Raport Badawczy

Research Report

RB/38/2013

Modeling consumption of energy by different devices in the center

W. Radziszewska, Z. Nahorski

Instytut Badań Systemowych
Polska Akademia Nauk

Systems Research Institute
Polish Academy of Sciences

POLSKA AKADEMIA NAUK

Instytut Badań Systemowych

ul. Newelska 6

01-447 Warszawa

tel.: (+48) (22) 3810100

fax: (+48) (22) 3810105

Kierownik Zakładu zgłaszający pracę:
Prof. dr hab. inż. Zbigniew Nahorski

Warszawa 2013

SYSTEMS RESEARCH INSTITUTE
POLISH ACADEMY OF SCIENCES

Weronika Radziszewska, Zbigniew Nahorski

Modeling consumption of energy by different devices in the center

Warszawa 2013

Contents

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 4

Experiments

The simulator of consumer behavior imitates real world behavior from the devices. To achieve this, it is developed using probability profiles, usage profiles, rules and a combination of rules and usage profiles. It generates a pseudo random behavior of consumers, mimicking the typical, expected behavior. The simulator can generate the power usage of multiple nodes in given intervals. To run simulations of the Short-time Power Balancing System in shorter time the time factor is used to simulate a speed-up clock. The downside to speeding up the simulation, is that the amount of data in a small time interval increases with the speed-up factor. This results in an amount of data, that comes at a speed which poses problems with processing and storing. The multiagent system has to balance within defined time limits, but if these get too short the system cannot manage to read all information and consequently fails to balance. This effectively puts an upper limit on how much the simulation can be sped up.

The first test was performed with the intention of making sure the system works as expected: communication between nodes, transfer of data, storage of data and possibility of analysis of the outcomes. A first test on a single computer quickly showed the limits of running both the database and a number of nodes (each with a set of agents) on a single machine. To allow for a more elaborate configuration, a test on a computer network was performed. The test was run on multiple computers: each computer hosted the agents associated with one node. The details and results of this experiments were described in [8]. These tests did not use the advancely simulated data, but rather a simpler, random approach. While less consistent with the real world, it provided with sudden changes at unexpected times, which were interesting for this short functionality test. It was possible to speed up the simulation by a factor of 120, while still having all imbalances covered within the defined time (in this case, 1 minute).

As it is possible to speed up the simulation with a factor of 120 and one node per computer it might be possible to decrease the factor, but at the same time increase the number of nodes modeled in a computer. This would allow to upscale the simulation from a few nodes to a large number of them. It needs to be noted that all agents of a node write to the database, so this might still be a limiting factor. Furthermore, all computers communicate via the network, so also this might be a bottleneck.

For this larger scale test, 128 nodes over a network were simulated: ten computers were used to host the agents associated with the nodes, one computer hosted the JADE framework and specific agents (e.g. Morris column), and one computer hosted the database for the results. To further make the simulation more realistic, proper simulators for both consumers and producers were used. The first observation is that it was possible to run the simulation approx. 30 times faster than real time. The database contained no signs of starvation of specific nodes, nor did any nodes got abnormally high preference. The second observation was that the network (a 1 Gbit network, all computers connected to the same switch) posed no bottleneck for the communication. The system does require some communication, but as these are all small data packets, the amount of traffic was far below the capacity of the network. The last observation unfortunately was that there were a few imbalances uncovered and that the time of balancing was longer than expected. This is what we expect to happen if the system runs into a bottleneck: the same behavior was observed on a single computer when too many nodes were simulated. To explain the current imbalances, we need to consider the system on which the experiments were run. As it is not straight forward to obtain full access to 13 computers, we were given access to the school's PC room. This room contains fairly standard PC's, on which a lot of software was installed and running. We noticed occasional lag when using the computers, and suspect that - to some extent - software present on the systems or processes running on the systems might have upset our simulation. The computers also had a relatively low amount of memory, which may pose a problem for the database in particular: all agents are writing to the database, and updating it. Any problem with the database would immediately result in issues with balancing. The database was fine tuned and optimized to improve performance, but it did not prevent the issues from oc-

