Raport Badawczy
Research Report

RB/27/2014

An intelligent distributed system for flexible management of variable energy supply and demand in microgrids

W. Radziszewska

Część II

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 2014

SYSTEMS RESEARCH INSTITUTE
POLISH ACADEMY OF SCIENCES

Weronika Radziszewska

An intelligent distributed system for flexible management of variable energy supply and demand in microgrids

Part II

Warszawa 2014

Chapter 7

Conclusion

Impressive changes in electricity grid structures have been initiated by the emergence of new technologies, the new regulations to fight against the global warming, increasing demand for the secure supply of energy and rising prices of electricity. These changes gravitate toward development of renewable energy sources, prosumers and microgrids. Recent research results indicate that it is possible to create an energy self-sufficient community, that can be even selling surpluses of energy. The energy produced by renewable sources is, however, volatile, as it depends on changing meteorological conditions. Also the consumption of the energy in microgrids is proportionally much more volatile than in bigger grids. The problems caused by uncertain production and consumption can be overcome by using the computer based Energy Management Systems.

In this work, a modular distributed EMS is presented. The novelty of the solution presented is first of all in the complex treatment of the problem. It includes two modules dealing with balancing the power produced and consumed in the microgrid. One module solves in advance the task scheduling problem, in order to find a suboptimal way of shifting the loads to be possibly covered by the energy produced within the microgrid. The short-time power balancing module balances the power in the real time by activating both the generation and the load side of the microgrid. For this, it uses the multi-agent technology. Thus, both production and consumption of the energy in the grid self-adapt to the changing energy needs and supply.

The main aim of the system is to optimize (generalized) costs of exploiting the electric energy in a Research and Education Center, which is simulated with a considerable high accuracy to allow for testing the EMS operation. As compared to the simple reduction of the energy bought, caused by straight exploitation of the renewable energy sources, application of the EMS provides savings due to making long-term deals with external power grid, which is cheaper in comparison to trading on the balancing (spot) market, and then possibly precisely following the contracted power trajectory, in spite of disturbances resulted from randomness in generation and demand of energy. In all decision making stages soft suboptimal algorithms are applied, as metaheuristic or multi-agent ones.

Although a Research and Educational Center is considered in the paper, the elaborated system and methodology is of a general character. Many solutions are opened and can be easily redefined. So, it can be applied as well for other grids.

To test the system the insolation, wind speed, water level and consumption simulators had to be designed and implemented. For weather data some specific requirements had to be met: data had to be adequate to the location of the microgrid and had to be calculated fast for long time (more than a year). For this purpose the Matched-Block Bootstrap was used. It is a fairly simple and fast method that generates data that have satisfying statistical properties.

Simulating power consumption proved to be more complex and much less researched problem than weather simulation. The most common method of describing the consumption are 24-hour or longer profiles, which is not enough for system that should balance continuous changes in power levels. Consumption simulator offers different, adjusted to the type of a device, ways of describing the behavior: profiles, probability profiles, rules and combination of rules with short profiles.

7.1 Open questions and problems

This work showed that agent approach is very suitable for considering balancing problem and that the computer system can balance the electric power in microgrid in desired time. The continuation of this project should aim at connecting the system to the real devices to check its operation in real-life conditions.

To use efficiently such system in real conditions it probably will be necessary to reimplement the system to more controllable environment and progrmming language. JAVA and JADE framework have a lot of advantages, but the move to more controllable and optimized programming language (e.g. C++) can be beneficial for performance.

The power storage units are mainly focused on covering very short and small imbalances. But this type of device can take part in more long-term planning. The possibility of scheduling charging and discharging batteries by the Planner might help decreasing imbalances. There should me more done to evaluate the usage of batteries and battery powered cars in such facility.

The island mode operation of microgrid was not considered with enough details in this work, mainly due to the inability to define the priorities of priority of switching on and off of devices in situation of power shortages. Additional research should be done to evaluate which devices have to be maintained operational in island mode and what is the procedure of changing the mode. Some devices require some time for safe switching off and others operation is crucial, but short deficit of power does not cause any damage to them.

The Research and Educational Center has one owner, which eliminates the problem of division of costs and gains. In the more general case such aspects should be considered. There is a number of scientists that work on that problem, e.g. [120] using game-theory approach.

There should be also a continuation of research considering demand response aspects of the problem. Introduction of more intelligent devices can make demand side management more efficient and allow for more optimal usage of the power. The amount of savings and the level of control of a device has still to be researched.

Trading with external network is the key to optimizing the cost of power. In the project the model of the power market for small amounts of electricity was considered. The existing balancing system should be extended to consider the long-term deals between the owner of microgrid and the power distributor. That would allow negotiating possibly cheaper deals for power. Such scenarios have still to be developed.

