed. 500 electrical devices were identified, mostly usage dependent. The modelling of users behaviour regarding the use of electric equipment is the most difficult part of simulation, as people do not like to be interrogated. Unfortunately, knowledge of typical human behaviours of using devices is crucial to carry out reliable power load simulators.

IV. Description of consumer behaviour

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.

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. Device profiles are made to represent energy usage by a device during a certain time period. Such profiles 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 coffee machine, a fridge or a freezer. Profiles are also reliable when there are many small consumers of energy, for example light bulbs. In this case a single device has little influence on the overall power consumption and multiple small deviations tend to level the usage. Profiles define the average, typical behaviour and are not suitable to describe events that happen with low frequency or of 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 behaviour. 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.

Power consumption of employees' computers might be dependent on the current circumstances, the work the person is doing, the habits of different people and it is difficult to obtain a general profile. The method of describing that behaviour may be a probability distribution of switching on the device. That means describing loads by a set of rules. This type of description is introduced in [1] according to the Spanish behavioural data. The work of elements 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 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).

We required that the simulator developed should be as general as possible, to be able to simulate operation of most of existing devices. That can be obtained by combining the ideas of rules and profiles. The example of such description for devices connected to one node is presented in Fig. 2. For devices described by a profile, like for a fridge or a freezer, the profile is used. Devices that are activated by a person and person actions control them, are described by rules. For the loads that have defined profiles for actions, but the actions are executed by users with a certain probability, the simulator uses both the profile and the rules. 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 is a set of parameters that describe the operation of a device. These parameters describe the probability, the activation time and the intervals in which certain use of electric power happens. Different types of rules may define the time and the probability when the state of the device changes. For

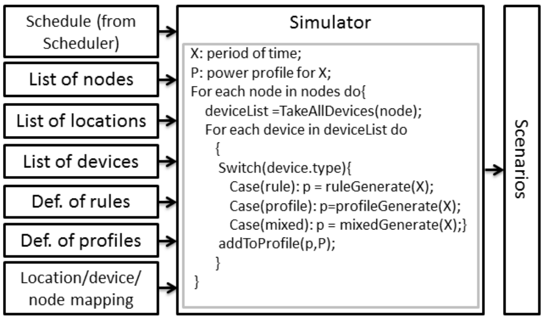

Fig. 3. Concept of the Simulator of consumption with data sources, outcome and general description of the algorithm.

example, the computer is switched on and continues this state until the user switches it off, which is also defined by a rule. Simulator use a definition of a consumption described as a set of rules with probabilities of activating an action. One rule is bound to one type of device but may be a complex one and consist of a probability of switching on, off and changing the working point of devices.

V. 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.

Data that have to be available for the simulator consists of the schedule made by the Scheduler, the list of nodes with information how many and what type of devices are connected to them, the mapping between devices, nodes localisations (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 nodes 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, at each sampling time. Each device is processed depending on the type of the device, and the load is generated from the profile or from the rule. The most important factor is the date and the time, as both rules and profiles are parametrised by them.

VI. 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. A real infrastructure for testing purposes is often not available. Detailed profiles of energy usage of devices can be measured, but they do not reflect the way people use devices. User behaviour is very varied and influenced by many factors. Simulator of energy consumption has to mimic this behaviour 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 behaviour. Based on that it creates time series of energy consumption aggregated per node, which is a tool for EMS testing.

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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