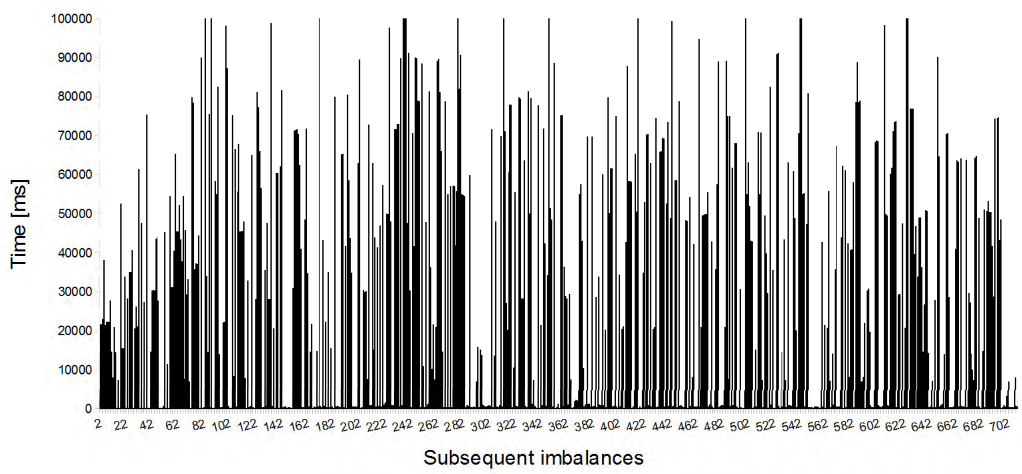

Figure 4.1: Time of balancing power during one of the performed stress tests.

curring. Further optimizations to the test configuration are needed in order to perform large scale experiments.

In Fig. 4.1 the time of covering the imbalances during the stress test is presented. While in test of one node per computer the average balancing time was less than 20 ms, here some times exceed 100 seconds which is far worse than expected. Good aspect is that the balancing always occur, which would suggest problems with inserting the data to the database, as agents are designed to refuse outdated balancing requests.

For future experiments, it is anticipated that a more controlled environment will provide more consistent results. This can be achieved by still using the PC room, but running a dedicated operating system in which we run our clients, or by obtaining computing time on a supercomputer.

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.

Bibliography

[1] Atlas de la demanda eléctrica española. Technical report, RED Eléctrica de españa, 1999.

[2] D. Allaway. Computers and monitors: When should i turn them off? Technical report, State of Oregon Department of Environmental Quality, August 2002.

[3] Dorota Kowalska, Mirosław Parol, Jacek Wasilewski, and Tomasz Wójtowicz. Komputerowe zarządzanie energią w ośrodku badawczo-szkoleniowym z rozproszonymi źródłami energii i zmiennym zapotrzebowaniem energetycznym na eksperymenty badawcze. zadanie pt. opracowanie modeli matematycznych sieci elektroenergetycznych, instalacji elektrycznych oraz instalacji (sieci) cieplnych, a także komputerowych modeli fizycznych i ekonomicznych: odbiorów energii elektrycznej, odbiorów ciepła, rozproszonych źródeł energii elektrycznej i ciepła, zasobników energii elektrycznej i ciepła w ośrodku badawczoszkoleniowym. Technical report, Instytut Badań Systemowych PAN, 2011. praca niepublikowana.

[4] A. B. Lovins, E. K.e Datta, T. Feiler, K. R. Rabago, J. N. Swisher, A. Lehmann, and K. Wicker. *Small is profitable: the hidden economic benefits of making electrical resources the right size.* Rocky Mountain Institute, 2002.

[5] Z. Nahorski, W. Radziszewska, and M. Osuch. Modeling electricity generation potential of a micro hydroelectric power plant. Technical report, Systems Research Institute Polish Academy of Sciences, 2013.