The testing of the system was very important, but could be done using simple generators of demand and uncontrollable supply. There should be done more research to analyse how people use the power and how demand is created. That is a crucial problem in creating microgrids which are more volatile to the small changes in demand patterns.

Abbreviation list

AI	Artificial Intelligence
AMS	Agent Management System
CGB	Condensing Gas Boilers
CHP	Combined Heat and Power
DEMS	Distributed Energy Management System
DSM	Demand Site Management
EMS	Energy Management System
FIPA	Foundation for Intelligent Physicl Agents
GUI	Graphical User Interface
GM	Gas Microturbine
JADE	JAVA Agent DEvelopment Framework
kW	Kilowatt
LECR	Laboratory of Energy Consumption Rationalization
LMEB	Laboratory of MicroCHP and Ecological Boilers
LPISE	Laboratory of Power Industry Safety Engineering
LST	Laboratory of Solar Techniques
LWPE	Laboratory of Wind Power Engineering
LV	Low Voltage
MABB	Matched-block bootstrap
MAS	Multi-agent System
MHPP	Micro Hydroelectric Power Plant
ms	miliseconds
MV	Medium Voltage
MVT	Micro Wind Turbines
P	power
PHEV	Plug-in hybrid electric vehicle
PV	Photovoltaic panels
Q	reactive power
RE	Reciprocating Engine
s	seconds
SMES	Superconducting Magnetic Energy Storage
SOA	System Oriented Architecture
U	voltage
VPP	virtual power plants
VP	virtual prosumer

Bibliography

[1] (1999): Atlas de la demanda eléctrica española. Tech. rep., RED Eléctrica de españa.

[2] Abbey, C. and Joos, G. (2005): Energy management strategies for optimization of energy storage in wind power hybrid system. *Power Electronics Specialists Conference, 2005. PESC'05. IEEE 36th*, 2066–2072, IEEE.

[3] Aghaei, S., Nematbakhsh, M. A., and Farsani, H. K. (2012): Evolution of the world wide web: From web 1.0 to web 4.0. *International Journal of Web and Semantic Technology*, **3**.

[4] Allaway, D. (2002): Computers and monitors: When should i turn them off? Tech. rep., State of Oregon Department of Environmental Quality.

[5] Anderson, C. and Anderson, J. (2004): *Electric and Hybrid Cars: A History, 2d ed.*. McFarland, Incorporated, Publishers.

[6] Arthur, W. B. (1994): Complexity in economic theory: Inductive reasoning and bounded rationality. *The American Economic Review*, **84**, 406–411.

[7] Bäck, T. (1996): *Evolutionary algorithms in theory and practice: evolution strategies, evolutionary programming, genetic algorithms*. Oxford University Press.

[8] Baczyński, D., Piotrowski, P., and Wasilewski, J. (2011): Algorytmy prognozowania zapotrzebowania na energię elektryczną i cieplną oraz wytwarzania energii elektrycznej i cieplnej. Tech. rep., Systems Research Institute PAS.

[9] Balijepalli, V., Pradhan, V., Khaparde, S., and Shereef, R. M. (2011): Review of demand response under smart grid paradigm. *Innovative Smart Grid Technologies - India (ISGT India), 2011 IEEE PES*, Dec, 236–243.

[10] Bellifemine, F. L., Caire, G., and Greenwood, D. (2007): *Developing Multi-Agent Systems with JADE*. John Wiley Sons Ltd.

[11] Bertsimas, D. and Tsitsiklis, J. (1999): Simulated annealing. *Statistical Science*, **8**, 10–15.

[12] Caragliu, A., Del Bo, C., and Nijkamp, P. (2009): Smart cities in Europe. Serie Research Memoranda 0048, VU University Amsterdam, Faculty of Economics, Business Administration and Econometrics.

[13] Carlstein, E., Do, K.-A., Hall, P., Hesterberg, T., and Kúnsch, H. R. (1996):, Matched-block bootstrap for dependent data.

[14] Carreras, B. A., Lynch, V. E., Dobson, I., and Newman, D. E. (2002): Dynamics, criticality and self-organization in a model for blackouts in power transmission systems. *Hawaii International Conference on System Sciences*, 63.

[15] Carreras, B. A., Newman, D. E., Dobson, I., and Poole, A. B. (2004): Evidence for self-organized criticality in a time series of electric power system blackouts. *IEEE TRANSACTIONS ON POWER SYSTEMS*, **51**.

