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 4

Multi-agent systems

4.1 Introduction

Computer systems are evolving faster than ever before. Increasing power of the hardware allowed for more demanding software, which became capable of calculating more complex problems. Wooldridge in [126] describes the most important trends in the history of computing: ubiquity, interconnection, intelligence, delegation and human orientation. Ubiquity means that computer systems are getting more common and appearing in places where no one expected them to be. It seems to be correct, as for instance in Europe there are statistically 124,7 mobile phone subscriptions per 100 people [68] and most of these are smartphones. Such devices are really small computers with not small computing power. The interconnection trend is real: computer systems are usually connected to the Internet or at least almost all of them have such ability. Furthermore, it reached a point where the network is the place where processing takes place and the device is just an interface to it (e.g. cloud computing, web applications). Artificial intelligence is a broadly researched topic, as systems are required to solve problems and fulfill their task using more advanced and complicated algorithms and methods. With the increase of complexity, the computer programs tend to be more autonomous. There also is a trend to facilitate the user interface, to the point that the system should be "guessing" what user wants. Personalization became a key word, the aim of the Graphical User Interface (GUI) is that people feel comfortable with it and want to use it. The user does not know anymore what exactly the program is doing or how it is achieving it, and as long as it works properly he tends not to bother with the details of implementation. Computers became more accessible to people without proper engineering expertise, interfaces aim to be more intuitive and resistant to errors.

Agents and multi-agent systems are part of this trend. The idea of agents has become the subject of research since about 1980 and was slowly gaining popularity, but the fashion for agent solutions came with the spread of Internet. Agents are seen as the next step in creating an intelligent network to make browsing for information and computing more effective. They are considered as autonomous and smart programs that realize tasks with minimal guidance from a user. This approach is still wishful thinking – real agent systems are computer systems with specific tasks and properties: they have some degree of autonomy and they interact with other systems and people. The biggest obstacles that agent systems have to deal with are too high expectations and overestimation of their abilities. There are multiple definitions of agent systems and they are often misinterpreted or abused. The term *agent* has multiple meanings depending on field of research. This can create confusion when the proper explanation of the term is not present. In this chapter, the definition of the agent will be discussed and the agent properties be presented.

4.2 Definition and history of agents

There are many definitions of the word "agent". Most of them look simplistic and all lead to a very similar and general concepts, but understanding what is an agent is much more difficult. In this chapter, only general concepts of agent-based approaches will be presented, for further details can be found in [126] and [108].

One of the simplest definitions of agents was given by Wooldridge [126]: an *agent* is an autonomous computer system, situated in some environment, that performs an action to fulfil tasks and goals defined by the user. An agent should realize its task independently, has decisive power and distinguish itself from the environment. Yoav Shoham in [108] gives slightly different definition: an agent is an entity whose state is viewed as consisting of mental components such as beliefs, capabilities, choices, and commitments. He comments that a number of things can be described in such way and that a clear and formally defined distinction is almost impossible. There are a number of formal definitions of agents ([126], section. 2.5), but they are cannot by applied to all agents in general, but rather to some specific subtype of agents.

A *multi-agent system* is system where a group of agents interact with each other in an environment. This interaction is usually realized by communication (defined in broad sense), which allows for autonomy in behavior.

When there are different definitions of agents (even formal ones), it is clear that there might not be a unity about understanding of agent concept. However, both Shoham and Wooldridge explain the same thing in their definition: an agent that is an approach of looking at programming from a higher level of abstraction. The agent is not a type of program, or a thing, it is the way we treat the program, a personification of computer code that simplifies the perception of the problem. Encapsulating the functionality into agent is very useful. The classic black-box concept, where only input and output are considered, is too simplified when tasks cannot be done unconditionally and require cooperation (or aggregation of results) of different elements. For such conditions, it needs to have the ability to delegate work, ask for help and cooperate. This lead to the addition of complicated processes and logic, which adds a behaviour. To emphasize these differences, the term agent was used to indicate a system that incorporates this.