[6] Z. Nahorski, W. Radziszewska, M. Parol, and P. Pałka. Intelligent power balancing systems in electric microgrids (in polish). *Rynek Energii*, 1(98):59–66, 2011.

[7] Z. Nahorski and B. Solarz-Niesłuchowski. Analiza potrzec i opracowanie założeń dla sieci i systemu komputerowego dla kompleksowej obsługi Centrum Badawczego PAN "Konwersja energii i źródła odnawialne" w gminie Jabłonna. Technical report, Instytut Badań Systemowych PAN, 2008.

[8] P. Pałka, W. Radziszewska, and Z. Nahorski. Balancing electric power in a microgrid via programmable agents auctions. *Control and Cybernetics*, 4(41):777–797, 2012.

[9] M. Parol. Profile dobowe zapotrzebowania na moc przewidzianych do realizacji eksperymentów badawczych oraz wybranych typów odbiorów w poszczególnych obiektach osrodka badawczo-szkoleniowego. Technical report, Systems Research Institute Polish Academy of Sciences, 2011.

[10] M. Parol, J. Wasilewski, T. Wójtowicz, and Z. Nahorski. Low voltage microgrid in a research and educational center. In *CD Proceedings of the Conference "Elektroenergetika ELEN 2012"*, page 15, September 2012.

[11] Mirosław Parol, Jacek Wasilewski, and Tomasz Wójtowicz. Komputerowe zarządzanie energią w ośrodku badawczo-szkoleniowym z rozproszonymi źródłami energii i zmiennym zapotrzebowaniem energetycznym na eksperymenty badawcze. zadanie pt. opracowanie projektu sieci elektroenergetycznej niskiego napięcia oraz fragmentów instalacji elektrycznych w poszczególnych obiektach ośrodka badawczo-szkoleniowego, łącznie z określeniem odbiorów energii elektrycznej oraz doborem rozproszonych źródeł energii elektrycznej (turbin wiatrowych, baterii fotowoltaicznych, turbin wodnych, silników tłokowych), a także zasobników energii elektrycznej (np. baterii akumulatorów) – etap i. Technical report, Instytut Badań Systemowych PAN, 2011. praca niepublikowana.

[12] M. Vasirani and S. Ossowski. A collaborative model for participatory load management in the smart grid. In *Proc. 1st Intnl. Conf. on Agreement Technologies*, pages 57–70. CEUR, 2012.

[13] H. Vogt, H. Weiss, P. Spiess, and A.P. Karduck. Market-based prosumer participation in the smart grid. In *4th IEEE International Conference on Digital Ecosystems and Technologies (DEST)*, pages 592–597. IEEE, 2010.

[14] P. Vytelingum, T. D. Voice, S. D. Ramchurn, A. Rogers, and N. R. Jennings. Agent-based micro-storage management for the smart grid. In *Proceedings of the 9th International Conference on Autonomous Agents and Multiagent Systems: Volume 1*, AAMAS '10, pages 39–46, Richland, SC, 2010. International Foundation for Autonomous Agents and Multiagent Systems.

[15] P. Vytelingum, Thomas D. Voice, S. D. Ramchurn, A. Rogers, and N. R. Jennings. Theoretical and practical foundations of large-scale agent-based micro-storage in the smart grid. *J. Artif. Int. Res.*, 42(1):765–813, September 2011.

[16] J. Wasilewski, M. Parol, T. Wojtowicz, and Z. Nahorski. A microgrid structure supplying a research and education centre - Polish case. In *Innovative Smart Grid Technologies (ISGT Europe), 2012 3rd IEEE PES International Conference and Exhibition on*, pages 1–8, 2012.

[17] J. Wasilewski, M. Parol, T. Wójtowicz, and Z. Nahorski. A micro-grid structure supplying a research and education centre – polish case. In *Pendrive Proceedings of the 3rd IEEE PES "Innovative Smart Grid Technologies (ISGT 2012) Europe Conference"*, page 8, October 2012.