[16] Chalkiadakis, G., Robu, V., Kota, R., Rogers, A., and Jennings, N. R. (2011): Co-operatives of distributed energy resources for efficient virtual power plants. *The 10th International Conference on Autonomous Agents and Multiagent Systems - Volume 2*, Richland, SC, 787–794, AAMAS '11, International Foundation for Autonomous Agents and Multiagent Systems.

[17] Chmiel, K., Gawinecki, M., Kaczmarek, P., Szymczak, M., and Paprzycki, M. (2005): Efficiency of JADE Agent Platform. *Scientific Programming*, **13**, 159–172.

[18] Cialdini, R. and Schultz, W. (2004): Understanding and motivating energy conservation via social norms. Tech. rep., William and Flora Hewlett Foundation.

[19] Cramer, G., Reekers, J., Rothert, M., and Wollny, M. (2003): The future of village electrification - More than two years of experiences with AC-coupled hybrid systems. *Proceedings of 2nd European PV-Hybrid and Mini-Grid Conference, Kassel, Germany*, September, 1–6.

[20] Department for Transport, T. R. H. M. F. M., The Rt Hon Norman Baker MP and for Low Emission Vehicles, O. (2013):, Hundreds of new chargepoints for electric cars. Https://www.gov.uk/government/news/hundreds-of-new-chargepoints-for-electric-cars.

[21] Derin, O. and Ferrante, A. (2010): Scheduling energy consumption with local renewable micro-generation and dynamic electricity prices. *CPSWEEK/GREEMBED 2010: Proceedings of the First Workshop on Green and Smart Embedded System Technology: Infrastructures, Methods and Tools*, Stockholm, Sweden, April.

[22] Eberle, U. and von Helmolt, R. (2010): Sustainable transportation based on electric vehicle concepts: a brief overview. *Energy Environ. Sci.*, **3**, 689–699.

[23] Efron, B. (1979): Bootstrap Methods: Another Look at the Jackknife. *The Annals of Statistics*, **7**, 1–26.

[24] Efron, B. and Tibshirani, R. (1993): *An Introduction to the Bootstrap*. Monographs on statistics and applied probability, Chapman & Hall.

[25] Efron, B. and Tibshirani, R. J. (1993): *An Introduction to the Bootstrap*. Chapman & Hall.

[26] Enumula, P. K. and Rao, S. (2008): The potluck problem. *CoRR*, **abs/0809.2136**.

[27] European Commission (2014): Cost-benefit analyses and state of play of smart metering deployment in the EU-27. Tech. rep., European Commision.

[28] Foundation for Intelligent Physical Agents. `http://fipa.org/`.

[29] FIPA (2001): FIPA ACL Message Structure Specification. Tech. rep., FIPA.

[30] FIPA (2002): FIPA Abstract Architecture Specification. Tech. rep., FIPA.

[31] FIPA (2002): FIPA Communicative Act Library Specification. Tech. rep., FIPA.

[32] Froehlich, J., Larson, E., Gupta, S., Cohn, G., Reynolds, M., and Patel, S. (2011): Disaggregated end-use energy sensing for the smart grid. *Pervasive Computing, IEEE*, **10**, 28–39.

[33] Garey, M. and Johnson, D. (1979): *Computers and Intractability: A Guide to the Theory of NP-Completeness*. W. H. Freeman.

[34] Gorczyca, M., Janiak, W., Krysiak, T., and Lichtenstein, M. (2013): Własności oraz algorytmy przybliżone harmonogramowania zdarzeń w ośrodku badawczo-szkoleniowym z rozproszonymi źródłami energii i zmiennym zapotrzebowaniem energetycznym. Tech. rep., Systems Research Institute PAS.

[35] Gorczyca, M., Krysiak, T., and Lichtenstein, M. (2011): Przegląd i analiza możliwości zastosowania metod szeregowania zadań związanych z poborem energii w ośrodku badawczym. Tech. rep., Systems Research Institute PAS.

[36] Gorczyca, M., Krysiak, T., and Lichtenstein, M. (2013): Planista - opis funkcjonalności, instrukcja obsługi. Tech. rep., Systems Research Institute PAS.

[37] Gorczyca, M., Krysiak, T., and Lichtenstein, M. (2013): Power economic dispatch problem with modern cost functions - the complexity and approximation algorithms. *Energy Conversion and Management*.

[38] Gorczyca, M., Krysiak, T., and Lichtenstein, M. (2013): Scheduling activities in a research facility to minimize total cost of consumed energy. *International Journal on Production Economics*.

[39] Hatziargyriou, N., Asano, H., Iravani, R., and Marnay, C. (2007): Microgrids: An overview of ongoing research, development, and demonstration projects. *IEEE Power & Energy Magazine*, **July/August**, 19.