The above interpretation is supported by the history of agents and multi-agent systems. Computer system are evolving to be more efficient, operate on more complicated structure. The amount of data in computer systems is growing at very fast rate - people start having problem with grasping the whole complexity of data. Consequently, the computer systems had to start using more intelligent techniques to process and present data in manageable way. Among recently published articles, some current trends in software computing are visible. Many research goes towards autonomous systems that can understand linguistic terms and understand the context of the requests. There is the desire that systems would understand imprecise requirements, search for the solution by themselves, but on the other hand they have to be obedient, should not know private data and for sure not abuse them. It is a kind of personification of the system, treating computer system on higher level of abstraction.

In Fig. 4.1 a simplified schema of programming evolution is presented: the agent concept emerged from the development of computer programming. With time the computers become more popular and started developing more complex structure. The era of the object oriented programming came and programmers had to learn to encapsulate the logic of the system to make it more understandable. The programs started to be so big and complicated that such an approach was necessary. With the further development, this also stopped being enough – programs started to be divided into modules, libraries, etc. It was necessary to grasp the full logic, the different levels of details. The modules had to be compatible with each other. The need for even higher abstraction level appeared

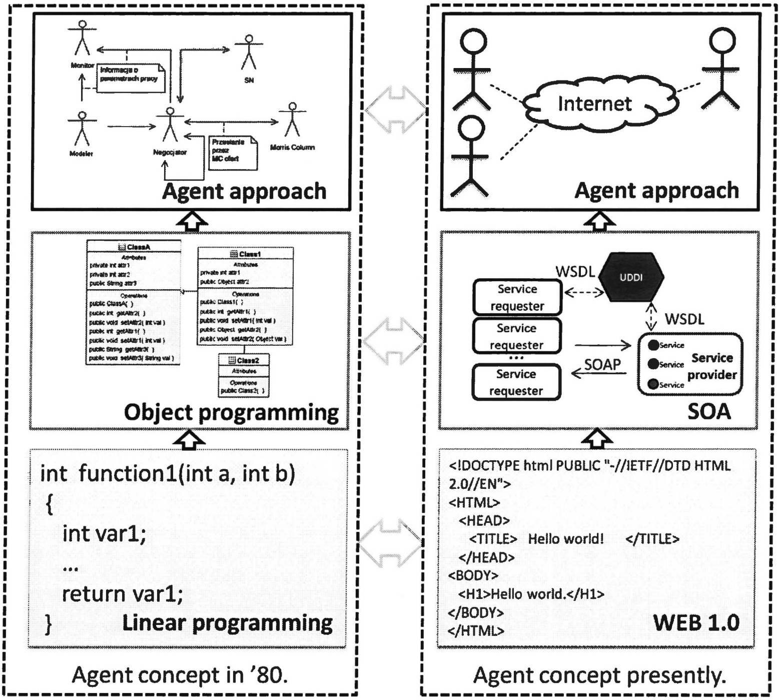

Figure 4.1: Development of Agent's concept.

– an agent. But agent approach has really gained its popularity with the development and popularization of Internet (appearance of Web 2.0 concept). Up to this point, the agent approach was mainly a research model (mainly used in logic architectures as e.g. Agent0 made in 1991 by Shoham [107]), which at the heart is a distributed system. There was not really a practical application for the concept. The technological advancements in hardware, and then the birth of web 1.0 changed the concept of separate computers into a network. This can essentially be used as a distributed system, and the agent approach was reconsidered in this context. The development of Internet technologies opened the door for new concepts: Web 2.0, Web 3.0 and Web 4.0 [3]. Web 2.0 is an idea of web as place of social interactions where people create the content and the web pages provide just the tool to do that. Unlike the web 2.0, which is a fact, the following technologies are still the subject of research and have not yet reached the necessary popularity. Web 3.0 is a so called semantic web – an idea to standardize the information representation to make it more accessible to machines and thus ease data processing. Web 4.0 is a different name for using intelligent agents to gain new experience in interaction with computer systems. It considers using agents for gathering and processing data in such a way that would be very human like, e.g. agent would present data in natural language adjusting the information to the perception abilities of a user. This is still a field of research and will not be implemented in near future as understanding and processing natural language is difficult task.