[40] Hesterberg, T. (1997): Matched-block bootstrap for long memory processes. Tech. rep., MathSoft, Inc.

[41] Islam, F. M. R. (2013): *Impact and Utilization of Emerging PHEV in Smart Power Systems*. Ph.D. thesis, School of Engineering and Information Technology, The University of New South Wales, Canberra, Australia.

[42] Iwayemi, A., Yi, P., Dong, X., and Zhou, C. (2011): Knowing when to act: an optimal stopping method for smart grid demand response. *IEEE Network*, **25**, 44–49.

[43] Kaleta, M. and Traczyk, T. (eds.) (2012): *Modeling Multi-commodity Trade: Information Exchange Methods*, vol. 121 of *Advances in Intelligent and Soft Computing*. Springer.

[44] Komninos, N. (2000): Intelligent cities: towards interactive and global innovation environments. *International Journal of Innovation and Regional Development*, **Volume 1**, 337–355.

[45] Kowalska, D., Parol, M., Wasilewski, J., and Wójtowicz, T. (2010): Opracowanie uproszczonego (przez przyjęcie zintegrowanych modeli urządzeń i instalacji cieplnych) projektu sieci (fragmentów instalacji) cieplnej w poszczególnych obiektach ośrodka badawczo-szkoleniowego, łącznie z określeniem odbiorów ciepła oraz doborem rozproszonych źródeł ciepła (kolektorów słonecznych, kotłów do spalania biomasy), a także zasobników ciepła (urządzeń grzewczych, urządzeń chłodniczych). Tech. rep., Systems Research Institute PAS.

[46] Kowalska, D., Parol, M., Wasilewski, J., and Wójtowicz, T. (2011): 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. Tech. rep., Systems Research Institute PAS.

[47] Kwak, J., Varantham, P., Mahesvaran, R., Tambe, M., Jazizadeh, F., Kavulya, G., Klein, L., Becerik-Gerber, B., Hayes, T., and Wood, W. (2012): Saves: A sustanable multiagent application to conserve building energy considering occupantants. Conitzer, Winikoff, Padgham, and van der Hoek (eds.), *Proceedings of the 11th International Conference on Autonomous Agents and Multiagent Systems - Innovative Applications Track (AAMAS 2012).*

[48] LAB-EL Elektronika Laboratoryjna, Opis stacji meteo warszawa.

[49] Lagorse, J., Simões, M., and Miraoui, A. (2009): A multiagent fuzzy-logic-based energy management of hybrid systems. *Industry Applications, IEEE Transactions on*, **45**, 2123–2129.

[50] Lall, U. and Sharma, A. (1996): A nearest neighbor bootstrap for resampling hydrologic time series. *Water Resources Research*, **32**, 679–693.

[51] Lasseter, R., Akhil, A., Marnay, C., Stephens, J., Dagle, J., Guttromson, R., Meliopoulous, A. S., Yinger, R., and Eto, J. (2002): White paper on integration of distributed energy resources: The certs microgrid concept. Tech. rep., CERTS.

[52] Leady, J. R. (2007):, If nobody is going there anymore because it's too crowded, then who is going? experimental evidence of learning and imitation in the el farol coordination game.

[53] Linden, D. and Reddy, T. (2001): *Handbook Of Batteries*. McGraw-Hill handbooks, McGraw-Hill Education.

[54] Linnenberg, T., Wior, I., Schreiber, S., and Fay, A. (2011): A market-based multiagent-system for decentralized power and grid control. Z., M. (ed.), *Proceedings of 2011 IEEE 16th Conference on Emerging Technologies & Factory Automation ETFA 2011*, 1–8, Paul Sabatier University, Toulouse.

[55] Liu, R., Chen, F., Yang, H., Chu, W. C., and Lai, Y.-B. (2004): Agent-based web services evolution for pervasive computing. *Asia-Pacific Software Engineering Conference*, 726–731.

[56] Lovins, A., Odum, M., Rowe, J., and Rowe, J. (2011): *Reinventing Fire: Bold Business Solutions for the New Energy Era*. Chelsea Green Publishing Company.

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

[58] Machiwal, D. and Jha, M. (2012): *Hydrologic Time Series Analysis: Theory and Practice*. Springer.

[59] Malinowski, J. (2012): Opracowanie metod wyznaczania parametrów modeli niezawodnościowych elektroenergetycznych sieci rozdzielczych. Tech. rep., Systems Research Institute PAS.

[60] Malinowski, J. (2012): A simulation model for complex repairable systems with inter-component dependencies and three types of component failures. *Ch. Bérenguer, A. Grall, C. Guedes Soares (Eds.) Advances in Safety, Reliability and Risk Management*, 790–795.

[61] Malinowski, J. (2013): A computer program for the analysis and visualization of a flow network with changing topology. *X.T. Nguyen (Hrsg.) Modellierung und Simulation von Ökosystemen*, 149–163.

[62] Malinowski, J. (2013): Metodyka wyznaczania wskaźników niezawodnościowych charakteryzujących ciągłość zasilania w elektroenergetycznej sieci rozdzielczej ośrodka badawczo-szkoleniowego. Tech. rep., Systems Research Institute PAS.

[63] Malinowski, J. (2014): A method of computing the inter-state transition intensities for multi-state series-parallel systems. *Safety, Reliability and Risk Analysis: Beyond the Horizon*, 1213–1219.

[64] McArthur, S., Davidson, E., Catterson, V., Dimeas, A., Hatziargyriou, N., Ponci, F., and Funabashi, T. (2007): Multi-agent systems for power engineering applications part i: concepts, approaches, and technical challenges. *Power Systems, IEEE Transactions on*, **22**, 1743–1752.

[65] McArthur, S., Davidson, E., Catterson, V., Dimeas, A., Hatziargyriou, N., Ponci, F., and Funabashi, T. (2007): Multi-agent systems for power engineering applications part ii: technologies, standards, and tools for building multi-agent systems. *Power Systems, IEEE Transactions on*, **22**, 1753–1759.

[66] Ministry for Economic and Business Affairs (Denmark) the Regulatory Reform Group (the Netherlands) and the Department for Business, Innovation and Skills (UK), Smart regulation a cleaner, fairer and more competitive eu.

[67] Minkel, J. R. (2008): The 2003 northeast blackout–five years later. *Scientific American*.

[68] mobiThinking, Global mobile statistics 2014 Part A: Mobile subscribers; handset market share; mobile operators. `http://mobithinking.com/mobile-marketing-tools/latest-mobile-stats/a#subscribers/`.

[69] Motors, T. (2013):, Tesla roadster by the numbers. Http://www.teslamotors.com/roadster.

[70] Murray, B. (2009): *Power Markets and Economics: Energy Costs, Trading, Emissions*. Wiley.

[71] Nahorski, Z., Pałka, P., Radziszewska, W., and Stańczak, J. (2011): Założenia dla systemu wieloagentowego do bieżącego bilansowania energii generowanej i pobieranej. Tech. rep., Systems Research Institute PAS.

[72] Nahorski, Z., Pałka, P., Radziszewska, W., and Stańczak, J. (2011): Założenia dla systemu wieloagentowego do bieżącego bilansowania energii generowaneji pobieranej. Tech. rep., RB/61/2011, Systems Research Institute, Polish Academy of Science.

[73] Nahorski, Z., Pałka, P., Stańczak, J., and Radziszewska, W. (2011): Wieloagentowa metodyka zarzadzania niedoborami i nadmiarami energii w sieciach dystrybucyjnych. *Rynek Energii*, **1**, 22–27.

[74] Nahorski, Z. and Radziszewska, W. (2011): Inteligentne systemy bilansowania mocy w mikrosieciach elektroenergetycznych. Tech. rep., Systems Research Institute PAS.

[75] Nahorski, Z. and Radziszewska, W. (2011): Ogólny projekt systemow bilansowania energii w ośrodku badawczo-szkoleniowym. Tech. rep., RB/77/2011, Systems Research Institute, Polish Academy of Science.

[76] Nahorski, Z. and Radziszewska, W. (2011): Ogólny projekt systemów bilansowania energii w ośrodku badawczo-szkoleniowym. Tech. rep., Systems Research Institute PAS.

[77] Nahorski, Z., Radziszewska, W., Parol, M., and Pałka, P. (2012): Intelligent power balancing systems in electric microgrids (in polish). *Rynek Energii*, **1**, 59–66.

[78] Nikonowicz, L. and Milewski, J. (2012): Virtual power plants-general review: structure, application and optimization. *Journal of Power Technologies*, **92**, 135–149.

[79] Nistor, S., Wu, J., Sooriyabandara, M., and Ekanayake, J. (2011): Cost optimization of smart appliances. *Innovative Smart Grid Technologies (ISGT Europe), 2011 2nd IEEE PES International Conference and Exhibition on*, dec., 1 –5.

[80] Pałka, P., Radziszewska, W., and Nahorski, Z. (2013): Application of an auction algorithm in an agent-based power balancing system. Pechenizkiy, M. and Wojciechowski, M. (eds.), *New Trends in Databases and Information Systems*, vol. 185 of *Advances in Intelligent Systems and Computing*, 231–240, Springer Berlin Heidelberg.