Very often there is confusion on when agents can be described as intelligent. The intelligent agents have following properties[126]: reactivity, proactiveness and social ability. Reactivity means that agent perceives the environment and is aware of the changes that happen in it and acts accordingly. Proactiveness means that an agent has a goal and actively pursuits it, the agent takes initiative. Social ability is an interaction with other agents which requires more than just exchange of information: it includes cooperation, negotiation and argumentation. As can be seen in this description the intelligent agent do not require ability of learning or mobility. Considering this definition of intelligent agents, the agents described in chapter 5 can be considered intelligent agents.

4.3 Agents and SOA

Service Oriented Architecture (SOA) is a concept of building computer systems from a collection of services which can be called in order to perform a task. Originally, the motivation for SOA was to overcome problems with integration of heterogeneous information systems and provide agile development of new solutions. Over time, with the fast growth of the Internet and the advent of ubiquitous environments, the services have become web services and the standards developed for enterprises reached their limits. However, fresh ideas in this area, often in the from of extension of existing standards, are continuously generated, especially by communities centered around semantic web and ubiquitous computing. Several results, especially service registries, service discovery and composition methods etc., exist and can be reused or at least serve as an inspiration for developing new architectures.

There is a wide range of applications to the Web Services, not only in context of SOA. Accordingly to the authors of [55], they are considered the future of distributed computing. The above is well specified, self descriptive and platform independent technology which also goes with an idea of encapsulation and granularity.

The Web Service is a stateless request-response application. It is simple and easy to use by systems on all platforms and made using different technologies. Because Web Services are considered by some as the main element of SOA, an increasing number of applications are using them or integrating with them, as service oriented architecture is considered to be start of the new generation of web-based business applications.

Web Services are designed to be simple, stateless elements delivering limited, coherent pieces of information. The above makes them easy to use, but is also limits their application. To perform complicated tasks, there is a need to interact, to send many different messages, as well as react accordingly to the development of the situation. The interaction is a core element of agents and their interoperability.

The Web Services and the agents are characterized by following common features:

- Both have detailed specifications made by FIPA for agent systems and W3C for Web Services.
- They both have got some kind of register for discovering and registering existing agents or Web Services.
- Thanks to the detailed specification they can communicate with any system that uses specific communication protocols, independently from the technology or the platform.

4.4 Limitations and problems with agent concept

In [127], the authors identify the most common problems with development of agent-based systems, and divide them into categories: political, conceptual, management, analysis and design, micro level, macro level and implementation issues. The general conclusion is the result of 10-year experience with agent system development and can be summarized into four typical issues: there is not enough understanding of what is an agent and why it is used; there are too high expectations about the abilities of agents; people are forgetting that agents are computer programs that have special requirements; and they should be implemented according to well defined development standards.

The misinterpretation of the agent definition leads to abusing the term, the authors of [127] even fear that it will become a buzzword which will undermine its research status. Agents are sometimes considered to be distributed, generic tools using artificial intelligence (AI), completely forgetting that the implementation of such a system is an extremely difficult task and requires well-defined constraints and requirement analysis. Such programs exist, but often remain in the prototype phase of development.

Agents are meant to be distributed systems and this makes their implementation more difficult and requires one to use a number of mechanisms for handling exceptional states of the system. In a well designed and implemented system, the death or malfunction of one agent can disturb the task but should not disturb the multi-agent system. This adds additional code which is not fully connected to the required functionality. Consequently, the systems tends to be complex, often sacrificing the efficiency and speed. It has to be carefully weighted with the overhead whether using the agent approach is justified for the given problem and if the usage of agent architecture provides real benefits.