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

[82] Palma-Behnke, R., Benavides, C., Aranda, E., Llanos, J., and Saez, D. (2011): Energy management system for a renewable based microgrid with a demand side management mechanism. *Computational Intelligence Applications In Smart Grid (CIASG), 2011 IEEE Symposium on*, 1–8, IEEE.

[83] Parol, M. (2011): Modele komputerowe wewnętrznej sieci elektroenergetycznej, instalacji elektrycznych w budynkach, odbiorów energii elektrycznej, rozproszonych źródeł energii elektrycznej, zasobników energii elektrycznej, a także instalacji (sieci) cieplnych w budynkach, odbiorów ciepła, rozproszonych źródeł ciepła oraz zasobników ciepła w ośrodku badawczo-szkoleniowym. Instrukcja obsługi programu. Tech. rep., Systems Research Institute PAS.

[84] Parol, M. (2012): Opracowanie programu, pracującego w trybie wsadowym, do wyznaczania rozpływu mocy w wewnętrznej sieci elektroenergetycznej oraz w instalacjach elektrycznych poszczególnych obiektów ośrodka badawczo-szkoleniowego, z uwzględnieniem rozproszonych źródeł, zasobników oraz odbiorów energii elektrycznej. Tech. rep., Systems Research Institute PAS.

[85] Parol, M. (2012): "opracowanie scenariuszy działania ośrodka badawczo-szkoleniowego i wykonanie symulacji komputerowych (rozpływów mocy) w oparciu o ustalone zapotrzebowanie na energię (moc) elektryczną i ciepło ośrodka oraz możliwości generacyjne projektowanych rozproszonych źródeł energii. instrukcja obsługi programu". Tech. rep., Systems Research Institute PAS.

[86] Parol, M. (2013): Opracowanie programu komputerowego do wyznaczania wskaźników ciągłości zasilania w węzłach –punktach poboru mocy wewnętrznej sieci elektroenergetycznej ośrodka badawczo-szkoleniowego w stanie pracy synchronicznej z siecią spółki dystrybucyjnej. Tech. rep., Systems Research Institute PAS.

[87] Parol, M. and Wasilewski, J. (2011): Opracowanie scenariuszy działania ośrodka badawczo-szkoleniowego i wykonanie symulacji komputerowych (rozpływów mocy) w oparciu o ustalone zapotrzebowanie na energię (moc) elektryczną i ciepło ośrodka oraz możliwości generacyjne projektowanych rozproszonych źródeł energii - Etap I: Opracowanie prototypu programu do wyznaczania rozpływu mocy w wewnętrznej sieci elektroenergetycznej oraz w instalacjach elektrycznych poszczególnych obiektów ośrodka badawczo-szkoleniowego, z uwzględnieniem rozproszonych źródeł, zasobników oraz odbiorów energii elektrycznej. Opracowanie profili dobowych zapotrzebowania na moc przewidzianych do realizacji eksperymentów badawczych oraz wybranych typów odbiorów w poszczególnych obiektach ośrodka badawczo-szkoleniowego. Tech. rep., Systems Research Institute PAS.

[88] Parol, M. and Wasilewski, J. (2012): Dokonanie przeglądu w zakresie parametrów i funkcji niezawodnościowych wybranych urządzeņ i elementów elektroenergetycznych sieci dystrybucyjnych SN i nn. Opracowanie koncepcji modelu niezawodnościowego sieci dystrybucyjnych SN i nn ośrodka badawczo-szkoleniowego. Opracowanie modeli niezawodnościowych źródeł i zasobników energii elektrycznej w ośrodku badawczo-szkoleniowym. Tech. rep., Systems Research Institute PAS.

[89] Parol, M. and Wasilewski, J. (2012): "opracowanie scenariuszy działania ośrodka badawczo-szkoleniowego i wykonanie symulacji komputerowych (rozpływów mocy) w oparciu o ustalone zapotrzebowanie na energię (moc) elektryczną i ciepło ośrodka oraz możliwości generacyjne projektowanych rozproszonych źródeł energii - etap ii: Opracowanie scenariuszy działania ośrodka badawczo-szkoleniowego. opracowanie końcowej wersji programu do wyznaczania rozpływu mocy w wewnętrznej sieci elektroenergetycznej oraz w instalacjach elektrycznych poszczególnych obiektów ośrodka badawczo-szkoleniowego, a także rozpływu mocy cieplnych w poszczególnych obiektach tego ośrodka, z uwzględnieniem rozproszonych źródeł, zasobników oraz odbiorów energii elektrycznej bądź ciepła. wykonanie symulacji komputerowych (rozpływów mocy) w oparciu o ustalone zapotrzebowanie na moc elektryczną i ciepło ośrodka oraz możliwości generacyjne projektowanych rozproszonych źródeł energii". Tech. rep., Systems Research Institute PAS.