4.5 Standards and protocols

FIPA – The Foundation for Intelligent Physical Agents is an IEEE Computer Society standards organization that defines the standards regarding agent technologies and protocols of communication between them. It was accepted by the IEEE in 2005 to promote the agent-based approach [28]. Since 1997, FIPA published a number of specifications of abstract architectures of agents and multi-agent systems. The politics of FIPA is to create standards that would organize the agents cooperation but without limiting access to new technologies or ideas: they assume that the technology used to create an agent is not important as long as it would be able to use some pre-defined protocols and have a minimal set of features. The areas of which FIPA takes care the most are: agents, communication between agents, services, agent management and integration of agent with different technology agents.

FIPA defines necessary elements necessary to proper functioning of the whole multi-agent system:

- Agent management system (AMS) which manages the life-cycle of an agents: it can start, stop, suspend and deregister agents from the system.
- White pages is a service for agent identification which translates between the name of an agent and the physical address of the agent.
- Yellow pages is a service identifying the services that are offered by agents in the system.
- Message transport service is a service that forms the communication medium between the agents.

The agent's features, behavior and the way of communication are very well specified by the set of specifications developed by FIPA ([30],[31], [29]).

4.6 Java Agent Development Framework (JADE)

The Java Agent Development Framework (JADE) [10] is used to implement the agent systems in this work. It is fairly popular and was shown to be efficient enough to be used in implementing large-scale multi-agent programs [17]. JADE contains a library for implementing agents and their functionality, the launching environment which gives the abilities of the multi-agent environment, and a set of tools that help to monitor agents behavior.

JADE is implemented in JAVA, so it works on a virtual machine over the operating system of the computer and requires Java version of 1.4 or older. Due to JAVA, there are some performance limitations, but on the other hand it allows launching JADE agents on all devices that run JAVA. It is a distributed as an open source software under the terms of the LGPL (Lesser General Public License Version 2). The JADE Board consist of: Telecom Italia, Motorola, Whitestein Technologies AG, Profactor GmbH, and France Telecom R&D.

JADE organizes agents into platforms – the logical structure that defines the boundaries of the multiagent environment. Platforms hold containers, which group agents. A platform can be spread over multiple networked computers, whereas a container is tied to a pre-defined machine. JADE allows for migrating the containers and agents between different physical machines in a transparent way, from the point of view of an agent. Platform and containers are necessary to comply with the standards of FIPA: in a platform, agents have names while their physical address (including IP address) is stored in the white pages service. Containers allow for freezing, moving and restarting agents, and allow for transport of messages between agents.

The biggest advantage of JADE is that it is not limiting the programmers. The JADE offers a very good library which allow to easily create basic agent functions, but the detailed functionality can be implemented using all available libraries in JAVA.

4.7 Future of agents

The work on agents is continuing, there are more research fields where the concept of agents brings added value. There is also an increased recognition of what an agent is and now its properties are better defined. Agent is a concept that opens a way to more anthropomorphic way of thinking about computer systems and modeling. Agent modeling is closely related to such fields as linguistic reasoning, fuzzy computing, game theory mechanisms, theory of communication, negotiations, social behaviors, parallel computing, distributed systems, etc. There are no real autonomous agents yet, but the work continues; the use of artificial intelligence and expert systems is very promising. A better understanding of the term agent will help to clarify when to use the concept and when it is not suitable.

4.8 Agent systems in energy modeling

The use of the agent concept in the electric energy modeling was widely researched and there is a consensus that the energy management systems can benefit from agent approach. The work of IEEE Power Engineering Society's Multi-Agent Systems (MAS) Working Group, published in [64] and [65], presents the discussion over the usability of agents in the energy sector. The authors underlined the features that are very desired in the energy management applications: extendibility, flexibility, using open standards, heterogeneity of agent programing languages, suitability for modeling destributed system and high fault tolerance.

The applications where agent systems would be especially suitable according to [64] are: diagnostics, monitoring, distributed control, modeling, simulation and protection. Many implementations of EMS systems for distributed energy management exist: [122, 54, 2, 47, 49, 98, 105].

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): Cooperatives 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 multiagent 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