[90] Parol, M., Wasilewski, J., and Wójtowicz, T. (2010): 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. Tech. rep., Systems Research Institute PAS.

[91] Parol, M., Wasilewski, J., and Wójtowicz, T. (2011): 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 II. Tech. rep., Systems Research Institute PAS.

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

[93] Piekut, S., Skoczek, S., and Dąbrowski, L. (2012):, Raport o rynku energii elektrycznej w Polsce. RWE Stoen.

[94] Radziszewska, W., Kowalczyk, R., and Nahorski, Z. (2014): El farol bar problem, potluck problem and electric energy balancing - on the importance of communication. M. Ganzha, M. P., L. Maciaszek (ed.), *Proceedings of the 2014 Federated Conference on Computer Science and Information Systems*, vol. 2 of *Annals of Computer Science and Information Systems*, 1515–1523., IEEE.

[95] Radziszewska, W. and Nahorski, Z. (2013): Energy management in a microgrid using a multiagent system. Tech. rep., Systems Research Institute PAS.

[96] Radziszewska, W., Nahorski, Z., Parol, M., and Pałka, P. (2014): Intelligent computations in an agent-based prosumer-type electric microgrid control system. Kóczy, L. T., Pozna, C. R., and Kacprzyk, J. (eds.), *Issues and Challenges of Intelligent Systems and Computational Intelligence*, vol. 530 of *Studies in Computational Intelligence*, 293–312, Springer.

[97] Ramchurn, S., Vytelingum, P., Rogers, A., and Jennings, N. (2012): Putting the 'smarts' into the smart grid: a grand challenge for artifitial intelligence. *Communications of ACM*, **55**, 86–97.

[98] Ricalde, L., Ordonez, E., Gamez, M., and Sanchez, E. (2011): Design of a smart grid management system with renewable energy generation. *Computational Intelligence Applications In Smart Grid (CIASG), 2011 IEEE Symposium on*, 1–4, IEEE.

[99] Rogers, A., Ramchurn, S., and Jennings, N. (2012): Delivering the smart grid: challenges for autonomous agents and multi-agent systems research. *Proceedings of the 26th AAAI Conference on Artificial Intelligence*, 2166–2172.

[100] Rohbogner, G., Fey, S., Hahnel, U., Benoit, P., and Wille-Haussmann, B. (2012): What the term agent stands for in the smart grid definition of agents and multi-agent systems from an engineer's perspective. *Computer Science and Information Systems (FedCSIS), 2012 Federated Conference on*, 1301–1305.

[101] Royal Academy of Engineering, Smart building people and performance.

[102] Rua, D., Pereira, L., Gil, N., and Lopes, J. (2011): Impact of multi-microgrid communication systems in islanded operation. *Innovative Smart Grid Technologies (ISGT Europe), 2011 2nd IEEE PES International Conference and Exhibition on*, Dec, 1–6.

[103] Samsung, Samsung school – smart education solution. Http://www.samsung.com/global/business/business-images/resource/brochure/2013/04/SamsungSchoolBrochure0423-0.pdf.

[104] Samsung, Smart education.

[105] Schaerf, A., Shoham, Y., and Tennenholtz, M. (1995): Adaptive load balancing: A study in multi-agent learning. *Journal of Artificial Intelligence Research*, **2**, 475–500.

[106] Sharma, A., Tarboton, D. G., and Lall, U. (1997): Streamflow simulation: A nonparametric approach. *Water Resour. Res*, **33**, 291–308.

[107] Shoham, Y. (1991): Agento: A simple agent language and its interpreter. *Proceedings of the Ninth National Conference on Artificial Intelligence*.

[108] Shoham, Y. (1993): Agent oriented programming. *Artificial Inteligence*, **60**, 51–92.

[109] Siemens, Smart lighting public lighting control and maintenance save the environment by saving energy.

[110] Srinivas, V. V. and Srinivasan, K. (2005): Matched block bootstrap for resampling multiseason hydrologic time series. *Hydrological Processes*, **19**, 3659–3682.

[111] Stańczak, J. (2013): Podsystem handlu energią elektryczną z operatorem sieci zewnętrznej. Metoda generowania cen przez operatora. Tech. rep., Systems Research Institute PAS.

[112] System, A. G., Smart streetlights.

[113] The energy law act dated april 10, 1997.

[114] Tixador, P. (2008): Superconducting Magnetic Energy Storage: Status and Perspective. *IEEE/CSC & ESAS EUROPEAN SUPERCONDUCTIVITY NEWS FORUM*, **3**.

[115] Toczyłowski, E., Kaleta, M., Kacprzak, P., and Pałka, P. (2007): Modelowanie rynków energii elektrycznej wybrane zagadnienia. Tech. rep., Systems Research Institute PAS.

[116] Tsikalakis, A. G. and Hatziargyriou, N. D. (2008): Centralized control for optimizing microgrids operation. *IEEE Transactions on Energy Conversion*, **23**, 241–248.

[117] Tsikalakis, A. G. and Hatziargyriou, N. D. (2011): Centralized control for optimizing microgrids operation. *Power and Energy Society General Meeting, 2011 IEEE*, 1–8, IEEE.

[118] Vamosi, R. (2011): Smart meters interfering with home electronics. *SecurityWeek*, http://www.securityweek.com/smart-meters-interfering-home-electronics.

[119] Vanoutrive, T. (2013): *Smart Transport Networks*. NECTAR Series on Transportation and Communications Networks Research Series, Edward Elgar Publishing, Incorporated.

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

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

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

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

[124] Wang W.S., L. Y., Hu Sh. (2011): Wavelet transform method for synthetic generation of daily streamflow. *Water Resources Management*, **25**, 41–57.

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

[126] Wooldridge, M. (2001): *Introduction to Multiagent Systems*. John Wiley & Sons, Inc.

[127] Wooldridge, M. and Jennings, N. R. (1998): Pitfalls of agent-oriented development. *Proceedings of the second international conference on Autonomous agents*, 385–391, ACM.

[128] Wymazał, I. (2014):, Jabłonna. budowa centrum badawczego polskiej akademii nauk.

[129] Zhu, X. and Genton, M. G. (2012): Short-term wind speed forecasting for power system operations. *International Statistical Review*, **80**, 2–23.

Index

agent, 30, 53, 54
agent management system, 57
artificial inteligence, 56

balancing of power, 29
battery, 9, 22, 70
behaviour, 65
  cyclic, 65
  ticker, 65
bootstrap, 32
  matched-block, 32

combined heat and power units, 17
condensing gas boilers, 17
conditional supplying, 18
conditionally reserved, 18, 22
container, 72
controllable device, 7, 8, 20, 62, 63

demand side management, 4, 7, 20, 25, 52

el farol bar, 11
electric load-flow simulator, 22
electric vehicles, 8
energy management system, 8, 17, 18, 22
energy trading, 31
engine, 70
external grid, 66

FIPA, 57, 61
flywheel, 9, 22, 71

gas microturbine, 17, 21, 70

hydropower plant, 21, 62

intelligent agent, 55
irradiance, 32
island mode, 22
island mode operation, 9, 20

JADE, 57, 61, 63, 70

Launcher, 72
load-flow simulator, 24

matched-block bootstrap, 34
message transport service, 57
microgrid, 5
  island mode, 5
  synchronous mode, 5
Microgrid Balancer, 63
Microgrid Environmental Interface, 61
multi-agent system, 53, 54

node, 20
non-spinning reserve, 4

operating point, 7, 59, 60, 66
operation point, 65

photovoltaic panel, 21, 70
physical agent, 70
Planner, 25
platform, 57, 72
plug-in hybrid electric vehicle, 10
potluck problem, 12
power market, 31
power storage units, 10
production side management, 10
prosumer, 5

range anxiety, 10
reciprocating engine, 20, 21
regulation capabilities, 62
reliability factors, 31
renewable power, 5
renewable sources, 23

scheduling multiprocessor jobs, 26
service oriented architecture, 56
short-time balancing, 28
  balancer, 63
  database, 60
  environmental interface, 61, 72
    battery agent, 62
    consumer agent, 62
    source controllable agent, 62
  physical agent, 63
  structures, 61
  time factor, 65
short-time power balancing, 60

short-time system balancing
  regulation capabilities, 66
simulated annealing, 26
simulated microgrid, 18
smart city, 3
smart grid, 4
smart meters, 4
spinning reserve, 4
superconductor, 9

temperature, 32
time factor, 68

unconditional supplying, 18
unconditionally reserved, 19, 22
uncontrollable device, 7, 20, 63

virtual power plant, 31
virtual prosumer, 31

water flow, 33, 62
web 4.0, 55
white pages, 57
wind speed, 33
wind turbine, 20

yellow pages, 57